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   Bilz, M., Kell, S.P., Maxted, N. and Lansdown, R.V. 2011. European Red List of Vascular Plants. Luxembourg: Publications Office of the European Union

   UN-ECE, United Nations Economic Commission for Europe (1994). Manual on Methods and Criteria for Harmonised Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests. BFH, Hamburg, Germany

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A plot-level exploratory analysis of European forest based on the results from the BioSoil Forest Biodiversity project

Marta Galluzzi, [1]

Email marta.galluzzi@unifi.it

Francesca Giannetti, [1]

Email francesca.giannetti@unifi.it

Nicola Puletti, [2]

Email nicola.puletti@crea.gov.it

Roberto Canullo, [3]

Email roberto.canullo@unicam.it

Duccio Rocchini, [4]

Email fduccio.rocchini@unitn.it

Annemarie Bastrup-Birk, [5]

Email Annemarie.Bastrup-Birk@eea.europa.eu

Gherardo Chirici, [1]

Email gherardo.chirici@unifi.it

[1] Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Via San Bonaventura 13, 50145 Florence, Italy

[2] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Research Centre for Forestry and Wood, Piazza Nicolini 6, 38123 Trento, Italy

[3] Plant Diversity and Ecosystems Management Unit, School of Biosciences and Veterinary Medicine, University of Camerino, Camerino, MC, Italy

[4] Centre for Integrative Biology, University of Trento, Via E. Mach, 1, 38010 San Michele all'Adige, TN, Italy

[5] European Environmental Agency, Kongens Nytorv 6, 1050 Copenhagen, Denmark

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Abstract

The lack of multi-dimensional data is one of the major gaps which limit the knowledge and the assessment possibilities of European forests. Nowadays, the most extensive and complete data on the European forest statuses are given by National Forest Inventories (NFIs) which provide information about the extent of ~~a~~ forest's resources and their composition and structure. Traditionally, NFIs collect data related to trees, with a limited consideration of other habitat components, such as ground vegetation. This information which goes beyond the mere arboreal component is instead essential for a more complete forest biodiversity assessment. This paper is aimed at introducing the ICP Forests LI-BioDiv database which resulted from BioSoil Forest Biodiversity, a large collaborative European project. This database is organized as a multi-dimensional forest geodatabase that contains forest structure and vegetation records collected in 19 European countries in the period of 2005–2008. The data were acquired from 3311 geocoded plots where several different types of data were gathered: stand-level general information, tree-level data, deadwood, canopy closure and floristic composition. This paper is structured in order to: (1) give a clear overview of the raw data available in the database and to (2) present an elaboration of raw data to calculate simple plot-level forest variables (biomass, deadwood volume, alpha diversity). On the basis of the results we achieved, the LI-BioDiv database appears useful mainly for research purposes aimed at studying cross-relationships between multiple forest variables and not for an operative use for monitoring and assessing European forest. In particular, we hope that this contribution can stimulate scientists to carry out cross-analysis of the database for defining future forest biodiversity indicators that could be introduced into the field protocols of the NFIs in Europe.

AQ1

AQ2

Keywords

ICP Forests
Data structure
Ground vegetation
monitoring programme
NFIs

Communicated by Arne Nothdurft.

Introduction

European forest monitoring

For many years, Hunter (1990) has recognized the multi-dimensional characteristics of forest biodiversity, and trees are no longer solely considered, but also all other living organisms as well. The importance of forest biodiversity was addressed in several international agreements: the 1992 Convention on Biological Diversity (CBD) of the United Nations Conference on Environment and Development, the Ministerial Conference on the Protection of Forests of Europe (MCPFE 2002) and the Montréal Process (2006). In 2003, as part of the

Convention on Biological Diversity (1992), world leaders committed to achieving a significant reduction in biodiversity loss by 2010 at the Ministerial Conference on the Protection of Forests in Europe (MCPFE) where all dimensions of sustainable forest management (SFM) in the pan-European region, including the protection of biodiversity, were addressed (MCPFE 2002). Despite the rise of the scientific research and the efforts made on a global scale, forests are becoming progressively more simplified and fragmented, leading to a loss in biodiversity (Noss 1990; Foley et al. 2005). In 2010 on the European scale, forest biodiversity did not improve, and the amount of biodiversity loss did not diminished (Butchart et al. ~~(~~2010). Nowadays, the most extensive and complete data on the status of European forests is given by the National Forest Inventories (NFIs), which provide information about the extent of forest resources (Chirici et al. 2011). This information mainly concerns trees but usually marginally considers other ecosystem components as well, such as ground vegetation (which are included in the NFIs, for example, of Finland, Belgium, Denmark, Netherlands, etc.), shrubs (e.g. in Norway), or habitat trees, albeit a first step to integrating a standardized tree-related microhabitat survey into NFIs was recently done by Larrieu et al. (2018). In Europe, a part from the NFIs, other forest monitoring networks exist. The Long-Term Ecosystem Research (LTER) network through a multi-scale monitoring system is aimed at improving our knowledge about the structure and functions of ecosystems and their long-term response to environmental, societal and economic drivers since 2003 (http://www.lter-europe.net). FunDivEUROPE, established in 2010, is a research project funded in the 7th Framework Program to quantify the role of forest biodiversity for ecosystem functioning and the delivery of goods and services in major European forest types (www.fundiveurope.eu). Additionally, the Global Forest Biodiversity Initiative is a compilation of data acquired in the field in 777,126 permanent plots in 44 countries (Liang et al. 2016). The compilation of an exhaustive list of international forest monitoring networks developed for long-term activities or just for the duration of specific research projects is out of the ~~purview~~ purposes of this paper, but for a recent review we refer to Danielewska et al. (2013). Despite European political efforts to halt biodiversity loss, a monitoring system to assess the role of forests in reducing the impact of climate change and providing ecosystem services still does not exist (FAO 2017). More information needs to be acquired, within the framework of NFIs or not, for a more complete assessment of forest ecosystems functionality and biodiversity (Mura et al. 2016). The demand for reliable national forestry data at continental level has grown considerably in recent years (FAO 2017). European countries should urgently establish a national forest monitoring system in order to provide timely and reliable forest information on multiple scales. In this regard, FAO (2017) has defined guidelines for planning and implementing multipurpose national forest monitoring systems with the aim of providing a tool to strengthen sustainable forest management on both a local and global scale. Therefore, the new institutional challenge of FAO (2017) is to constitute a National Forest Monitoring System (NFMS) to provide a sound basis for data harmonization and comparability, which we still lack.

ICP Forests network and the BioSoil Forest Biodiversity project

The International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (hereafter ICP Forests) was established in 1985 under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) in order to provide a plots network and a platform to collect and exchange information on European forests (UNECE 1994, 1998; ICP 2006). The ICP Forests network was structured with two different levels of monitoring: level I or large-scale extensive monitoring, and level II or intensive monitoring, and for further information, we refer to the basic design principles for the ICP Forests Monitoring (Ferretti et al. 2010) and the information available at www.icp-forests.org. As part of ICP Forests, the BioSoil Forest Biodiversity project was designed to evaluate if ICP level I plots may be used for a large-scale European study providing harmonized "soil" and "biodiversity" data (the BioSoil Forest Biodiversity project is related to the biodiversity component), thus contributing to: (1) issues related to a better comprehension of forest ecology and (2) supporting forest policies, including sustainable forest management (Hiederer and Durrant 2010). The BioSoil Forest Biodiversity project approach has focused on stand structure, deadwood and ground vegetation information to increase the knowledge of European forest complexity and its ecological significance for forest biodiversity. There are approximately 5700 ICP level I plots used in the BioSoil Forest Biodiversity project. Field measurements concern tree diameters, status and species of all woody plants taller than 1.30 m, top height of at least three of the largest trees, coarse woody debris, vascular species list of ground vegetation and assessment of canopy closure and tree layering. The original BioSoil Forest Biodiversity dataset was unavailable even for research activities due to data policy restrictions. The need for the level I data measured in the BioSoil Forest Biodiversity project was recognized by ICP Forests during the Joint Expert Panel Meeting on European Level Data Evaluation (28th Task Force Meeting, Białowieża, PL, 2012) (Canullo 2016). So, the ICP Forests and the Expert Panel on Biodiversity and Ground Vegetation supported by Camerino University asked the countries involved to voluntarily re-submit the data to be incorporate into a collaborative ICP Forests dataset named as LI-BioDiv dataset (Canullo 2016). Although the BioSoil Forest Biodiversity project represents a unique pan-European effort for a standardized multi-dimensional forest biological diversity monitoring survey, the LI-BioDiv dataset is still underutilized by scientists and the data are available ~~by a request form~~ at www.icp-forests.org ~~(however, it is labelled as "BioSoil/BioDiv" data)~~ (Canullo 2016). As far as we know, despite technical reports such as Hiederer and Durrant (2010), Canullo (2016), and the analysis of the deadwood component recently reported by Puletti et al. (2017), no complete and exhaustive exploratory analysis of the dataset was carried out until now. The aim of this paper is to present the LI-BioDiv dataset aiming at: (1) providing a first complete overview of the data available for the different variables and the different involved countries which is an essential prerequisite to evaluate the consistency, and thus the scientific added value, of the database, and (2) presenting the biomass of living trees and the alpha diversity, which represents potential candidates as forest indicators following for FOREST EUROPE (2015) and EEA (2010).

Materials and methods

In this section, we have included a description of the LI-BioDiv database and the methods used for the calculation of structural and compositional forest biodiversity indicators. For a detailed description on the methods used for the field data collection, we refer to the BioSoil Forest Biodiversity field manual (Aamlid et al. 2007; WGFB 2011). It is important to note that~~ below~~ we present the database as it is, with the data available following the point of view of a potential user of the LI-BioDiv database.

Sampling design

Level I network is made of point locations systematically placed on a 16x16 km grid. The starting coordinate and the orientation of the sampling grid were individually decided by ICP participating country teams (Travaglini et al. 2013). In the BioSoil Forest Biodiversity project, a circular plot with inner nested subplots was created around a subset of level I point locations. The selection of the ICP level I plots to be included in the BioSoil Forest Biodiversity project was carried out by the countries~~,~~. Belgium, Czech Rep., Finland, Latvia, Lithuania and Spain~~, who~~ subjectively selected the points in order to homogeneously cover the area, whereas the UK set up an entirely new ~~random~~ grid ~~network~~ (~~always~~on the basis of a 16X16km grid) specifically for the project as reported by Hiederer and Durrant (2010) (Table 1).

Table 1

Percentage of Li-BioDiv plots chosen from ICP level I network

Country	ICP level I plots (*)	Li-BioDiv plots	%

Country	ICP level I plots (*)	Li-BioDiv plots	%
Austria	136	135	99
Belgium	29	10	34
Cyprus	15	15	100
Czech Republic	205	146	71
Denmark	25	26	> 100
Estonia	97	96	99
Finland	931	630	68
France	553	548	99
Germany	451	425	94
Hungary	74	78	> 100
Ireland	32	36	> 100
Italy	265	239	90
Latvia	207	95	46
Lithuania	82	62	76
Slovak Republic	111	112	> 100
Slovenia	45	45	100
Spain	620	272	44
Sweden	790	795	> 100
UK	89	167	> 100

UK set up a new network for the BioSoil Forest Biodiversity project. (*) Number of ICP level I plots were derived from Lorenz et al. (2005); Michel and Seidling (2016, 2017) as the maximum number of plots surveyed between 1992 and 2016

Around the selected ICP level I points, a plot having a radius of 25.24 m ($2000\,m^2$) with two concentric subplots was created in BioSoil Forest Biodiversity: Subplot 1 has a radius of 3.09 m ($30\,m^2$) and subplot 2 has~~with~~ a radius of 11.28 m ($400\,m^2$) (Fig. 1). In addition, four squared sampling units (A, B, C, D, 10×10 each) were optionally installed for specific surveys (WGFB 2011). The combination of A, B, C and D sampling areas is the same of the two subplots 2 ($400\,m^2$) (Fig. 1). The LI-BioDiv dataset consists of 3311 plots georeferenced in ETRS89 Lambert Azimuthal Equal Area Coordinate Reference System (ETRS-LAEA) (Fig. 2). The plots were surveyed in the field between 2005 and 2008.

Fig. 1

The BioSoil Forest Biodiversity plot.
WGFB (2011), modified

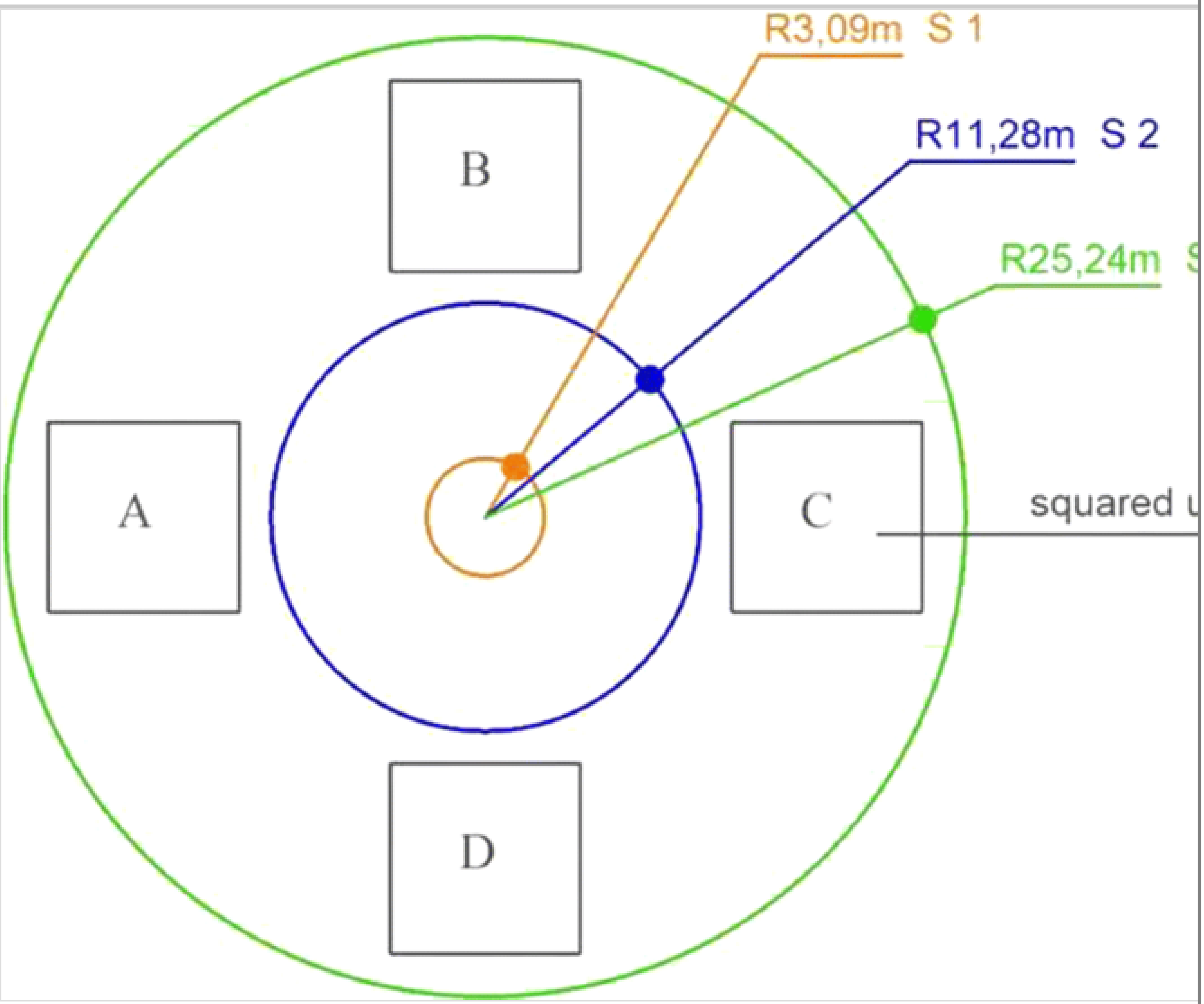
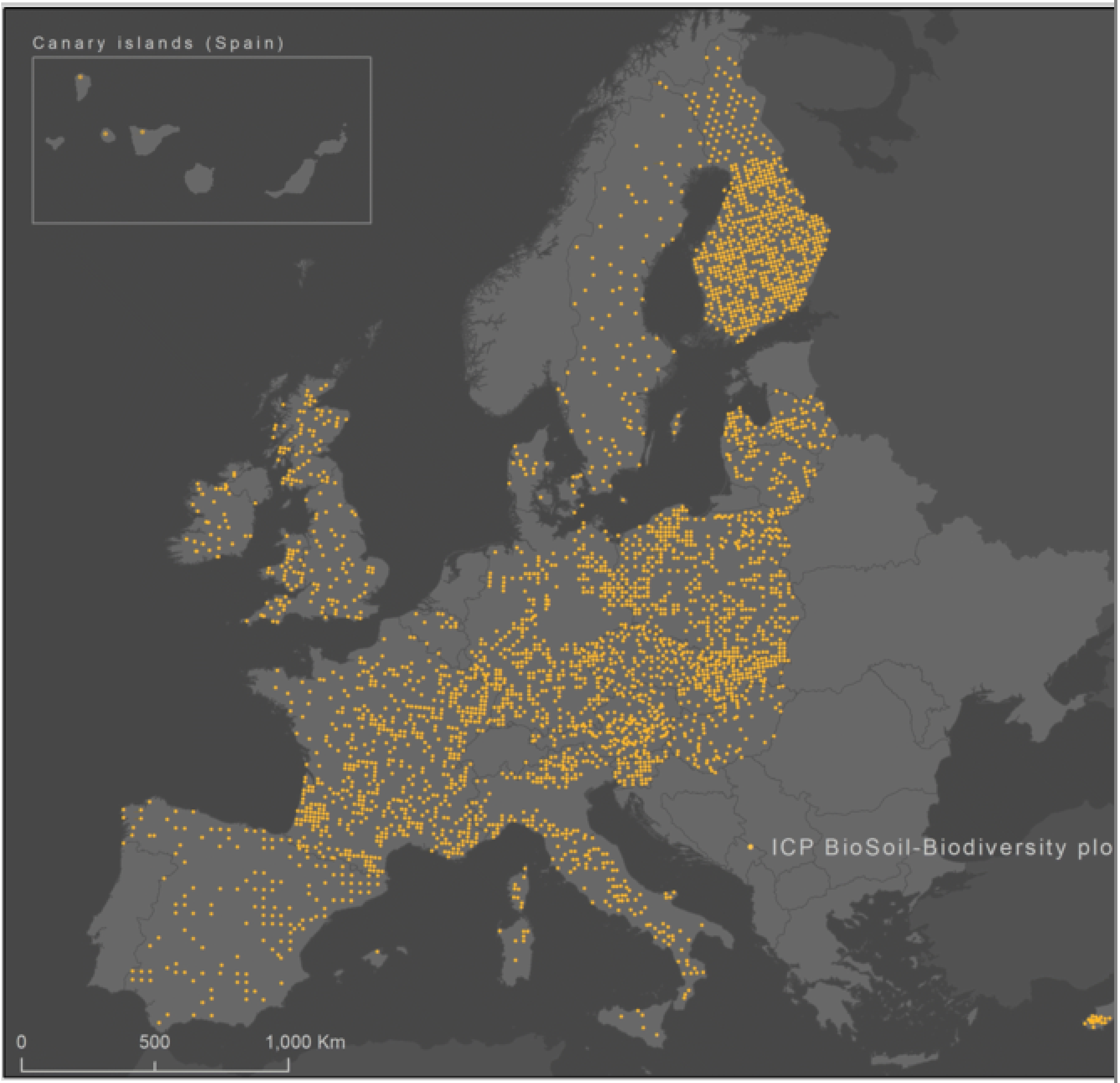


Fig. 2

Distribution of the ICP forest LI-BioDiv dataset unit used in this study (3311 plots)



General information about plots

For each plot, general information ~~was~~ were acquired in the field: geographic coordinates, date of the field measurements, elevation, aspect, slope, previous land use, origin of the stand, management intensity, management type, signs of removal of coarse woody debris, pattern of tree mixture, mean age of the stand, presence of fence and forest type according to the classification of EEA (2006). The canopy closure (CAN) was visually estimated as the percentage of trees canopy cover projected on the ground, referred to subplot 2; it was expressed in classes; the number of tree layers was also assessed. See “Appendix A” for a detailed description of the information acquired.

Biomass of living trees

During the BioSoil Forest Biodiversity, project stems belonging to living and dead trees (standing or lying) were measured if taller than 130 cm adopting a minimum DBH of 0 cm in subplot 1, a minimum DBH of 10 cm in subplot 2 and a minimum DBH of 50 cm in the whole plot (Hiederer and Durrant 2010). For each stem DBH, species and canopy characteristics were recorded. Trees height (THT) was measured for the 3 to 5 trees with the largest DBH in the whole plot. For the explorative purposes of this study, we calculated the plot-level above ground biomass (expressed in kg ha^{-1}) of standing living trees surveyed in subplot 2, where all trees with DBH $> 10\,\mathrm{cm}$ were measured ~~recorded~~. To do so, we found that a multivariate approach for modelling biomass on the basis of tree DBH and height was not feasible because tree height was collected in the field only for trees with the largest DBH, and for this reason, it was not possible to predict tree heights for smaller trees. To overcome this limitation, we decided to model biomass on the basis of DBH only. To do so, we used the European Allometric Equations available at GlobAllomeTree (http://www.globallometree.org/), an online platform which provides a consistent and harmonized database of tree allometric equations for volume, biomass and carbon assessment of trees Henry et al. (2013). Single-tree biomass estimates were then aggregated at plot level as per hectare~~s~~ values. Additionally for each plot, we calculated the basal area too.

Deadwood

The deadwood data and its distribution in Europe were derived from a previous study. Please refer to Puletti et al. (2017) for the methodology ~~of~~ used to calculate~~ing~~ the total deadwood volume of BioSoil Forest Biodiversity plots.

Ground vegetation data

Under the ICP Forests BioSoil network, the objective of the ground vegetation survey was to provide information on species richness and specific abundance at the plot level, following a common and standardized field work method (Aamlid et al. 2007). A mandatory common sampling area (CSA) of 400 m^2 was adopted in order to achieve comparability of results between countries (Aamlid et al. 2007). The ground vegetation assessment was based on a census of the species listed in the Flora Europaea and identified by a nine-digit code (WGFB 2011). The layers where vegetation was evaluated are the moss layer (i.e. terricolous bryophytes and lichens), the herb layer (all non-ligneous and ligneous $\leq$ 0.5 m height), the shrub layer (only ligneous and all climbers > 0.5 m height, up to 5 m) and the tree layer (only ligneous and all climbers > 5 m height). In some plots of France, Luxembourg and Slovenia two layers were used for shrubs: lower shrubs and upper shrubs. In the CSA of $400\,\mathrm{m}^2$, only the vascular plant species list was mandatory assessed. However, as optional variables, some countries have also recorded terricolous lichens and bryophytes, and/or the specific coverage in the various layers using a percentage scale. For the purposes of this work, we calculated the alpha diversity as the total number of species recorded in each CSA for each one of the plots of the LI-BioDiv database. Therefore, to have the same information for all plots, we excluded lichens and bryophytes, as well as the specific coverage of vascular plants, from the analysis (Fig. 11).

Results

In this section, we first present the consistency of the raw data available in the LI-BioDiv database, and then the results of our elaboration for calculating plot-level aggregated values for biomass of living trees, deadwood volume and alpha diversity. The complete description of record layout of the different tables of the LI-BioDiv database is instead available in "Appendix A".

LI-BioDiv database consistency

The DBH, DWD and CAN tables contain records that belong to twenty countries: France, Belgium, Germany, Italy, UK, Ireland, Denmark, Spain, Sweden, Austria, Finland, Hungary, Poland, Slovak Republic, Norway, Lithuania, Czech Republic, Slovenia, Latvia, Cyprus and Canary Islands. The same countries contributed for the GVG dataset, with the exclusion of Sweden. The map representing the spatial distribution of data across countries is presented in "Appendix B". The DBH table counts 3189 plots, but for 59 of them the geographic coordinates are not available (Table 2, "Appendix B", Fig. 9). The DWD table has 2885 plots, but 51 of them are not georeferenced (Table 2). The CAN table has 3214 plots, 176 of them are not georeferenced (Table 2, "Appendix B", Fig. 10). GVG dataset counts 3123 plots, 30 of them are not georeferenced (Table 2).

Table 2

Total number of available plots (TOT) and the number of plots with geographic coordinates information (GEO), by country, in the ICP Forests LI-BioDiv dataset

Country	Code	DBH		DWD		CAN		GVG	
		TOT	GEO	TOT	GEO	TOT	GEO	TOT	GEO
France	1	539	530	504	504	538	538	547	547
Belgium	2	10	10	10	10	10	10	10	10
Germany	4	225	224	212	212	223	222	312	312
Italy	5	219	218	179	176	220	219	201	199

In the LI-BioDiv database, the Canary Islands are considered separately from the rest of Spain, so we presented the data accordingly with the database code

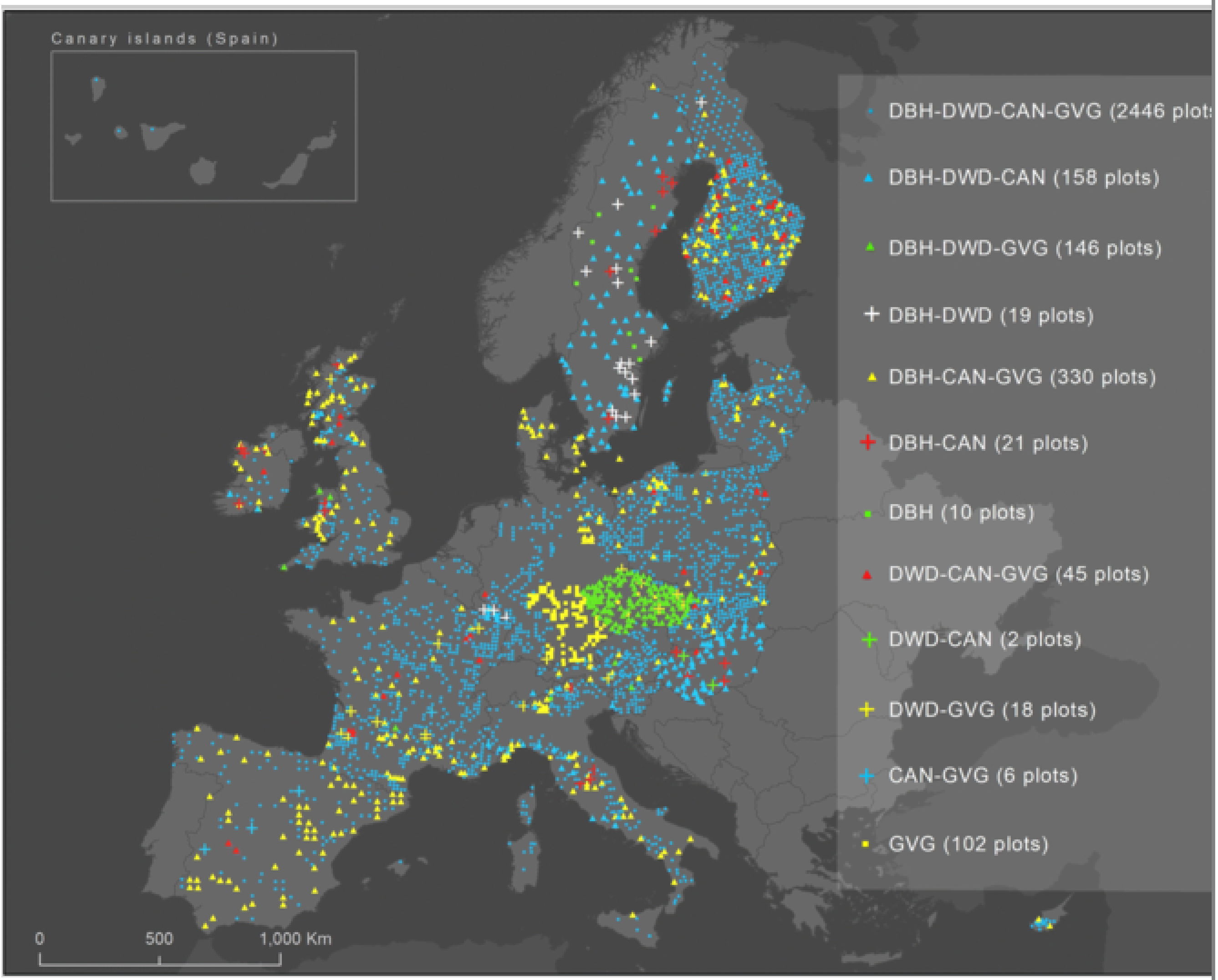
Country	Code	DBH TOT	DBH GEO	DWD TOT	DWD GEO	CAN TOT	CAN GEO	GVG TOT	GVG GEO
UK	6	163	163	121	119	163	163	157	157
Ireland	7	35	34	35	21	35	35	29	29
Denmark	8	22	22	5	5	22	22	22	22
Spain	11	145	142	92	86	151	151	151	147
Sweden	13	100	100	85	85	100	76	–	–
Austria	14	135	135	128	128	133	133	136	136
Finland	15	621	606	577	577	630	625	629	629
Hungary	51	77	75	74	74	78	78	18	18
Poland	53	432	411	408	390	438	438	438	418
Slovak Republic	54	107	106	104	101	108	108	108	107
Lithuania	56	62	61	58	57	62	62	62	61
Czech Republic	58	139	137	142	142	141	–	146	146
Slovenia	60	40	40	40	40	44	40	39	39
Latvia	64	95	95	88	88	95	95	95	95
Cyprus	66	19	18	19	16	19	19	19	18
Canaries islands	95	4	3	4	3	4	4	4	3
	Tot	3189	3130	2885	2834	3214	3038	3123	3093

In the Li-BioDiv database, the Canary Islands are considered separately from the rest of Spain, so we presented the data accordingly with the database code

Regarding GVG dataset, France, Belgium, Germany, Italy, UK, Spain, Finland, Poland, Slovak Rep., Czech Rep., Slovenia and Canary Islands have surveyed the optional percentage coverage of each vascular plant species ("Appendix B", Fig. 11). In reference to the surveying period, the data were recorded between February and December and Galluzzi et al. (2018) provide a description of data variability and the surveying period. As a result of our preliminary analysis on a total of 3311 plots, 74% of them (2446) contain information about all data type (Fig. 3). The remaining plots contain one or more data type, but not all of them. A total of 330 plots contain only DBH, CAN and GVG data, 158 plots contain only DBH, DWD and CAN data, 146 plots gather DBH, DWD and GVG data and 102 plots contained only GVG data. From 2005 to 2008, all data types were collected in each plot at one time with the exception of 283 plots in CAN dataset from France that have been visited in both 2006 and 2007.

Fig. 3

Data type availability for each plot from the ICP Forests LI-BioDiv dataset

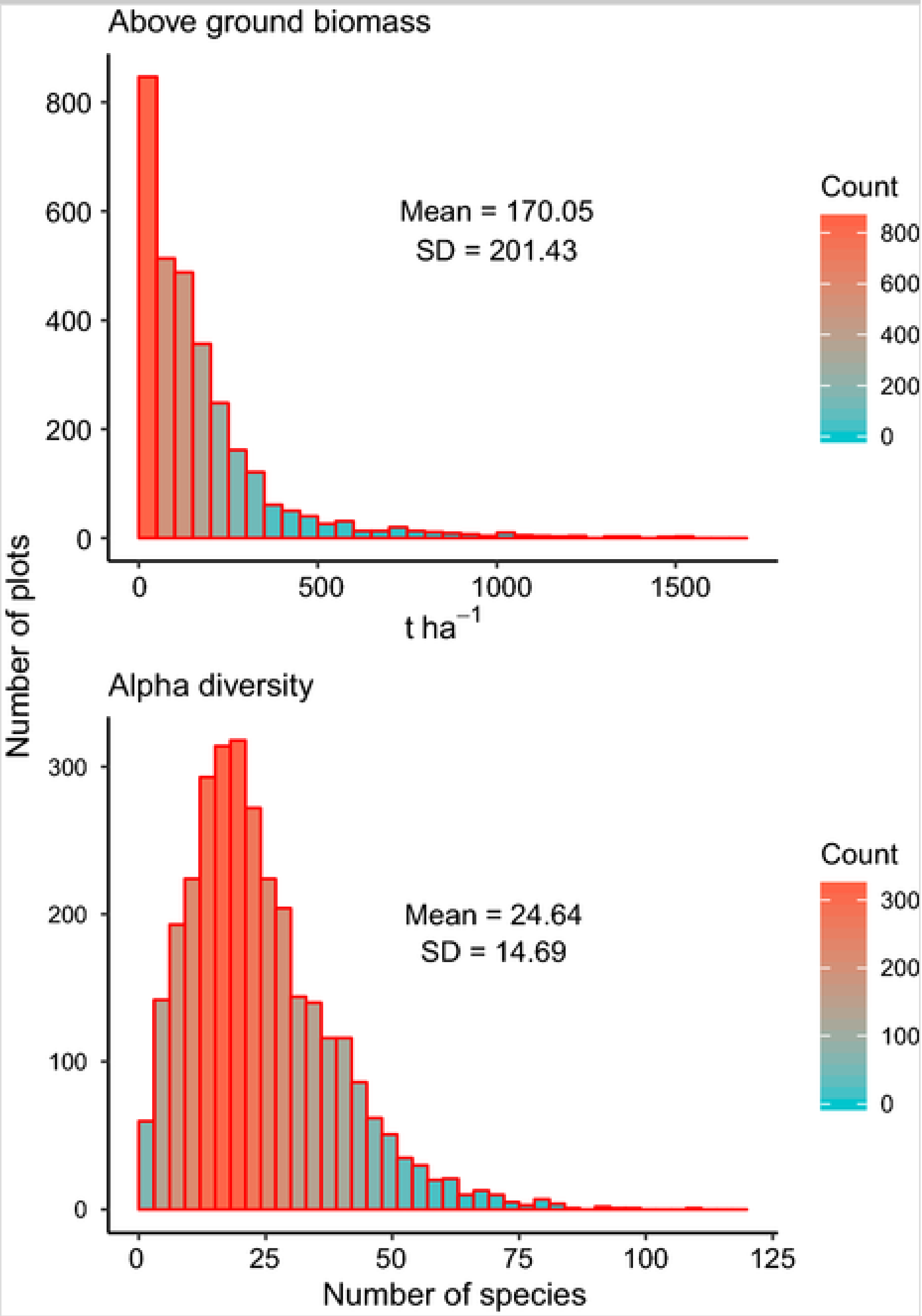


Plot-level aggregated variables

The growing stock and deadwood volume, as well as the alpha diversity distributions through the 3311 plots, are shown in Fig. 4.

Fig. 4

Distribution of the number of plot related with above ground biomass ($\mathrm{t\,ha^{-1}}$) and alpha diversity across the LI-BioDiv database



Above ground biomass ranges between 40 and 120 t ha^{-1} for 50% of the plots (Fig. 5). In order to assess the characteristics of the plots included in the LI-BioDiv, we compared aggregated values by countries with biomass data coming from NFIs (Avitabile and Camia 2018) (Table 3). We found a positive significant relationship between the two data sources ($R^2 = 0.35, F = 9.6, p < 0.01$, Fig. 6).

Fig. 5

Above ground biomass ($\mathrm{t\,ha}^{-1}$) in the plots from the LI-BioDiv database

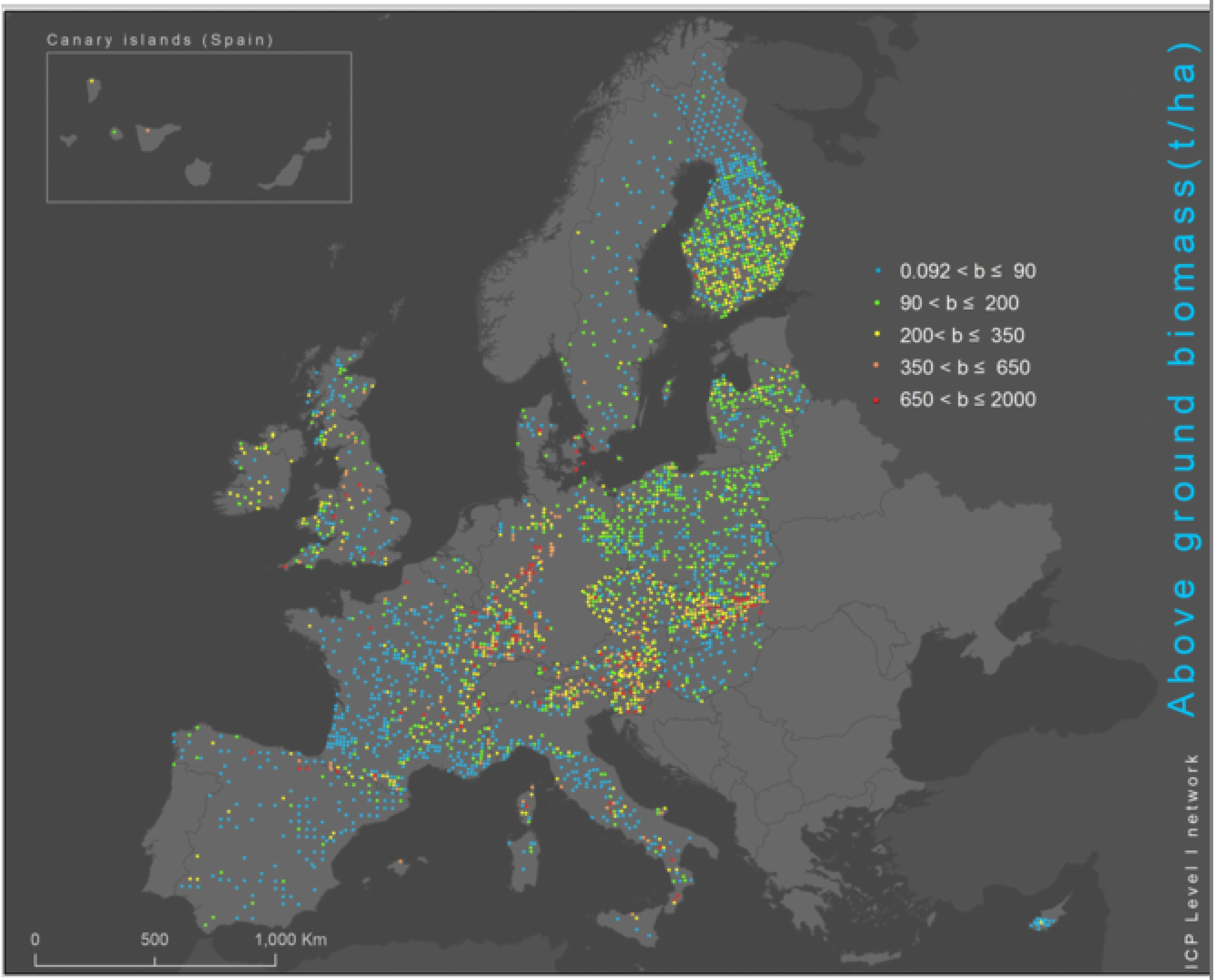


Table 3

Average values of above ground biomass (AGB) by country, data from Liv-BioDiv database and from National Forest Inventories (NFI)

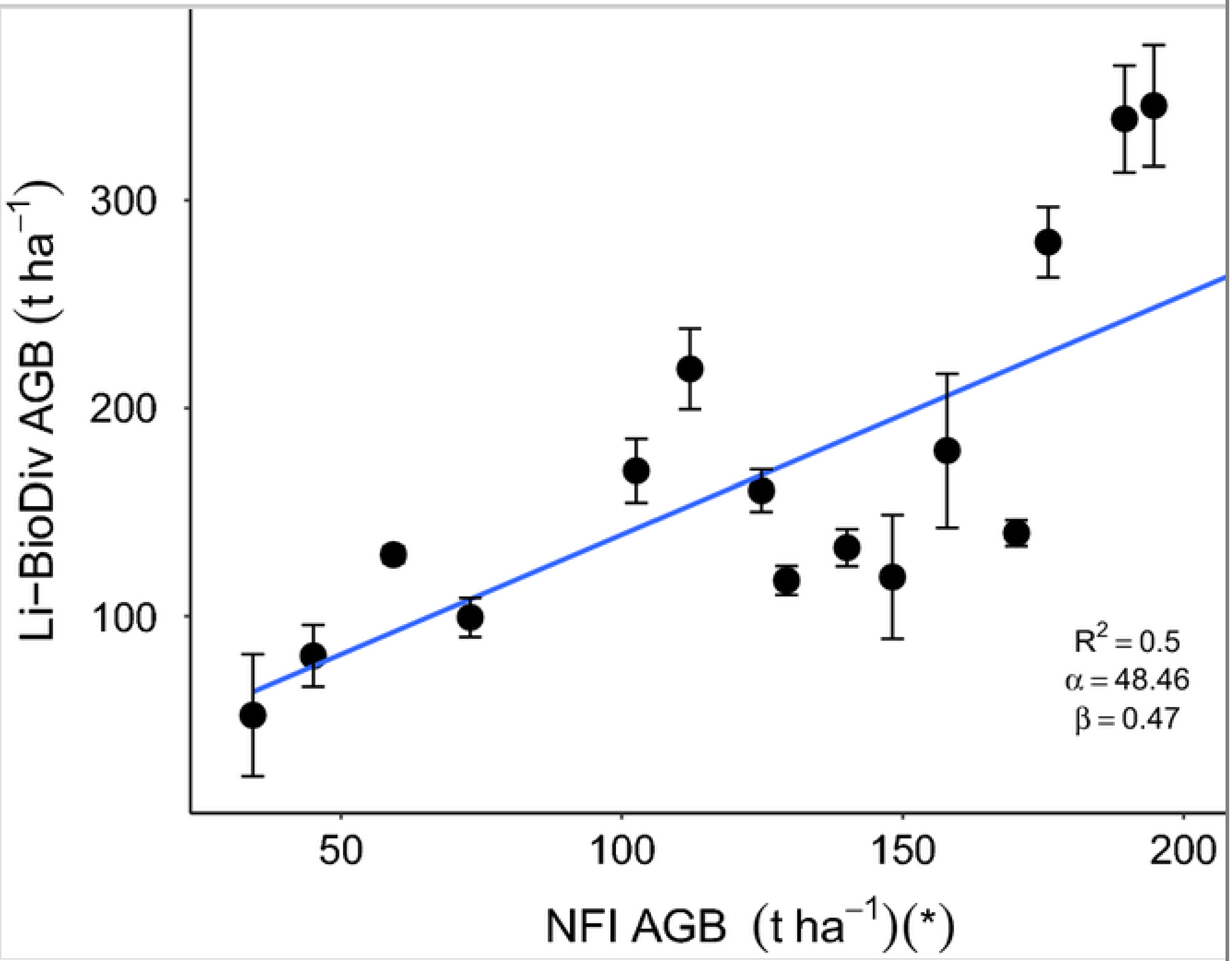
Country	Country code	Li-BioDiv AGB ($\mathrm{t\,ha^{-1}}$)	NFI AGB ($\mathrm{t\,ha^{-1}}$) (*)
France	1	133	140
Belgium	2	180	158
Germany	4	280	176
Italy	5	170	103
Ireland	7	219	112
Denmark	8	343	114
Spain	11	81	45
Sweden	13	100	73

*Data source: Avitabile and Camia (2018)

Country	Country code	Li-BioDiv AGB ($\mathrm{t\,ha^{-1}}$)	NFI AGB ($\mathrm{t\,ha^{-1}}$) (*)
Austria	14	339	189
Finland	15	130	59
Hungary	51	119	148
Poland	53	140	170
Slovak Republic	54	345	195
Lithuania	56	117	129
Czech Republic	58	203	211
Latvia	64	160	125
Cyprus	66	52	34
*Data source: Avitabile and Camia (2018)			

Fig. 6

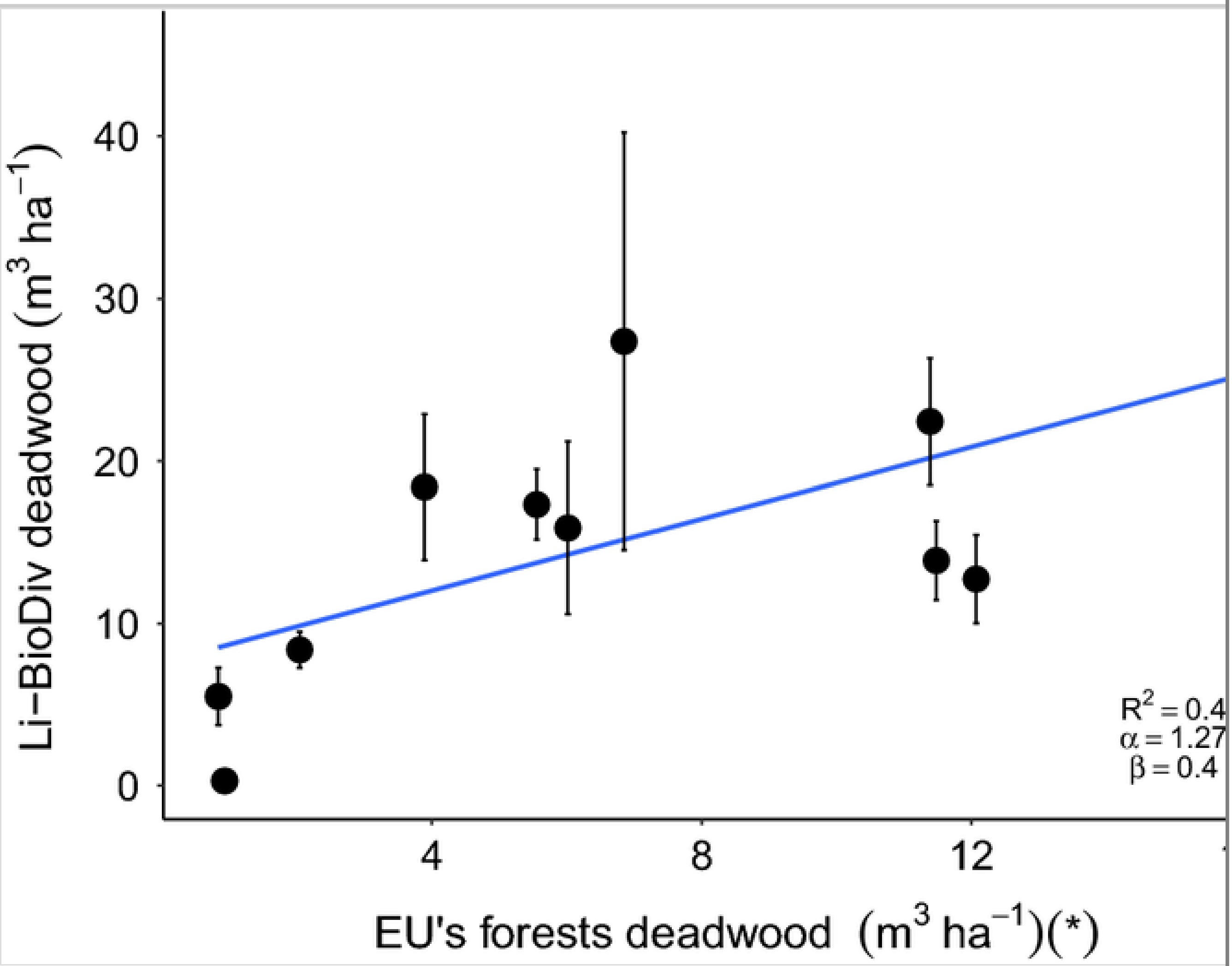
Relationship between Li-BioDiv above ground biomass (AGB) data NFIs AGB. (*) Data source: Avitabile and Camia (2018) ($R^2 = 0.5, F = 16.28, p < 0.01$)



We compared our results of Li-BioDiv data, with standing and lying deadwood data coming from MCPFE (2007), and we found a positive significant relationship ($R^2 = 0.4, F = 8, p < 0.05$) (Fig. 7).

Fig. 7

Relationship between Li-BioDiv standing and lying deadwood data and EU's forests standing and lying deadwood data [(*) data coming from MCPFE (2007)] ($R^2 = 0.4, F = 8, p < 0.05$)



Alpha diversity has almost a normal distribution with the values ranging between 14 and 33 species per plot for 50% of all plots (Fig. 11). We present data across the MCPFE region (Table 4). The highest values of species richness were found in the South–West Europe region with 1102 species and in the North-West Europe region with 1061 species (Table 4). A total of 873 species were recorded in the Central Europe region, while in the Nordic/Baltic region, we found an average lower number of species (433) as well as in South–East Europe region with 473 species (Table 4). Observing the spatial pattern of alpha diversity, it is possible to see that the north-west part of Europe has continuously lower values of species (Table 4). Furthermore, we compared tree and vascular species stored in the Li-BioDiv database with threatened species listed in the IUCN Red List Categories (Bilz et al. 2011). We compared our results with the Forest Europe indicator 4.8 ”Threatened forest species” (MCPFE 2007). Very few threatened, albeit some, vascular species were found in the Li-BioDiv database (Fig. 5) compared with data reported by MCPFE (2007), where no tree threatened species were found (Table 5).

Fig. 8

Alpha diversity, measured as the number of vascular species, in the plots from the LI-BioDiv dataset

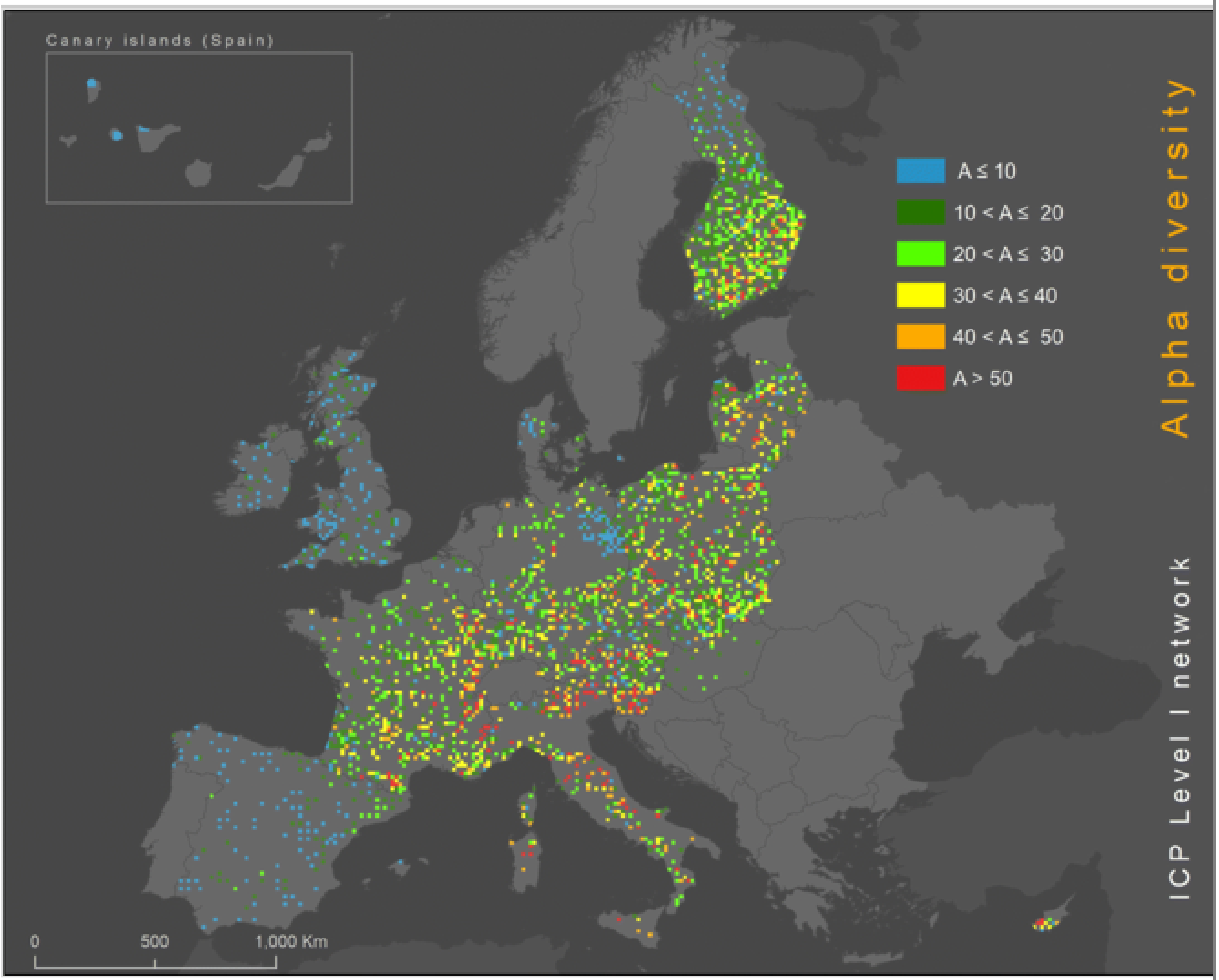


Table 4

Average number of species from the LI-BioDiv dataset by MCPFE region

Region		Species richness
Central	Europe	873
North-West	Europe	1061
North/Baltic	Europe	433
South–East	Europe	473
South–West	Europe	1102

Table 5

Numbers of threatened vascular species [IUCN Red List Categories (Bilz et al. 2011)] founded in the Li-BioDiv database

Country	Country code	Li-BioDiv threatened	EU threatened (*)
France	1	3	–
Belgium	2	1	14
Germany	4	2	–
Italy	5	5	–
UK	6	1	32
Ireland	7	0	–
Denmark	8	1	–
Spain	11	1	–
Sweden	13	0	45
Austria	14	5	270
Finland	15	0	35
Hungary	51	2	–
Poland	53	3	–
Slovak Republic	54	2	207
Lithuania	56	0	–
Czech Republic	58	2	771
Slovenia	60	2	–
Latvia	64	1	28
Cyprus	66	0	17
*Data from MCPFE (2007), 4.8 indicator “Threatened forest species”			

Discussion

In physical sciences, it is not possible to assess phenomena until they are measured. When dealing with forest monitoring, the collection and aggregation of meaningful forest-related physical, compositional and structural data are needed to guarantee an efficient and effective analysis of forests changes in space and time. A wide variety of monitoring networks have been developed in Europe for reporting purposes or for analysing ecological functioning of forest habitats and their relations with climate change, air pollution and human activities. NFIs are the official sources for reporting national and international level statistics on a wide variety of ecosystem services produced by forests (Tomppo et al. 2010). Unfortunately, NFIs still suffer from a lack of consistency at the international level because in the different countries, they adopt~~ed~~ different definitions for a large number of forest variables (McRoberts et al. 2009). As a result, statistics from the NFIs need to be harmonized before comparison or aggregation at the international level. This is relatively simple for some traditional forest variables (Vidal et al. 2008), but it is extremely difficult, or totally impossible, for variables needed for the computation of biodiversity indicators such as deadwood (Rondeux et al. 2012) or ground vegetation (Winter et al. 2008; Chirici et al. 2011, 2012). As a result, forest biodiversity monitoring based on NFI data was frequently based on the calculation of a limited number of compositional or structural indexes which only took into consideration the tree component of flora (McRoberts et al. 2008; Corona et al. 2011). In this context, the ICP BioSoil LI-BioDiv database represents the only standardized dataset of multiple forest variables measurements available at pan-European level (Simpson et al. 2006). In this paper, we presented the multi-dimensionality of the different dataset available in the LI-BioDiv database demonstrating its potential relevance for the derivation of multiple indicators on different forest biodiversity components. The multi-dimensionality of the LI-BioDiv database is ~~seen~~ maximum in 2446 plots, where all the different variables are available (74% of the total plots investigated in the BioSoil Forest Biodiversity project). Regarding the above ground biomass, we compared the per-country aggregated values of the LI-BioDiv data~~base~~ with those from Avitabile and Camia (2018) which are based on NFIs official statistics. We found that the biomass in the plots of the LI-BioDiv database is always higher. It is difficult to find a specific reason for this. Of course, the number of plots available in the LI-BioDiv database is much lower than those available from NFIs, and thus, the uncertainty of our estimations is much greater. Allometric equations are sensitive to sample size (as number of sample units), and small sample size may lead to an overestimation in biomass (Chave et al. 2014; Duncanson et al. 2015). Furthermore, the Li-BioDiv plots surveyed in the field ~~were~~ are a subset of the ICP level I ~~network~~ plots and the method used ~~to~~ for their selection ~~the Li-BioDiv plots from the ICP level I dataset~~ is still unclear. It is possible that less disturbed plots were selected, ~~which~~ this may have ~~manipulated~~ a direct impact on the data creating an overall positive bias in biomass values~~estimation~~. However, a strong positive relationship was found between Li-BioDiv data and the NFIs data. The results regarding deadwood are similar. At country-level, deadwood volume data from Li-BioDiv are always higher than official statistics reported ~~from~~ by12 countries. Even if a consistent statistical relationship exists between the two (Fig. 7), the reason for this difference may be the same ~~as how~~ we hypothesized for the biomass overestimation effect. If the Li-BioDiv plots are less disturbed than those of the ICP level I set, th~~e~~an these plots probably accumulated larger amounts of deadwood too. In addition, this difference could be due to different methods of deadwood measure (Fig. 8).

Regarding data of alpha diversity such as species richness, the geographic patterns markedly differ across the continent, with the lowest values in South-Western European countries (e.g. Spain). Our results are partly in agreement with the highest values of species richness distribution in Central Europe, in particular mountainous regions, which ~~discovered~~ was reported by Kalwij et al. (2014). From this comparison, the UK also seems to have lower values of species richness. Actually, there is not any extensive or comprehensive vascular plant distribution datasets that would be useful for comparing our alpha diversity results. Comparison with Forest Europe indicator 4.8 "threatened forest species" highlighted a weakness and a limitation of the ground vegetation dataset. Most of the species contained in the IUCN Red List categories have a very restricted distribution. Hence, the level of experience of the observer is crucial to the success of the surveys. The value of this collection of data lies in the combination of forest structure with floristic data. This is a unique dataset on the European scale leading us to consider the use of ICP Forests BioSoil Forest Biodiversity data and possibly integrating it as useful dataset for supporting the creation of an integrated system for monitoring forest biodiversity in Europe.

Conclusion

This work is aimed at presenting one of the first elaborations of the LI-BioDiv dataset acquired in the framework of the BioSoil Forest Biodiversity project in a set of 3311 plots belonging to the pan-European systematic grid of the ICP level I network. More specifically, we considered the information related to living trees, deadwood components, shrub and species composition. We clarified the characteristics and consistency of the data available, and we completed some basic pre-elaborations calculating plot-level variables as potentially useful forest biodiversity indicators: above ground biomass and alpha biodiversity (in terms of total number of plant species), and we compared our species with the species listed in IUCN Red List Categories. We found a consistent ~~a~~ statistical relationship between above ground biomass and total deadwood with NFI's data, while there were not any good results with regard to the comparison of plant species using the IUCN red list categories. Furthermore, with this paper we have provided a tool to understand how Li-BioDiv data can be used beyond the countries boundaries and how data can be used to explore across the European ~~MCPFE~~ regions. Some conclusions can be derived from the results obtained. The LI-BioDiv database is a standardized source of information ~~on European forests~~ which may have a relevant importance for the scientific analysis of the relationships between the multiple characteristics of European forests. In particular, some scientific questions, relevant for forest biodiversity monitoring, could be answered by analysing Li-BioDiv database:

- to link tree data with functional traits, exploring functional biodiversity of European forest and their adaptation to climate changes (e.g. to study the drought tolerance of forest species and their distributional changes related to different climatic scenarios);

- how forest structure and composition change according to stand age, management intensity, management type and forest type;

- to understand if forest landscape composition influence forest characteristics (e.g. if forest fragmentation, such as dimension of forests patches and patches connectivity, affects patches biodiversity);

- to link tree variables with Natura 2000 sites, when possible, and to define indices that can support conservation strategies;

- to explor~~inge~~e if some biodiversity characteristics (i.e. functional diversity) show~~s~~ a relationship with remote sensing data.

The LI-BioDiv, and more in general the ICP level I data~~network~~, can be used to develop future multi-dimensional monitoring programmes including information on additional variables relevant for a more complete biodiversity assessment, for example including other flora (such as bryophytes and lichens) and fauna components. More importantly, it is imperative to take into account the effect of the selection, made by countries, of the ICP level I plots to be included in the BioSoil Forest Biodiversity project. Based on our results and discussion, ~~make the~~ the Li-BioDiv ~~monitoring~~ data cannot be considered as resulting from a true probabilistic sampling. ~~In addition~~, As a consequence the Li-BioDiv database cannot be used for statistical inference for the derivation of estimation at pan-European level, ~~because~~ also in consideration of ~~its~~ the limited number of plots ~~and the selection of a subsample from the ICP Forest level I plots~~. Furthermore, we encourage institutions responsible for the implementation of NFIs in Europe to consider the inclusion of more complete and formal ground vegetation surveys in NFIs field protocols, at least for those countries where this is not yet the case. Finally, we encourage a more consistent integration of ICP level I network with NFIs networks, also following existing technical proposals (Travaglini et al. 2013), towards the implementation of a European forest monitoring system able to support forest policy decision at pan-European level for halting the loss of biodiversity.

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Appendix A

Information about dataset table is presented below, including detailed descriptions of all attributes within the tables. Each attribute in a table is listed with its abbreviated name followed by a description of the attribute. Attributes that are coded include a list of the codes and their meanings. The attribute called “quality” has been defined for easily filtering the necessary data for each data type.

Common attributes to all data type:

- *id_unique* progressive number that identified the rows;
- *survey_year* year when the surveys were carried out;
- *code_country* number that identifies the country (Table 1);
- *code_plot* number that identifies the plot;
- *index* links “code_country” and “code_plot” to the unique plot record;
- *bd_subplot* (only for level I): subplot number where the diameters were recorded. Code 1—subplot with a radius of 3.09 m (30 m^2). Code 2—subplot with a radius of 11.28 m (400 m^2). Code 3—subplot with a radius of 25.24 m (2000 m^2).

Specific attributes to GPL dataset:

- *Latitude*
- *Longitude*
- *gps_elevation* values of elevation;
- *code_orientaion* Code 1—North. Code 2—North-east. Code 3—East. Code 4—South-east. Code 5—South. Code 6—South-west. Code 7—West. Code 8—North-west. Code 9—Flat.
- *Slope*

- *Code_preuse* previous land use. Code 1—Forested more than 300 years. Code 2—Forested more than 100 years. Code 3—Forested for 25–100 years ago. Code 4—Forested in the past 25 years. Code 5—No information.
- *Code_stand_actual* Code 1—Planted. Code 2—Seeded. Code 3—Natural regeneration. Code 4—Mixed. Code 9—Unknown.
- *Code_manage_intensity* Code 1—Unmanaged (no evidence). Code 2—Management (evidence but for more than 10 years ago). Code 3—Managed (within the last 10 years). Code 9—Unknown.
- *Code_manage_type_bd* Code 1—High forest—Femelschlag. Code 2—High–Small groups. Code 3—High forest (uneven aged)—Plenterwald. Code 4—High forest (other). Code 5—Young/Medium forest (under development to high forest). Code 6—Coppice without standards. Code 7—Coppice with standards. Code 8—Other.
- *Code_dw_rem* Removal of coarse woody debris. Code 1—Yes, all stems and main branches have been removed. Code 2—Yes, stems and main branches have been removed. Code 3—No, stems and main branches are lying in the forest. Code 4—Partly, some stems and main branches have been removed, others still present. Code 5—Unknown. Code 6—Introduced. Code 7—Presence of accumulation (branches have been stacked in piles or in rows).
- *Code_treemix* Pattern of tree mixture. Code 1—Intimate (different tree species are mixed throughout the stand). Code 2—Non-intimate (different trees occur in clusters). Code 3—No mixture.
- *Code_meanage_bd* mean age of stand. Code 1—0–20 years. Code 2—21–40 years. Code 3—41–60 years. Code 4—61–80 years. Code 5—81–100 years. Code 6—101–120 years. Code 7—> 120 years. Code 8—Irregular stands. Code 9—Unknown.
- *Code_fencing* fancing of the plot. Code 1—Fenced. Code 2—Not Fenced. Code 3—Fenced in parts.
- *Code_forest_type_bd* code in accordance with EEA (2006).

Specific attributes to DBH dataset:

- *tree_number* number that identified the tree inside each plots;
- *dw_dbh* values of diameters (cm);
- *code_tree_status* Code 1—standing living tree. Code 2—standing dead tree.

Code 3—lying dead tree;

- *code_tree_species* number that identifies the tree species;

- *quality* attribute to filter data availability. Code 1—Fields holding "diameter", "code_tree_status" and "code_tree_species" ($D > 10$ cm). Code 2—Fields holding "diameter" , "code_tree_species" and does not contain "code_tree_status"($D > 10$ cm). Code 3—Fields holding "diameter", "code_tree_status" and does not contain "code_tree_species" ($D > 10$ cm). Code 4—Fields holding "diameter", "code_tree_status" and "code_tree_species" ($3 \leq D \leq 10$ cm). Code 5—Fields holding "diameter", "code_tree_species" and does not contain "code_tree_status" ($3 \leq D \leq 10$ cm). Code 6—Fields holding "diameter", "code_tree_status" and does not contain "code_tree_species" ($3 \leq D \leq 10$ cm). Code 999—Unclassified or incorrect data;

- *code_decay* deadwood decomposition is assigned in 5 decay classes according to Hunter (1990). Code 1—No evidence of decay. Code 2—Solid wood. Less than 10 % changed structure due to decomposition. The wood is solid at its surface. The wood is attacked only to a very mall degree by wood decomposing organisms. Code 3—Slightly decayed. 10–25% of the wood has a changed structure due to decomposition. This can be assessed by sticking the wood with a harp object. Code 4—Decomposed wood 26–75% of the wood is soft to very soft. Code 5—Very decomposed wood. 76%–100% of the wood is soft.

Specific attributes to deadwood (DWD) dataset:

- *deadwood_id* number that identified the wood inside each plots;

- *dw_type* existing classification based on type of deadwood detected. Code 1—Coarse woody debris ($D > 10$ cm). Includes stems, limbs, branches lying on the ground. Code 2—Fine woody debris (5 cm $< D <$ 10 cm). Includes small wood pieces. Code 3—Snag (height > 1.3 m and DBH > 10 cm). Standing deadwood without branches. Code 4—Stump (height <1.3 m and D at cut > 10 cm). Stump is a snag below breast height. Code 5—Other. All cases with values falling outside the above mentioned definitions or undefined. (e.g.: values < 5 cm for diameter with code = 2 or unsolvable code or definition conflicts). Code 9—Special cases. Threshold values, erroneously not defined in the old manual (i.e.: $D = 10$ cm, $D = 5$ cm, DBH = 10 cm, height = 1.3 m);

- *code_dw_species* number that identifies the group of tree species. Code 1—

deciduous, code 2—conifer, code 3—unknown;

- *diameter* values of diameters (cm);
- *dw_length* values of length of woody debris (m);
- *code_decay* deadwood decomposition is assigned in 5 decay classes according to Hunter (1990), see DBH dataset code decay;
- *quality* attribute to filter data availability. Code 1—Fields holding "diameter", ""dw_length", "code_dw_species" and "code_decay" (CWD). Code 2—Fields holding "diameter", "dw_length", "code_dw_species" and does not contain "code_decay" (CWD). Code 3—Fields holding "diameter", "code_dw_species", "code_decay" and does not contain "dw_length" (CWD). Code 4—Fields holding "diameter", "dw_length", "code_decay" and does not contain "code_dw_species" (CWD). Code 5—Fields holding "diameter", "dw_length", "code_dw_species" and "code_decay" (FWD). Code 6—Fields holding "diameter", "dw_length", "code_decay" and does not contain "code_dw_species" (FWD). Code 7—Fields holding "diameter", "dw_length", "code_dw_species" and does not contain "code_decay" (FWD). Code 8—Fields holding "diameter", "code_dw_species", "code_decay" and does not contain "dw_length" (FWD). Code 999—Unclassified or incorrect data.

Specific attributes to canopy (CAN) dataset:

- *code_canopy* code that identified the average percentage of canopy cover. Code 1—open sky. Code 2—1–25%. Code 3—25–50%. Code 4—50–75%. Code 5—> 75%;
- *n_tree_layer* number of distinct tree layer. Code 1—one layer (one dominant tree layer). Code 2—two layers (dominant tree layer plus 1 sublayer). Code 3—three layers (dominant plus two sublayers). Code 4—more than three layers. Code 5—no tree layer;
- *n_trees* number of trees in the plot;
- *quality* attribute to filter data availability. Code 1—Fields holding "code_canopy", "n_tree_layer" and "n_trees". Code 2—Fields holding "code_canopy", "n_tree_layer" and does not contain the "n_trees". Code 3—Fields holding "code_canopy" and does not contain the "n_tree_layer" and "n_trees". Code 4—Fields holding "code_canopy", "n_trees" and does not contain the "n_tree_layer". Code 999—Unclassified or incorrect data.

Specific attributes to ground vegetation (GVG) dataset:

- *code_species* number that identifies the species;

- *code_layer_surface* code of layers where vegetation was evaluated. Code 1—tree layer (only ligneous and all climbers) > 5 m height, code 2—shrub layer (only ligneous an all climbers) > 0.5 m height, code 3—herb layer (all non-ligneous and ligneous < 0.5m height), code 4—moss layer (i.e. terricolous bryophytes and lichens), code 5—lower Shrubs, code 6—upper Shrubs;

- *cover* percentage of coverage of the species;

- *quality* attribute to filter data availability. Code 1—Fields holding “code_species” and “cover”. Code 2—Fields holding “code_species” and does not contain “cover” and “code_layer_surface”. Code 3—Fields holding “code_species”, “cover” and “code_layer_surface”. Code 4—Fields holding “code_species”, “code_layer_surface” and does not contain “cover”;

- *class* Field refers to “code_species”. Code S, “code_species” identified the species. Code G, “code_species” identified the genus.

Appendix B

See Figs. 9, 10 and 11).

Fig. 9

Basal area ($\mathrm{m}^2\ \mathrm{ha}^{-1}$) from the ICP Forests LI-BioDiv dataset

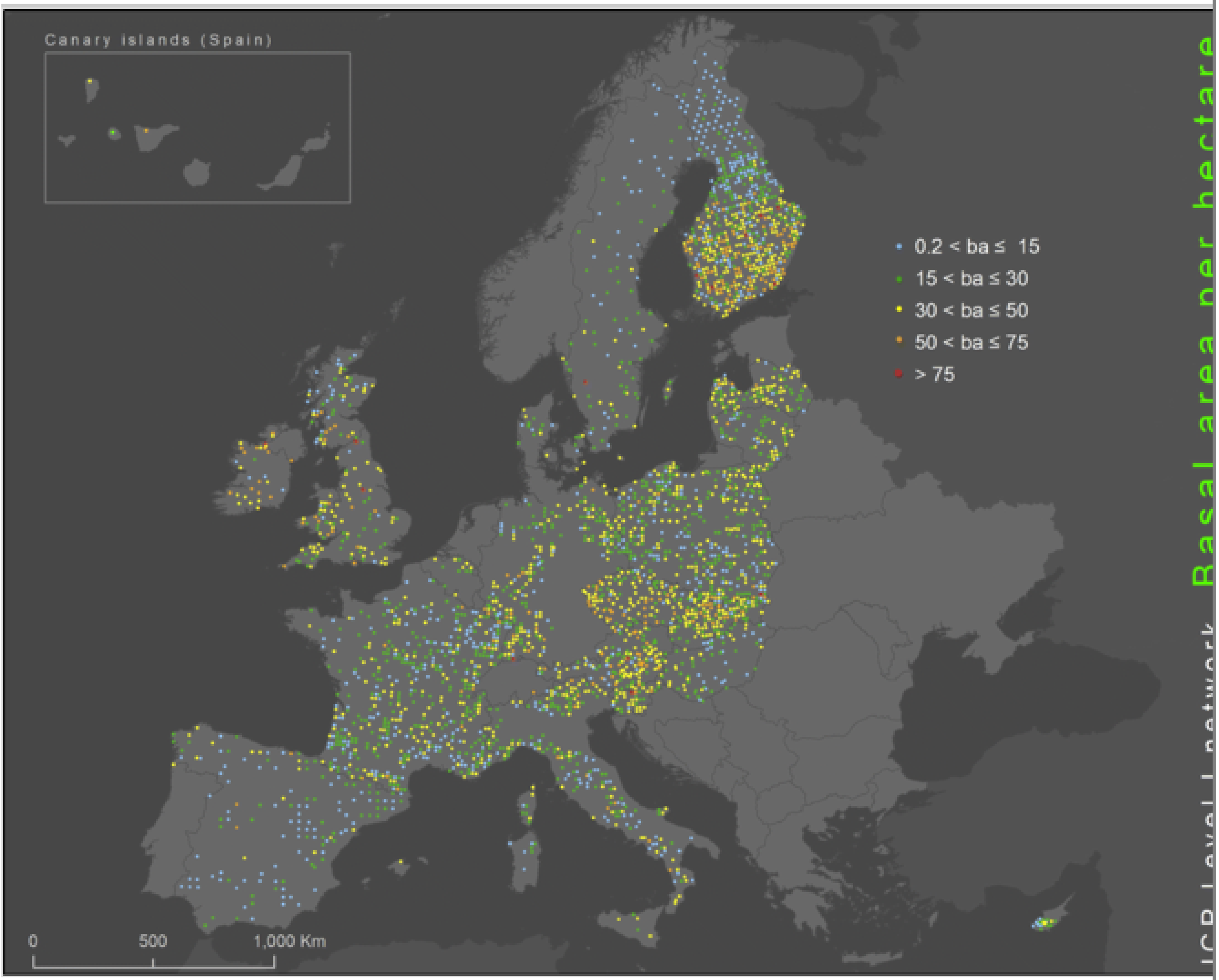


Fig. 10

CAN data available from the ICP Forests LI-BioDiv dataset and canopy cover variation

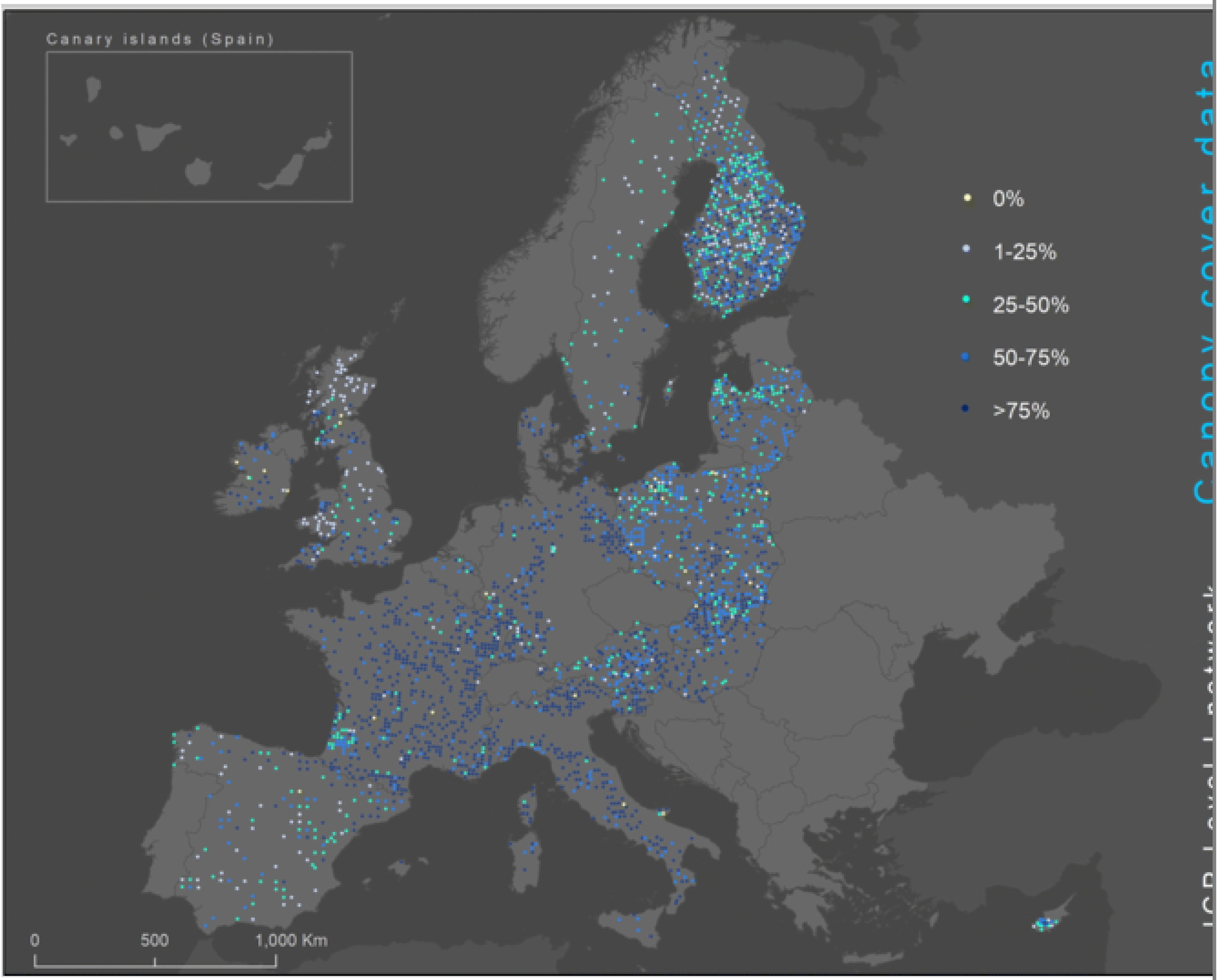
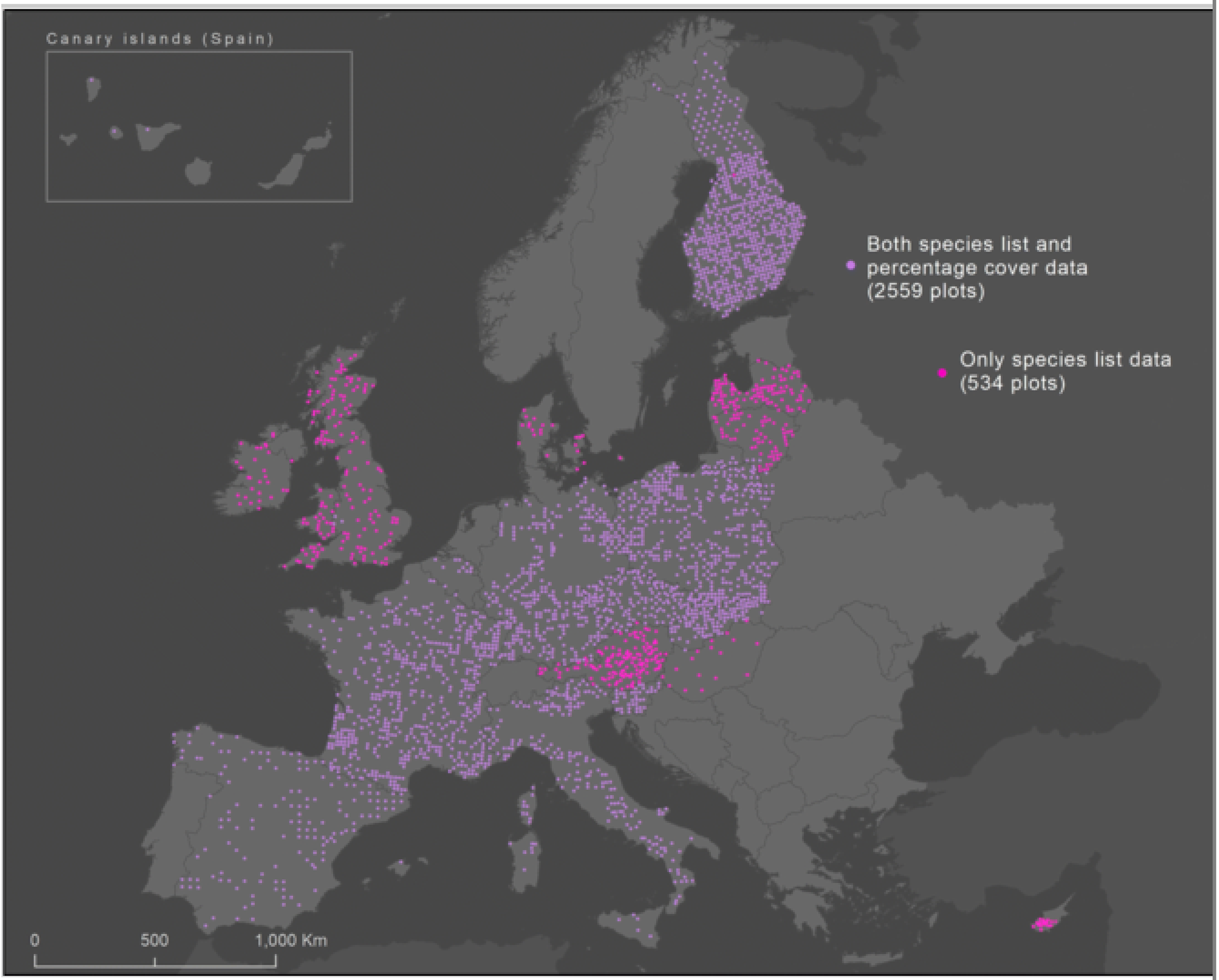


Fig. 11

Type of GVG data available from the ICP Forests LI-BioDiv dataset



AQ3

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