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Current extent and stratification of agroforestry in the European Union

Michael den Herder[1,*], Gerardo Moreno[2], Rosa M. Mosquera-Losada[3], João H.N. Palma[4], Anna Sidiropoulou[5], Jose J. Santiago Freijanes[3], Josep Crous-Duran[4], Joana A. Paulo[4], Margarida Tomé[4], Anastasia Pantera[6], Vasilios P. Papanastasis[5], Kostas Mantzanas[5], Przemko Pachana[1], Andreas Papadopoulos[6], Tobias Plieninger[7], Paul J. Burgess[8]

[1]European Forest Institute, Yliopistokatu 6, FI-80100 Joensuu, Finland
[2]Forestry Research Group, Universidad de Extremadura, Spain
[3]Crop Production Department, Escuela Politécnica Superior, Universidad de Santiago de Compostela, 27002 Lugo, Spain
[4]Forest Research Centre, School of Agriculture, University of Lisbon, 1349-017 Tapada da Ajuda, Lisbon, Portugal
[5]Faculty of Forestry and Natural Environment, Aristotle University of Thessaloniki, 54124 Greece
[6]Forestry and Natural Environment Management, TEI Stereas Elladas, 36100 Greece
[7]University of Copenhagen, Department of Geosciences and Natural Resource Management, Rolighedsvej 23, 1958 Frederiksberg C, Denmark
[8]Cranfield University, Cranfield, Bedfordshire, MK43 0AL, United Kingdom

[*]Corresponding author: e-mail: michael.denherder@efi.int, tel.: +358 10 773 4343, fax: +358 10 773 4377

Abstract

An accurate and objective estimate on the extent of agroforestry in Europe is critical for the development of supporting policies. For this reason, a more harmonized and uniform Pan-European estimate is needed. The aim of this study was to quantify and map the distribution of agroforestry in the European Union. We classified agroforestry into three main types of agroforestry systems: arable agroforestry, livestock agroforestry and high value tree agroforestry. These three classes are partly overlapping as high value tree agroforestry can be part of either arable or livestock agroforestry. Agroforestry areas were mapped using LUCAS Land Use and Land Cover data (Eurostat, 2015). By identifying certain combinations of primary and secondary land cover and/or land management it was possible to identify agroforestry points and stratify them in the three different systems. According to our estimate using the LUCAS database the total area under agroforestry in the EU 27 is about 15.4 million ha which is equivalent to about 3.6% of the territorial area and 8.8% of the utilised agricultural area. Of our three studied systems, livestock agroforestry covers about 15.1 million ha which is by far the largest area. High value tree agroforestry and arable agroforestry cover 1.1 and 0.3 million ha respectively. Spain (5.6 million ha), France (1.6 million ha), Greece (1.6 million ha), Italy (1.4 million ha), Portugal (1.2 million ha), Romania (0.9 million ha) and Bulgaria (0.9 million ha) have the largest absolute area of agroforestry. However the extent of agroforestry, expressed as a proportion of the utilised agricultural area (UAA), is greatest in

countries like Cyprus (40% of UAA), Portugal (32% of UAA) and Greece (31% of UAA). A cluster analysis revealed that a high abundance of agroforestry areas can be found in the south-west quadrat of the Iberian Peninsula, the south of France, Sardinia, south and central Italy, central and north-east Greece, south and central Bulgaria, and central Romania. Since the data were collected and analysed in a uniform manner it is now possible to make comparisons between countries and identify regions in Europe where agroforestry is already widely practiced and areas where there are opportunities for practicing agroforestry on a larger area and introducing novel practices. In addition, with this method it is possible to make more precise estimates on the extent of agroforestry in Europe and changes over time. Because agroforestry covers a considerable part of the agricultural land in the EU, it is crucial that it gets a more prominent and clearer place in EU statistical reporting in order to provide decision makers with more reliable information on the extent and nature of agroforestry. Reliable information, in turn, should help to guide policy development and implementation, and the evaluation of the impact of agricultural and other policies on agroforestry.

Keywords: land use, land cover, high natural and cultural value, high value trees, Land Use/Cover Area frame Survey (LUCAS)

1. Introduction

The European Commission (2013) defines agroforestry as "land use systems in which trees are grown in combination with agriculture on the same land". Other authors have defined agroforestry as the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions (Burgess et al., 2015 building on MacDicken & Vergara, 1990 and Nair, 1993) and providing agricultural products from the understory (Sommariba 1992; Mosquera-Losada et al. 2016). There are several categories of common agroforestry practices worldwide and also in Europe (Mosquera-Losada et al., 2009; 2016; den Herder et al., 2015); these include wood pastures, hedgerows, windbreaks, riparian buffer strips, intercropped and grazed orchards, grazed forests, forest farming and more novel silvoarable and silvopastoral practices and systems such as alley cropping, alley coppice, and woodland chicken. What all of these practices have in common is that the interactive benefits from combining trees and shrubs with crops and/or livestock offers land owners and managers the opportunity to create an integrated land-use system (Lundgren and Raintree, 1982; Leakey, 1996). In addition, the improvement in public ecosystem services provided by agroforestry systems and practices is widely acknowledged (e.g. Dupraz and Liagre 2008; Jose 2009; Bughalo et al., 2011; Torralba et al 2016; Mosquera-Losada et al. 2016). Agroforestry systems are often associated with high conservation values and provide a wide variety of goods and ecosystem services (Jose, 2009; Bughalo et al., 2011).

An accurate and objective estimate on the extent and geographical distribution of different agroforestry types in Europe is crucial for the development of supporting policies. Despite agroforestry being almost everywhere, it is difficult to find reliable data on the global extent of agroforestry (Zomer et al., 2009) and the same applies to Europe. The lack of European data, and a narrow definition of agroforestry, has led in the past to the misconception that agroforestry is unimportant in the European context and this in turn has led to agroforestry not being included in policy decisions concerning land use and environmental challenges (Rigueiro et al., 2009). This problem can best be tackled by providing an objective estimate of the extent of agroforestry in Europe. This is especially important since agroforestry has recently gained momentum not only in research but also in farm and policy circles. The revived interest in agroforestry originates from an increasing amount of evidence of environmental (Palma et al. 2007a, 2007b; Reisner et al., 2007; Rigueiro et al. 2009;

Andrianarisoa et al., 2015; Cardinael et al., 2015), social and economic benefits (Graves et al. 2007; Glover et al., 2013; Mercer et al., 2014; Ranca et al., 2014) of this land use system. However, many of these systems are declining, showing high vulnerability to changes in disturbance regimes such as fire and drought (Acácio et al., 2009; Guiomar et al., 2015; Paulo et al.,2016) and to pests and diseases (Hansen, 2015; Tiberi et al., 2016). Gibbons et al (2008) showed that the progressive loss of trees in agrarian landscapes has been a global pattern. Nevertheless, agroforestry practices can improve sustainability of farming systems and can, for example, mitigate emissions from the agricultural sector (Paolotti et al., 2016). Therefore, forthcoming EU commitments as expressed in the second amendment of Kyoto Protocol and commitments at the UN Climate Change Conference at Paris in 2015 include agroforestry practices within the Land Use Land Use Change and Forestry (LULUCF) carbon accounting framework (Mosquera-Losada et al., 2016). One important focus in contemporary agroforestry research is envisaging how adaptive management of agroforestry systems can contribute to climate change mitigation (Palma et al., 2015).

Databases providing an estimate on the extent of agroforestry in Europe are already available. The Corine land cover classification (European Environment Agency, 1995) contains land cover data for Europe and includes the land cover class “agroforestry”. According to the Corine database, agroforestry covers about 3.3 million hectares in Europe, mainly in Spain, Portugal and Italy with some smaller areas in France and Austria. However, previous studies, often based on a literature review, have documented greater areas of agroforestry practices in Europe (Herzog, 1998; Eichhorn et al., 2006; Bergmeier et al., 2010; Plieninger et al., 2015) and it is clear that the Corine database is presently underestimating the agroforestry area. Agroforestry was recorded by CORINE only for regions where it is the prevailing land use. A recent literature study, summarising the currently available data sources estimated that agroforestry in Europe is practiced at least on an area of 10.6 million hectares equivalent to 6.5% of the utilized agricultural area in Europe (den Herder et al., 2015). Wood pastures cover the largest area and are distributed around Europe in all climatic zones ranging from the Mediterranean to boreal zones (Rigueiro et al., 2009; Bergmeier et al., 2010; Plieninger et al., 2015). Oak tree systems in the Mediterranean and reindeer husbandry in northernmost Fennoscandia are particularly area-extensive (Jernsletten and Klokov, 2002; Eichhorn et al., 2006; Mosquera-Losada et al., 2009). Other systems include grazing or intercropping of fruit tree systems in the continental (Herzog, 1998) and Mediterranean regions of Europe, with large areas of olive agroforestry in the Mediterranean region (Eichhorn et al., 2006).

Zomer et al. (2009) made a first attempt to quantify the extent of agroforestry at the global scale. One surprising result was the unexpectedly large extent of agroforestry worldwide. Globally, approximately 46% of all agricultural land had at least 10% tree cover. For Europe, the corresponding figure amounted to 40% of all agricultural land (Zomer et al., 2009). A key conclusion was that agroforestry is a significant feature of agriculture in all regions around the world. In the 2014 update on the global extent of agroforestry, Zomer et al. (2014) reported that approximately 48% (i.e. about 113.5 million ha) of all agricultural land in Europe had at least 10% tree cover. Thus, estimates on the extent of agroforestry depend a lot on the definition of agroforestry, the scale, the spatial resolution of the available data and the type of analysis.

Agroforestry can be classified in different ways, for example on the basis of components, products, agro-ecological zones, and socio-economic groupings (Nair, 1993; Sinclair, 1999; Mosquera-Losada et al. 2009; McAdam et al., 2009). For any attempt to map agroforestry,

first clear boundaries are needed to frame what is and what is not agroforestry. In this assessment, agroforestry systems linked to farm and landscape have been stratified according to the main farming focus (annual crop, permanent woody crops and livestock) and components (forest and fruit trees, herbaceous crops and/or livestock). Accordingly, we classified agroforestry into three main categories: arable agroforestry, livestock agroforestry and high value tree agroforestry, all of them with subsequent subcategories (Burgess et al., 2015). The aim was to provide a systematic estimate on the current extent and geographic distribution of these types of agroforestry in the European Union at country level, based on existing Pan-European statistical land use and land cover data (Eurostat, 2015). We then defined certain regions of high likelihood to find agroforestry systems that correspond to regions where extensive traditional agroforestry systems are still extant.

2. Material and methods

Agroforestry areas in the EU were mapped using LUCAS data (Land Use and Land Cover survey; Eurostat, 2015). Hereafter, the results were compared with values available in the literature.

2.1 The Land Use/Cover Area frame Survey (LUCAS)

We used data collected in the LUCAS survey, a harmonised *in situ* land cover and land use data collection exercise that extends over the whole of the EU and is performed by the EU Statistical Office (Eurostat, 2015). We took the data from the 2012 survey which covered all of the then 27 Member States. Croatia joined the EU in 2013 and was not yet included.

LUCAS is a two phase sample survey. The first phase is a systematic sample with points spaced 2 km apart in the four cardinal directions covering the whole of the EU's territory (~ 1.1 million different points). Each point of the first phase sample was photo-interpreted and assigned to one of the following seven pre-defined land cover strata: arable land, permanent crops, grassland, wooded areas and shrubland, bareland, artificial land, and water. From the stratified first phase sample, a representative subset of 270,000 points was retained for the further field survey. The selection of the points is based on the stratification information producing a quasi-regular grid with a LUCAS sample point in every block of 4 km x 4 km, on average. However, points above 1500 metres and far from the road network were considered inaccessible and therefore not included (Eurostat, 2015). The 270000 points selected for the second phase were visited on the spot by field surveyors in 2012.

Due to the intensive sampling effort taken in LUCAS, the set of points can be viewed as representative of the land cover at EU and also for the larger countries at national scales. The number of sampling points per country ranged from 79 in Malta to 38338 in France. To estimate the extent of agroforestry in hectares based on points coded as agroforestry according to the criteria detailed below, we divided the number of points coded as agroforestry in each country by the total number of LUCAS points in this country and multiplied this by the surface of the country.

LUCAS uses a double classification system for land covers with multiple layers, for instance agroforestry systems where a tree layer is typically accompanied by a secondary layer composed of crops or grass. In such cases, LUCAS would enter trees as the primary land cover (LC1) and crops, grass or bare soil as the secondary land cover (LC2) (see Eurostat 2012 for more information). These two separate land covers (LC1 and LC2) are used only for specific landscapes, such as agroforestry and complex or heterogeneous areas. For example, the database contains points coded as "apple trees" (B71) for land cover 1 (LC1) and also coded as "common wheat" (B11) for land cover 2 (LC2). It is likely that points with this particular combination of primary and secondary land cover represent a silvoarable practice using a combination of apple trees and common wheat.

Another useful variable included in the LUCAS database is land management, which contains information if there are signs of grazing. By identifying certain combinations of primary and secondary land cover and land management it is possible to identify agroforestry points and stratify them into different agroforestry categories. We assigned different criteria to LUCAS variables to identify the three main agroforestry categories considered in this study: arable agroforestry, livestock agroforestry and agroforestry with high value trees, with their subsequent subcategories (Burgess et al., 2015; den Herder et al., 2015):

1. Arable agroforestry where crops are integrated with trees. The three subcategories are crops combined with (a) permanent woody crops, (b) woodlands (> 10% tree cover), and (c) rangelands with sparse trees.

2. Livestock agroforestry where livestock production is integrated with trees. The four subcategories are: livestock combined with (a) permanent woody crops, (b) woodlands, (c) arable lands with sparse trees, and (d) grasslands with sparse trees.

3. High value tree agroforestry where the primary land use is permanent woody crops such as fruit orchards, olive groves, and nut trees. The two subcategories are (a) grazed and (b) intercropped.

It should be noted that these categories are not mutually exclusive. High value tree agroforestry can either be practiced as an arable system (category 1) or a livestock system (category 2). Nevertheless, we prefer to recognise high value tree agroforestry as a separate system as the farmer's objectives and the main component of this system (trees producing fruits or high value wood) are different compared to arable or livestock agroforesty, where the main components are crops or livestock. Based on the distribution of these agroforestry categories all together, we then defined the likelihood map of agroforestry systems.

2.1.1 Arable agroforestry

To identify arable agroforestry systems, we selected combinations of LC1 and LC2 which potentially indicate intercropped permanent crops, woodlands or shrubland. Specifically, the following layers were considered: "permanent crops" (classes B71 to B84), "woodland" (classes C10-C33) or "shrubland with sparse tree cover" (class D10) as primary land cover (LC1). As a secondary land cover we selected "crops" (classes B11-B54), indicating that there were crops grown under planted or forest trees (Table A.1).

2.1.2 Livestock agroforestry

Agroforestry livestock systems were identified by selecting areas with woody vegetation which show clear signs of grazing. First, we selected the same primary land cover classes (LC1) as selected above under arable agroforestry: "permanent crops" (B71 to B84), "woodland" (C10 to C33) or "shrublands with sparse tree cover" (D10) (Table A.1). To this selection we added "grasslands with sparse tree cover" (E10). From this set of points, only those showing signs of grazing ("Land Management" column: 1 = "signs of grazing"; 2 = "no signs of grazing") were recorded as livestock agroforestry.

2.1.3 Agroforestry with high value trees

For the purposes of this study we defined "high value trees" as trees which are able to provide an annual or biennial harvest product. As a first step in identifying agroforestry areas containing high value trees, we selected the following primary land cover classifications (LC1) indicating points with high value trees: B71 apple, B72 pear, B73 cherry, B74 nuts, B75 other fruit trees and berries, B76 oranges, B77 other citrus fruits, B81 olive groves, B82 vineyards and B84 industrial crops (only mulberry and carob were included) (Table A.1).

As a next step, from our selection of points containing high value trees, we identified those which can be described as grazed or intercropped orchards and olive groves. Grazing is coded in "Land Management" column as aforementioned, and intercropping was defined here by classes B11 to B54 as secondary land cover (LC2).

2.1.4 Total extent of agroforestry in Europe

As noted before, the three main agroforestry categories are not mutually exclusive. Points coded as agroforestry with high value trees are also coded as either livestock agroforestry or arable agroforestry. Therefore, to estimate and map the total extent of agroforestry, we combined the two queries which were used to identify arable and livestock agroforestry. First, we selected the same primary land cover classes (LC1) as described above under the arable and livestock systems: "permanent crops" (B71 to B84), "woodland" (C10 to C33), "shrublands with sparse tree cover" (D10) and "grasslands with sparse tree cover" (E10). From this selection, we then selected all LUCAS points which had "crops" (classes B11-B54) as a secondary land cover or which had "signs of grazing" (Table A.1).

2.2 Likelihood map of agroforestry systems

We defined areas where agroforestry is a prevailing land use by the analysis of contiguous clusters. Clusters of agroforestry points could indicate that for example wood pastures are relatively well connected in a particular area or that they would cover larger areas. To visualise clustering of agroforestry points, we used the point density tool in ArcMap 10 (ESRI, 2015). This tool calculates the density of a feature in a neighbourhood around the

feature. In our case we used the tool to calculate the density of LUCAS agroforestry points around each agroforestry point and the results were visualised in a grid. We used equal intervals to define the thresholds of the point density classes. The average nearest neighbour tool was used to determine if the LUCAS agroforestry points show a statistically significant level of clustering or dispersion (ESRI, 2015). The tool does this by measuring the distance from each feature to its single nearest neighbour and calculating the average distance of all the measurements. We used the Euclidean distance method (the straight-line distance between two points). Hereafter, the tool creates a hypothetical, randomly distributed data across the same study area and calculates the average distance again. The degree of clustering is measured by how much the index for the real data differs from the hypothetical data, so the tool is used to see if the physical locations are closer together than would be expected with a random distribution. If the nearest neighbour ratio is less than one, then the data are considered to be clustered; if it is more than one, then the data are exhibiting a trend towards dispersion.

3. Results

3.1 Arable agroforestry systems

Arable agroforestry covers about 358,000 hectares corresponding to about 0.1% of the territorial area in the EU (Table 1) and 0.39% of the arable lands. 62% of this surface includes permanent crops (especially with olive trees, with 109,000 ha), 37% are in woodlands (especially broadleaves woodlands, with 130,000 ha) and less than 1% is shrublands with sparse trees. Most frequent combinations are broadleaves woodlands with cereals, and olive groves with either cereal or vegetables.

The largest extent of arable agroforestry occurs in Spain (117,000 ha) followed by Italy (106,100 ha) and Portugal (76,500 ha) (Table 1, Figure 1A). The largest extent of arable agroforestry with permanent crops (planted fruit, nut and olive trees) is found in Italy (90,300 ha) accompanied by Spain (52,100 ha) and Portugal (36,400 ha) (Table 1). The largest extent of arable agroforestry in woodlands is found in Spain (64,800 ha) and Portugal (40,100 ha). These mainly oak-dominated woodlands often combine silvopastoral and silvoarable practices and are called *dehesas* and *montados.* Cereal cultivation and natural or improved pasture management are the most common arable practises in these oak woodlands.

Table 1. Extent and distribution of arable agroforestry systems in Europe based on LUCAS data including agroforestry areas under permanent crops (fruit, nut and olive trees), woodlands and shrubland with sparse trees.

Country	Total territorial area[1]	Permanent crops	Woodland	Shrubland with sparse trees	All arable agroforestry	
	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	%
Austria	8388	1.3	0.0	0.0	1.3	0.0
Belgium	3053	0.0	0.0	0.0	0.0	0.0
Bulgaria	11090	3.3	0.0	0.0	3.3	0.0
Cyprus	925	3.8	0.0	0.0	3.8	0.4
Czech Republic	7887	0.0	0.0	0.0	0.0	0.0
Denmark	4290	0.0	1.2	0.0	1.2	0.0
Estonia	4523	0.0	0.0	0.0	0.0	0.0
Finland	33843	0.0	0.0	0.0	0.0	0.0
France	54397	5.7	0.0	0.0	5.7	0.0
Germany	35713	0.0	4.3	1.4	5.7	0.0
Greece	13196	13.5	1.7	0.0	15.2	0.1
Hungary	9302	2.0	0.0	0.0	2.0	0.0
Ireland	6980	0.0	0.0	0.0	0.0	0.0
Italy	30134	90.3	15.8	0.0	106.1	0.4
Latvia	6456	0.0	0.0	0.0	0.0	0.0
Lithuania	6530	1.7	0.0	0.0	1.7	0.0
Luxembourg	259	0.0	0.0	0.0	0.0	0.0
Malta	32	0.0	0.0	0.0	0.0	0.0
Netherlands	4154	0.0	0.0	0.0	0.0	0.0
Poland	31268	2.9	0.0	0.0	2.9	0.0
Portugal	8909	36.4	40.1	0.0	76.5	0.9
Romania	23839	6.7	1.7	1.7	10.0	0.0
Slovakia	4904	2.0	0.0	0.0	2.0	0.0
Slovenia	2027	0.0	0.0	0.0	0.0	0.0
Spain	49851	52.1	64.8	0.0	117.0	0.2
Sweden	43858	0.0	2.0	0.0	2.0	0.0
United Kingdom	24853	0.0	2.0	0.0	2.0	0.0
EU-27 total	**430659**	**222**	**134**	**3**	**358**	**0.1**

[1]Source: Eurostat Online data sources: Land cover overview, available online at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/LAN_LCV_OV

3.2 Livestock agroforestry

Agroforestry systems with livestock cover about 15.1 million hectares corresponding to about 3.5% of the territorial area in the EU (Table 2). This amounts roughly to the 15% of the European grasslands, but up to 35% of the actually grazed lands. Livestock agroforestry is dominated by grazed woodlands (50%, mostly broadleaves woodlands) and grasslands with sparse trees (32%). Only 5.6% of the area livestock agroforestry is covered with permanent crop (about half of this in olive groves, but also important in apple and nut trees plantations).

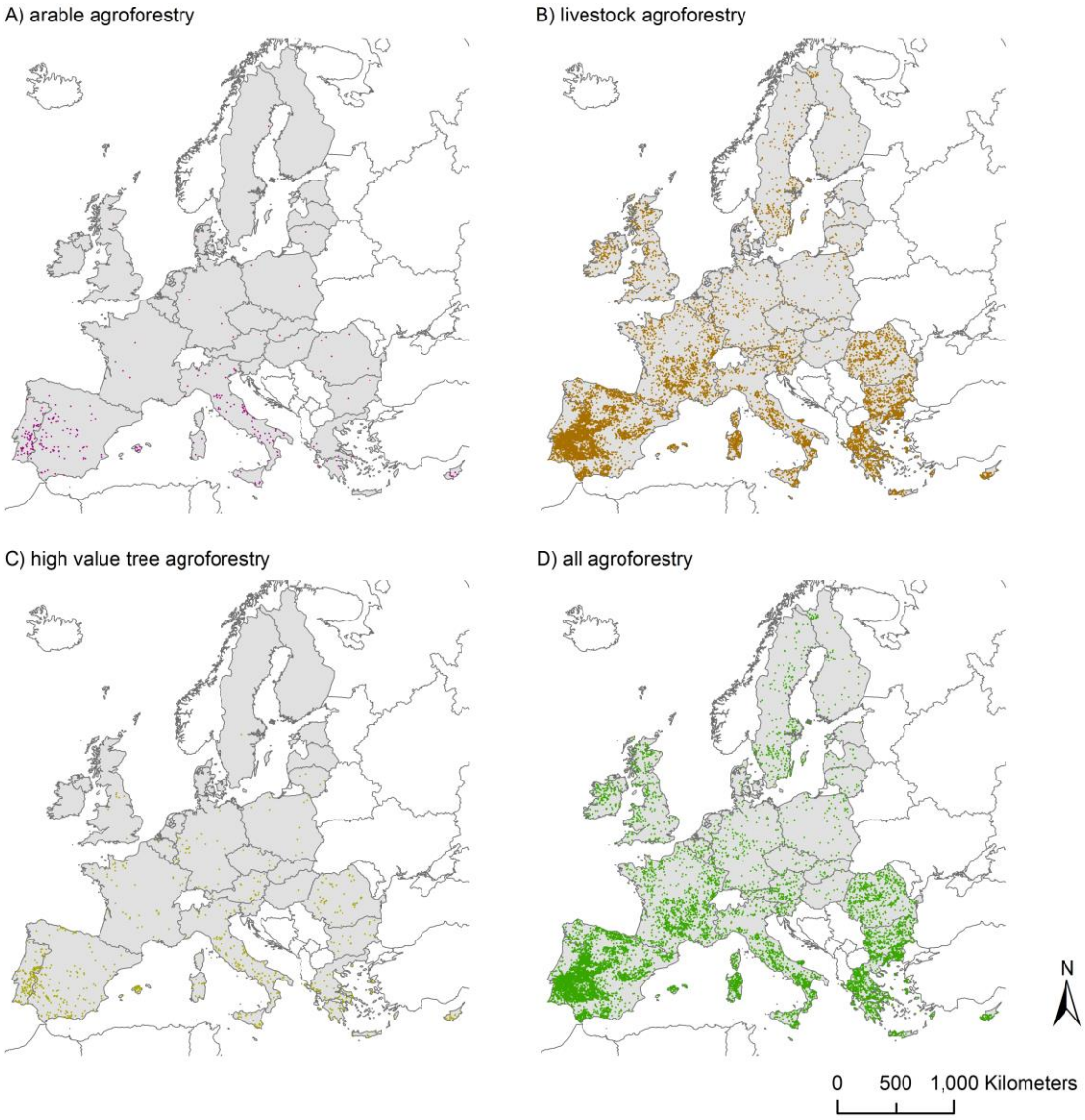

Figure 1. Distribution of agroforestry in Europe. A) arable agroforestry, B) livestock agroforestry, C) high value tree agroforestry, and D) total extent of agroforestry. Distribution maps of agroforestry sub-categories as presented in Tables 1-4 are available as supplementary material.

The largest extent of livestock agroforestry systems can be found in the Mediterranean countries, such as Spain (5.5 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.3 million ha) and Portugal (1.1 million ha) (Table 2, Figure 1B). The largest extent of livestock systems associated with high value tree crops occurs in Spain (217,000 ha) and Portugal (122,700 ha). The largest areas of livestock systems on woodland are concentrated in Spain (3.5 million ha), Portugal (799,100 ha), Greece (655,700 ha), France (648,400 ha) and Italy (622,400 ha). The largest extent of livestock agroforestry on shrublands with sparse tree cover is found in Spain (589,000 ha) and Greece (534,000 ha). The largest extent of livestock agroforestry on grassland with sparse tree cover is found in Spain (1.2 million ha), France (749,200 ha) and Romania (669,500 ha).

Table 2. Extent and distribution of agroforestry for livestock systems in Europe based on LUCAS data. Included are agroforestry areas under permanent crops (fruit, nut and olive trees), woodlands, shrubland and grassland with sparse tree cover.

Country	Total territorial area	Permanent crops	Woodland	Shrubland with sparse tree cover	Grassland with sparse tree cover	All livestock agroforestry	
	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	%
Austria	8388	22.0	92.1	6.5	37.6	158.2	1.9
Belgium	3053	2.5	6.2	0.0	34.9	43.7	1.4
Bulgaria	11090	23.4	167.0	91.8	584.4	866.5	7.8
Cyprus	925	6.4	12.2	12.2	12.8	43.6	4.7
Czech Rep.	7887	7.2	31.5	0.0	7.2	45.8	0.6
Denmark	4290	0.0	8.7	1.2	5.0	14.9	0.3
Estonia	4523	0.0	8.2	0.0	6.2	14.4	0.3
Finland	33843	0.0	143.1	5.0	10.0	158.1	0.5
France	54397	53.9	648.4	106.4	749.2	1557.9	2.9
Germany	35713	35.8	116.0	10.0	95.9	257.7	0.7
Greece	13196	123.0	655.7	534.3	288.2	1601.2	12.1
Hungary	9302	0.0	12.0	2.0	22.1	36.1	0.4
Ireland	6980	0.0	94.2	24.0	106.2	224.4	3.2
Italy	30134	116.2	622.4	235.2	329.8	1303.6	4.3
Latvia	6456	0.0	13.1	0.0	10.2	23.4	0.4
Lithuania	6530	6.7	10.1	0.0	20.1	36.9	0.6
Luxembourg	259	2.4	2.4	0.0	2.4	7.2	2.8
Malta	32	0.0	0.0	0.4	0.0	0.4	1.3
Netherlands	4154	3.7	9.3	3.7	11.1	27.8	0.7
Poland	31268	11.5	37.3	1.4	47.3	97.5	0.3
Portugal	8909	122.7	799.1	43.7	139.7	1105.1	12.4
Romania	23839	73.5	93.5	41.7	669.5	878.2	3.7
Slovakia	4904	0.0	20.0	4.0	18.0	41.9	0.9
Slovenia	2027	3.8	17.5	7.5	27.5	56.3	2.8
Spain	49851	217.0	3520.0	589.0	1163.9	5490.0	11.0
Sweden	43858	2.0	279.7	9.8	172.1	463.6	1.1
United Kingdom	24853	14.2	243.4	50.7	239.3	547.6	2.2
EU-27 total	**430659**	**848**	**7663**	**1781**	**4811**	**15102**	**3.5**

3.3 High value tree agroforestry

Agroforestry involving high value trees cover about 1.1 million hectares corresponding to about 0.2% of the territorial area in the EU (Table 3). 21% of these hectares are intercropped and 79% are grazed. Indeed, 5% of the lands with permanent crops are grazed (up to 9.5 for apple orchards, 6.9% of the nut groves and 6.5% of the olive groves). By contrast, only 1.1% of the European land with permanent crops are intercropped, 57% of them with olive groves. More common crops are vegetables, cereals (barley and oats) and permanent grasslands.

Table 3. Extent of intercropped, grazed and total extent of high value tree agroforestry practices in Europe based on LUCAS data.

Country	Total territorial area	Intercropped fruit, olive and nut tree area	Grazed fruit, olive and nut tree area	All high value tree agroforestry	
	1000 ha	1000 ha	1000 ha	1000 ha	%
Austria	8388	1.3	22.0	23.3	0.3
Belgium	3053	0.0	2.5	2.5	0.1
Bulgaria	11090	3.3	23.4	26.7	0.2
Cyprus	925	3.8	6.4	10.3	1.1
Czech Republic	7887	0.0	7.2	7.2	0.1
Denmark	4290	0.0	0.0	0.0	0.0
Estonia	4523	0.0	0.0	0.0	0.0
Finland	33843	0.0	0.0	0.0	0.0
France	54397	5.7	53.9	58.2	0.1
Germany	35713	0.0	35.8	35.8	0.1
Greece	13196	13.5	123.0	136.5	1.0
Hungary	9302	2.0	0.0	2.0	0.0
Ireland	6980	0.0	0.0	0.0	0.0
Italy	30134	90.3	116.2	202.2	0.7
Latvia	6456	0.0	0.0	0.0	0.0
Lithuania	6530	1.7	6.7	8.4	0.1
Luxembourg	259	0.0	2.4	2.4	0.9
Malta	32	0.0	0.0	0.0	0.0
Netherlands	4154	0.0	3.7	3.7	0.1
Poland	31268	2.9	11.5	14.3	0.0
Portugal	8909	36.4	122.7	154.2	1.7
Romania	23839	6.7	73.5	80.1	0.3
Slovakia	4904	2.0	0.0	2.0	0.0
Slovenia	2027	0.0	3.8	3.8	0.2
Spain	49851	52.1	217.0	260.7	0.5
Sweden	43858	0.0	2.0	2.0	0.0
United Kingdom	24853	0.0	14.2	14.2	0.1
EU-27 total	**430659**	**222**	**848**	**1050**	**0.2**

The largest extent of agroforestry with high value trees is found in Spain (260,700 ha) followed by Italy (202,200 ha) and Portugal (154,200 ha) (Table 3, Figure 1C). Greece, Romania and France also have a considerable area under agroforestry with high value trees. The largest extent of intercropped high value trees is found in Italy (90,300 ha) followed by Spain (52,100 ha) and Portugal (36,400 ha) (Table 3). The largest extent of grazed high value tree practices is found in Spain (217,000 ha), Portugal (122,700 ha), Greece (123,000 ha) and Italy (116,200 ha) (Table 3).

3.4 Total extent of agroforestry area in Europe

The total area under agroforestry in the EU amounts to about 15.4 million ha which is equivalent to 3.6% of the territorial area or 8.8% of the utilised agricultural area (Table 4, Figure 1D). Among our three studied systems, livestock agroforestry covers about 15.1 million ha which is by far the largest area among them. High value tree agroforestry and arable agroforestry, with 1.1 million ha and 358,000 ha respectively, cover substantially smaller areas. Note that the categories are not mutually exclusive as agroforestry with high value tree is also coded as arable or livestock agroforestry.

Spain (5.6 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.4 million ha), Portugal (1.2 million ha), Romania (888,200 ha) and Bulgaria (869,900 ha) have the largest absolute extent of agroforestry (Table 4, Figure 1D). However, if we look at the extent of agroforestry in relation to the utilised agricultural area (UAA), countries like Cyprus (40% of UAA), Portugal (32% of UAA) and Greece (31% of UAA) rank highest (Table 4). Some countries have a particularly small agroforestry cover, both in absolute terms and as a proportion of the UAA such as Denmark, Estonia, the Netherlands, Belgium, Luxembourg and Malta. Other countries, which have significant areas of agroforestry in absolute terms but a low area expressed as proportion of their UAA (1-2%), include Poland, Germany, Denmark and the Czech Republic, that have only 1% to 2% of their UAA under agroforestry.

Table 4. Extent and distribution of agroforestry in Europe based on LUCAS data categorised according to the three different systems and total extent.

Country	Total territorial area	Utilised Agricultural area (UAA)[1]	Arable agroforestry	Livestock agroforestry	High value tree agroforestry	All agroforestry	Estimated proportion of total territorial area	Estimated proportion of UAA
	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	%	%
Austria	8388	2878	1.3	158.2	23.3	160.8	1.9	5.6
Belgium	3053	1358	0.0	43.7	2.5	43.7	1.4	3.2
Bulgaria	11090	4476	3.3	866.5	26.7	869.9	7.8	19.4
Cyprus	925	118	3.8	43.6	10.3	47.5	5.1	40.1
Czech Republic	7887	3484	0.0	45.8	7.2	45.8	0.6	1.3
Denmark	4290	2647	1.2	14.9	0.0	16.2	0.4	0.6
Estonia	4523	941	0.0	14.4	0.0	14.4	0.3	1.5
Finland	33843	2291	0.0	158.1	0.0	158.1	0.5	6.9
France	54397	27837	5.7	1557.9	58.2	1562.2	2.9	5.6
Germany	35713	16704	5.7	257.7	35.8	263.5	0.7	1.6
Greece	13196	5178	15.2	1601.2	136.5	1616.4	12.2	31.2
Hungary	9302	4686	2.0	36.1	2.0	38.1	0.4	0.8
Ireland	6980	4991	0.0	224.4	0.0	224.4	3.2	4.5
Italy	30134	12856	106.1	1303.6	202.2	1403.9	4.7	10.9
Latvia	6456	1796	0.0	23.4	0.0	23.4	0.4	1.3
Lithuania	6530	2743	1.7	36.9	8.4	38.6	0.6	1.4
Luxembourg	259	131	0.0	7.2	2.4	7.2	2.8	5.5
Malta	32	11	0.0	0.4	0.0	0.4	1.3	3.5
Netherlands	4154	1872	0.0	27.8	3.7	27.8	0.7	1.5
Poland	31268	14447	2.9	97.5	14.3	100.4	0.3	0.7
Portugal	8909	3668	76.5	1105.1	154.2	1168.3	13.1	31.8
Romania	23839	13306	10.0	878.2	80.1	888.2	3.7	6.7
Slovakia	4904	1896	2.0	41.9	2.0	43.9	0.9	2.3
Slovenia	2027	483	0.0	56.3	3.8	56.3	2.8	11.7
Spain	49851	23753	117.0	5490.0	260.7	5584.4	11.2	23.5
Sweden	43858	3066	2.0	463.6	2.0	465.5	1.1	15.2
United Kingdom	24853	16882	2.0	547.6	14.2	551.7	2.2	3.3
EU-27 total	**430659**	**174499**	**358**	**15102**	**1050**	**15421**	**3.6**	**8.8**

[1]Source: Eurostat online data sources: Farm structure statistics (2010). Available online: http://ec.europa.eu/eurostat/statistics-explained/index.php/Farm_structure_statistics

3.5 Likelihood map of agroforestry systems

Cluster analysis revealed that a high abundance of agroforestry LUCAS points is found in south, central and north-east Portugal, south-west, central and parts of north Spain, south of France, Sardinia, south and central Italy, central and north-east Greece, south and central Bulgaria, and central Romania (Fig. 2). A set of features that occurs in a totally random distribution would have a nearest neighbour ratio of 1, while our agroforestry points returned a ratio of 0.0078, indicating that they are significantly clustered (nearest neighbour ratio = 0.0078, z-score = -193.5, $p < 0.001$). The nature of these clusters of agroforestry points could range from many small fragments of wood pastures situated relatively close together to, at another extreme, large areas with continuous wood pasture cover.

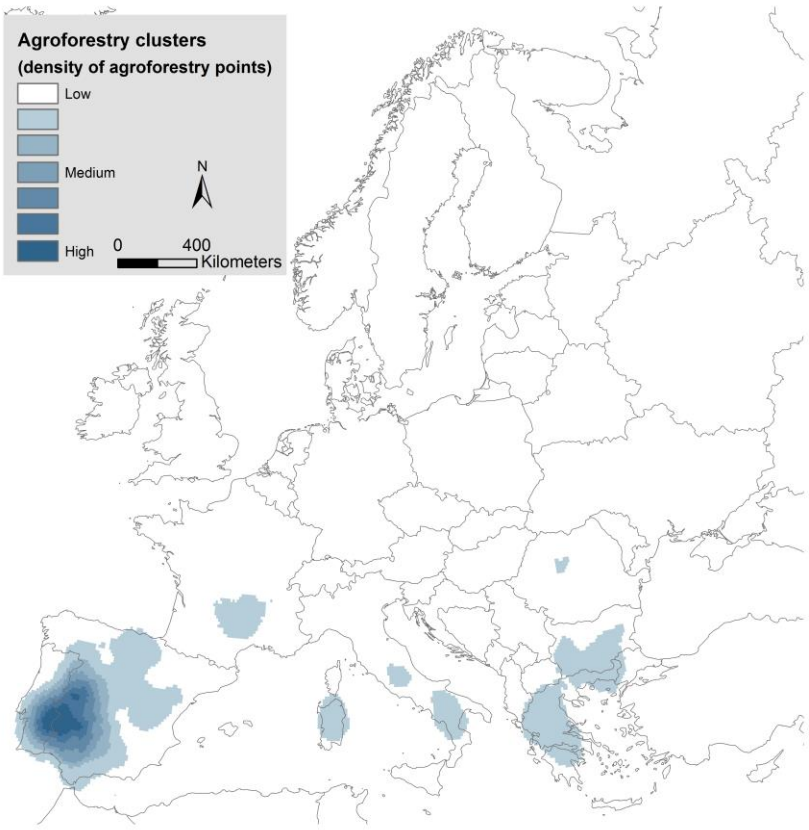

Figure 2. Agroforestry clusters in Europe. Agroforestry clusters (dark blue) are represented by a high density of points which were defined as "agroforestry" in the LUCAS database.

4. Discussion

Our exercise estimated an agroforestry cover of about 15.4 million ha in the European Union (EU27, Croatia was not yet included) which is equivalent to 3.6% of the territorial area and 8.8% of the utilised agricultural area. This estimate is considerably larger than the previous estimate by den Herder et al. (2015a) who, based on a review of the literature, suggested that agroforestry occupied at least 10.6 million ha. The higher estimate for the agroforestry area

using the LUCAS data than the literature review can be partly explained by the addition of data from Bulgaria (0.9 million ha) and several other countries (Estonia, Latvia, Lithuania, Luxembourg and Malta) with a small agroforestry cover. But also to the higher estimates for Spain (+1.7 million ha), France (+1.0 million ha), Romania (+0.7 million ha) and Italy (+0.4 million ha) (Table A.2). Large differences between the two estimates for some countries can be due to several reasons. It is likely that there is a rich source of agroforestry literature for those countries where agroforestry is traditionally practiced on a relatively large scale. It is also possible that, even though the review by den Herder et al. (2015) was able to retrieve a good sample of the published literature, there are still some agroforestry systems which are not well described. For example, in our LUCAS estimate, the higher estimate for Spain is primarily a result of including other silvopastoral systems in addition to the *dehesas* (e.g. grazing in forests is a still a common practice and useful for the control of wildfire). Furthermore, it is quite understandable that countries which do not have a wide-spread agroforestry (e.g. The Netherlands), do not have much literature describing these practices. This explains why for many countries the estimate from literature review would be far from complete or does not exist. By using the LUCAS database, we were now able to make a uniform estimate covering the whole EU.

Inconsistencies between our mapping exercise and the literature review may also have arisen from the fact that they are based on different understandings of the agroforestry. The published literature, may consider only formalized agroforestry systems, for example a typical well-managed, dense orchard meadow (e.g. *streuobst* and *pré-verger*) in Germany and France or the well-known *montados* and *dehesas* in Portugal and Spain. By using LUCAS data, we also included grasslands with low tree density that could have been recorded as treeless grasslands in other inventories. Neither of these two perspectives is wrong. It just depends on the underlying assumptions and understanding what is included in the agroforestry concept.

Finally, the resolution of maps and database also matters. At low resolution, each large "unit of land" (pixels, plots, polygons) probably includes different land uses that taken together can be coded as an agroforestry land use. This would explain the huge values estimated by Zomer et al (2014) for trees on European farmlands. Using pixels of 1 km^2 they estimated that 80% of the European agricultural lands included a certain level of tree cover (14% on average; 48% of the European agricultural land had more than 10% tree cover). Where woodlots and tree lines are found within 1 km distance from agricultural lands, the pixel easily is coded as agroforestry. In addition, in their analysis, Zomer et al. (2009; 2014) probably included abandoned/encroached farms and traditional woody crops (e.g. olive and nut groves with low tree density) as agroforestry.

Our estimations and maps are not fully free of this inaccuracy as points defined as agroforestry may not correspond to a deliberate combination of components within the farm or plot. Indeed, some LUCAS sites might be located at an ecotone, for example at a forest edge. In this case, they might have a grass land cover and a tree land cover, but on adjacent sites and not on the same land unit. In this analysis, we interpreted these sites as agroforestry, although this may not have been the intention of the land managers. Indeed, some of the points coded as agroforestry may not be managed as agroforestry plots/farms, but the delivery of some ecosystem services from these areas, e.g. control of runoff, will arise from the combination of trees with farming and thereby agroforestry processes and practices. Hence, our estimate should not be primarily considered as an estimate of agroforestry at the farm/plot

scale but rather as an estimate of agroforestry at the landscape scale, which in turn will affect the delivery of ecosystem services. This is important as extensive forms of silvopastoral agroforestry, such as wood pastures, are frequently formed from a mosaic pattern of agricultural and forest lands, whose administrative designation differs between countries and regions. Hence their inclusion in the regional and national statistics are inconsistent across Europe.

In addition, it must be noted that the LUCAS data have to be interpreted with caution as mountainous and other remote areas are underrepresented in the LUCAS survey. For example, reindeer husbandry in northernmost Fennoscandia is probably underestimated since very remote areas had lower sampling intensity and the evidence of grazing was probably too low to be noted by the surveyors and therefore misinterpreted during the survey. As a result, some sites may have been recorded as areas with "no signs of grazing" while in fact they were grazed. There can also be an effect of sample size. The LUCAS sampling grid may result in reasonably accurate estimates for the larger countries as these are covered by a higher number of sample points. Smaller countries are covered by a lower number of samples and therefore sampling error increases. There can be an effect of the sampling method. Similarly, accuracy is higher for more common agroforestry categories than for infrequent categories or subcategories.

Since the data were collected and analysed in a consistent manner, our study allows, for the first time, the comparison between countries and the identification of regions in Europe where agroforestry is widely practiced or not. Overall, we have shown that European agroforestry is dominated by silvopasture such as grazed broadleaved woodlands and grasslands with sparse trees, but also grazed permanent crops such as olive groves in the Mediterranean and fruit orchards in continental and Atlantic regions. Arable agroforestry is much less frequent, although certain combinations such as broadleaves woodlands with cereal and olive groves with cereal or vegetables are not uncommon in the Mediterranean region (see also Eichhorn et al., 2006). This information provides a baseline for the identification of regionally adapted policy and management options. In areas where agroforestry is already widely practiced, the focus could be on safeguarding and enhancing provisioning of ecosystem services from existing mostly traditional agroforestry practices. In areas where agroforestry is not widely practiced, there are opportunities to apply agroforestry on a wider scale and to introduce novel agroforestry practices.

In addition to the three agroforestry types described in this paper, the AGFORWARD European research project also refers to agroforestry of "high natural and cultural value" (Burgess et al., 2015). Currently there is no universally accepted definition of the concept of "high natural and cultural value" agroforestry systems (see den Herder et al., 2015 for a preliminary stratification of agroforestry systems). It is built on the concept of high nature value (HNV) farming that was proposed by the European Environment Agency (Parachini et al. 2006). This concept recognizes that specific farming practices and systems support high biodiversity levels (Pointereau et al., 2007). According to Paracchini et al. (2006) there are three types of high nature value farmland: 1) farmland with a high proportion of semi-natural vegetation, 2) farmland with a mosaic of low intensity agriculture and natural and structural elements, such as field margins, stone walls, patches of woodland or shrub, small rivers, and 3) farmland supporting rare species or a high proportion of European or world populations. Frequently HNV farms are extensive, traditional, low-input farms. None of these trees categories refer exclusively to agroforestry, but agroforestry is frequently present in the two

first types of HNV farm systems. For instance, the *dehesas* and *montados* in Spain and Portugal, and *bocage* in France, clearly belong to the high nature value farming systems in Europe (Moreno et al., 2016; Bugalho et al., 2011; Pointereau et al., 2007, respectively). Although LUCAS does not include information about the natural and/or cultural value of the surveyed points, the cluster map could be viewed as an indicator of regions where agroforestry is abundant. This could mean that many small scattered agroforestry patches occur in these areas or that agroforestry covers larger areas. Many of the remaining agroforestry practices are a legacy of traditional land uses. Clusters of agroforestry points would indicate areas where these mostly traditional practices and their associated cultural values still exist. These regions are mostly found in southern and eastern European countries.

Agroforestry integrates trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land (Alavalapati et al., 2005). This paper only focuses on a spatial analysis of simultaneous agroforestry; it does not consider sequential systems where, for example, agricultural land is afforested, the trees are eventually harvested, and the land is then returned to agriculture.

Considering the fact that the area of agroforestry is equivalent to 8.8% of the agricultural land in the EU, it is crucial that it gets a more prominent and clear place in EU statistical reporting, what should help to implement best fit policies. This is not difficult to implement. For example, the LUCAS Land Use classes “agriculture” and “forestry” could get a secondary land use class “agroforestry” indication in case a silvoarable or silvopastoral agroforestry practice is observed during the field survey. Including a few changes to better incorporate agroforestry in the LUCAS reporting method would make it easier to give more precise estimates on the extent of agroforestry in Europe and changes in its extent. In addition, it would facilitate the inclusion of other types of agroforestry, for instance forest farming, that cannot be mapped due to the lack of statistics (Mosquera-Losada et al.2016).

Making estimates on the current extent of European agroforestry was challenging but it is important for a) developing measures and policies to promote this sustainable land use practice and b) evaluating the impact of certain measures on agroforestry. By using the LUCAS database, this study demonstrates that it is possible to produce a comparable and uniform estimate on the extent of agroforestry in Europe. Improved reporting is important in giving agroforestry its appropriate place on the political map.

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Appendices

Table A.1. Criteria used for identifying arable, livestock, high value tree (grazed and intercropped) and all agroforestry systems. LC1 = primary land cover, LC2 = secondary land cover, dash (-): the variable was included in the analysis but there were no observations where this particular land cover occurred in an agroforestry system.

Land cover / variable	Code[1]	LUCAS class	Arable agroforestry	Livestock agroforestry	High value tree agroforestry		All agroforestry
					Intercropped	Grazed	
Cereals	B11	Common wheat	LC2		LC2		LC2
	B12	Durum wheat	LC2		LC2		LC2
	B13	Barley	LC2		LC2		LC2
	B14	Rye	LC2		LC2		LC2
	B15	Oats	LC2		LC2		LC2
	B16	Maize	LC2		LC2		LC2
	B17	Rice	-		-		-
	B18	Triticale	LC2		-		LC2
	B19	Other cereals	LC2		LC2		LC2
Root crops	B21	Potatoes	LC2		LC2		LC2
	B22	Sugar beet	-		-		-
	B23	Other root crops	LC2		LC2		LC2
Non-permanent industrial crops	B31	Sunflower	LC2		LC2		LC2
	B32	Rape and turnip rape	-		-		-
	B33	Soya	-		-		-
	B34	Cotton	-		-		-
	B35	Other fibre and oleaginous crops	LC2		LC2		LC2
	B36	Tobacco	LC2		LC2		LC2
	B37	Other non-permanent industrial crops	-		-		-
Dry pulses, vegetables and flowers	B41	Dry pulses	LC2		LC2		LC2
	B42	Tomatoes	LC2		LC2		LC2
	B43	Other fresh vegetables	LC2		LC2		LC2
	B44	Floriculture and ornamental plants	LC2		LC2		LC2
	B45	Strawberries	LC2		LC2		LC2
Fodder crops	B51	Clovers	LC2		LC2		LC2
	B52	Lucern	LC2		LC2		LC2
	B53	Other leguminous and mixtures for fodder	LC2		LC2		LC2
	B54	Mix of cereals	LC2		LC2		LC2
Permanent crops: fruit trees	B71	Apple	LC1	LC1	LC1	LC1	LC1
	B72	Pear	LC1	LC1	LC1	LC1	LC1
	B73	Cherry	LC1	LC1	LC1	LC1	LC1
	B74	Nut trees	LC1	LC1	LC1	LC1	LC1
	B75	Other fruit trees and berries	LC1	LC1	LC1	LC1	LC1
	B76	Oranges	LC1	LC1	LC1	LC1	LC1
	B77	Other citrus fruit	LC1	LC1	LC1	LC1	LC1
Other permanent crops	B81	Olive groves	LC1	LC1	LC1	LC1	LC1
	B82	Vineyards	LC1/LC2	LC1	LC1/LC2	LC1	LC1/LC2

Land cover / variable	Code[1]	LUCAS class	Arable agroforestry	Livestock agroforestry	High value tree agroforestry		All agroforestry
					Intercropped	Grazed	
Permanent industrial crops	B84k	Mulberries and carob	LC1	LC1	LC1	LC1	LC1
	B84m	Willow	-	LC1			LC1
Woodland	C10	Broadleaved woodland	LC1	LC1			LC1
	C21	Spruce dominated woodland	-	LC1			LC1
	C22	Pine dominated woodland	LC1	LC1			LC1
	C23	Other coniferous woodland	LC1	LC1			LC1
	C31	Spruce dominated mixed woodland	-	LC1			LC1
	C32	Pine dominated mixed woodland	LC1	LC1			LC1
	C33	Other mixed woodland	-	LC1			LC1
Shrubland	D10	Shrubland with sparse tree cover	LC1	LC1			LC1
Grassland	E10	Grassland with sparse tree cover		LC1			LC1
Land management	1	Signs of grazing		Yes		Yes	Yes

[1]See Eurostat (2012) for more detailed information on the LUCAS land cover classification.

Table A.2. Total extent of agroforestry (total area x 1000 ha) in Europe according to the literature study (den Herder et al. 2015) and the LUCAS estimate.

Country	All agroforestry (literature estimate)	All agroforestry (LUCAS estimate)	Difference (LUCAS – literature)
	1000 ha	1000 ha	1000 ha
Austria	48.6	160.8	112.3
Belgium	12.4	43.7	31.3
Bulgaria		869.9	869.9
Croatia	64.5		
Cyprus		47.5	47.5
Czech Republic	9.2	45.8	36.5
Denmark	3.2	16.2	12.9
Estonia		14.4	14.4
Finland	7.3	158.1	150.8
France	510.1	1562.2	1052.0
Germany	480.5	263.5	-217.0
Greece	2096.7	1616.4	-480.3
Hungary	22.8	38.1	15.3
Ireland		224.4	224.4
Italy	967.0	1403.9	436.9
Latvia		23.4	23.4
Lithuania		38.6	38.6
Luxembourg		7.2	7.2
Malta		0.4	0.4
Netherlands	3.0	27.8	24.8
Poland	200.0	100.4	-99.6
Portugal	1842.3	1168.3	-674.1
Romania	180.1	888.2	708.1
Slovakia	92.0	43.9	-48.1
Slovenia	185.0	56.3	-128.7
Spain	3839.9	5584.4	1744.5
Sweden	100.0	465.5	365.5
Switzerland	97.3		
United Kingdom	157.5	551.7	394.2
EU-27 total	**10643**	**15421**	**4778**

Supplementary material

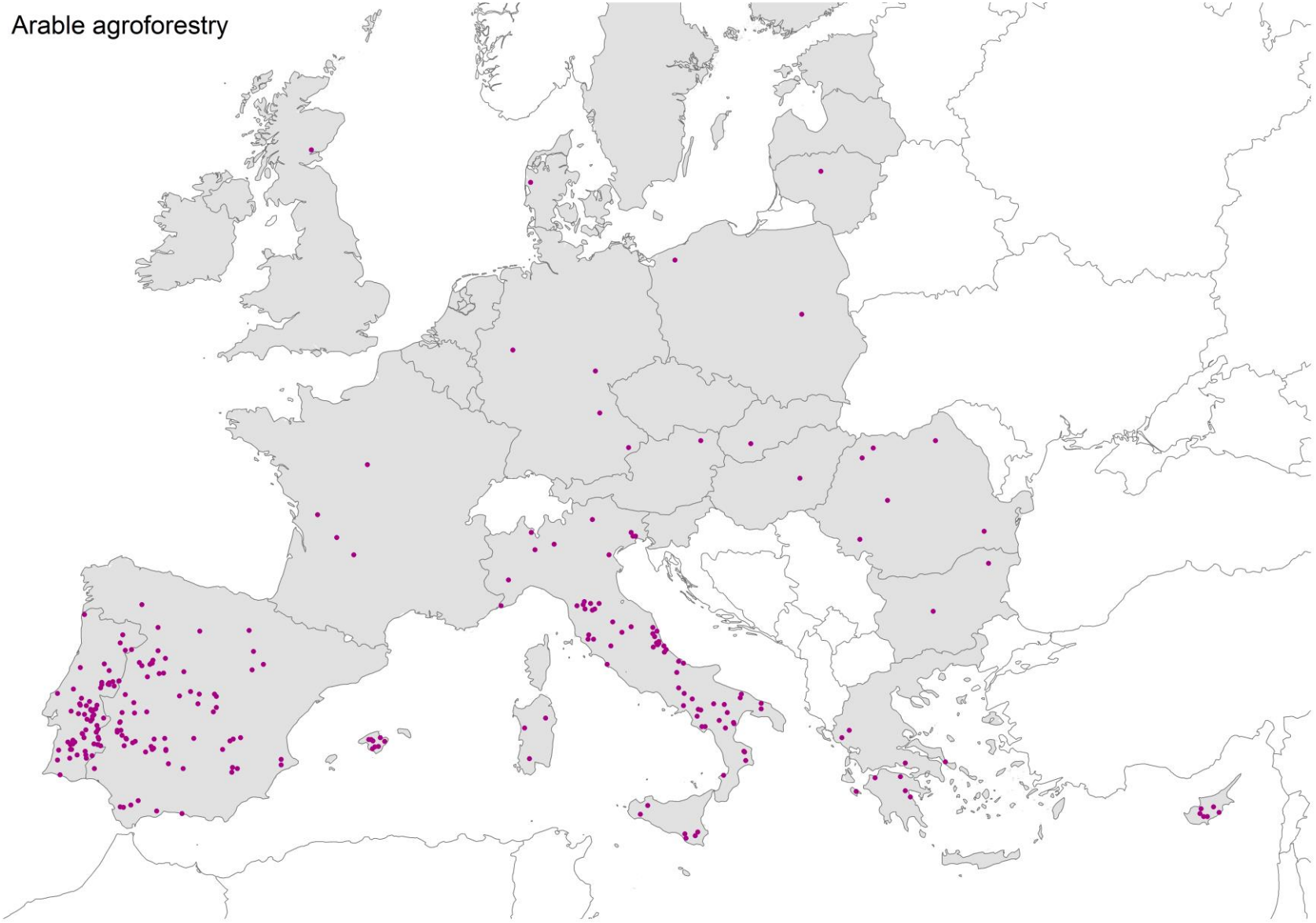

Figure S1. Distribution of arable agroforestry in Europe.

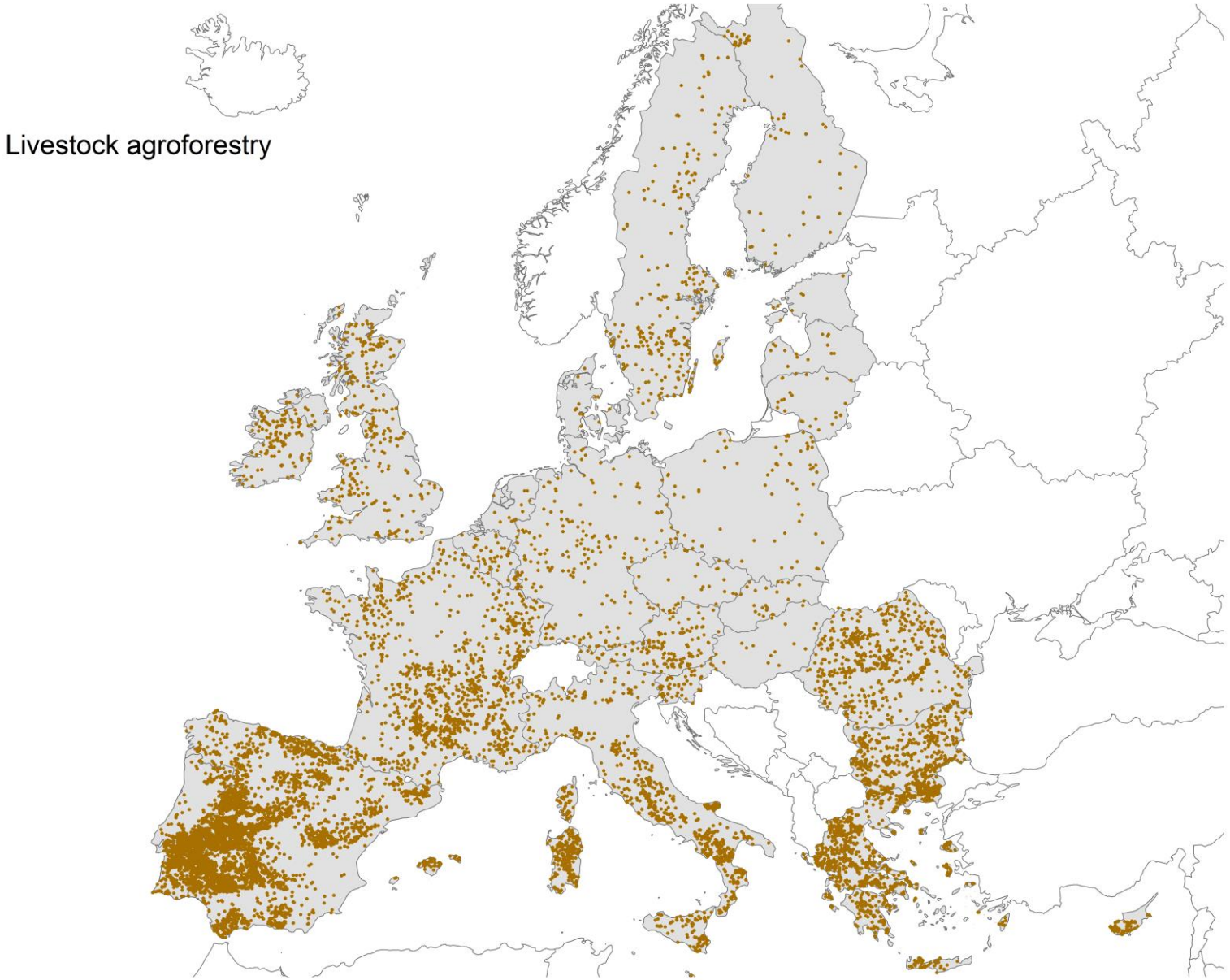

Figure S2. Distribution of livestock agroforestry in Europe.

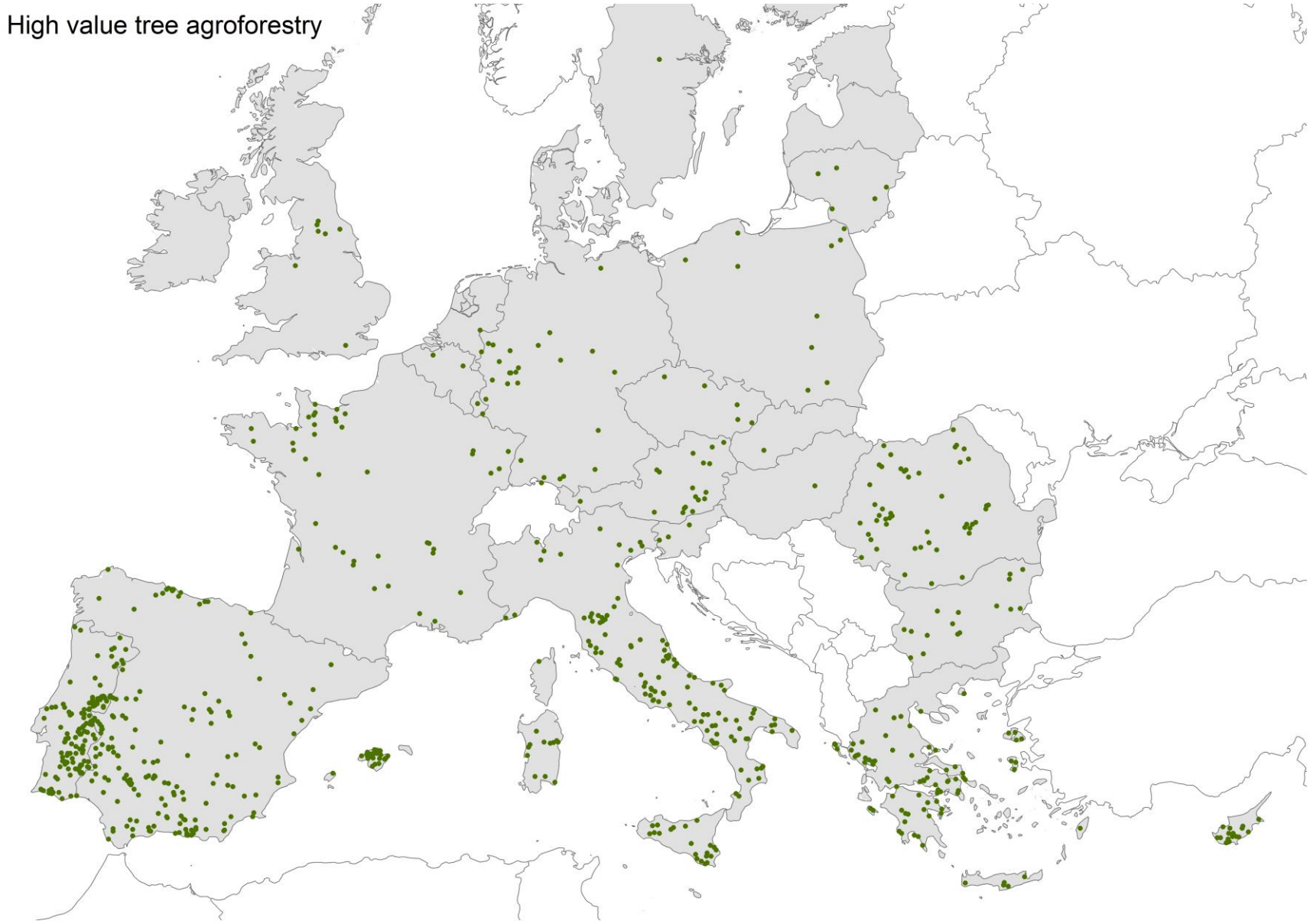

Figure S3. Distribution of high value tree agroforestry in Europe.

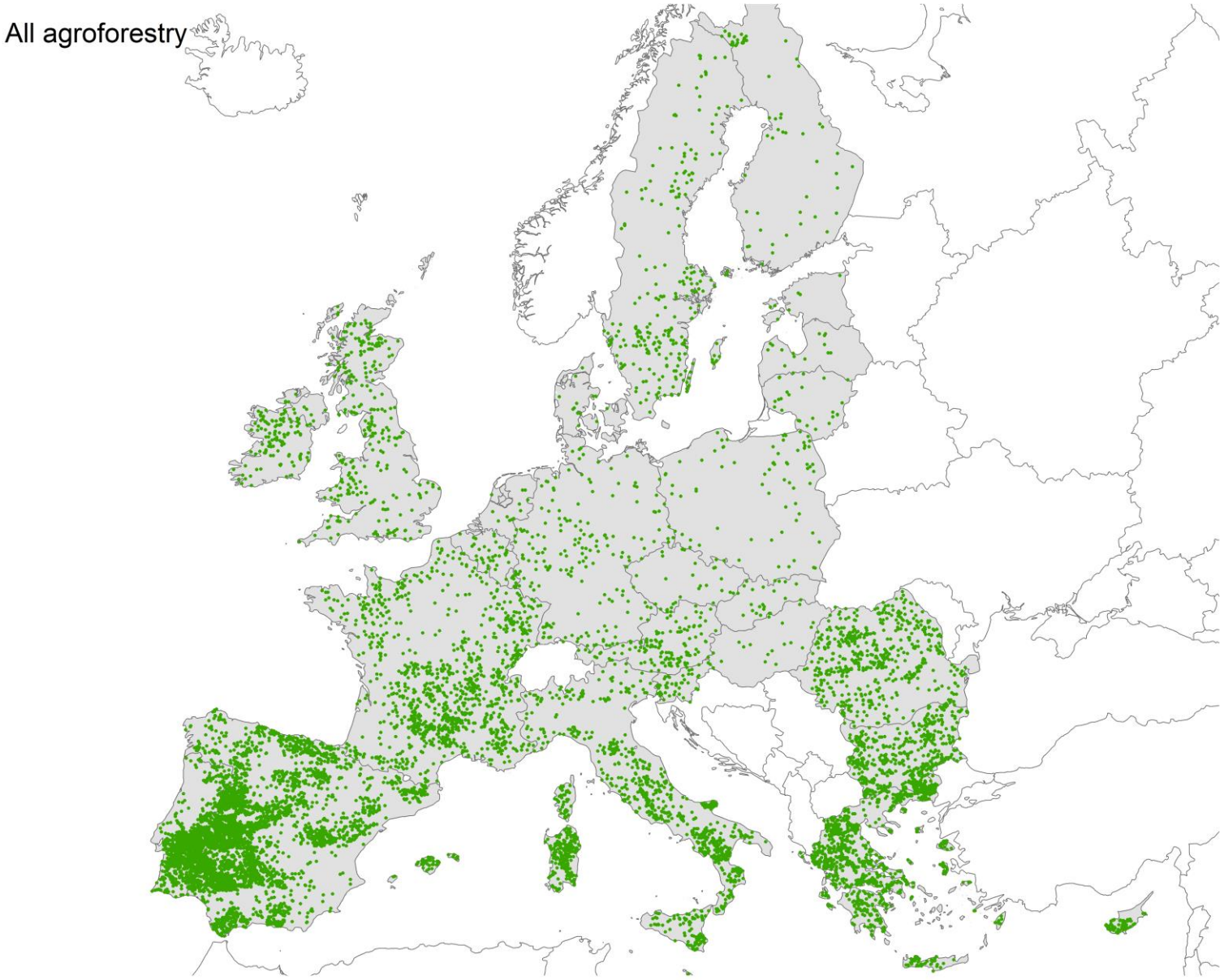

Figure S4. Total extent of agroforestry in Europe.

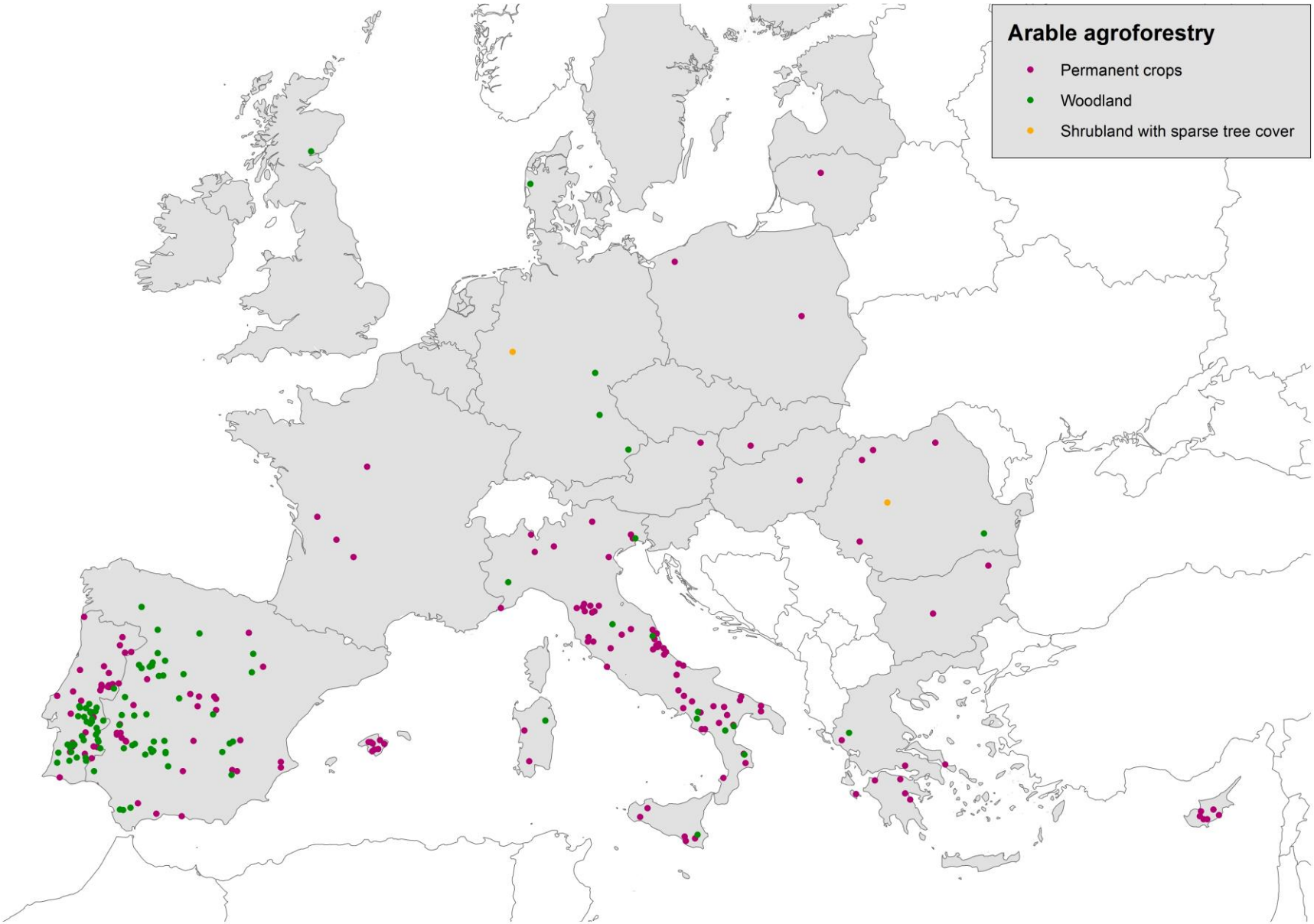

Figure S5. Distribution of arable agroforestry by sub-categories: Included are agroforestry areas under permanent crops (fruit, nut and olive trees), woodlands and shrubland with sparse trees.

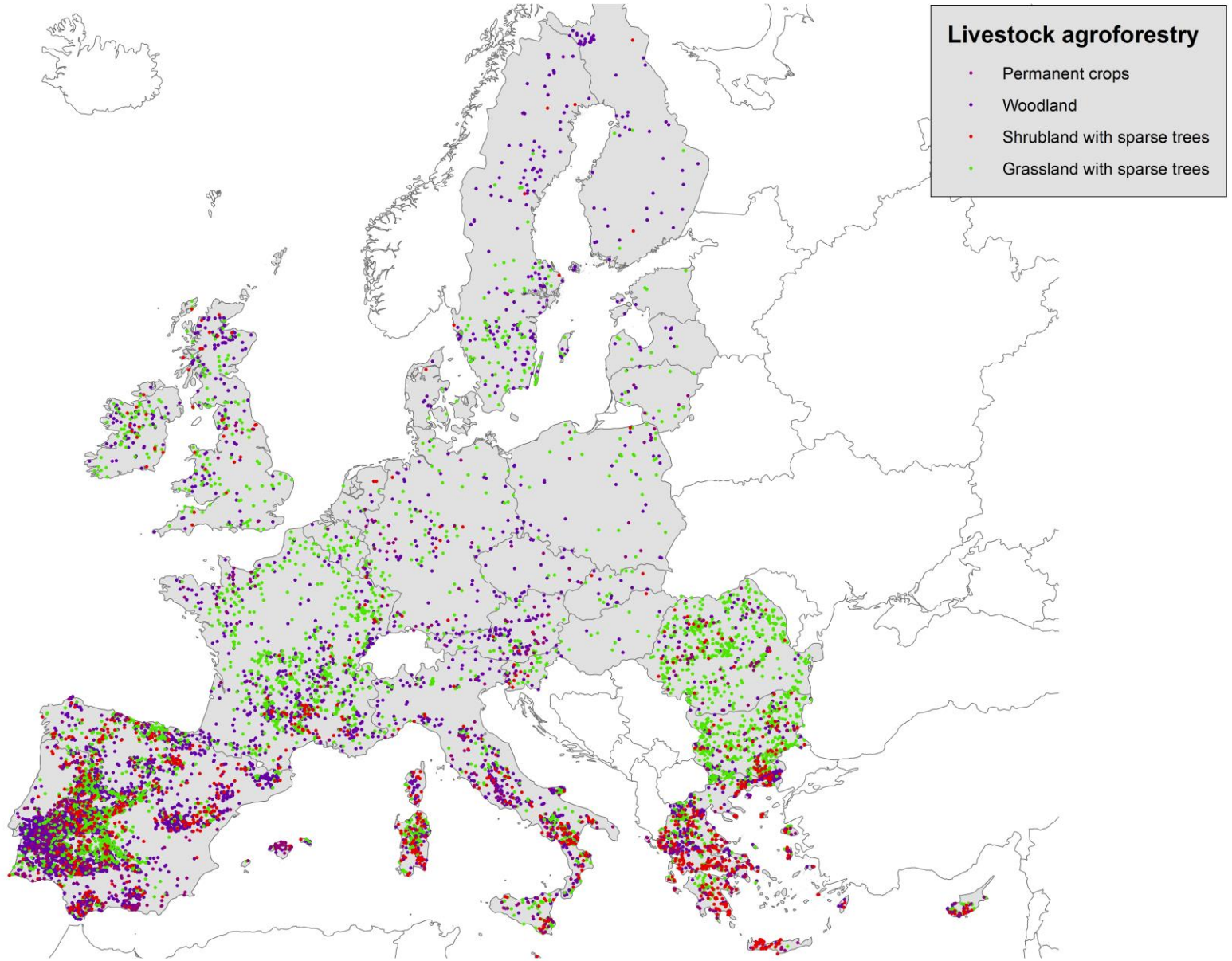

Figure S6. Distribution of livestock agroforestry by sub-categories: Included are agroforestry areas under permanent crops (fruit, nut and olive trees), woodlands, shrubland and grassland with sparse tree cover.

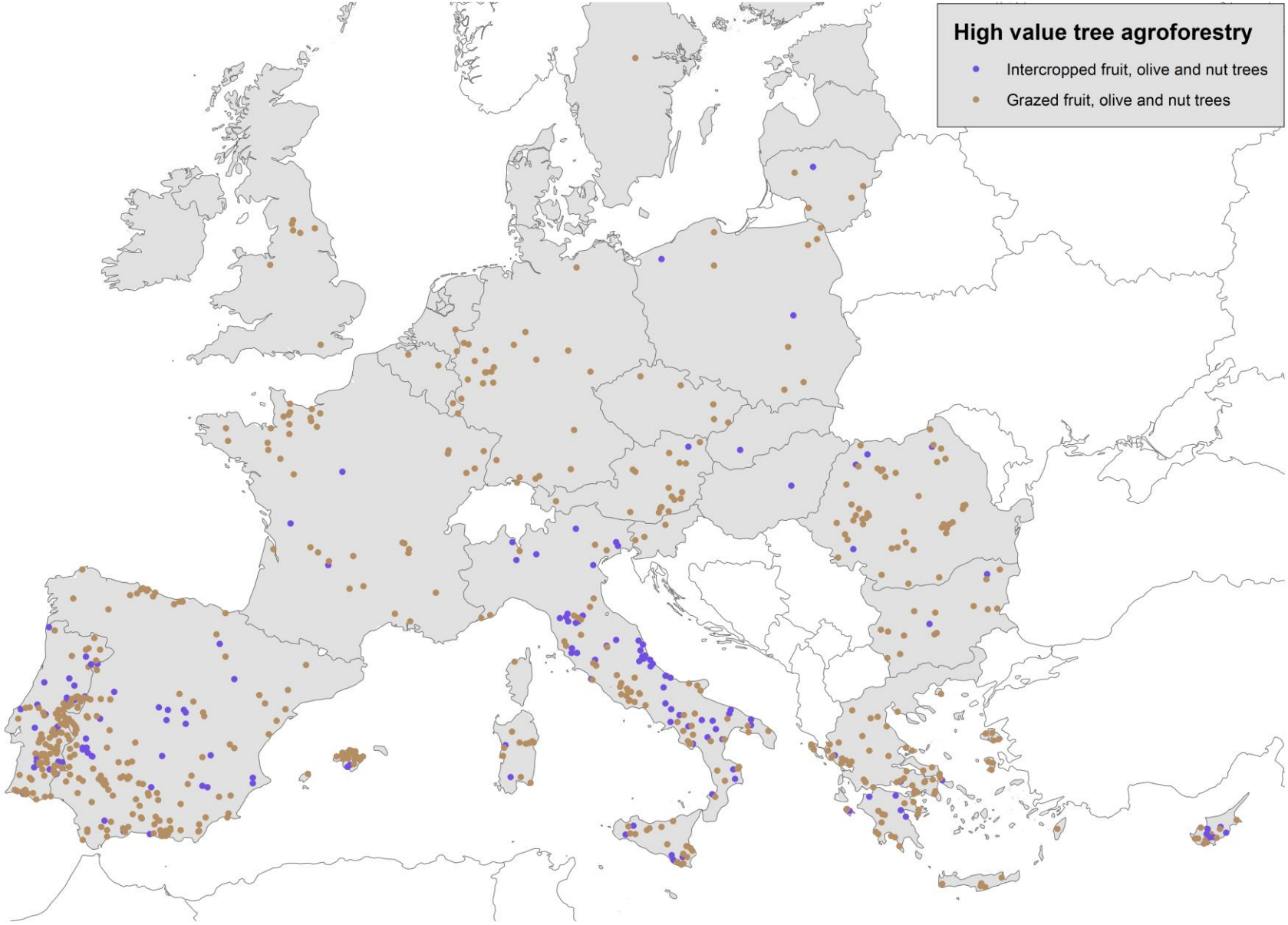

Figure S7. Distribution of high value tree agroforestry by sub-categories: Included are intercropped and grazed high value tree agroforestry practices.