ForestNavigator

D2.1 Multilayered forest geodatabase at the service of monitoring and modelling carbon and biodiversity

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Abstract

This report describes the data delivered in D2.1, which consists of the first installment and version 1 of the forest geodatabase. This report provides a brief summary of the data layers included in D2.1, the methods applied, existing data sources used, and data curation efforts to date. Existing and planned validation steps of the data are also briefly described.

Keywords

Forest data layers, EU, datacube, forest harvest data

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Nature of the deliverable *		DATA

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Abbreviations

CRF	Common reporting format
ESA	European Space Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Green house gas
NIR	National inventory report
SBTN	Science Based Targets for Land
WP	Work Package
NFI	National forest inventory

1. Introducing the forest geodatabase

Work package (WP) 2 as part of ForestNavigator is focusing on providing quality data and data driven assessments towards the project objectives. The aim is to ensure that state-of-the-art and up-to-date, consistently integrated data streams are provided and used in data-driven analysis, Green House Gases (GHG) inventory estimation, and in certain for forward-looking models to enable transparent monitoring of progress towards the national and EU climate change mitigation targets.

The development of the ForestNavigator forest geodatabase is a first important project step for compiling key data sources in WP2 for downstream uptake in the various data analysis and modeling WPs ("forest4model" Datacube). It provides different information layers relevant to the project. The database includes an updated "picture" of the current and recent past forest status and use. Generating the database combines different data streams from remote sensing, statistics, and inventories for a consistent and comprehensive dynamic representation of forests for a spatially explicit assessment of forest changes, aboveground biomass/carbon stocks, forest age, and structural diversity. The data streams will form the base for data-driven assessments, for improving GHG Inventories and support downstream modeling efforts. Some key datasets will be presented and disseminated through the ForestNavigator Portal.

A dialog between data and modeling expert groups in the project has been carried out during the first year of the project to specify the types and characteristics of datasets the geodatabase should contain. The following criteria have been defined as important and guiding for the database development:

- Consistent: integrating remote sensing, field data and (where needed/possible) reconcile with national and (sub)national statistics.
- Spatially distributed and high-resolution: make best use of available remote sensing data and tools able of bridging the different scales and obtain more punctual information on forest status and change.
- Comprehensive: include key baseline forest information and in particular cover dimensions that have not been extensively covered in the past (e.g. climate, biodiversity).
- Transparent: data should be open source and easy to find, accessible, interoperative, and reusable - allowing reproducibility and stimulate understanding and sharing among many stakeholders.
- Timely: need to address rapid changes happening in European forests, i.e. all data should be 2020.
- EU wide: cover the entire region at the same level of detail and quality.

Based on these considerations, we create a findable, accessible, interoperable, and reusable (FAIR) multi-layered harmonised geodatabase representing the near past (2000-2020) and present status of EU forests to be used for carbon and biodiversity monitoring and modelling. Furthermore, we integrate components in the geodatabase for consistent mapping and updating of forest carbon stocks and forest structures under climate and management drivers. This state-of-the-art and up-to-date, EU-wide forest geodatabase is consistent with reporting, transparent monitoring, and forward-looking modelling needs. The database's primary audience is the project modeling efforts but could be useful for other purposes as well.

In this document, we describe the Earth Observation-based data and methodology that was used to generate the 14 high-resolution (100m spatial resolution) data sets (i.e. Datacube) that were prepared and are included in this version of the forest geodatabase and its corresponding data curation processes. The final result is a Datacube with data layers that describe EU forest cover, disturbance history and biodiversity and structure parameters. We also explain the data validation efforts that have been undertaken to date, and the next data validation steps and updates that are still foreseen (section 4).

Additionally, under Section 3, sub-national National Forest Inventory (NFI) census data on harvest volumes was screened and collected, as well as data from Green House Gases national inventories (GHGI). Table 1 gives an overview of the 17 data sets included in the forest geodatabase (including 14 from the Datacube). The database presented here is in its first version. During the duration of the ForestNavigator projects will be refined; in particular from a continued dialog with the modeling groups.

Table 1: Overview of data sets curated for the forest geodatabase and the forest4model Datacube

Data set	Description	Unit	Specification
Forest cover	Forest cover in the year 2020, based on a minimum of 10 % tree cover, >= 5 m tree height and a minimum of 0.5 ha	binary: 1; signed integers 16 bit	2020, 100 m spatial resolution
Forest cover fraction	Forest cover fraction from 30 m spatial resolution to 100 m	0-1; signed integers 16 bit; scale factor 0.001	2020, 100 m spatial resolution
Forest extent stable	The identified stable forest area between 2000 and 2020	binary: 1; signed integers 16 bit	2000-2020, 100 m spatial resolution
Forest extent loss	The identified forest extent loss between 2000 and 2020	binary: 1; signed integers 16 bit	2000-2020, 100 m spatial resolution
Forest extent gain	The identified forest extent gain between 2000 and 2020	binary: 1; signed integers 16 bit	2000-2020, 100 m spatial resolution
Deadwood distribution	Deadwood volume estimates	m^3/ha	2006-2008, 1km spatial resolution
Disturbance year	The identified disturbance and disturbance year	1986-2020; signed integers 16 bit	1986-2020, 100 m spatial resolution
Disturbance fraction	The fraction of identified disturbed pixels at 30 m spatial resolution in the	0-1; signed integers 16 bit; scale factor 0.001	1986-2020, 100 m spatial resolution

Data set	Description	Unit	Specification
	100 m spatial resolution		
Forest aboveground biomass	The estimated aboveground biomass in forest areas	0-631; signed integers 16 bit	2020, 100 m spatial resolution
Forest age	The estimated forest age	1-300; signed integers 16 bit	2020, 100 m spatial resolution
Forest canopy height	The estimated forest canopy height 2020	0-50; signed integers 16 bit	2020, 100 m spatial resolution
Forest Type	Identified forest types as in broadleaved, coniferous forests, mixed forest areas, and undefined	1,2,3,4; signed integers 16 bit	2018, 100 m spatial resolution
Forest fragmentation	The identified forest fragments in 2020	0-1; signed integers 16 bit; scale factor 0.001	2020, 100 m spatial resolution
Forest fragmentation change	The identified change in forest fragments in between 2000 and 2020	0-1; signed integers 16 bit; scale factor 0.001	2000-2020, 100 m spatial resolution
Natural forests	Unmanaged or minimally managed natural forest	1,2; signed integers 16 bit	2020, 100 m spatial resolution
Forest harvest, sub-national, 2000-2020	Harvest volumes for coniferous and non-coniferous species from NFI census statistics for available NFI periods	tC/yr	sub-national (NUTS2/NUTS3) census data
GHG inventories forest estimates	Carbon pools changes (emissions/removals) extracted from GHGI	t C/ha, kt C	1990-2021 National scale

2. Forest Datacube

We here present the forest4model Datacube version 1. The Datacube consists of 14 data layers[1]. The individual data layers and their processing steps are described below. For the first version of the Datacube we curated existing and published data sets on the state of EU forests and harmonised these to a common grid and scale. We anticipate a version 2 of the Datacube to be evolve over the next 1-2 project years, which will include further data layers and an update based on feedback and improvements from the forest modelling community.

We applied two general processing steps to all data layers included in the Datacube. All data sets were upscaled to 100 m spatial resolution as a uniform common output resolution. For this we used the gdal.Warp() function. For the general processing steps we worked with the Lambert Azimuthal Equal Area Projection (EPSG: 3035, ETRS89 / LAEA Europe) as this is an equal area projection and some of the data processing steps rely on an equal area. The output projection of the final products, however, is the World Geodetic System 1984 (EPSG: 4326, WGS84), as this is more commonly applied in modelling studies. Hence, as a last step, all data sets were reprojected to geographic coordinates. For this we used the gdal.Warp() function. The output project was World Geodetic System 1984 (EPSG: 4326, WGS84). The forest4model Datacube is provided in netCDF format.

2.1. Forest cover 2020

The forest cover 2020 data set describes forest cover in Europe as a binary data set. For this, we used published data sets for 2020 and combined them to obtain a coherent and harmonised forest cover map. Based on the FAO definition of forest, we included areas with a tree cover > 10%, tree height of >= 5m, and a minimum area of 0.5 ha only.

As the forest cover 2020 with a 100 m spatial resolution is derived from two inputs with a higher spatial resolution (10 m and 30 m), we also provide a forest cover fraction layer for 2020 at 100 m spatial resolution. The forest cover fraction 100 m data set gives detailed insights in the forest cover at 100 m spatial resolution and enables uncertainty estimations of the modelling results that arise from the different spatial scale.

2.1.1. Data used

Input for the forest cover 2020 and forest cover fraction at 100 m data set is the European Space Agency (ESA) WorldCover 10 m 2020 v100 product (Zanaga et al. 2021). The ESA WorldCover is a global land cover product based on Copernicus Sentinel data. The classification contains a tree cover class, which indicates areas that are dominated by trees with a cover of 10% and more. Further specifications can be found in the product user manual (Zanaga et al. 2021).

A second input for the forest cover 2020 and forest cover fraction at 100 m data set is the tree height 2020 product from Potapov et al. (2022). As part of the global 2000-2020 land cover and land use change dataset, they derived the tree height based on the Global Ecosystem Dynamics Investigation LiDAR (GEDI) data and the Landsat archive. Further tree height product specifications can be found in the accompanying publication (Potapov et al. 2022).

[1] Excludes deadwood and forest harvest, sub-national, 2000-2020, and GHG inventories forest estimates datasets

2.1.2. Methodology

The individual processing steps that were applied to derive the forest cover 2020 data set and the underlying forest cover fraction at 100 m data set are described in Table 2 and Table 3.

Table 2: List of the processing steps to derive the forest cover 2020 data

Step	Description	Comment	Spatial resolution	Data set
1. Input	ESA WorldCover 10 m 2020 v100	tree cover > 10%	10 m	Zanaga et al. (2021)
	Tree height	tree height in meter	30 m	Potapov et al. (2022)
2. Upscale	ESA WorldCover 10 m 2020 v100	upscale algorithm: mode	30 m	ESA WorldCover **30 m** 2020
3. Forest mask	Combine world cover and tree height	WorldCover tree cover > 10% and tree height >= 5 m	30 m	
4. Forest mask II	remove small objects	remove identified forest areas that are < 0.5 ha (based on connectivity)	30 m	forest cover 2020 (binary)
5. Upscale	Upscale to 100 m	upscale algorithm: mode	100 m	forest cover 2020 100 m
6. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest cover 2020 100 m**

Table 3: List of the processing steps to derive the forest cover fraction at 100 m 2020 data.

Step	Description	Comment	Spatial resolution	Data set
1. Input	ESA WorldCover 10 m 2020 v100	tree cover > 10%	10 m	Zanaga et al. (2021)
	Tree height	tree height in meter	30 m	Potapov et al. (2021)
2. Upscale	ESA WorldCover 10 m 2020 v100	upscale algorithm: mode	30 m	ESA WorldCover 30 m 2020
3. Forest mask	Combine world cover and tree height	WorldCover tree cover > 10% and tree height >= 5 m	30 m	

Step	Description	Comment	Spatial resolution	Data set
4. Forest mask II	remove small objects	remove identified forest areas that are < 0.5 ha (based on connectivity)	30 m	forest cover 2020 (binary)
5. Forest mask III	change mask properties	0,1; to float32	30 m	forest cover 2020 (float)
6. Upscale	Upscale to 100 m	upscale algorithm: average	100 m	forest cover fraction 2020 100 m
7. Mask	Mask fraction data set with forest cover 2020 data set		100 m	forest cover fraction 2020 100 m
8. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest cover fraction 2020 100 m**

2.1.3. Datacube layer

- forest cover year
- forest cover fraction

2.2. Forest disturbance history

2.2.1. Data used

The primary inputs for the forest disturbance history are the European forest disturbance maps v1.1.4 (Senf and Seidl, 2021). The maps comprise annual forest disturbances across 35 European countries from 1986-2020 at 30 m spatial resolution. Further forest disturbance product specifications and methodology can be found in the accompanying publication.

We derived two disturbance products for the Datacube from the European forest disturbance maps. Firstly, we derived a disturbance year product that identifies the main disturbance year at 100 m spatial resolution. As the disturbances and the associated disturbance year were initially mapped at 30 m spatial resolution, we aggregated this information to a coarser resolution. Hence, the 100 m disturbance year product depicts the main disturbance year of that pixel and potentially also for a small area that was not identified as disturbed by Senf and Seidl (2021). Following this, we provide a second disturbance product, the disturbance fraction 100 m, which indicates the fraction of 30 m spatial resolution identified as disturbed that is represented in the 100 m aggregate product.

Additionally, we used Landsat-based forest extent data sets for 2000 and 2020 to identify temporal changes in forest extent (Potapov et al. 2022). For these products, Potapov et al. (2022) employed the tree height >= 5 m criteria of the FAO forest definition, but unlike the FAO, they included wildland, managed, and planted forests, agroforestry, orchages and natural tree regrowth and also did not employ the tree canopy cover criterion. Further forest extent product specifications and methodology can be found in the accompanying publication. These data sets enabled us to assess forest extent change between 2000 and 2020. We derived stable forest areas, forest extent loss, and forest extent gain for 2000 to 2020.

2.2.2. Methodology

The individual processing steps that were applied to derive the disturbance year at 100 m data set and underlying disturbance fraction at 100 m data set are described in *Table 4* and *Table 5*.

Table 4: List of the processing steps to derive the disturbance year 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	disturbance year 1986-2020	disturbance year layer is provided per country	30 m	Senf and Seidl (2021)
2. Upscale	Upscale to 100 m	upscale algorithm: mode	100 m	disturbance year 1986-2020 100 m
3. Mask	masking with forest cover 2020 map	eliminating small-scale disturbance patches and falsely identified disturbances in non-forest areas	100 m	disturbance year 1986-2020 100 m
4. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**disturbance year 1986-2020 100 m**

Table 5: List of the processing steps to derive the disturbance fraction 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	disturbance year 1986-2020	disturbance year layer is provided per country	30 m	Senf and Seidl (2021)
2. Preprocessing	convert disturbance year to float (0/1)	disturbance = 1, no disturbance = 0	30 m	disturbance year 1986-2020 binary
3. Upscale	Upscale to 100 m	upscale algorithm: average	100 m	disturbance fraction 100 m
4. Mask	masking with forest cover 2020 map	eliminating small-scale disturbance patches and falsely identified disturbances in non-	100 m	disturbance fraction 100 m

Step	Description	Comment	Spatial resolution	Data set
		forest areas		
5.Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**disturbance fraction 100 m**

Table 6: List of the processing steps to derive the forest extent stable, forest extent loss, and forest extent gain data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	forest extent 2000		30 m	Potapov et al. (2022)
	forest extent 2020		30 m	Potapov et al. (2022)
2. Upscale	Upscale to 100 m	upscale algorithm: mode	100 m	forest extent 2000/2020 100 m
3. Create	combine forest extent 2000 and 2020	identify areas that were forest in 2000 and 2020	100 m	forest extent stable 2000-2020 100 m
4. Create	combine stable forest extent and forest extent 2020	identify areas with forest extent gain in 2020	100 m	forest extent gain 2000-2020 100 m
5. Create	combine stable forest extent and forest extent 2000	identify areas with forest extent loss in 2020	100 m	forest extent loss 2000-2020 100 m
6. Mask	masking with forest cover 2020 map	eliminating small-scale disturbance patches and falsely identified disturbances in non-forest areas	100 m	forest extent stable/loss/gain 2000-2020 100 m
4. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest extent stable 2000-2020 100 m, forest extent loss 2000-2020 100 m, forest extent gain 2000-2020 100 m**

2.2.3. Datacube layer

- disturbance year
- disturbance fraction
- forest extent stable
- forest extent loss
- forest extent gain

2.3. Forest aboveground biomass 2020

2.3.1. Data used

The ESA Biomass Climate Change Initiative provides global maps of aboveground biomass (Santoro and Cartus, 2023). The latest version 4 of the product also provides a map for 2020. We used this data set to depict aboveground biomass in 2020 for European forests. Further product specifications and methodology can be found in the accompanying publication and data documentations provided by the ESA Biomass Climate Change initiative team.

2.3.2. Methodology

Table 7: List of the processing steps to derive the forest aboveground biomass 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	aboveground biomass 2020		100 m	Santoro and Cartus (2023)
2. Mask	masking with forest cover 2020 map	only depict aboveground biomass for forest area	100 m	forest aboveground biomass 100 m
3. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest aboveground biomass 100 m**

2.3.3. Datacube layer

- Forest aboveground biomass

2.4. Forest age and structure 2020

2.4.1. Data used

We developed a global forest age data set for 2020 at 100 m spatial resolution. This data set provides an ensemble of global estimation of global forest age, which is derived from forest inventories, biomass and climate data. The 2020 forest age data set is based on the Forest Age MPI-BGC v1.0 product, which was developed at 1 km spatial resolution (Besnard et al. 2021). The methodology described in this publication was adapted to the data set used here for 2020 at 100 m.

The Forest Age MPI-BGC v.2.0 presented here contains three main updates. First, the training dataset was expanded by including almost 3% more NFI observations and now includes forest canopy height as a co-variate. Second, we used more complex machine learning models for predicting forest age than in Besnard et al. (2021): XGBoost and multi-layer perceptron models. Finally, Forest Age MPI-BGC v.2.0 provides higher-spatial resolution estimates of forest age at the global scale (i.e., 100m pixel size vs. 1km pixel in v1.0) by relying on the ESA-CCI biomass v4 product (Santoro and Cartus, 2023).

We used the Landsat-based forest tree height data sets for 2020 (Potapov et al. 2022) to identify the forest canopy height. This forest canopy height product was downloaded from the GLAD data repository (https://glad.umd.edu/users/Potapov/GLCLUC2020/Forest_height_2020/) last accessed: 07/09/2023). The native pixel size of the Potapov et al. (2022) product is 30 m and we resampled to a 100 m pixel size using the average of all the non NO-DATA pixels. Further forest extent product specifications and methodology can be found in the accompanying publication.

2.4.2. Methodology

Table 8: List of the processing steps that were applied to adapt the forest age 2020 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	forest age 2020		100 m	Besnard et al. in prep
2. Mask	masking with forest cover 2020 map	only depict forest age for forest area	100 m	forest age 100 m
3. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest age 100 m**

Table 9: List of the processing steps that were applied to derive the forest canopy height 2020 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	tree height 2020		30 m	Potapov et al. (2022)
2. Upscale	Upscale to 100 m	upscale algorithm: average	100 m	tree height 100 m 2020
3. Mask	masking with forest cover 2020 map	only depict forest age for forest area	100 m	forest canopy height 100 m
4. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest canopy height 100 m**

2.4.3. Datacube layer

- Forest age
- Forest canopy height

2.5. Biodiversity and ecosystem indicators

2.5.1. Data used

We included the Copernicus High Resolution Layer: Forest Type (FTY) 2018 data set to differentiate between broadleaved, coniferous forest areas, and mixed zones (Copernicus, 2020). The data set shows the dominant leaf types at a minimum mapping unit of 0.5 ha and with a minimum of 10% tree cover density. The data set is provided at 100 m spatial resolution and for the year 2018. Further product specifications and methodology can be found in the accompanying data set documentation.

We included the global forest fragmentation product (Ma et al., 2023). This product is available for 2000 and 2020 at 4 km spatial resolution, including a change product between the two years. We downscaled the product for 2020 and the change product to 100 m. Further product specifications and methodology can be found in the accompanying publication.

We included the Science Based Targets for Land (SBTN) natural lands map from the World Resource Institute to depict natural forests (Mazur et al. 2023). For this, the Accountability Framework Initiative definition for natural forests was applied as 'Unmanaged or minimally managed natural forest, including with some human impacts'. To identify natural forests, they combined three data sets: the forest extent data product (Potapov et al. 2021), the Spatial Database on Planted Trees (SDPT) version 2.0 (Richter et al. in review) and the Intact Forest Landscapes (IFL) (Potapov et al., 2017). Following this, Mazur et al. (2023) differentiated natural forests from planted forests. Please see the technical documentation for the precise definitions and further specifications.

2.5.2. Methodology

The individual processing steps that were applied to the forest type data set at 100 m are described in *Table 10*, for the forest fragmentation 2020 and forest fragmentation change 100 m product in *Table 11* and *Table 12*, and for the natural forest data set in *Table 13*.

Table 10: List of the processing steps to adapt the forest type 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	HRL: Forest Type 2018	indicating broadleaved, coniferous and mixed forest areas	100 m	Copernicus (2020)
2. Mask	masking with forest cover 2020 map	only depict forest types for the forest cover area; classes: 1-undefined, 2 - broadleaved, 3-coniferous, 4-mixed	100 m	forest type 100 m
3. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**(adapted) forest type 100 m**

Table 11: List of the processing steps to adapt the forest fragmentation 2020 100 m and the forest fragmentation change data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	forest fragmentation 2020	indicating the distribution of forest fragments in 2020	4 km	Ma et al. (2023)
	forest fragmentation change 2000-2020	indicating the change in forest fragmentation between 2000 and 2020	4 km	Ma et al. (2023)
2. Downscale	Downscale to 100 m	downscale algorithm: mode	100 m	forest fragmentation 2020 100 m, forest fragmentation change 100 m
3. Mask	masking with forest cover 2020 map	only depict forest fragmentation for the forest cover area	100 m	forest fragmentation 2020 100 m, forest fragmentation change 100 m
4. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest fragmentation 2020 100 m, forest fragmentation change 100 m**

Table 12: List of the processing steps to adapt the forest fragmentation change 100 m data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	forest fragmentation 2020		4 km	Ma et al. (2023)
	forest fragmentation 2000		4 km	Ma et al. (2023)
2. Downscale	Downscale to 100 m	downscale algorithm: mode	100 m	forest fragmentation 2020/2000 100 m
3. Create	combine forest fragmentation 2000 and 2020	identify forest fragmentation change between 2000 and 2020	100 m	forest fragmentation change 100 m
4. Mask	masking with forest cover 2020 map	only depict forest fragmentation change for the forest cover area	100 m	forest fragmentation change 100 m
5. Reproject	reproject to geographic coordinates	reproject to WGS 84	100 m	**forest fragmentation change 100 m**

Table 13: List of the processing steps to adapt the natural forest 2020 data set.

Step	Description	Comment	Spatial resolution	Data set
1. Input	SBTN land classes	all natural land cover and non-natural land cover classes	100 m	Mazur et al. (2023)
2. Select	Select natural forest class	natural forest class = 2	100 m	natural forest 2020
3. Reproject	reproject to projected coordinates	reproject to EPSG: 3035, ETRS89 / LAEA Europe	100 m	natural forest 2020
4. Mask	masking with forest cover 2020 map	only depict natural forests for the forest cover area; 1 - non-natural forest, 2 - natural forest	100 m	natural forest 2020
5.	reproject to	reproject to WGS 84	100 m	**natural forest 2020**

Step	Description	Comment	Spatial resolution	Data set
Reproject	geographic coordinates			

2.5.3. Datacube layer

- Forest Type
- Forest fragmentation
- Forest fragmentation change
- Natural forest

2.6. Deadwood indicators

2.6.1. Data used

Deadwood, an important indicator of forest management sustainability, is a key old-growth element in European forests and a cornerstone of biodiversity conservation practices in the region. Deadwood at a 1 km^2 spatial resolution and representative of years 2006 to 2008 was generated using various data sources. The basis is a comprehensive dataset of deadwood amounts based on the large-scale biodiversity survey from the ICP forests network from 2006 and 2008 (Bastrup-Birk et al. 2006, Puletti et al. 2019). Deadwood amounts were combined with harmonized forest structure from remote sensing and socio-economic indicators. Further information and methodology can be found in (Augustynczik et al., forthcoming).

2.6.2. Methodology

A statistical and machine learning model was built for the spatial estimation of deadwood amounts in Europe, based on the ICP deadwood survey. The models were subsequently deployed on the gridded predictors to generate the dataset on deadwood distribution. *Table 14* describes the processing steps. Further details is available in (Augustynczik et al., forthcoming).

Table 14: List of the processing steps that were applied to estimate deadwood amounts.

Step	Description	Comment	Spatial resolution	Data set
1. Input	Deadwood amounts 2006 and 2008		Point estimates	Bastrup-Birk et al. 2006, Puletti et al. 20019
	Climate (historical precipitation and temperature)		1 km	WorldClim 2.1
	Terrain (elevation and slope)		25 m	EEA, 2016

Step	Description	Comment	Spatial resolution	Data set
	Forest attributes: age, biogeographical region, aboveground biomass, forest type , tree density, disturbance		1 km - 100 m 100 m 1 km 25 m	Besnard et al., 2021 EEA, 2016 Santoro et al., 2021 Buchhorn et al., 2020 Crother et al., 2015 Senf & Seidl, 2021
	Socio-economic attributes: accessibility 2015, management, public ownership, WDPA protection class		1 km 1 km NUTS2/3 100 m	Wess et al., 2018 Hengeveld et al., 2012 Pulla et al., 2013 CDDA, 2021
2. Identify drivers	Fit a statistical and machine learning model to assess deadwood drivers			
3. Harmoni-zation	Harmonize predictors and apply drivers to novel environments		1 km	
4. Reproject	reproject to geographic coordinates where necessary	reproject to WGS 84	1 km	
5. Mask	masking with forest cover map	only depict deadwood for the forest cover area	1 km	
6. Upscale	deploy deadwood models on the gridded predictors to upscale deadwood estimates	final estimates based on model averaging	1 km	**deadwood distribution 1 km**

Source: Augustynczik et al. (forthcoming)

2.6.3. Datacube layer

- Deadwood distribution 1 km

3. National forest monitoring data status

NFIs provide important information on the status and evolution of European forests. ForestNavigator models require different types of NFI data according to their different scope and resolution. NFI aggregated data (NUTS aggregated) and plot-based data are also required for different purposes in WP2 and WP3. While access to many NFI datasets is limited, different ways of use and availability have been developed to mitigate the limited accessibility and make good use of the type and characteristics of NFI data available. Accordingly, we have articulated our work according to the three points below:

1) Meeting WP3 forest types modelling calibration (lead IIASA/WP3 and project partners):
    a. Requires detailed tree level information on age, dbh, species etc. for the various modeling approach
    b. Such detailed is available from NFI’s but often not with precise geographic coordinates
    c. Engaging with EU Pathfinder Horizon project about them sharing NFI data (if and how), some level of harmonized NFI data is expected to become available from the project. This could include to develop specific requests to country partners about processing and access plot-level estimates from tree-level data, and make use of country partners in the project able to provide some level of data. Currently, IIASA also with support of the Pathfinder was able to retrieve plot level NFI data from: Sweden, Ireland, Czech Republic, Germany, Spain and France. Plot level data from the Finnish private forest owners inventories were also retrieved. Additionally, consortium partners have specific agreements for access to additional NFI plot data (Italy (CNR), Austria (BOKU), Poland (BOKU), Romania (BOKU).
2) NFI and harvesting statistics time series (lead WP2 – BOKU):
    a. Compile and reprocess NFI- and harvesting statistics-based estimates at spatial aggregate levels (i.e. NUTS3)
    b. Do that for many European countries (ideally and updated with most recent data available)
    c. Compare with remote sensing time series data of disturbances and/or carbon stocks
3) Integration of remote sensing and NFI/ground-based measurements (lead WP2 – GFZ):
    a. Compilation of reference data from NFI’s, research plots and airborne for forest carbon stocks and changes (requires exact coordinates)
    b. Integration with space-based biomass and biomass change estimations from different sources

Efforts to complete points 1) and 2) have been ongoing in the first year of ForestNavigator, respectively in WP3 and WP2. Work on point 3) will be the focus in year two (T2.2) and will be presented in Deliverable 2.2.

Within the first year of ForestNavigator, under WP2, we have screened the availability of sub-national inventory data for the period 2000-2020 and started to compile available data points into a database. This database will be the basis for the modeling of a consistent sub-national timeseries over the last twenty years on selected forest indicators, namely forest area, harvest, stock and increment for various sub-groups regarding, for instance, tree species.

3.1. Availability and accessibility of sub-national NFI data

Forest surveys in Europe have evolved gradually over the last decades and even centuries, often using varying definitions and surveying methods based on national histories and laws. Since 1946, national forest data are being collected by the FAO in the Forest Resource Assessment (FRA) based on questionnaires and can be downloaded from https://fra-data.fao.org/assessments/fra/ and https://www.fao.org/faostat/en/. In Europe, the Ministerial Conference on the Protection of Forests in Europe (MCPFE), later called FOREST EUROPE, was established in 1990. They provide data on forest indicators and sustainability criteria and publish the "State of Europe's Forests" reports periodically (Vidal et al., 2016). Although national NFI institutes assess their forests on a level of high spatial detail (from plot to district/county to national level), only national level data is published in these reports. Due to a lack of stringent harmonization of methods and definitions, comparability is limited (European Commission. Joint Research Centre., 2020).

Several efforts to collect and harmonize NFI data at a more detailed level across Europe are ongoing. The informal network called the European National Forest Inventory Network (ENFIN, 2023), funded by the EU program "Cooperation in Science and Technology", connects European NFIs and pursues efforts of harmonizing definitions and methodologies, but does not offer open access to all data collected by the individual NFIs (Tomppo et al., 2009). Currently, an initiative for a new EU "Framework for Forest Monitoring and Strategic Plans" that aims to "provide open access to detailed, accurate, regular and timely information on the condition and management of EU forests" (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13396-EU-forests-new-EU-Framework-for-Forest-Monitoring-and-Strategic-Plans_en) is being considered within the EU Forest strategy for 2030 by the European Commission and could fill this gap (European Commission, 2022). However, to date, the existing sub-national data on main forest indicators for Europe is not being collected in one openly accessible database, but published at various degrees of detail across the individual websites of the NFIs.

The European Forest Institute (EFI, 2023) has made a first attempt at collecting sub-national NFI data with the publicly available EFISCEN database (Schelhaas et al., 2006). The EFISCEN database provides (sub-)national data for 32 European countries and was used to initialize the EFISCEN model. Unfortunately, the database contains only data until the year 2001 and recent data have to be sourced elsewhere. A more recent collection of NFI datasets and reports is provided by the Forest Information System for Europe (FISE, 2023). The FISE, partnered with the European Commission and the European Environment Agency, collects and shares data, information and knowledge on the state of Europe's forests to support sustainable forest management. Their data catalogue includes access to collected NFI reports and data tables of 34 European countries and provides forest information data on varying regional levels (country, NUTS1-3 and LAU1-2). Besides collected NFI reports they also provide revised tables with additional information such as reorganized data in spreadsheet format that allow short and comprehensive overviews of the data in full pdf reports. Unfortunately, these data are subject to time lags and often do not include the latest NFI reports/data.

3.2. NFI data collection process

We have collected all available forest information on national and sub-national levels from the FISE and EFISCEN databases and conducted web searches across the national NFIs and their various databases to find the most recent and granular information related to our selected forest indicators. So far, we have collected data on key forest indicators for 88% of the EU-27 forest area (Figure 1).

Country	Country ID	Spatial reporting level*	Nr of years reported 2000-2022*	Forest indicators				Tree species information (con./non-con.)	% EU-27 forest area (EUROSTAT)
				Area	Harvest	Stock	Increment		
Austria	AT	NUTS2	17					yes	2%
Bulgaria	BG	NUTS0	6-18					yes	5%
Czech	CZ	NUTS3	4-13					yes	7%
Germany	DE	NUTS1	2-16					yes	14%
Estonia	EE	NUTS0/NUTS3	20					partially	15%
Spain	ES	NUTS2	3-14					yes	27%
Finland	FI	NUTS3	13-23					yes	41%
France	FR	NUTS2	5					yes	52%
Ireland	IE	NUTS3	11					yes	52%
Italy	IT	NUTS2	1-11					partially	58%
Poland	PL	NUTS2	8-18					yes	64%
Romania	RO	NUTS1/NUTS3	6-23					yes	69%
Sweden	SE	NUTS1/NUTS3	17					yes	86%
Slovenia	SI	NUTS3	1					partially	87%
Slovakia	SK	NUTS0/NUTS3	8-12					yes	88%
Belgium	BE	data extraction still ongoing							89%
Cyprus	CY								89%
Denmark	DK								89%
Greece	GR								92%
Croatia	HR								93%
Hungary	HU								94%
Lithuania	LT								95%
Luxembourg	LU								96%
Latvia	LV								98%
Malta	MT								98%
Netherlands	NL								98%
Portugal	PT								100%

* may vary between indicators

Figure 1: Current status of NFI data collection for EU-27 countries

Note: Green: data in database, red: data missing, yellow: screening ongoing

3.3. GHG inventories forest estimates

3.3.1. Data used

The GHG Inventories (GHGI) are collected according to UNFCCC defined standards. The UNFCCC publish on its web site the annual inventory submissions consisting of the national inventory report (NIR) and common reporting format (CRF) tables of all Parties included in Annex I under the Convention. The NIRs contain detailed descriptive and numerical information and the CRF tables contain all GHG emissions and removals, implied emission factors and activity data. Data are freely accessible under the UNFCCC website, in the section dedicated to the GHG inventories (https://unfccc.int/ghg-inventories-annex-i-parties/2023).

The CRF tables submission for 2023 contains the updated yearly GHG emissions/removals for 1990 to 2021. For ForestNavigator, we accessed the tables under the LULUCF (Land Use Land Use Change and Forestry) reporting sector (Sector 4), particularly the section 4.A (Forest Land).

3.3.2. Methodology

The data were extracted and organized in a tabular form (excel tables) by means of a script used by IIASA (script available: https://github.com/DenysGusti/ReadUNFCCC). The extraction created one file per country, including the land use categories and pools included under the CRF Table 4.A for each year (1990-2021). Emissions from Harvested Wood Products are also extracted from CRF Table 4. The extraction was repeated for the EU27 countries and UK (EU28). The single country files were merged into a consolidated file, where each sheet included a specific land category and pool. The pools were differentiated according to the three UNFCCC land categories FL-FL (Forest Land remaining Forest Land), L-FL (conversion of other Land to Forest Land), FL-L (conversion of Forest Land to other Land). The area/area change for each land use category and corresponding changes in carbon pools were extracted according to *Table 15*.

Table 15: Carbon pools changes (emissions/removals) extracted from GHGI, per hectare (in t C/ha) and total (in kt C)

Pool	Pool by land category
Net biomass	FL-FL
	L-FL
	FL-L
Net Deadwood	FL-FL
	L-FL
	FL-L
Net litter	FL-FL
	L-FL
	FL-L
Soil carbon mineral	FL-FL
	L-FL
	FL-L
Soil carbon organic	FL-FL
	L-FL
	FL-L
Organic soil emissions	FL (kt CO2)
	FL (kt N2O)
	FL (kt CH4)
Harvested Wood Products	(kt CO2)

4. Summary next steps

In the first project year, the focus has been on compiling “available” data. The first version of the forest4model Datacube presented here includes the currently curated existing and published data sets describing the state of European forests. The Datacube will be made available to ForestNavigator project partners and stakeholders via the ForestNavigator data portal progressively via the ForestNavigator WP2 public Git-repository. Future steps include firstly to revise the Datacube based on feedback from the ForestNavigator modelling community and secondly to add further data layers. We are currently working on three topics. An updated version 2 of the Datacube will be made available accordingly. The final version of the datacube will be both for project partners and some of the layers will be made public in the same repository.

During year 2, WP2 will also enhance the Datacube with additional data sources and streams, which ForestNavigator and outside partners and projects are working on.

These include:

- **Biomass/carbon stock changes**: we assess changes in carbon stocks of European forests over time – particularly for the recent history (since 2010) based on changes in tree height and changes in biomass derived from space-based datasets, in comparison to reference data. Collaborations with the ESA CCI Biomass and ESA Forest Carbon projects are established.
- **Species mapping**: we look into mapping the dominant species for Europe expanding on the species probability mapping work (Bonannella et al. 2022) and following this we anticipate a forest species map in collaboration with EU OpenEarthMonitor project.
- **Structural complexity**: we explore options to identify and derive forest structural complexities beyond the already available tree cover, height, age, and leaf type/leaf area index. Here we are interested in structurally-diverse versus even-aged forests and their characterization in relation to disturbance regimes. Combining S1/S2 time series and GEDI/ICESAT-2 data together with ground-level information will be the key input data sources for this effort.

An update on this work will be provided in D2.2. Furthermore, we are looking into refining the “near-real time” data updating framework, which is foreseen as part of WP2 tasks (2.3 and 2.4); also working in the context of three countries case studies. Datasets of forest disturbance (both from climate and forest change alerts) will be developed and incorporated as near-real time data streams to update the database.

5. References

Augustynczik A.L.D., Gusti M., di Fulvio F., Lauri P., Forsell N. & Havlík P. Improving forest habitat for biodiversity: what influences deadwood amount in European forests? Under review

Besnard, S., Koirala, S., Santoro, M., Weber, U., Nelson, J., Gütter, J., Herault, B., Kassi, J., N'Guessan, A., Neigh, C. and Poulter, B., 2021. Mapping global forest age from forest inventories, biomass and climate data. *Earth System Science Data*, *13*(10), pp.4881-4896.

Bonannella, C., Hengl, T., Heisig, J., Parente, L., Wright, M.N., Herold, M. and De Bruin, S., 2022. Forest tree species distribution for Europe 2000–2020: mapping potential and realized distributions using spatiotemporal machine learning. PeerJ, 10, p.e13728.

Copernicus, 2020: High Resolution Layer: Forest Type (FTY) 2018, url: https://land.copernicus.eu/pan-european/high-resolution-layers/forests/forest-type-1/status-maps/forest-type-2018?tab=metadata, data accessed 01.09.2023)

EFI, 2023. European Forest Institute (EFI) [WWW Document]. URL https://efi.int/about (accessed 9.5.23).

ENFIN, 2023. European National Forest Inventory Network (ENFIN) [WWW Document]. URL http://739uq.w4yserver.at/ (accessed 9.5.23).

European Commission, 2022. Forests: Commission consults on new EU framework for forest monitoring and strategic plans [WWW Document]. URL https://environment.ec.europa.eu/news/forests-commission-consults-new-eu-framework-forest-monitoring-and-strategic-plans-2022-08-25_en (accessed 9.5.23).

European Commission. Joint Research Centre., 2020. The biomass of European forests :an integrated assessment of forest biomass maps, field plots and national statistics. Publications Office, LU.

FISE, 2023. Forest Information System for Europe (FISE) [WWW Document]. URL https://forest.eea.europa.eu/ (accessed 9.5.23).

Ma, J., Li, J., Wu, W. and Liu, J., 2023. Global forest fragmentation change from 2000 to 2020. Nature Communications, 14(1), p.3752.

Mazur, E., Sims, M., Goldman, E., Schneider, M., Stolle, F., Daldoss Pirri, M., and Beatty, C. R., 2023. SBTN Natural Lands Map, World Resources Institute, World Wildlife Fund, Systemiq, Science Based Targets Network, https://sciencebasedtargetsnetwork.org/wp-content/uploads/2023/05/Technical-Guidance-2023-Step3-Land-v0.3-Natural-Lands-Map.pdf

Potapov, P., Hansen, M.C., Pickens, A., Hernandez-Serna, A., Tyukavina, A., Turubanova, S., Zalles, V., Li, X., Khan, A., Stolle, F. and Harris, N., 2022. The global 2000-2020 land cover and land use change dataset derived from the Landsat archive: first results. *Frontiers in Remote Sensing*, *3*, p.856903.

Potapov, P., Hansen, M.C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., Smith, W., Zhuravleva, I., Komarova, A., Minnemeyer, S. and Esipova, E., 2017. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. Science advances, 3(1), p.e1600821.

Richter, J., Harris, N.L., E.D. Goldman, and H.L. Harris J. Richter. In review. Spatial Database of Planted Trees Version 2.0. Technical Note. Washington, DC: World Resources Institute

Santoro, M., Cartus, O., 2023. ESA Biomass Climate Change Initiative (Biomass_cci): Global datasets of forest above-ground biomass for the years 2010, 2017, 2018, 2019 and 2020, v4. NERC EDS Centre for Environmental Data Analysis, 21 April 2023. doi:10.5285/af60720c1e404a9e9d2c145d2b2ead4e.

Schelhaas, M.J., Varis, S., Schuck, A., Nabuurs, G.J., 2006. EFISCEN Inventory Database, European Forest Institute, Joensuu, Finland.

Senf, C. and Seidl, R., 2021. Mapping the forest disturbance regimes of Europe. *Nature Sustainability*, *4*(1), pp.63-70.

Tomppo, E., Gschwandtner, T., Lawrence, M., McRoberts, R.E., 2009. National Forest Inventories. Pathways for Common Reporting.

Vidal, C., Alberdi, I., Redmond, J., Vestman, M., Lanz, A., Schadauer, K., 2016. The role of European National Forest Inventories for international forestry reporting. Ann. For. Sci. 73, 793–806. https://doi.org/10.1007/s13595-016-0545-6

Zanaga, D., Van De Kerchove, R., De Keersmaecker, W., Souverijns, N., Brockmann, C., Quast, R., Wevers, J., Grosu, A., Paccini, A., Vergnaud, S. and Cartus, O., 2021. ESA WorldCover 10 m 2020 v100, *Zenodo*.