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Tree species distribution data and maps for Europe

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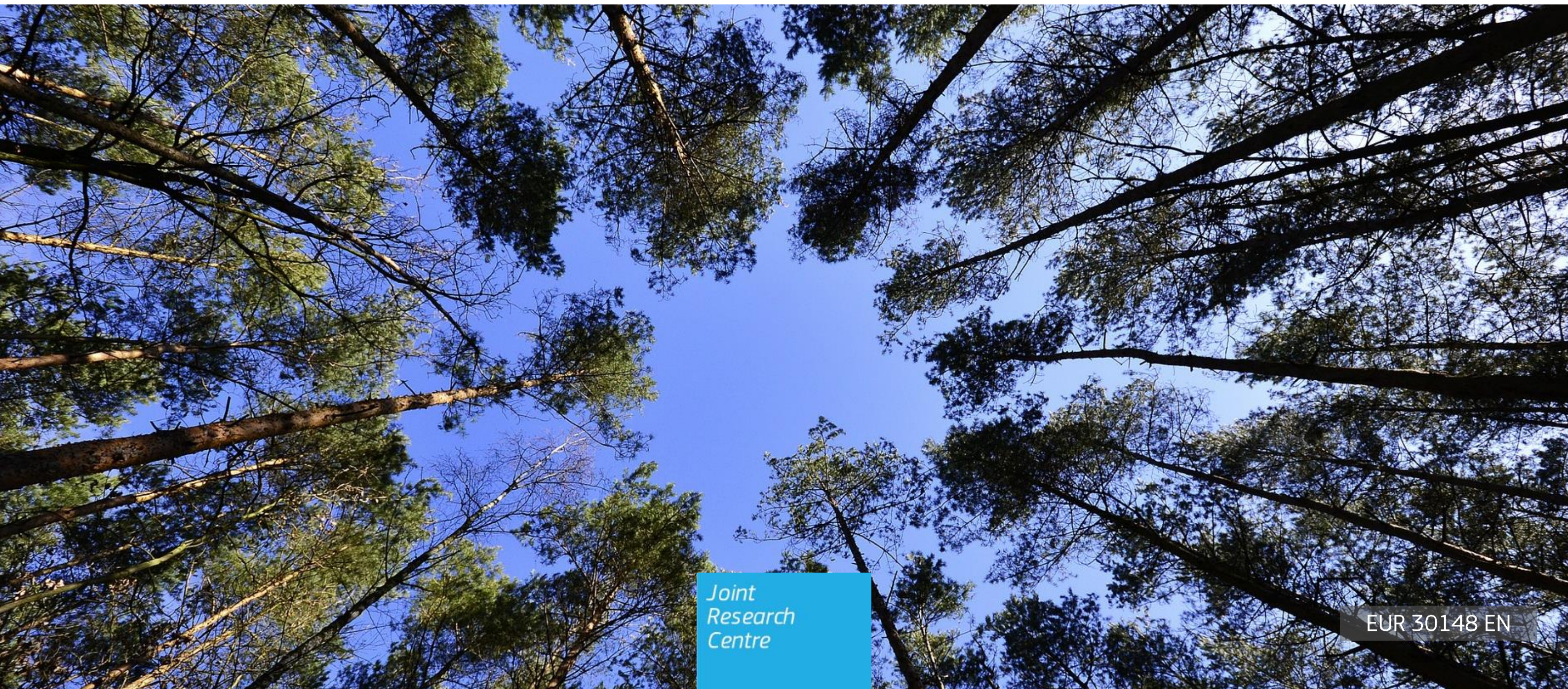

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Contents

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Abstract

This report describes the maps on tree species distribution routinely produced at Joint Research Centre, and the data sets used to produce them. Its aim is to help those searching for information on forest tree species distribution in Europe and to identify which of the maps might fit their needs, what their strengths and weaknesses are, and what data and methods were used to produce them. The report provides information on the different data sets reporting tree species occurrences in Europe on which the maps are based, highlighting the uncertainties and limitations affecting their use. The report then presents different types of tree species distribution maps based on these observational data sets. For each map type, it provides information for a correct use, including which questions a particularly map type is able to help answer and a suggested caption that can be used when reproducing a map. Finally, for two tree species, the report provides multiple distribution maps side-by-side, with annotations to help interpret the information, including uncertainty that they convey. These examples illustrate how different map types convey different types of information and how they are affected by data availability, which differs not only between source data sets but also between species within the same data set.

1 Introduction

Forests cover about a third of Europe's land surface. Their diversity of species and habitats provide myriad ecosystem services that influence climate and underpin Europe's forestry sector. These services are increasingly appreciated for their role in mitigating climate change, and as pillars of the EU's bio-economy. Europe (EU28) harbours 431 native tree species according to the IUCN [1], and 434 alien tree species [2], many of which are economically exploited. Climate change is accelerating shifts in ecosystems, exposing them to climate conditions they have not recently experienced and changing the areas where species can thrive. These changes in habitat suitability particularly affect tree species populations, as they are typically slow-growing and slow-moving and therefore limited in their ability to migrate to new areas with suitable conditions for their growth. Consequently, climate-induced stress might become widespread in tree populations. Climate change is also changing disturbance regimes in forests; damages from wildfires, storms, and from many tree pests are projected to increase as the climate warms. Exotic tree pests, which increasingly reach Europe alongside imported goods [3] [4], can be particularly damaging, as Europe's flora might have little resistance and climate-induced stress can make them even more harmful [5] [6].

To anticipate and mitigate threats to forest resources and to devise strategies for their sustainable use, knowing the current distribution of forest tree species in Europe is crucial. A variety of forest monitoring programmes exist in Europe; individual countries regularly survey plots as part of their own National Forest Inventory, while specific programmes have been run to coordinated surveys between countries. In addition, there are academic sources of species distribution data (e.g. the Croatian plant distribution geoportal developed by University of Zagreb[1]), and, more recently, citizen science data on species occurrences (e.g. iNaturalist[2], Biodiversity Data[3], Naturgucker[4]).

1.1 Types of tree species distribution maps available from the JRC

Based on these multiple data streams, the Joint Research Centre (JRC) produces maps of forest tree species distribution in Europe. Many were produced for the European Atlas of Forest Tree Species [7] while others were generated or reprocessed to support pest risk assessments by the Plant Health (PLH) Panel of the European Food Safety Authority (EFSA). Since 2011, EFSA has used JRC maps of host plant species for their scientific opinions assessing risks associated with forest pests. JRC produced different map types according to requested taxa and available data, such as observed host tree presence maps at European [8] and at global scale [9] or probability maps [10]. Maps outlining the distribution of individual tree species in Europe that were made at the JRC, were also adopted by the European Forest Genetic Resources Programme (EUFORGEN)[5].

Depending on the application, and the specific questions it raises, these maps need to convey different information and highlight different aspects of a species' distribution. For example, in some cases, only known occurrences of a species should be mapped, in others the probability of a species occurring is of interest, while in yet others the maps should show where a species could survive. The question, and its complexity, determines the requirements that are placed on the input data, and the data processing methods. This implies that not all existing *in situ* data on species distribution are used for all maps, and that the methods to produce different maps can vary widely in complexity. Furthermore, the availability and quality of data describing where species do or do not occur differs between species and regions. As maps based on these data are affected by these uncertainties, certain maps are more reliable for particular types of species or in certain

[1] hirc.botanic.hr/fcd
[2] www.inaturalist.org
[3] www.biodiversityireland.ie/record-biodiversity
[4] www.naturgucker.de
[5] www.euforgen.org

regions. To convey this, some of the maps are produced with an accompanying ‘trustability’ map.

2 The data behind the maps

Tree occurrences are recorded in various geo-databases; some report occurrences systematically on a regular, but coarse, geographical grid, while others follow no predefined geographical sampling scheme. Some databases record only the presence of a species, while others include both presence and absence. Data sets also differ greatly in the time span and geographical area they cover, as well as number and identity of species they cover.

Here, we classify data available at the JRC as *core* data sets and *ancillary* data sets. The former are at the cornerstone of the JRC's maps because they include the best quality data on forest tree species available in Europe. They have been recently harmonized to obtain a single data set for forest tree species in Europe, the *EU-Forest* data set [11], which covers most of Europe. The ancillary data sets, while often of lesser quality than the EU-Forest data, can fill in some of the geographical areas not covered by the core data sets such as former Yugoslavia and some of the Eastern European countries (see Annex 1). For instance, in addition to the EU-Forest data, a selection of occurrence records from the ancillary data were used to produce the first Atlas of European tree species [7]. Ancillary data were crucial to enrich the data set, and the maps created from it, with occurrences recorded in climatic conditions that are relatively uncommon in Europe, such as those in Turkey or Ukraine.

2.1 Core data sets

2.1.1 National Forest Inventories

The European database of National Forest Inventories (EU-NFI) contains data from National Forest Inventories and provides information on the forest tree species composition in approximately 375,000 sampling plots throughout 21 European countries [7]. The inventories associated with the records range from 1993 to 2009, with more than 90 % of the records made between 1998 and 2008, and more than half between 2004 and 2008. Less than 5 % of the records were made before 1995 or after 2008 [11].

To create EU-NFI, data from individual NFIs were harmonised to document tree species occurrences across most of Europe. To do this, the JRC and ENFIN, a network of NFI organizations, established a list of the ca. 250 most common forest tree species in Europe for which existing NFI records were assembled. The data in EU-NFI are registered in a 1 km geographical grid that does not retain the precise location of the NFI plots.

Forest inventories are autonomously organised by individual countries. While most common tree species are monitored by all the European NFIs, information on secondary species or taxa growing only in part of the continent may be missing from some NFIs. This is often also the case for smaller trees, alien and rare species, and species for agro-forestry or short-rotation forestry. As a list specifying the species recorded by each national inventory was not available, EU-NFI data set contains some uncertainties about species absences. Nevertheless, this remains the most comprehensive data set on *in situ* tree species occurrences in Europe.

2.1.2 ICP-Forests

The International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forest[6] (ICP-Forests) was launched in 1985 under the international Convention of the Long-Range Transboundary Air Pollution (CLRTAP) of the UN-ECE[7]. The aim of the project was to coordinate at European level the effect of air pollution collecting comparable data on changes in the forest environment related to state of the environment, and to contribute to the evaluation of the trends of damage and better understanding of the cause-reaction relationship. In 2003 the project ICP-Forest was included in the Forest

[6] icp-forests.net

[7] rod.eionet.europa.eu/instruments/578

Focus programme (EU regulation No.2152/2003) [12]. Under this scheme, other anthropogenic, biotic, and abiotic factors impacting forests, such as forest fires, were monitored. Moreover, the goal and methods of investigations were further developed to cover wider environmental aspects of the forest health state, including climate changes, biodiversity and state of forest soils. In 2009 ICP-Forest was then included under FutMon project[8] (38 contributing States) and co-financed by EU through the LIFE+ programme [13]. The monitoring method were developed again to make it more effective. New plots were implemented, connected also to national forest inventories. Since 2011 ICP-Forest is a large long-term monitoring project financed by 40 European countries as well as US and Canada. It has a harmonized and standardized survey method, an established network of sample points and an online platform for forest data storage and exchange.

Collected data in ICP-Forest database are designed in two monitoring levels:

- Level I for large scale monitoring of tree crown condition on a 16 x 16 km grid throughout Europe;
- Level II for intensive monitoring of around 500 plots in selected forest ecosystems with the aim of understanding the cause-effect relationships between natural stress factors (in particular air pollution) and forest condition.

The resulting geo-database covers 42 countries and includes 165 tree species, through more than 18,000 geo-located sample plots (active and historical), part of which were inherited by the Forest Focus projects [14] [15].

2.1.3 BioSoil

The BioSoil database was one of a number of studies initiated in the context of the ICP-Forest under the Forest Focus Regulation (EC) No. 2152/2003 [12]. The aim of the BioSoil project was to demonstrate how a large-scale European study can provide harmonised soil and forest biodiversity data, contributing to research and forest related policies [16] [17]. It comprised two modules: a Soil Module and a Biodiversity Module. The data set describing tree species occurrences came from the Biodiversity module, in which more than 200 plant species from both the tree layer and the ground vegetation layer were recorded in more than 3,300 sample plots in 19 European Countries. Data were mostly collected in the network of Forest Focus and ICP forest sample points for the countries that joined the project proposal, with some countries using a subset of their network, or setting up an entirely new network specifically for the project [17].

2.2 Ancillary data sets

2.2.1 EUFGIS

The European Information System on Forest Genetic Resources[9] (EUFGIS) is maintained by the European Forest Genetic Resources[10] (EUFORGEN) program, which aims to "maintain, conserve, restore and enhance the biological diversity of forests, including their genetic resources, through sustainable forest management" (Ministerial Conference on the Protection of Forest in Europe, 2007ref-52). The EUFGIS database is openly available through an online portal (http://portal.eufgis.org) that provides information on tree species composition of more than 3,200 forest units in 34 European countries and recording 107 target tree species as well as 45 other tree species growing in these units. The units form a network of forest stands managed for long-term conservation of genetic resources. It includes forest plots where tree populations grow in the environment they are naturally adapted to, as well as sites where trees were planted in other suitable conditions but outside their natural range [18].

[8] www.futmon.org; icp-forests.net/page/political-background
[9] www.eufgis.org
[10] www.euforgen.org

2.2.2 GBIF

The Global Biodiversity Information Facility[11] (GBIF) is a global network of about 60 countries and more than 30 organizations established in 2001. As such, it is the largest open data repository for species occurrences, with globally more than 600 million individual records and nearly 30,000 data sets, and steadily expanding [19]. This web archive, like several other ones, does not verify the geographical quality of published data, making it challenging to use the data in assessments of tree species distribution [20]. To circumvent this, we selected GBIF data sets from reputable sources (museums, universities, national inventories, and botanical projects) to inform the species distribution mapping. This selection of data sets obviously includes only a subset of the species and geographical areas covered by GBIF.

2.2.3 Conifers of the World

Conifers of the World[12] was created by the botanist Aljos Farjon and provides a collection of nearly 37,000 occurrence records of 792 conifer species all over the world (in Europe 2,700 records of about 60 species), some of which come also from historical reports from the 18th and 19th century [21].

2.2.4 Atlas Florae Europaeae

The Atlas Florae Europaeae[13] (AFE) is the main European atlas of native plant species. Sixteen volumes were published between 1972 and 2013, providing more than 4,000 species distribution maps in a Universal Transverse Mercator (UTM) grid with mostly 50x50 km cells (cells in the overlap of multiple UTM zones have deviating sizes). These maps are one of the most acknowledged sources for defining the range of European native plants. The ongoing AFE project follows the Englerian taxonomic sequence, starting from pteridophytes and gymnosperms up to part of Rosaceae in the latest volumes. Distribution information of many woody species was taken from volumes 2 and 3 [22] [23]. However not all tree species have been mapped, as this project is not yet complete and other tree species will be described in forthcoming volumes.

Table 1. Overview of data sets recording tree species occurrences in plots, where a 'record' is defined as a geo-located species occurrence in a data set.

Data set	N of plots	N of records	N of species	Data set's time span
EU National Forest Inventories	374,784	768,228	241	1993-2009
ICP Forest	18,205	3,094,479	165	1987-2014
Forest Focus	8,614	20,634	50	2001-2010
BioSoil	3,369	19,114	208	2005-2008
EUFGIS	2,431	8,332	152	1973-2013
Conifers of the World (in Europe)	20,803 (2,167)	36,773 (2,777)	792 (63)	1700-2012
Atlas Florae Europaeae	4,654	813,163	4,124	1972-2004

[11] www.gbif.org
[12] herbaria.plants.ox.ac.uk/bol/conifers
[13] www.luomus.fi/en/atlas-florae-europaeae-afe-distribution-vascular-plants-europe

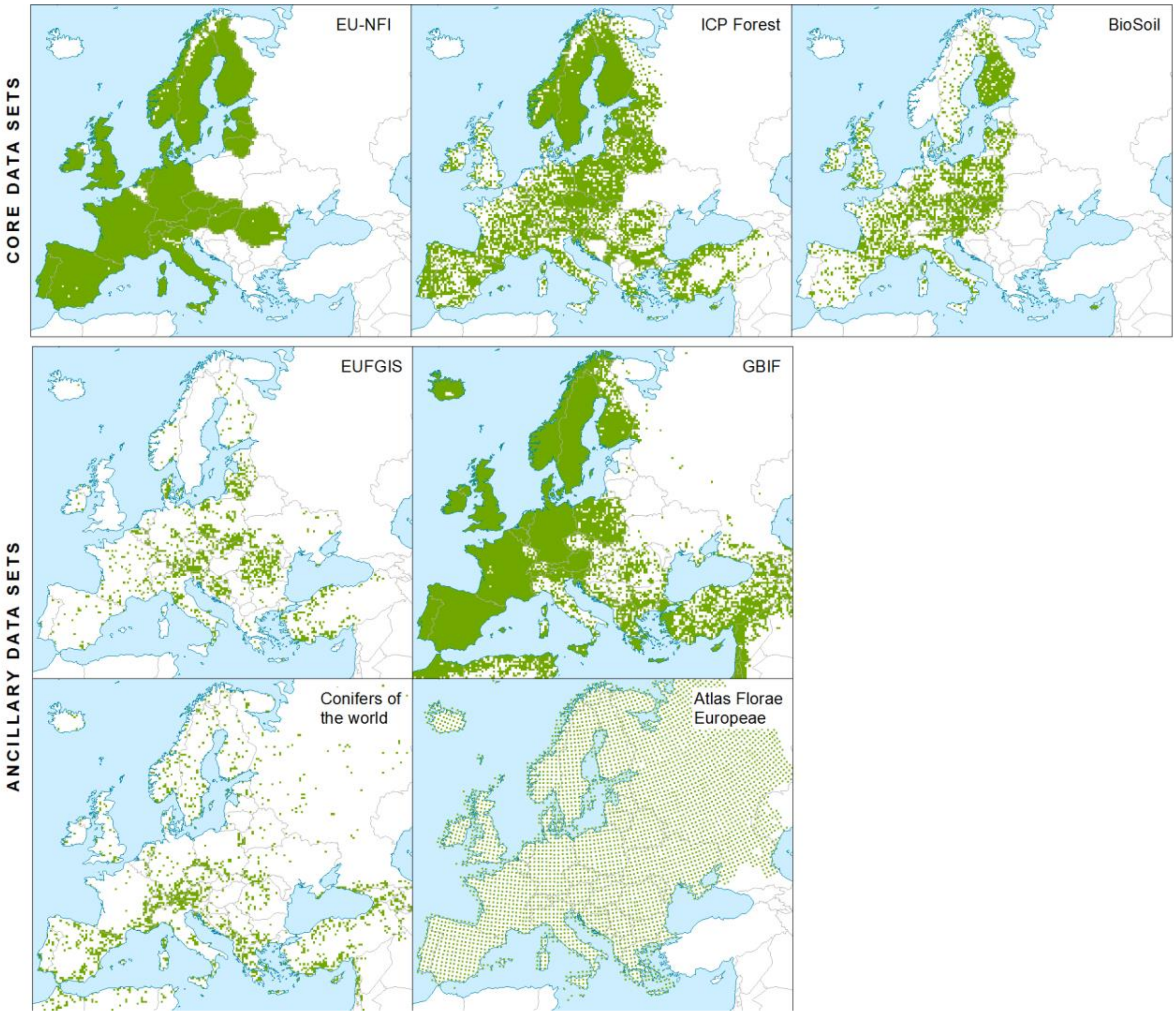


Figure 1. Locations of observations in different data sets recording tree species, illustrating the wide range in the density, extent, and sampling strategies of the data sets. The data sets were used to generate tree species distribution maps. EU-NFI, ICP Forest and BioSoil were considered core data sets, and EUFGIS, GBIF, Conifers of the World, and Atlas Florae Europaeae served as ancillary data sets.

2.3 Features and limitations of data sets for species distribution mapping

The following table highlights main features and some strengths and weaknesses of the individual databases for Europe-wide tree species distribution mapping.

Table 2. Features, strength and limitations of the collected tree species databases.

DATABASE	SPATIAL PATTERN	OCCURRENCE TYPE	STRENGTH	WEAKNESSES
EU National Forest Inventories (EU-NFI)	1 km^2 grid in LAEA projection	Presence/ (Absence for limited species and country/sub-country areas)	- Freely available. - Highest data density in Europe. - High spatial resolution with data on 1 km^2 grid. - Covers a broad range of tree species, and can thus inform biodiversity studies. - For certain species, absences from plots can be inferred. Such data aids species distribution modelling.	- Alien species, shrub species, and trees of limited interest to the local forestry sector, are not always recorded. - Some trees that are difficult to classify at the species level are recorded at the genus level only. - The recorded species differ among countries; an authoritative list of which species are recorded where is not available making absences highly uncertain for some species. - Information about sample plot size and species abundances is not available. - Sampling spatial density is irregular among countries, but partly remedied by the 1 km resolution of the data.
Forest Focus	Geo-located sample plots	Presence/ absence	- Freely available at 1 km^2 grid. - Repeated measurements over 6 years (2003-2009).	- Covers relatively few tree species (ca. 50). - Low spatial accuracy. - Sampling spatial density is irregular among countries.
BioSoil	Geo-located sample plots	Presence/ absence	- Freely available.	- Low number of sample plots (ca. 3300). - Sampling spatial density is irregular among countries.
ICP Forest	Geo-located sample plots	Presence	- Covering most of European countries with a relatively high data spatial density.	- Restricted data.
EUFGIS	Geo-located sample plots	Presence	- Freely available.	- Moderate number and irregularly distributed conservation units (ca. 3200 plots).

DATABASE	SPATIAL PATTERN	OCCURRENCE TYPE	STRENGTH	WEAKNESSES
Conifers of the World	Geo-located sample plots	Presence	- Covers all coniferous species and subspecies of the world. - Global extent, including observations in all European countries. - Freely available.	- Many presence records come from historical data (starting in the 18^{th} century) and may no longer be valid. - Records only species presences, not absences.
GBIF	Geo-located sample plots	Presence	- Freely available. - Includes a wide range of species. - Near-global extent. - Constantly updated.	- Contains regional and national databases, but leaves large areas of Europe uncovered. - Records only species presences, not absences. - Not systematically checked for quality.
Atlas Florae Europaeae	~50 km^2 UTM grid	Presence/ Absence	- Covers a broader selection of vascular plants besides tree species. - Covers all of Europe except Turkey and the Caucasus. - Records the presence and the absence of species within each grid cell.	- Records presences in a very coarse spatial grid only. - Sampling intensity varies among countries (especially the easternmost ones) and among grid cells according to their accessibility, which leads to some false species absences. - As the project is ongoing, it does not include all woody species yet. - Dated source that was never updated. - Not freely available.

2.4 EU-Forest, a harmonized tree species occurrence data set

EU-Forest is a an open-source and publicly available data set resulting from the merger of the three highest-quality tree species distribution data sets available to the JRC in 2017: the tree occurrence data provided by Forest Focus (ICP-Forest database from 2003 to 2009), by Biosoil and by EU-NFI. The latter accounts for the brunt of data in EU-Forest, as it includes more than 350 woody species and more than half a million of occurrence records spread over 19 EU Member States and two neighbouring countries (Norway and Switzerland).

EU-Forest was harmonized in terms of taxonomic naming and spatial resolution, and is free from duplicates or incomplete records. The data set refers to an INSPIRE [24] compliant geospatial grid, with a spatial resolution of 1 km² in the ETRS89 Lambert Azimuthal Equal-Area geospatial projection (LAEA, EPSG: 3035[14]), which has been inherited from the EU-NFI. In addition, occurrence records from Forest Focus and Biosoil, up-scaled to a spatial resolution of 1 km², were implemented to fill in some important gaps in Belarus, Bulgaria, Greece, Croatia, Northern Ireland, Poland, Slovenia, Cyprus, and Belgium. The result is the largest sample plot collection recording tree species in Europe, by far.

The EU-Forest is at the core of the European Atlas on Forest Tree Species, which relied heavily on it to generate distribution maps for more than 80 tree species found in Europe. In the creation of the Atlas, a selection of occurrences from additional databases (i.e. EUFGIS) was also used to cover some of those areas not covered by EU-Forest, such as the Balkans, Turkey, and Ukraine.

2.5 Trees outside forests

Most data sets recording tree species in field plots concentrate on forest species; this is true for National Forest Inventories as well as for Biosoil (BS), Forest Focus (FF) and EUFGIS, which were specifically designed for forest ecosystem monitoring. For this reason, these surveys are based on plots that are located in forests and they ignore trees outside forests, such as 1) tree species that can naturally occur in marginal non-forest habitats (e.g. poplars and willows along water courses); 2) trees planted on agricultural or urban land (e.g. fruit trees and trees for short rotation forestry); 3) ornamental and horticultural trees (i.e. park and garden trees).

Many tree species occur both in- and outside forests, but plot data sets targeting forests, and the JRC maps derived from them, greatly underestimate their range. However, tree species that mostly occur outside rather than inside forests are predominantly non-native ornamental species, and are recorded only rarely or not at all. The Lawson cypress (*Chamaecyparis lawsoniana*), for example, has been planted in parks and gardens across most of Europe, but shows up rarely in the plot-based data. When it does, it is mostly in those countries where the species is planted for its timber.

[14] spatialreference.org/ref/epsg/etrs89-etrs-laea

3 Maps produced by the JRC

The JRC produces different types of tree species distribution maps that can help answer a range of questions. To make it easier to distinguish these map types, we here provide examples of each one, and notes on the data that goes into them, the questions they address, and their limitations and sources of uncertainty. For those maps available online, you'll find a web-link.

3.1 Occurrence maps

3.1.1 Presence maps

The presence maps show the locations where the geo-databases report the presence of the species.

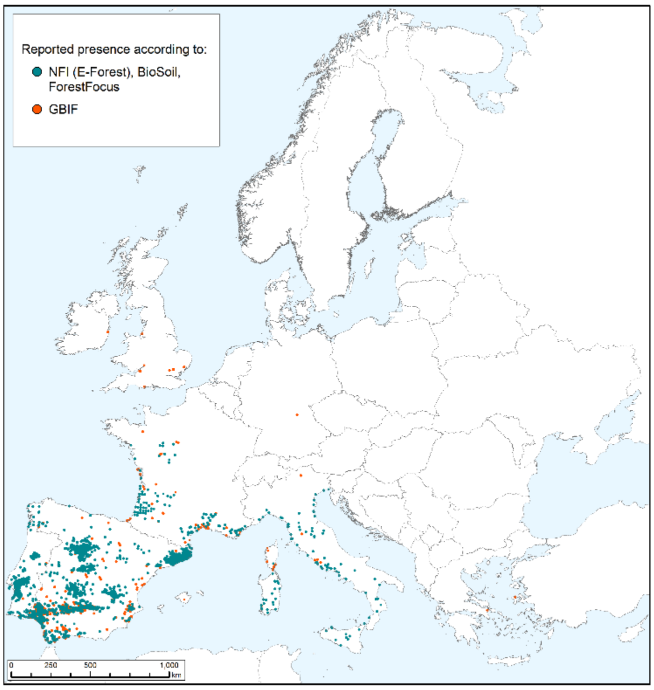


Figure 2. A presence map of Pinus pinea *in Europe using several sources of plot-based data. This map, generated by the JRC, was published by EFSA for a scientific opinion on the phytosanitary risk posed by the pine wood nematode* Bursaphelenchus xylophilus *to some coniferous species [9].*

Input data sets

All data sets providing location of plots, or other sites, where the species was found can be used to generate presence maps, such as EU-NFI, Forest Focus, BioSoil, ICP Forest, EUFGIS, Conifers of the World and GBIF. The AFE database cannot be used, because it does not provide a precise localization of the species occurrence, but the presence inside a grid of cells of 50 km.

Units

In principle, the locations are shown as dots on the map as the positional uncertainty of the locations is negligible at the scale of the map.

Questions these maps can answer

- *Where is a certain species reported to occur?*

Presence maps show where a species occurs. For species that have few records, e.g. because they are endemic or otherwise rare, this is often the only map type that is reasonable. The low number of records can namely not be robustly aggregated to model distribution or habitat suitability patterns.

Limitations and sources of uncertainty

Species presence maps are strongly biased by the plot design of the databases, which are rarely systematic. In geographic areas not covered by databases, they may (falsely) suggest the species is absent.

Conversely, continental scale maps may suggest the species is present over large areas, which does not imply the species is abundant anywhere.

Suggested caption

Known occurrences of species {*species name*} in Europe, based on {*list of used data sets*}.

3.1.2 Presence-absence maps

These maps show not only where a species was recorded as present, but also where it was recorded as absent, thus revealing the spatial pattern of sample plots.

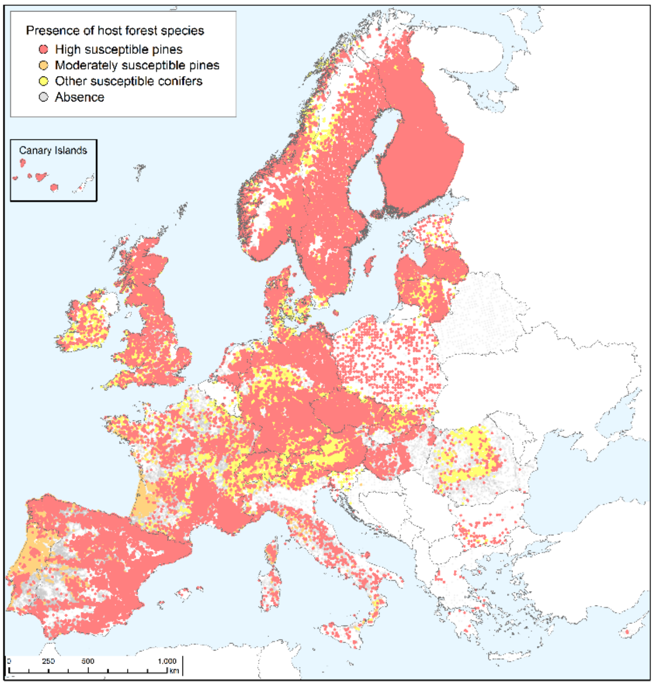


Figure 3. Presence-absence map of coniferous tree species that are susceptible to the fungus Scirrhia pini*, and distinguishing their degree of susceptibility. This map was used in EFSA's risk evaluation of this fungus in Europe [8].*

Input data sets

Presence-absence maps require databases that record a known set of species inside each sampling plot. Those databases provide not only information on where a species occurs, but, critically, also on where it is not found. Usable databases for this purpose are EU-NFI, Forest Focus, BioSoil and AFE. The records in the EU-NFI data have an inherent limitation; different nations namely include different tree species in their inventories, but the precise species lists are not always known, and may vary at subnational level. As a result, field observations where the presence of a certain species is not confirmed may have various explanations. Simply, the species (either present or absent) may have been ignored and not recorded in the plots within a specific region, or the species was actually not found in a specific plot.

Units

These maps are binary in their original form, distinguishing with separate point symbols, plots were the species was found, and plots where it was not found.

Questions these maps can answer

- *Where is a species known to occur and where does it appear to occur more rarely or not at all?*
- *Where has the presence of a species been checked?*
- *Where, and with which intensity, has Europe been surveyed for a species?*

Presence-absence maps provide a direct visualization of species occurrences and absences as recorded in plots. These maps also show the spatial extent and density of the available data. This provides insight into the sampling effort, and may distinguish where a species is outside its niche (no recorded presences despite dense sampling), from where its prevalence is unknown (low sampling density).

Limitations and sources of uncertainty

Because they are a direct representation of the data in the plot databases, the presence-absence maps will reflect the quality and spatial extent of these databases. The maps show no data in areas not covered by the databases, and any recording errors may be visible in the maps, such as confusing between 'not-present' and 'not-recorded' in the EU-NFI data set. Moreover, the map reliability varies with plot density: the prevalence of a species can be more reliably estimated where more plots are available.

Suggested caption

Known occurrences and absences of species {*species name*} in Europe, based on {*list of used data sets*}.

3.2 Chorological maps

Chorological[15] maps provide a synoptic overview of a species' distribution, as result of overlaps and comparisons of numerous and heterogeneous sources (book and paper maps, spatial data sets, and expert reviews). Chorological maps cover the complete species geographical range, extending in some cases beyond Europe.

Input data sets

These maps are based on both historical and recent sources providing information about a species' range from regional to continental scales [25, 26]. Maps are available on the European Atlas of Forest Tree Species web portal[16].

Units

The chorological maps represent species ranges at continental scale. They are more detailed where local information about the species is available. As a result, their minimum mapping unit is not strictly defined. Maps show, as polygons, the native range of a species and as points isolated populations and naturalized introductions.

Questions these maps can answer

- *Broadly speaking, where does a species occur in Europe?*
- *Where is a species native, where are isolated populations, and where has the species been introduced?*

Limitations and sources of uncertainty

This data set draws upon a collection of maps and other records of the species range, which cannot be easily used as numerical maps for modelling. These maps are available only for a limited number of tree species.

[15] Chorology (from Greek χῶρος, khōros, "place, space"; and -λογία, -logia, "speech") is the study of the spatial distribution of organisms.

[16] https://forest.jrc.ec.europa.eu/en/european-atlas/atlas-data-and-metadata

Suggested caption

Chorological map of {*species name*} in Europe, indicating, in broad terms, where the species is native, and where it has been introduced and naturalized [25, 26].

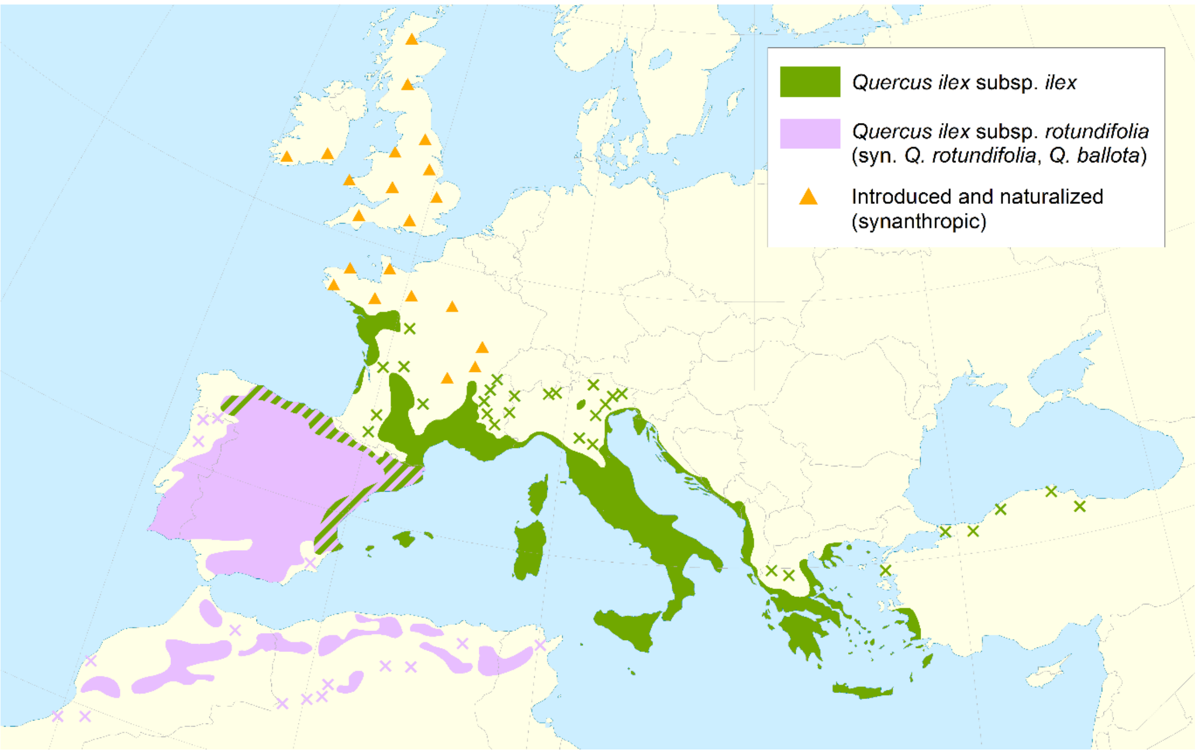


*Figure 4. Chorological map of holm oak (*Quercus ilex*). This map shows the distributions ranges of the two subspecies in different colours. Where both subspecies occur, alternating colour bands are used. Isolated populations and synanthropic areas are shown as point features and symbolized in the map as crosses and triangles, respectively. The map was used as example in the publication presenting a new chorological data set for tree species in Europe [25].*

3.3 Model-derived maps

3.3.1 Relative Probability of Presence (RPP) maps

These maps represent the probability of finding at least one individual of the taxon in a plot placed randomly within the grid cell, assuming that the plot has negligible area compared with the cell. This probability of presence is relative to the specific tree taxon, irrespective of the potential co-occurrence of other tree taxa within the measured plots, and should not be confused with the absolute abundance or proportion of each taxon in the plots. Consequently, the sum of the RPPs associated with different taxa in the same area can exceed 100 %. For example, in a forest with two co-dominant tree species, which are homogeneously mixed, the RPP of both may be 100 %. The RPP maps are produced from the EU-NFI, BioSoil, Forest Focus data with ancillary information using an integrated, adaptive methodology: the constrained spatial multi-scale frequency analysis (C-SMFA) [27, 28].

The spatial density of observations in the plot data set varies greatly throughout Europe and leaves large areas poorly covered by the sample plots. Low plot density is particularly problematic in heterogeneous landscapes, such as mountainous regions and areas with many different land use and cover types, where a plot in one location is not representative of many nearby locations. To account for the spatial variation in plot density, the C-SMFA model considers multiple spatial scales when estimating RPP. Furthermore, statistical resampling is systematically applied to mitigate the cumulated data-driven uncertainty.

The presence or absence of a given forest tree species then refers to an idealised standard field sample of negligible size compared with the 1 km^2 pixel size of the spatial grid of the harmonised data. C-SMFA considered these presence/absence measures as if they were random samples of a binary quantity (the punctual presence/absence, not the pixel one). This binary quantity is a random variable that has its own probability distribution which is a function of the unknown average probability of finding the given tree species within a plot of negligible area belonging to the considered 1 km^2 pixel [27]. This unknown statistic is denoted hereinafter as "probability of presence".

C-SMFA performs a spatial frequency analysis of plot data, creating a preliminary RPP map with an interactive procedure [27]. A set of bell-shaped kernels[17] (asymptotically equivalent to Gaussian kernels) was defined with different sizes distributed logarithmically (so small kernels are more frequent and larger kernels much less frequent). For each 1 square kilometre grid cell, C-SMFA estimates kernel densities over the range of kernels to compute the probability that a given species is present in that cell. The entire array of multi-scale spatial kernels is then aggregated with adaptive weights based on the local pattern of data density. Thus, in areas where plot data are scarce or inconsistent, the method tends to put more weight on larger kernels. However, wherever denser local data are available, these are given more weight to ensure a more detailed local RPP estimation.

The probability to find a single broadleaved (or coniferous) species in a 1 km² grid cell cannot be higher than the probability of presence of all the broadleaved (or coniferous) tree species combined. Thus, to improve the accuracy of the maps, the preliminary RPP values were constrained to not exceed the local forest-type cover fraction. The forest-type cover fraction was estimated from the classes of the Corine Land Cover maps (CLC), which contain a component of forest trees [29, 30]. The CLC maps also define the spatial domain of the relative probability of presence maps, which cover EU28 and another 11 European Environmental Agency members and collaborating countries.

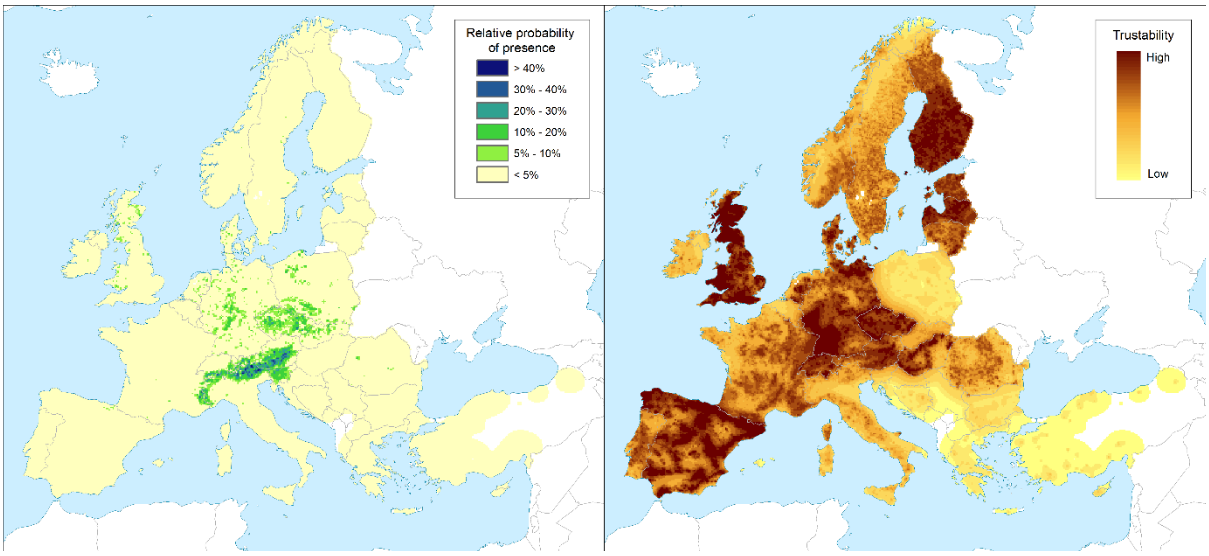


Figure 5. Relative Probability of Presence map (left) and the related Trustability map (right) for the genus Larix *in Europe. These maps have been published in the EFSA's paper about the bark beetle* Ips cembrae *that affects larch trees [31].*

The robustness of RPP maps strongly depends on sample plot density in the in the available data, as areas with few field observations are mapped with greater uncertainty (using

[17] A kernel is a numerical (usually small) matrix N x N used to reclassify each cell value of an image according to neighbouring cells.

larger kernels). This uncertainty is shown qualitatively in the map of 'RPP Trustability'; the Trustability map is computed based on the aggregated equivalent number of sample plots in each grid cell (equivalent local density of plot data). Trustability maps may for example vary among species based on the number of data sets that report them [7] [27] [28].

Input data sets

RPP maps require databases with information about the species presence and absence, such as EU-NFI, Forest Focus and BioSoil.. C-SMFA performed a robust cross-filtering of the input data with an adaptive statistical resampling, to reconstruct the information equivalent with the more likely integrated pattern of presence/absence. This statistical approach is necessary, since in EU-NFI the absences of species in some countries may be false negatives (as not all tree species were recorded in all national forest inventories). RPP maps are available on the European Atlas of Forest Tree Species web portal[18].

Units

RPP maps quantify the probability that a species is present, more precisely the probability of finding at least one individual of the tree species in a plot placed randomly within the grid cell (which is usually 1 km^2), assuming that the plot has negligible area compared with the cell. The Trustability map is dimensionless, as it is a relative measure.

Both RPP and Trustability are mapped at 1 km^2 spatial resolution. To improve visualization at continental scale, these maps can be aggregated, i.e. 10x10 pixels or 25x25 pixels (respectively summarising the information for aggregated spatial cells of 100 km^2 and 625 km^2), by averaging the values in larger grid cells.

The following guidelines can be used to interpret the original probability values:

Table 3. Thresholds used to display RPP maps in the European Atlas of Forest Tree Species [7] including the map value ranges corresponding to the labels in the map legends and their colours.

Map value	Label	Colour scale used in [7]		
		Hex code	RGB code	Colour
- 1	Uncertain, no data	#E7E7E8	231-231-231	
0 – 0.05	Marginal/no presence	#FEF2E2	254-242-226	
0.05 – 0.1	Low presence	#EEF2D9	238-242-217	
0.1 – 0.3	Low-medium presence	#DAE79B	218-231-155	
0.3 – 0.5	Medium presence	#ACC32A	172-195-42	
0.5 – 0.7	Medium-high presence	#81A146	129-161-70	
0.7 – 0.9	High presence	#52753B	82-117-59	
> 0.9	Very high presence	#38572E	56-87-46	

The Trustability values for a particular tree species depend on the number of databases used for computing RPP, as not all tree species are recorded in all databases. To facilitate their visible interpretation, Trustability maps are typically shown in a colour scheme that ensures all colour shades are equally abundant in the map. When displayed like this, the colour scale is specific to an individual Trustability map.

Questions these maps can answer

- *What is the probability of a species occurring in a given area, and, in broad terms, how much do we trust this estimate?*

These maps are used to quantify the relative probability of a species occurring, and can be used for species distribution modelling. It is important to interpret the RPP estimates alongside the Trustability map, which highlights where RPP values have higher or lower levels of uncertainty.

[18] https://forest.jrc.ec.europa.eu/en/european-atlas/atlas-data-and-metadata

Limitations and sources of uncertainty

The uncertainty around RPP values depends strongly on sample plot density, and areas scarcely covered by plots in the used data sets have lower Trustability. For this reason, the RPP of rare or alien species cannot be mapped. Moreover, as the forest-type cover fraction was estimated from the classes of the Corine Land Cover (CLC) maps, the RPP inherits the uncertainties of the CLC data set.

Suggested caption

Relative probability of presence (RPP) map of {*taxon name*} mapped at 1 km^2 resolution. The underlying data are from Europe-wide forest monitoring data sets and from national forest inventories generated from plot-based observations. RPP represents the probability of finding at least one individual of the taxon in a standard plot placed randomly within the 1 km^2 grid cell [27, 28, 32].

Trustability map of RPP expressing the abundance and consistency of the information available to estimate RPP in each grid cell, which depends on the spatial variability in forest plot density. The colour scale of the Trustability map is obtained by plotting the cumulative probabilities of the Trustability values, which are ordinal.

3.3.2 Maximum Habitat Suitability (MHS) maps

The Maximum Habitat Suitability (MHS) maps of a species or other taxon describes where bio-climatic conditions should allow it to survive – regardless of whether the species currently occurs there. High values are assigned to areas where bio-climatic conditions are very similar to those prevailing in at least some of the locations where the species occurs, according to the field observations in the occurrence data sets. Conversely, lower values are assigned to areas where the conditions make it unlikely that the species would survive.

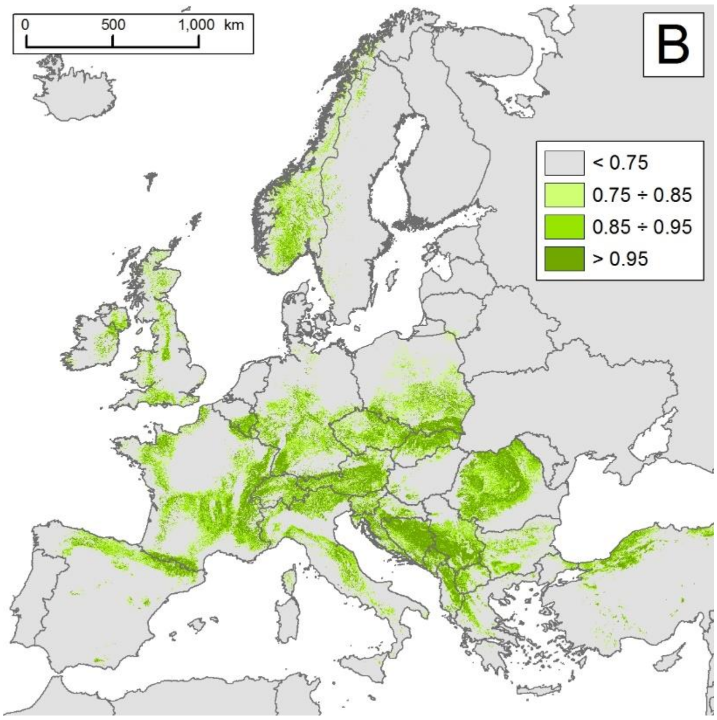


*Figure 6. Map of the Maximum Habitat Suitability of silver fir (*Abies alba*). It was published in the JRC Technical Report for the PESETA II project, and used to assess how the spatial distribution of habitats suitable for silver fir might change under future climatic scenarios [32].*

MHS is modelled following the Relative Distance Similarity (RDS) methodology that considers the bio-climatic and topographic factors (temperature, precipitation, elevation, etc.) of areas where the species is known to occur [32]. RDS typifies those conditions associated with the species' occurrences and then maps where similar climatic and geographic factors conditions are met.

To mitigate the impact of outliers (e.g. peculiar single occurrences of a species in atypical conditions), a statistical resampling technique with block-bootstrap approach was adopted. The approach is summarised in the following sequence of logical steps:

- Splitting data set in random training blocks and one validation block.
- Computing habitat suitability based on isolated blocks.
- Aggregation of blocks via block-bootstrapping (multiple runs).
- Robust ensemble modelling:
  - from multiple runs to final estimation via weighted median
  - from multiple runs to qualitative spatial reliability assessment
- Final validation

The data set was split into 100 random blocks, and based on each one, the climate and topographic characteristics of cells where the species occurred were estimated. As each run produced a slightly different prediction of habitat suitability for each grid cell, the values obtained from the 100 runs had to be aggregated. To do this, a Weighted Median Filter, with weights proportional to similarity, was implemented [33,34]. This aggregation method favours runs with higher similarity, thus mitigating the effects of outliers and preserving the more robust information.

In the final maps, areas where estimated MHS was low (< 0.55; a threshold set based on experience), were labelled as 'negligible suitability' and assigned a value of 0.2 (see Table 5). We used another two metrics from the model to label areas where the maps are particularly uncertain.

The first one, 'Density', describes, for each cell, how similar its bioclimatic conditions are to the ones the MHS model was trained on. When this similarity is low (and there is a low 'Density' of points surrounding the cell in the multidimensional space made up of environmental gradients), the MHS prediction might be unreliable. In the final MHS maps, cells were labelled as "Uncertain, no-data", when the 'Density' were below 0.55 and assigned a value of 0.

The second one, 'Variability', describes, for each cell, how variable the MHS estimates produced by the different model runs were. When this 'Variability' is high, the final aggregated model estimate is less certain. For the final MHS maps, cells with 'Variability' greater than 0.12 were labelled as "Uncertain, no-data" for this reason and assigned a value of 0.

The MHS estimates were validated by comparing them to reported presences. The recorded absences were not used in the validation, as a species recorded as absent in a field plot might be present elsewhere within the spatial cell where the plot falls. For this reason, a classical sensitivity and specificity analysis cannot be performed for the MHS model. However, an assessment of accuracy and specificity was performed for the MHS model for *Abies alba* and illustrates the learning ability of the model: For this species, the area where MHS is greater than 85 % encompasses 78 % of reported presences. Areas with low MHS are associated with negligible presence of the species (less than 0.5 % of reported presences in areas where MHS is less than 50 %). [32].

Input data sets

MHS was modelled using a subset of the EU-NFI, Forest Focus and BioSoil, using both presence and absence observations. This subset was less than 2 % of the total available observations, selected among the ones without obvious indications of problems in the characterisation of "absences", and ensuring reasonable coverage of the overall space of covariates.

The topographic variables were produced from a Digital Elevation Model (DEM) at 100-m spatial resolution [35]. Standard deviation of elevation, elevation range and slope were processed at the original DEM grid size and then averaged at 1-km. The four aspect factors were processed at 100-m grid-size and then the ratio of cells of each major orientation added to a 1 km grid-size.

The annual potential global solar radiation was produced by using the r.sun[19] model implemented in GRASS-GIS (v 6.4) and the DEM at 1 km. Twelve maps of solar radiation (atmospheric turbidity and albedo coefficient absent) for the central day of each month were produced. The annual potential global radiation was computed by integrating the data of the 12 grid maps using the trapezoidal rule.

The WorldClim version 1.4 was used for defining the 23 climate variables. WorldClim contains monthly mean, minimum and maximum temperature and precipitation averaged for the period ~1950-2000 with most of the data for the 1960-1990 period [36]. The WorldClim original maps at 30 arc-seconds were re-projected to LAEA at 1 km resolution.

Table 4. Set of climatic and topographic variables use for computing the Maximum Habitat Suitability.

VARIABLE	DESCRIPTION
SD Elevation	Standard deviation of elevation
Elevation range	Range in elevation
Slope (%)	Slope of terrain
Aspect N*	Proportion oriented to North
Aspect S*	Proportion oriented to South
Aspect W*	Proportion oriented to West
Aspect E*	Proportion oriented to East
Global radiation	Annual potential global solar radiation
Annual average T	Annual mean T
Max T of warmest month	Maximum of monthly mean of Maximum T
Min T of coldest month	Minimum of monthly mean of Minimum T
Annual T range	Max T of warmest month - Min T of coldest month
Mean T of warmest quarter	Mean T of the consecutive warmest 3 months
Mean T of coldest quarter	Mean T of the consecutive coldest 3 months
Winter mean T	Mean T of Jan., Feb., Mar.
Spring mean T	Mean T of Apr., May, Jun.
Summer mean T	Mean T of Jul., Aug., Set.
Autumn mean T	Mean T of Oct., Nov., Dec.
Mean of monthly T range	Mean of monthly maximum T - minimum T
Isothermality	Mean of monthly T range / Annual T range
Annual P	Total annual P
Sum of P of wettest month	Total P of the wettest month
Sum of P of driest month	Total P of the driest month
Sum of P of wettest quarter	Sum of P of the consecutive wettest 3 months
Sum of P of driest quarter	Sum of P of the consecutive driest 3 months
Sum of P of Winter	Sum of P of Jan., Feb., Mar.
Sum of P of Spring	Sum of P of Apr., May, Jun.
Sum of P of Summer	Sum of P of Jul., Aug., Set.
Sum of P of Autumn	Sum of P of Oct., Nov., Dec.
T seasonality	Std. dev. of monthly mean T / Annual mean T
P seasonality	Std. dev. of monthly sum of P / Annual P

* Quantities averaged with a spatial moving window of 3x3 km

The produced MHS maps were finally masked with a tundra map. In this cold desert biome, the tree growth is hindered by the low temperature and short growing season. For this reason, the absence of any tree species in the cells where tundra occurs is considered certain. The tundra domain was defined according to the Nordenskiöld index [37]: mean temperature of warmest month + 0.1 * (mean temperature of coldest month) – 9. Cells masked with tundra were assigned a value of 0.3.

MHS maps are available on the European Atlas of Forest Tree Species web portal[20].

[19] grass.osgeo.org/grass64/manuals/r.sun.html
[20] https://forest.jrc.ec.europa.eu/en/european-atlas/atlas-data-and-metadata

Units

MHS is unitless and ranges between 0 (low suitability) and 1 (high suitability). In cells where the species had actually been observed, MHS was set to 1. MHS values that are below of 0.55 indicate that the likelihood of the species surviving is low.

Questions these maps can answer

- *Where is a species likely to survive given the prevailing climatic, or other environmental, conditions?*

By design, the MHS maps are more trustworthy indicators of where a species is *unlikely* to survive than of where it is likely to survive. This stems from the fact that where MHS is low, the model estimates that one or more of the conditions necessary for its survival are not met. Such conditions are determined based on the climatic and other environmental factors considered in the model. Where MHS is high, however, the model indicates the species is likely to survive, yet the possibility exists that there are biotic or management factors preventing this, but that are not represented in the model, because of lack of data describing them (see next section).

Table 5. Thresholds used to display MHS maps in the European Atlas of Forest Tree Species [7] including the map value ranges corresponding to the labels in the map legends and their colours.

Map value	Label	Colour scale used in [7]		
		Hex code	RGB code	Colour
0	Uncertain, no-data	#E7E7E8	231-231-231	
0.2	Negligible suitability	#F7B571	247-181-113	
0.3	Tundra, cold desert	#FFFFFF	255-255-255	
0.55 – 0.65	Low suitability	#FADF92	250-223-146	
0.65 – 0.75	Low-medium suitability	#F2ECD0	242-236-208	
0.75 – 0.85	Medium suitability	#ADCEED	173-206-237	
0.85 – 0.95	Medium-high suitability	#7AB6DB	122-182-219	
> 0.95	High suitability	#3F75B8	63-117-184	

Limitations and sources of uncertainty

As the MHS model evaluates only a subset of the bioclimatic parameter that matter for species survival, the MHS maps tend to overestimate the potential suitable areas. The temperature, radiation, and precipitation at a particular site might allow a species to survive, but other parameter not included in the MHS model might not (e.g. soil pH, water table level, species competition, silvicultural practices, etc.). Moreover, the used set of bio-climatic parameters are not able to describe the MHS of a species if the number of recorded presences is limited or concentrated in small areas (i.e. rare species, alien species), or if the species is associated with peculiar ecological conditions.

Suggested caption

Maximum Habitat Suitability of {*species name*} based on bio-climatic and topographic factors, indicating how likely a species is to survive, and following the methods described in [27, 28, 32].

4 Commented maps

The following section provides, for two tree species, annotated examples of different types of distribution maps.

The usefulness of the maps varies between tree species and the observational data available for them. Some species are widespread, others are rare; some species are of high interest to the forestry sector (and therefore included in most forest inventories, e.g. hornbeam), while others are not and often bypassed during inventories (e.g. hazelnut).

These examples allow a direct comparison of map types, among and between species.

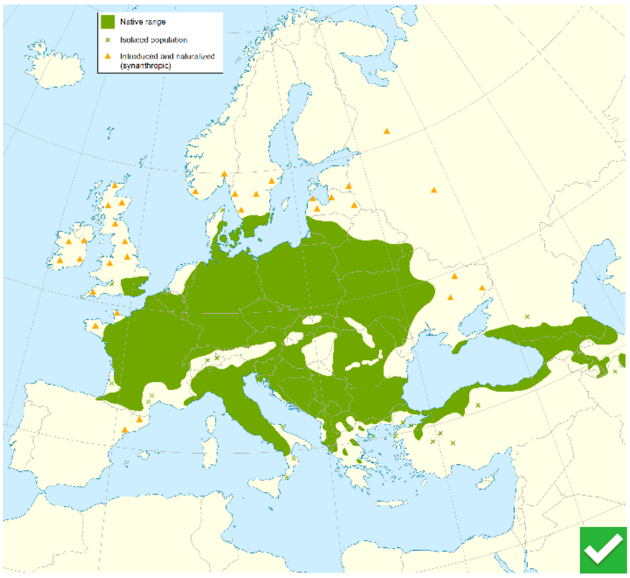
For each species, the chorological and AFE maps first show the general distribution of the species in Europe. The presence and presence-absence maps then show the actual records available in the plot-databases for the species maps. Finally, the RPP and MHS maps show where the species are expected, or able, to occur. The comments alongside the map aid their interpretation, highlighting their strengths and weaknesses depending on the data available for the species. Green or red symbols in the bottom right corner of the figures show whether a particular map is useful, or whether it is likely to be misleading or misinterpreted.

✔ Useful map

✘ Misleading/biased map

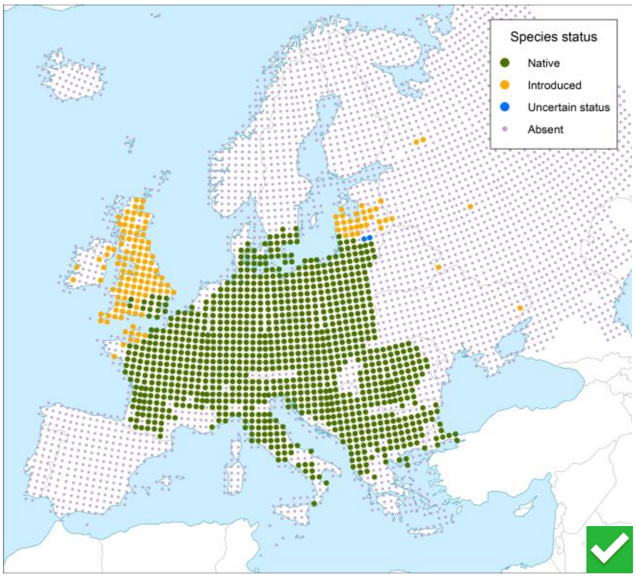
4.1 Hornbeam (*Carpinus betulus*)

The hornbeam is a widespread tree species occurring frequently in mixed temperate forests of Central-Southern Europe. This tree species only rarely forms pure stands and is more often a secondary species in oak or beech forests. The species is common in most of Europe and is recorded in all available databases, owing to its value to forestry. As a result, the different distribution maps for hornbeam have high reliability, especially in Central and Northern Europe.



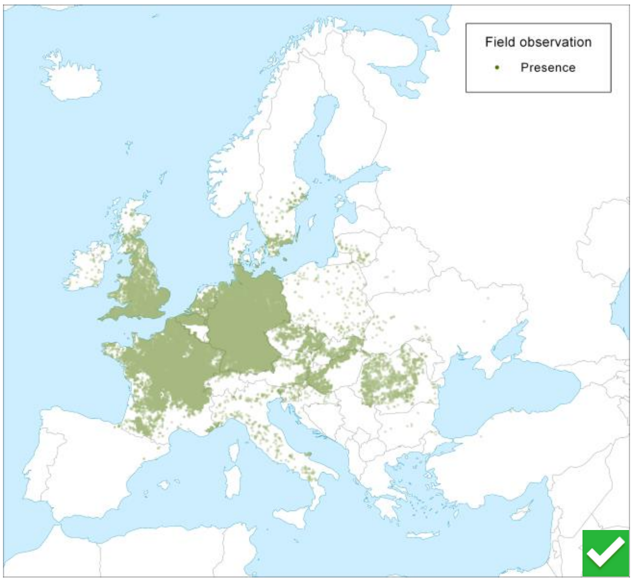
CHOROLOGICAL MAP

The hornbeam has a wide natural range which covers southern Europe (excluding the Iberian Peninsula), Central Europe, up to southern England and southern Sweden. It also occurs East of the Black Sea reaching the Caucasus and northern Iran. It was commonly planted and has now naturalized beyond its natural northern limits, reaching Scotland, Norway, and Estonia. It was also introduced in northern Spain.



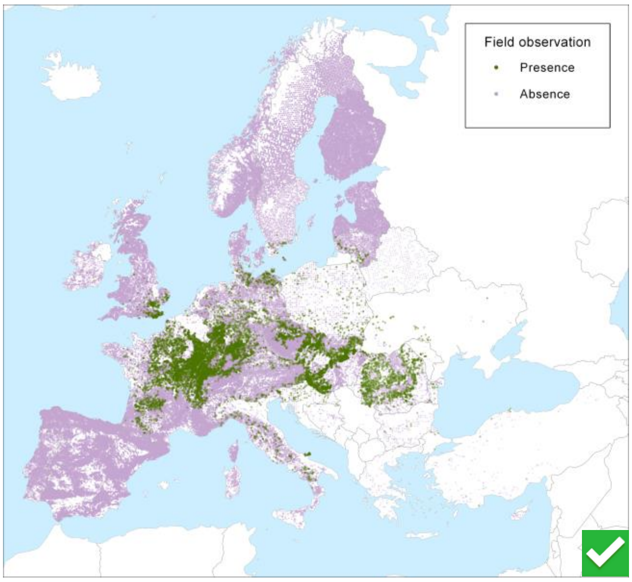
ATLAS FLORAE EUROPAEAE (AFE) MAP

The AFE map was a main source of information to create the chorology map [17]. The AFE map differs from the chorology map in Turkey and the Caucasus, which are out of the AFE's scope, and in areas where the species was introduced more recently (at the northern end of its range and in Spain).



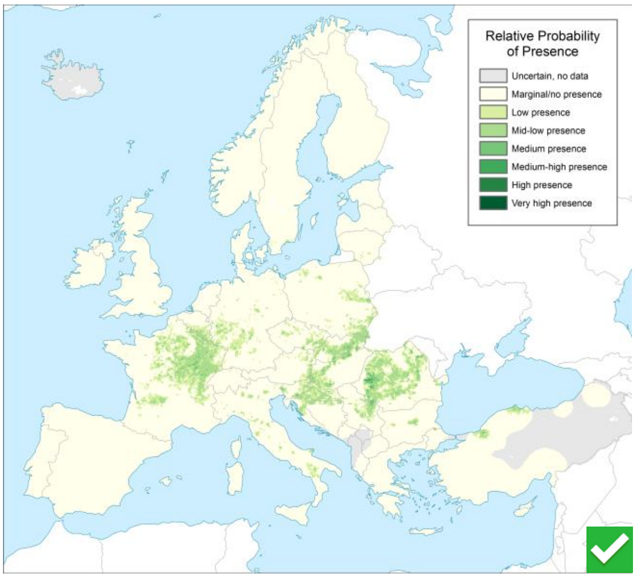
PRESENCE-ONLY MAP

Occurrences of geo-databases show a large and continuous hornbeam presence in central-northern Europe. However, in certain areas the species appears to be not or scarcely recorded, rather than not present: e.g. in southern Belgium, on the Balkan Peninsula and in northern Turkey. For this reason presence maps have to be used with caution because they can be easily misinterpreted. Note that the data contain a single record in South Turkey, which is not seen in the chorology (and hard to spot in this map), and otherwise unconfirmed.



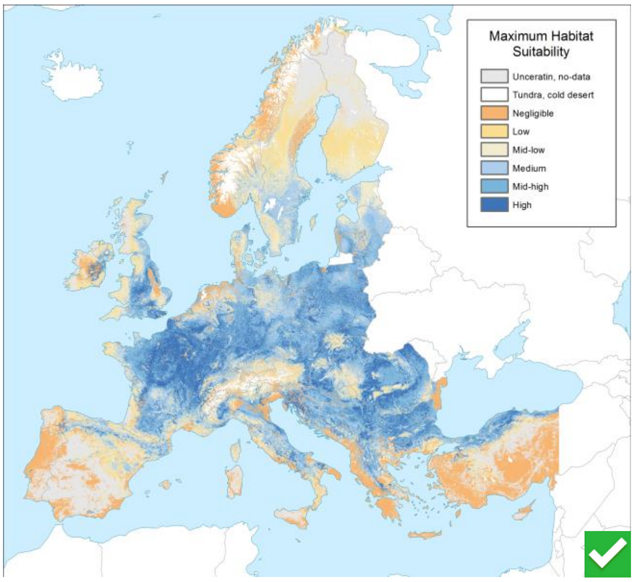
PRESENCE-ABSENCE MAP

This map shows presences of hornbeam by any of the more reliable datasets (EU-NFI, Forest Focus, Biosoil, ICP-Forest). In addition, the map distinguishes absences (in purple) from the remaining areas where no observations are available (in white). Geographical differences in sampling density are evident, which tends to decrease towards the South-East of Europe. As this map does not use the GBIF database (whereas the presence-only maps does), it (wrongly) suggests that hornbeam is largely absent from the northern UK and southern Fennoscandia.



RELATIVE PROBABILTY OF PRESENCE (RPP) MAP

For species that are well-represented in the field data sets, the relative probability of presence can be mapped. Compared with the presence-absence map, RPP removes artefacts due to sudden changes in the observation density. To provide a robust assessment, the RPP calculation discards isolated samples that cannot be modelled. Samples that behave as outliers, tend to be down-weighted in the model (e.g. the single occurrence in Southern Turkey).

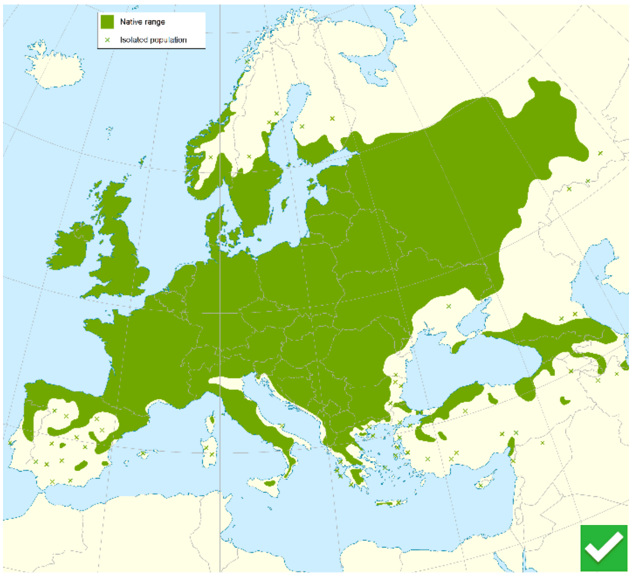


MAXIUM HABITAT SUITABILITY (MHS) MAP

The MHS map shows how hornbeam could survive across large parts of Europe, a result consistent with the independently generated chorology map. It also shows that large parts of northern Europe are environmentally suitable for hornbeam; these are also areas where the species was introduced and is now naturalized. On the other hand, most Mediterranean areas appear unsuitable for hornbeam, supporting the interpretation of the single presence record in Southern Turkey as an outlier.

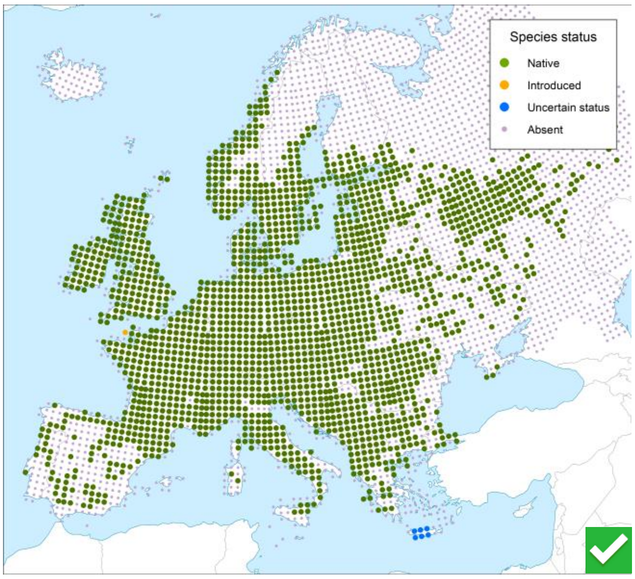
4.2 Hazelnut (*Corylus avellana*)

Like hornbeam, hazelnut is widespread in the mixed European temperate forests. As the species typically grows in shrub form in the understorey with a multi-stemmed trunk and only occasionally grows taller than 10 m, it is of low value to the forestry sector for wood production. As a result, not all National Forest Inventories record hazelnut occurrences, despite its prevalence in many forest habitats from southern to northern Europe. However, in some countries (principally in Turkey and Caucasus Region) this species is cultivated for nut production, often outside forests. For these reasons, distribution maps derived from the forest-focused data sets described here tend to underestimate the species' range.



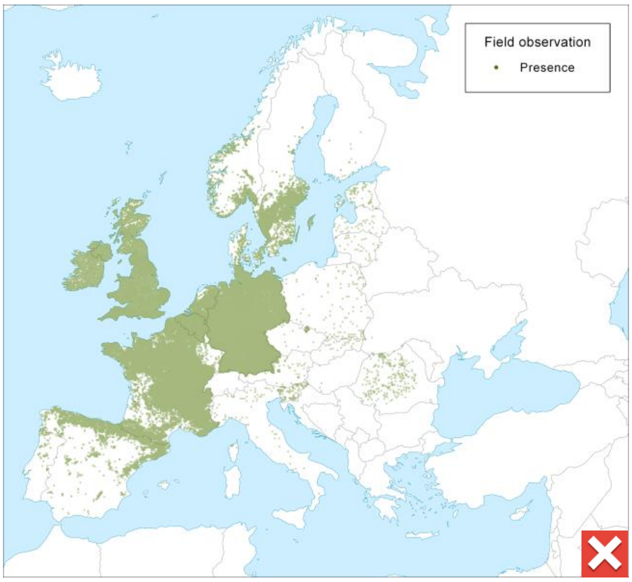
CHOROLOGY MAP

Hazelnut is widely distributed in Europe, from Spain to the Caucasus, and from the Scandinavian Peninsula to the Mediterranean Islands. It is absent only in the northernmost and southernmost extremes of the European continent.



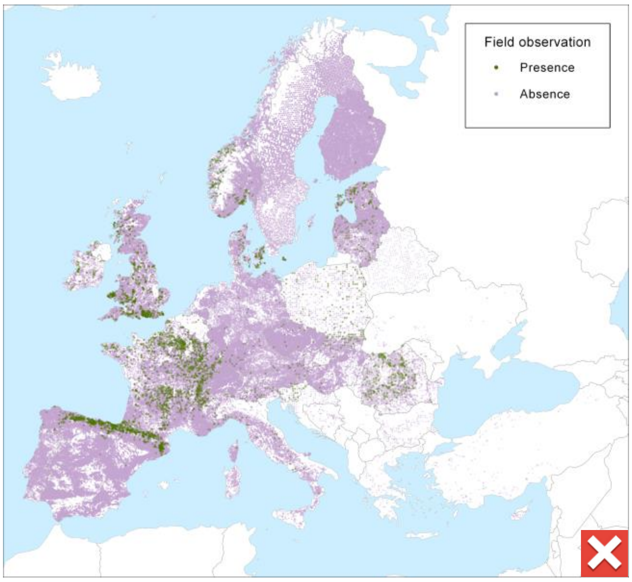
ATLAS FLORAE EUROPAEAE (AFE) MAP

The AFE map provides a similar distribution overview for hazelnut as the chorology maps do. Unlike the chorology maps, however, the AFE maps suggests that hazelnut is less widespread towards the east of its range. This is most likely an artefact caused by the fact that AFE grid cells were less intensely surveyed in that region compared to the rest of Europe.



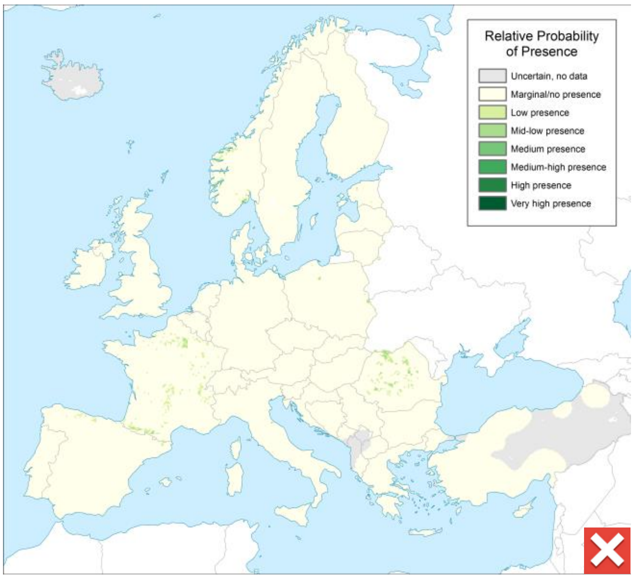
PRESENCE-ONLY MAP

The map of hazelnut occurrences using all available databases shows a near-continuous area of presence in Central and Western Europe. Nonetheless, the pattern suggests large differences between sampling schemes, with potentially lower plot densities in Eastern Europe, and missing data for example in the Balkan Peninsula, Russia, and Turkey. For this reason, this map should not be used.



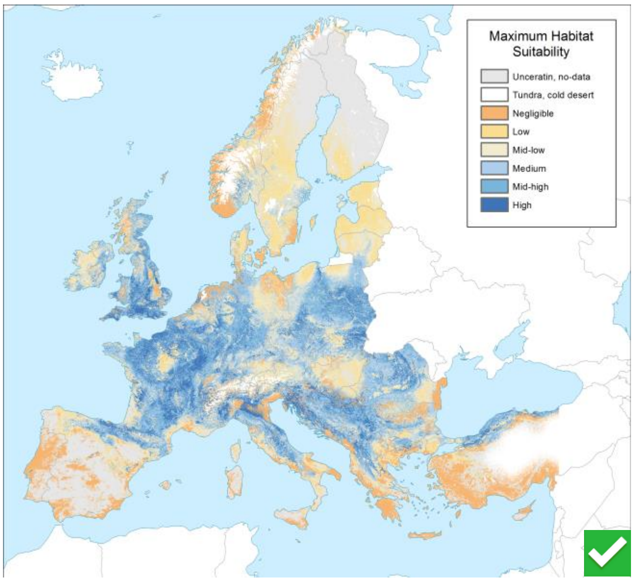
PRESENCE-ABSENCE MAP

Compared with the presence map, the number of occurrences is clearly lower, especially in Germany and Sweden. There hazelnut has not been recorded by the National Forest Inventories as it was not considered a valuable species for forestry purposes. Consequently, this map shows a wrong impression of hazelnut absences in Germany and Sweden despite the high sampling density. For this reason, this map can be considered unreliable and should not be used.



RELATIVE PROBABILTY OF PRESENCE (RPP) MAP

The RPP modelling process is able to filter isolated occurrences. Using presence/absence data sets (see previous map) the RPP of hazelnut is barely visible only in those countries where the species was recorded in the National Forest Inventories (e.g. Spain, France, Romania, etc.). Therefore, this map, like the presence-absence one, is misleading.



MAXIMUM HABITAT SUITABILITY (MHS) MAP

The MHS map indicates most of Europe is suitable for the hazelnut. This result is consistent with the chorology and AFE maps, and indicates that hazelnut is able to survive in several habitats with different climates, and is therefore partly widespread in Europe.

5 Conclusions

This report provides a detailed description of the forest data sets available to the Joint Research Centre, highlighting their origins and some of their strengths and weaknesses for tree species distribution mapping. We provided illustrative examples of each data set with a summary of their main features to help users select the appropriate data sets for their own purposes. For instance, chorological maps are best suited to grasp the general distribution of a species, Maximum Habitat Suitability maps are better suited to show the potential distribution of a species, while plot-data are crucial to represent with high spatial resolution the confirmed presence or absence of a species (although not for all of them or everywhere).

Plot-data are an invaluable resource to produce Europe-wide distribution maps of tree species. The quality of these maps is to a great extent determined by the accuracy and precision of the available plot data. As a consequence, increased access to plot data, including their complete species composition and location, will enhance the quality and detail of maps derived from them through geospatial analysis.

The maps described here are regularly used by the European Food Safety Authority for forest pests risk assessments and can help mitigate the threats posed by emerging forest diseases. In particular, detailed maps of tree species that are capable of hosting harmful pathogens provide an important resource in the context of pest-spread modelling and management.

More broadly, the data sets and maps described in this report can serve ecological and conservation studies. For instance, detailed data on large-scale tree species distribution may help orient conservation efforts by informing the development of accurate biodiversity indicators. Moreover, they may help improve our understanding of the impact of climate change on European forests, and therefore ecosystem services and functions.

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List of abbreviations and definitions

AFE	Atlas Florae Europaeae
CLC	Corine Land Cover
C-SMFA	Constrained spatial multi-scale frequency analysis
DEM	Digital Elevation Model
EFSA	European Food Safety Authority
EUFGIS	European Information System on Forest Genetic Resources
EUFORGEN	European Forest Genetic Resources Programme
EU-NFI	European database of National Forest Inventories
GBIF	Global Biodiversity Information Facility
JRC	Joint Research Centre
LAEA	Lambert Azimuthal Equal-Area
MHS	Maximum Habitat Suitability
RDS	Relative Distance Similarity
RPP	Relative Probability of Presence
UTM	Universal Transverse Mercator

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Annexes

Annex 1. Countries covered by each data set

COUNTRY	EU28	EEA39	EU-NFI	Biosoil	ICP-Forest	EUFGIS	COTW	GBIF	AFE
Austria	x	x	x	x	x		x	x	x
Belgium	x	x		x	x	x	x	x	x
Bulgaria	x	x			x	x	x	x	x
Croatia	x	x			x	x	x	x	x
Cyprus	x	x		x	x		x	x	x
Czechia	x	x	x	x	x	x	x	x	x
Denmark	x	x	x	x	x	x	x	x	x
Estonia	x	x	x		x	x	x	x	x
Finland	x	x	x	x	x	x	x	x	x
France	x	x	x	x	x	x	x	x	x
Germany	x	x	x	x	x	x	x	x	x
Greece	x	x			x	x	x	x	x
Hungary	x	x	x	x	x	x	x	x	x
Ireland	x	x	x	x	x	x	x	x	x
Italy	x	x	x	x	x	x	x	x	x
Latvia	x	x	x	x	x	x	x	x	x
Lithuania	x	x	x	x	x	x	x		x
Luxembourg	x	x			x	x	x	x	x
Malta	x	x						x	x
Netherlands	x	x	x		x	x	x	x	x
Poland	x	x		x	x	x	x	x	x
Portugal	x	x	x		x	x	x	x	x
Romania	x	x	x		x	x	x	x	x
Slovakia	x	x	x	x	x	x	x	x	x
Slovenia	x	x		x	x	x	x	x	x
Spain	x	x	x	x	x	x	x	x	x
Sweden	x	x	x	x	x	x	x	x	x
United Kingdom	x	x	x		x	x	x	x	x
Albania		x				x	x	x	x
Bosnia and Herzegovina		x				x	x	x	x
Iceland		x				x	x	x	x
Kosovo*		x					x	x	x
Liechtenstein		x						x	x
Montenegro		x			x		x	x	x
North Macedonia		x				x	x	x	x
Norway		x	x			x	x	x	x
Serbia		x			x	x	x	x	x
Switzerland		x	x			x	x	x	x
Turkey		x			x	x	x	x	
Belarus					x		x		x
Moldova						x	x		x
Russian Federation					x		x	x	x
Ukraine						x	x	x	x
Caucasus							x	x	
Near East							x	x	
North Africa							x	x	

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