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Research paper

Analysis of landrace cultivation in Europe: A means to support *in situ* conservation of crop diversity

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ABSTRACT

During the last century, the progressive substitution of landraces with modern, high yielding varieties, led to a dramatic reduction of *in situ* conserved crop diversity in Europe. Nowadays there is limited and scattered information on where landraces are cultivated. To fill this gap and lay the groundwork for a regional landrace *in situ* conservation strategy, information on more than 19,335 geo-referenced landrace cultivation sites were collated from 14 European countries. According to collected data, landraces of 141 herbaceous and 48 tree species are cultivated across Europe: Italy (107 species), Greece (93), Portugal (45) and Spain (44) hold the highest numbers. Common bean, onion, tomato, potato and apple are the species of main interest in the covered countries. As from collected data, about 19.8% of landrace cultivation sites are in protected areas of the Natura 2000 network. We also got evidence that 16.7% and 19.3% of conservation varieties of agricultural species and vegetables are currently cultivated, respectively. Results of the GIS analysis allowed the identification of 1261 cells (25 km × 25 km) including all the cultivation sites, distributed across all European biogeographical regions. Data of this study constitute the largest ever produced database of *in situ*-maintained landraces and the first

Abbreviations: LrCSs, Landrace Cultivation Sites; CWR, Crop Wild Relatives; PGRFA, Plant Genetic Resources for Food and Agriculture; CBD, Convention on Biological Diversity; ITPGRFA, International Treaty on Plant Genetic Resources for Food and Agriculture; CAP, Common Agricultural Policy; ECPGR, European Cooperative Programme for Plant Genetic Resources; GIS, Geographic Information System; EC, European Commission; EU, European Union.

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attempt to create an inventory for the entire Europe. The availability of such resource will serve for better planning of actions and development of policies to protect landraces and foster their use.

1. Introduction

Agrobiodiversity, a vital sub-set of biodiversity for humankind, is the result of the interaction between plant, animal and microbe genetic resources with the environment, management systems and cultivation practices of diverse cultural settings (FAO, 1999). The portion of plant agrobiodiversity with present or potential value for human nutrition is commonly referred to as Plant Genetic Resources for Food and Agriculture (PGRFA). Our future food supplies depend on the continuous availability of a wide range of PGRFA for use by farmers, researchers and breeders and in particular of landraces and of crop wild relatives (CWR). Currently, due to the increasingly extreme impacts of climate change on food production and transformation of socio-economic contexts, genetic resources are becoming even more important. In fact, agrobiodiversity is a key factor providing agroecosystems with resilience and the ability of buffering negative effects caused by the climate change (Altieri, 1999; Cardinale et al., 2012; Newton et al., 2009). Nevertheless, we are currently facing an exceptionally high rate of agrobiodiversity loss in which landscapes, species and within-species diversity forms are continuously disappearing (FAO, 2019).

Conservation of agrobiodiversity encompasses a range of diverse strategies and consequent actions are to be taken to prevent its loss. At present, most PGRFA are held *ex situ* in gene banks as seed samples. However, *ex situ* conservation is equated with static conservation: removing PGRFA from their natural environments and placing the germplasm in gene banks literally freezes their evolutionary and adaptive potential. It has been argued that to maximise the level of conserved diversity, *ex situ* should be integrated with *in situ* conservation (Brush, 2004; de Haan et al., 2013; Maxted et al., 1997; Wang et al., 2016). Indeed, *in situ* conservation is seen as a means of capturing the evolutionary adaptation of resources that, being exposed to the changing environment, can provide a valuable reservoir of adaptive traits (Gepts, 2006; Maxted et al., 2020; Tiranti and Negri, 2007; Vigouroux et al., 2011). It has also been suggested that diversity can support ecosystems functioning, resilience and productivity (Tilman et al., 2006 and refs therein); with specific reference to cultivated materials, landrace *in situ* conservation (*i.e.* on-farm) can provide different environmental and genetic values to multiple segments of the society (Chable et al., 2020; Jarvis et al., 2016). For these reasons, it appears crucial to promote on-farm conservation of landraces and other heterogeneous materials at regional level wherever appropriate (ECPGR, 2017). In Europe, the approaches to maintain diversity on-farm can be quite diverse as a consequence of the different aspects that are of main interest in different socio-ecological contexts: the maintenance of the genetic materials themselves, the adoption of agro-ecological approaches, the promotion of stronger interactions among different actors involved in food production "from farm to fork", a just recognition of farmers' rights and of their role as custodians of local varieties, the promotion of the establishment of farmer networks as well as of community seed banks. Several examples across Europe have demonstrated the efficacy of the different approaches in increasing cultivated diversity on-farm (Chable et al., 2020; Maxted et al., 1997).

The importance of crop genetic diversity within agricultural systems is currently widely recognized and a number of international policies and agreements calls for the conservation and sustainable use of PGRFA like the Convention on Biological Diversity (CBD) (United Nations, 1992) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001) to which all the 27 European Union (EU) member countries have already given consent to be bound.

The EU Biodiversity Strategy, adopted in 2012, already identified six major target areas where action was required to address the key pressures on nature and ecosystem services within the EU, one of these targets aimed at increasing the contribution of agriculture and forestry to biodiversity conservation. Natura 2000 is a network of protected areas, designated under the Birds Directive (Special Protection Areas or SPAs) (European Commission, 1979) and the Habitats Directive (Sites of Community Importance or SCIs, and Special Areas of Conservation or SACs) (European Commission, 1992), inclusive of EU's most valuable and threatened species, covering almost 20% of EU's terrestrial area. A significant number of its sites have been designated to protect species or habitats that depend upon or are closely associated with agriculture that explains why around 40% of the land in the Network is, or was once, managed farmland (European Commission, 2018). Protected areas are often associated with those of low agricultural outputs, most of the farmland in Natura 2000 are in marginal areas where landraces are commonly cultivated. As for these aspects, focusing on sites of the Natura 2000 network of protected areas plays a strategic role in achieving effective conservation of the two main components of PGRFA, landraces and CWR. In addition, according to the recent EU's strategy 'Farm to Fork', at the heart of the 'Green Deal' (European Commission, 2019), the Commission will take measures to ensure easier market access for traditional and locally adapted varieties, facilitating their wider use and demand; within the same framework, registration of heterogeneous materials suitable for organic farming will be promoted. It also appears that the current draft of the revised Common Agricultural Policy (CAP) in the European Union, to be implemented in 2023, does include specific measures to support *in situ* conservation of PGRFA also being applied in non-EU countries such as the UK Parliament (2020). Recently, the decline of genetic diversity, as well as the need of promoting and facilitating the use of traditional crop varieties, have been confirmed in the new EU Biodiversity Strategy (European Commission, 2020).

Despite this global and European policy context, the legislative foundation for *in situ* landrace and CWR diversity conservation in Europe is still patchy and based on Environmental Stewardship Schemes not specifically designed. Up to now, overall, few coordinated actions have been undertaken to monitor the presence, characteristics and availability of *in situ* maintained PGRFA. Meanwhile, due to the profound transformation of production systems and socio-economic contexts occurred in the 20th century, landraces are dramatically threatened with a great portion already being lost (Grigg, 1992; Maxted et al., 1997) due to the effect of different factors (Heinonen, 2014; Heinonen and Veteläinen, 2009; Maxted et al., 2008; Stickland, 1998; Vellvé, 1992).

Although most of European agricultural production currently relies on formally registered and genetically uniform cultivars, landraces are still grown *in situ*. However, a European inventory of *in situ*-maintained landraces is still lacking and, consequently, there is limited and scattered information on where these materials are grown and to which species they belong to. The compilation of such inventory is of great relevance for the promotion of actions aimed at improving landraces conservation and use (Hammer, 1990; Maxted et al., 2009). Inventories are required because, without knowing the extant, it is rather difficult for governments to properly plan and implement the systematic conservation and use of landraces. In addition, countries that ratified the ITPGRFA are required to "survey and inventory PGRFA" (Art. 5.a) (FAO, 2001). Geographical distribution and pedo-climatic characteristics of sites where landraces are cultivated are also of great relevance. Different landraces, cultivated in diverse environments, hold traits for local adaptation. Biogeographical regions (Roekaerts, 2002) are useful investigation means, especially when landscape characterization are pursued at transnational level.

In the literature, the term 'landrace' refers to a broad range of definitions that have evolved over time (Camacho Villa et al., 2005; Casañas et al., 2017 and references therein; Maxted et al., 2020; Negri et al., 2009 and references therein). A recent approach (ECPGR, 2017) rather than giving additional and/or broader definition to the term itself put the attention on the materials that are object of *in situ* conservation including 'true landraces' (Negri et al., 2009) but also introduced landraces, cross-composite populations (Goldringer et al., 2006; Raggi et al., 2016a, 2016b) and varietal mixtures (Barot et al., 2017; Harlan and Martini, 1938). All these materials, characterised by within-population genetic diversity and hereafter collectively referred to as 'landraces' in a broad sense, are of pivotal importance for *in situ* conservation of agrobiodiversity and are the object of this research.

This study aims at laying the foundation for the development of the first European catalogue of landraces extant *in situ* and of their cultivation sites in relationship with the different European biogeographical regions and the network of protected areas Natura 2000. Cultivation of conservation varieties is also explored to measure their contribution to *in situ* conservation of crop diversity in Europe.

2. Materials and methods

2.1. Building a first European inventory of in situ landraces

In order to collate data on known Landrace Cultivation Sites (LrCSs) across Europe, an *ad hoc* template was developed starting from the *Descriptors for web-enabled national in situ landrace inventories* document (Negri et al., 2012) (Table A1, Supplementary materials; available as an online appendix). The use of the template for data collection allowed to gather information on inventory of reference, landrace taxon, the local name used to identify a landrace, and precise location of the cultivation site. The template was circulated among the Members of the project Farmer's Pride that involves more than 40 national and international organizations representing groups with an interest in the conservation and sustainable use of plant genetic resources and among the National Coordinators of European Cooperative Programme for Plant Genetic Resources (ECPGR).

First, collected data were organised in a database where all the information related to each LrCS were stored as unique database record. Data were checked for crop nomenclature consistency and Latin names were confirmed against the US Germplasm Resources Information Network Taxonomy (USDA-ARS-GRIN, 2017). Number of species and LrCSs were calculated overall and by country together with corresponding number of LrCSs; results were graphically displayed as circle charts using the Excel software. Crop species of major interest - regarding landrace cultivation - were identified by picking the most frequent species among the top 5 in each country. Finally, for each country, number of landraces characterised by distinct local names was calculated for both herbaceous and tree species.

Data were subsequently imported into ArcGIS 10 software (®Esri, Redlands, CA, USA) specifying the geographic reference system WGS84 (EPSG: 4326) not projected, compliant with the LAT/LONG DD format. A spatial consistency verification was then carried out to verify that the LAT/LONG DD fields of all identified LrCSs fell within borders of the declared country. For the definition of national borders, the polygonal shape file (scale of 1:1 000 000) of the administrative borders of the EU countries was used (Eurostat, 2019). In a second calibration step, information of the secondary administrative subdivision was used to locate misplaced LrCSs within the respective countries with an average approximation error < 10 km. The geographical location of LrCSs was graphically elaborated using the same software.

2.2. Density analysis and biogeographical regions attribution

Georeferenced sites and administrative borders shapefiles (NUTS0 georeferenced in EPSG: 4326) were used for density analysis. Grids, and relative cells, were obtained from those available at the European Commission (EC) website (European Environment Agency, 2017) commonly used as mapping standard. The grids, georeferenced in EPSG: 3035 (Lambert Azimuthal Equal Area), are characterised by steps of 10 and 100 km. By applying the sampling functionality 'create fishnet command', each of the initial 10,000 km^2 cells (side length $= 100$ km) was divided into 16 smaller cells (side length $= 25$ km); the topological relationship among cells is of the 'totally included' type. Indeed, starting from the 'EEA reference grid', the used approach allowed to maintain spatial homogeneity of quadrants and their localization. Finally, cells characterised by the presence of ≥ 1 landrace were identified and number of LrCSs per cell calculated.

Each cell identified in the density analysis was attributed to one of the European biogeographical regions and the respective countries. Cartography of the biogeographical regions, updated to January 2016, was retrieved from the European Environmental Agency (European Environment Agency, 2019) accounts for delineations used in the Habitats Directive (92/43 / EEC) and for those of the EMERALD Network set up under the 'Convention on the Conservation of European Wildlife and Natural Habitats' (*i.e.*, Bern Convention) (Council of Europe, 1979). The same analyses performed in 2.1 (based on country attribution only) were also performed taking biogeographical regions into consideration.

2.3. Landraces cultivation in Natura 2000 network sites

To assess whether the cultivation of the identified landraces occurs in protected areas, the cartography of the Natura 2000 network, updated to March 2020, was retrieved from https://www.eea.europa.eu/data-and-maps/data/natura-11. The geographical location of LrCSs occurring into the network was graphically elaborated using ArcGIS 10 software. For each country covered by this study data regarding the total terrestrial land area in Europe and the terrestrial land area in Natura 2000 protected areas was retrieved from the 'Natura 2 000 Barometer' under the 'European Environment Agency' web site (https://www.eea.europa.eu/data-and-maps/dashboards/natura-2000-barometer). Percentages of i) land area, ii) landrace cultivation sites and iii) crop species in Natura 2000 protected areas were calculated by country and graphically displayed by means of pie charts using the Excel software. Finally, herbaceous and tree species more commonly cultivated in the protected areas across Europe were identified.

2.4. Conservation varieties cultivation

The most updated list of conservation varieties was retrieved from the EU Plant variety database (v3.2.1) for both 'Agricultural plant species' and 'Vegetables'. This database allows a rapid access to all the varieties registered for the two main group of species whose seed can be marketed throughout the EU according to the current seed marketing legislation. The presence of each conservation variety was tested against the here developed European inventory of *in situ* landraces by means of automatic text analysis using Excel software. Results were visually inspected and verified to avoid miss assignments due to misspelled landrace names in the developed database (*e.g.*, incorrect use of special ASCII characters) or minor inconsistencies among names of the same landrace in the two databases. Species or group of species (as defined in the EU Plant variety database) of main interest across Europe for agricultural species and vegetables were identified according to the number of conservation varieties and of cultivation sites; results were graphically displayed by means of circle chart using the Excel software.

3. Results

3.1. A snapshot of landrace cultivation in Europe

Seventeen Institutions from 14 European countries contributed with data describing a total of 19,335 Landrace Cultivation Sites (LrCSs) (Table A2, Supplementary materials; available as an online appendix).

Number of LrCSs were quite different in the covered countries ranging from a few tens (*e.g.*, in Estonia and Croatia) to thousands of sites recorded in Italy, Greece and Portugal (Fig. 1, top); the density of recorded sites, with regard to country land area, were also quite different with Austria, Greece, Portugal and Italy showing the highest values (Fig. 1, bottom).

Crop identification was provided for landraces cultivated in 99.9% of the sites (19,323 LrCSs out of the total 19,335). As from this data we got evidence that landraces of 189 different crop species are still present *in situ* across Europe, of these 141 are herbaceous species (74.6% of the total) while 48 are tree species. The complete list of crop species cultivated as landraces and corresponding number of LrCSs is available in Table A3, Supplementary materials, available as an online appendix. Italy (107 species), Greece (93), Portugal (45) and Spain (44) hold the highest numbers of crop species while lower numbers were observed in the other countries (Table 1); the same was also observed for LrCSs. A

Table 1
Number of species and of landrace cultivation sites (LrCSs) by country.

Country	Total species	LrCSs
Austria	23	4489
Croatia	7	24
Czech Republic	11	196
Denmark	21	103
Estonia	10	17
Finland	20	213
Germany	11	214
Greece	93	4688
Italy	107	5434
Portugal	45	3050
Romania	21	128
Spain	44	366
Sweden	13	137
United Kingdom	25	264

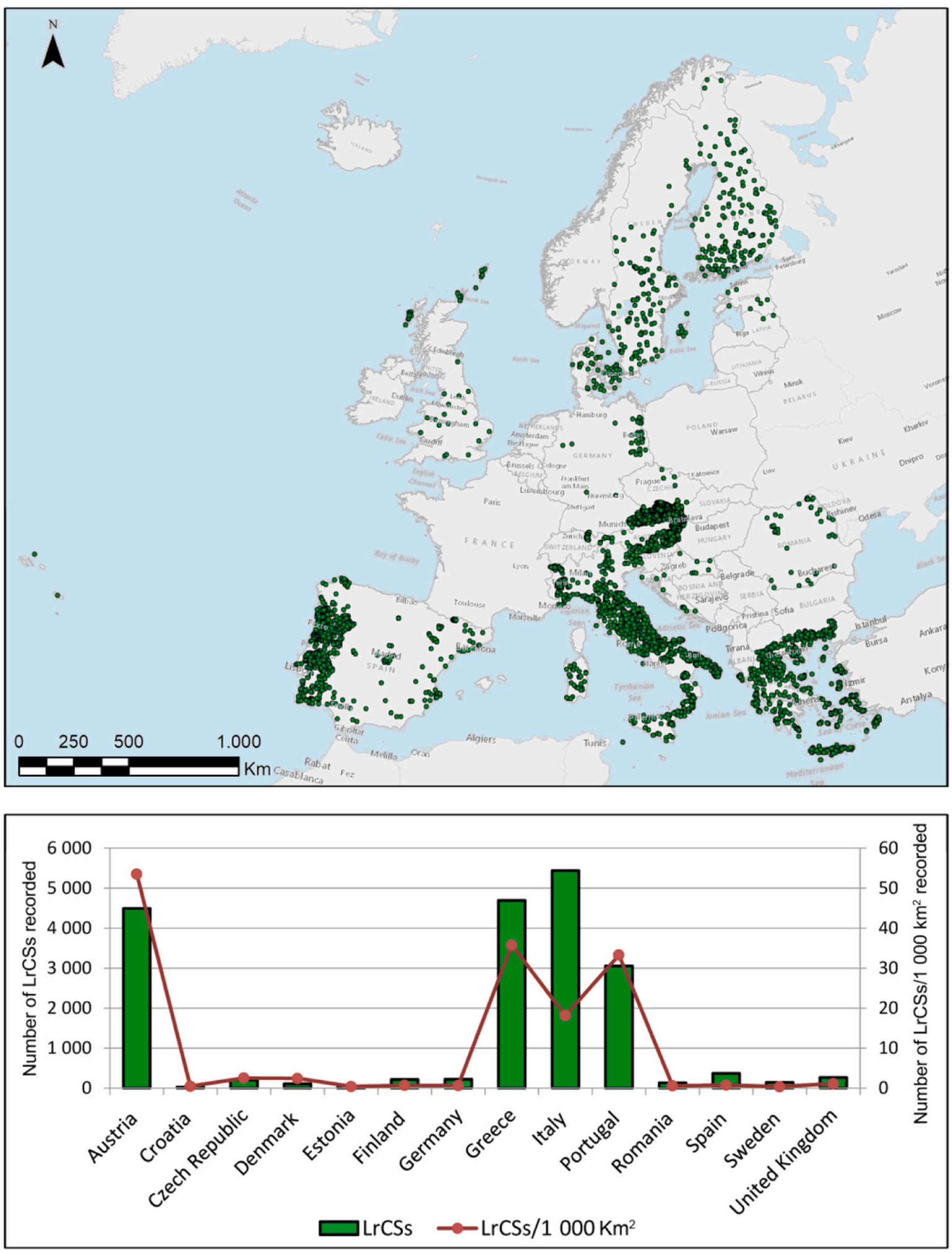

Fig. 1. Geographical distribution (top), number and density by country (bottom) of the 19,335 landrace cultivation sites (LrCSs) recorded.

diverse condition was observed in Austria, where landraces of few crop species (23) are in many LrCSs (4489).

Considering species cultivated as landraces, *Triticum aestivum* subsp. *spelta* (spelt) is the most cultivated herbaceous species (1820 LrCSs) even if the interest for this species is almost exclusive to Austria where most of the sites are located (1804); the same applies to *Fagopyrum esculentum* (buckwheat) landraces whose cultivation mostly occurs in Austria (774 LrCSs). On the other hand, among the other species of main interest, cultivation of landraces of *Phaseolus vulgaris* (common bean, 1785 LrCSs) mainly occurs in Southern European countries: Portugal (767), Greece (579), Italy (329) and Spain (31) and in Romania (40). The same applies to *Solanum lycopersicum* (tomato) for which, out of a total of 855 LrCSs recorded, 433 occur in Greece, 172 in Italy, 141 in Portugal and 63 in Spain. In addition, *Secale cereale* (rye), *Zea mays* (maize), *Cucumis melo* (melon), *Papaver somniferum* (poppy) and different subspecies of *Brassica oleracea* stand among the most cultivated herbaceous landrace species across Europe (Fig. A1, Supplementary materials; available as an online appendix). As for tree landraces, *Malus domestica* (apple) resulted the most cultivated (1061 LrCSs) mainly in Italy (812), Czech Republic (125) and Finland (83), followed by *Pyrus communis* (pear, 748 LrCSs) mainly in Italy (691) and Czech Republic (45), *Prunus avium* (cherry, 525 LrCSs), *Vitis vinifera* (grape) and *Olea europaea* (olive) (Fig. A1).

Looking at species of main interest in each country, along with their incidences, a quite diversified situation emerges from the analysis (Fig. 2). *M. domestica* resulted the dominant species (highest incidence) in both Czech Republic (63.8% of total LrCSs in the country) and Finland (39.0%) while *Pisum sativum* (pea) in Denmark (48.5%) and Sweden (43.1%), *T. aestivum* subsp. *spelta* in Austria (40.2%) and *V. vinifera* in Croatia (37.5%) (Fig. 2). Because of the variegate spectrum of species scattered over many LrCSs, no dominant species was observed in Greece, Italy and Spain (Fig. 2). Looking at commonalities, *P. vulgaris* is of main interest in 8 countries followed by *M. domestica* (5 countries), *Allium cepa* (onion), *S. lycopersicum* and *Solanum tuberosum* (potato) (4 countries), *P. communis*, *S. cereale* and *Z. mays* (3 countries) (Fig. 2). Number of LrCSs of each crop species in each country is available in Table A4 (Supplementary materials; available as an online appendix).

Focusing on landraces characterised by distinct local names, Italy accounts the highest number (2257) (Fig. 3) where *M. domestica* has a rich landrace diversity (392 landraces) followed by *P. communis* (351), *V. vinifera* (157), *P. avium* (103) and *O. europea* (84). As for the herbaceous crop species cultivated in Italy, *P. vulgaris* (196), *S. lycopersicum* (69) and *Capsicum annuum* (pepper) (22) are the species characterised by the highest number of landraces with distinct local names. Greece follows with 569 landraces with distinct local names: *P. vulgaris* (101), *S. lycopersicum* (62), *C. melo* (46), *Triticum aestivum* subsp. *aestivum* (bread wheat, 30), *Z. mays* (23) and *Vigna unguiculata* (cowpea, 21) (Fig. 3). In Portugal 498 landraces were inventoried and mainly included common bean (144 landraces), *B. oleracea* (36) and *Z. mays* (28). In Spain the 267 inventoried landraces with distinct local name mainly belong to *S. lycopersicum* (49 landraces), *M. domestica* (26), *C. annuum* (21) and *P. vulgaris* (17). Lower number of landraces with different local names were recorded in the other countries covered by this study (Fig. 3).

3.2. Landrace cultivation across European biogeographical regions

As for collected data, from a total of 11,025 cells (25 × 25 km) covering the 37 European administrative units, 11.4% (1261 cells) includes at least one LrCS which distribution is available in Table A5 (Supplementary materials; available as an online appendix). Landraces are cultivated across all European biogeographical regions covered by the study; the highest number of cells including LrCSs are located in the Mediterranean (583) corresponding to 10,742 LrCSs mainly scattered over Greece, Italy, Portugal and Spain (Table 2). *P. vulgaris*, *S. lycopersicum*, *M. domestica*, *P. communis*, *P. avium*, *C. melo*, *Cucurbita pepo* (pumpkin), *B. oleracea*, *Z. mays* and *C. annuum* are the most cultivated species in this biogeographical region. The Continental area counts 273 cells including 5375 LrCSs principally located in Austria, Italy and Greece; in this case *T. spelta*, *F. esculentum*, *P. somniferum*, *S. cereale*, *M. domestica*, *Triticum monococcum* subsp. *monococcum* (einkorn), *P. vulgaris*, *P. communis*, *C. melo* and *Trifolium pratense* (red clover) are the most cultivated species. In the Boreal region, the 217 cells identified are mainly in Finland and Sweden; a total of 354 LrCSs are located in this area where *M. domestica*, *P. sativum*, *A. cepa*, *P. vulgaris* and *Rheum rhabarbarum* (garden rhubarb) are mainly cultivated. In the Alpine region (149 cells) *T. aestivum* subsp. *spelta*, *F. esculentum*, *P. vulgaris*, *M. domestica*, and *S. cereale* are mainly in Austria, Italy and Greece. In the Atlantic region only 70 cells are characterised by ≥1 LrCSs and are mainly distributed over Portugal and United Kingdom including 860 LrCSs where *P. vulgaris*, *Z. mays*, *A. sativum* (garlic) and *S. cereale* are the more common crop species cultivated as landraces. Finally, according to collected data, Macaronesia and Steppic regions resulted not relevant in terms of total covered area and number of cells holding landrace diversity (Table 2).

Having ascertained the great diversity of agricultural species still cultivated as landraces and of the distribution of their cultivation sites in European countries and biogeographic regions, the extent of landrace cultivation sites is also quite diverse according to collected data. Size of cultivation sites ranges from few square meters, a common characteristic of several crops commonly grown in home gardens, up to extensive cultivation areas of cereals were spelt landraces *Ostro, Attergauer Dinkel* and *Ebners Rotkorn* have been recorded in 133, 78 and 234 LrCSs corresponding to >1000, >700 and > 200 ha in Austria, respectively and the rye *Norddeutscher Champagnerroggen* and barley *Dr. Francks Grannenabwerfende Imperialgerste* in 30 and 9 LrCSs (total of ca 600 and > 200 ha, respectively) in Germany. Tomato *Da serbo* (4 LrCSs, >100 ha), potato *Leccese* and *Leccese Rossa* (3 and 1 LrCS for a total of ca 100 ha each), onion *Rossa di Acquaviva* (10 LrCSs, ca 90 ha) and chicory *Catalogna di Galatina* (10 LrCs, >80 ha) are the landraces cultivated on largest areas in Italy (all in Apulia Region). Onion landraces *Calçots de valls* (1 LrCS, ca 200 ha) and *Cebolla Dulce de Fuentes*(1 LrCS, ca 150 ha) together with common bean *Ganxet* (1 LrCS, >70 ha) and tomato *Tomàquet de Penjar* (1 LrCS, >70 ha) in Spain while onion *Kremmydi Thespion* (1 LrCSs, >150 ha) and muskmelon *Chrisi kefali* (4 LrCSs, >30 ha) in Greece.

3.3. Landraces in the Natura 2000 network

Results of GIS analysis revealed that 19.8% of total LrCSs (3829 out of 19,323) are located in protected areas of the Natura 2000 network (Fig. 4) corresponding to the 73.0% of total species identified in the study (138 out of 189). Greece is the country with the highest number of LrCSs in Natura 2000 (1480), corresponding to 31.6% of its total LrCSs, followed by Italy with 1066 (19.6%), Portugal 745 (24.4%) and Spain 91 (25.1%); high percentages were also observed in Germany (35.5%), Estonia (29.4%) and Czech Republic (26.0%), were a lower number of LrCSs are present (Fig. 5, Landrace cultivation sites). Similarly, the highest numbers of species cultivated in Natura 2000 protected areas are in Greece (81), Italy (73) and Portugal (38) also corresponding to high percentages (87.1, 69.5 and 84.4%, respectively) (Fig. 5, Landrace species); looking at relative values only, high percentages of total crop species in protected areas are also observed in Germany, Czech Republic and Austria (80.0, 66.7 and 60.9%, respectively) (Fig. 5, Landrace species). With more than 100 LrCSs recorded each, landraces of the following species are the most common in the protected areas: *P. vulgaris, P. communis, M. domestica, C. melo*, *S. lycopersicum, Z. mays T. aestivum* subsp. *spelta, S. cereale, C. pepo and C. annum.* The complete list of crop species cultivated as landraces in Natura 2000 network and relative number of cultivation sites is available in Table 3.

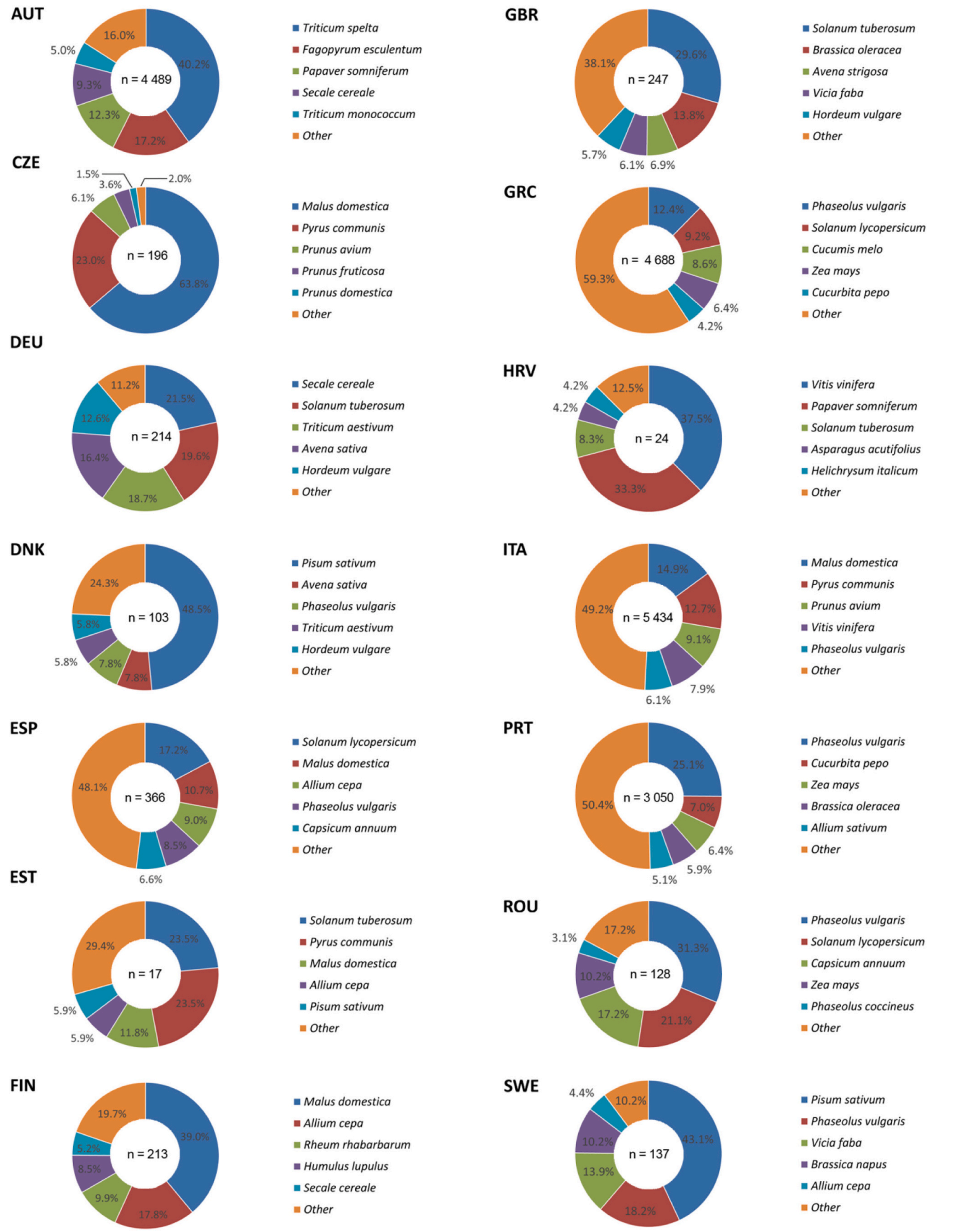

Fig. 2. List of the 5 most cultivated species in each of the 14 covered countries with corresponding number of landrace cultivation sites (LrCSs) and percentages over the total number (n). *Other* (species) groups the sum of the percentages of all the other species cultivated as landraces in the country.

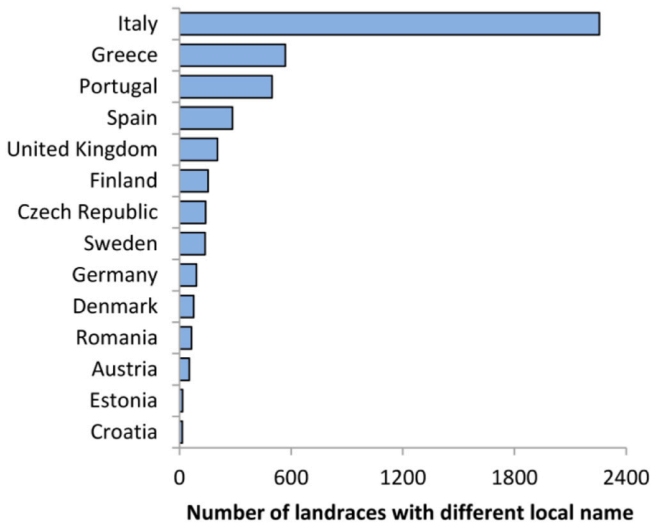

Fig. 3. Number of landraces characterised by unique local name in each of the 14 covered countries.

3.4. *The extent of conservation varieties in situ*

After testing the database against the most updated list of conservation varieties of agricultural species, results indicated that 63 (16.7%) conservation varieties are cultivated in 351 LrCSs across Europe. Using the nomenclature of the database, potato, rye, maize, wheat and swede are the species accounting for the highest number of conservation varieties (Fig. 6, top left) while red clover, rye and maize for highest number of LrCSs (Fig. 6, top right). The Austrian red clover *Steirerklee* (119 LrCSs), the German rye *Norddeutscher Champagnerroggen* (37), the maize *Knillis Landmais* (35), the oat *Obernberger Schwarzhafer* (26) and the flax *Ötztaler* (14) are the conservation varieties cultivated in the highest number of LrCSs corresponding to >380, >600, >45, >25 and >45 ha, respectively. The same procedure, carried out for vegetables, highlighted the presence of 31 conservation varieties (19.3%) in 165 LrCSs. Climbing French bean group, chili peppers, cepa group, tomato and dwarf French bean group are those accounting for the highest number of conservation varieties (Fig. 6, bottom left) while chili pepper and climbing French bean group for highest number of LrCSs (Fig. 6, bottom right). In this case, the most represented conservation varieties are the Italian peppers *Corno di Carmagnola* and *Quadrato di Carmagnola* (35 LrCSs each), *Cuneo* (16), the round pea *Quarantin di Casalborgone* (11) and the Portuguese climbing French bean *Tarreste* (8).

Of the 14 countries taking part of this study, conservation varieties of agricultural species are cultivated in 7 while of vegetables in 6, respectively. Considering agricultural species, Austria ranks first with 16 conservation varieties (mainly of rye, wheat and maize) present in 259 LrCSs, followed by Finland with 12 (mainly of rye) in 12 sites and Italy with (11) (mainly of maize) in 16 sites (Fig. A2, Supplementary materials; available as an online appendix). As for vegetables, Italy ranks first with 23 different conservation varieties cultivated over 139 sites and 3 pepper conservation varieties accounting for the 64.0% of the identified sites (Fig. A2); the other countries are characterised by radically lower numbers: 1 or 2 conservation varieties on a maximum of 14 cultivation sites in Portugal.

4. Discussion

The great diversity of material cultivated before the advent of high-yielding varieties and the selective pressure operated by farmers over time produced a *plethora* of landraces of different crop species that, in some cases, are still present *in situ*. This paper gives first insights on the status of landrace cultivation in Europe measuring its extent in the region. Although still incomplete, what is presented here is the largest collection of this type of data for Europe, prepared as a first step toward the development of National and the European Landrace Catalogues. Such catalogues appear as a necessary foundation for the implementation of the new EU Biodiversity Strategy (European Commission, 2020) as well as of the 'Farm to Fork' strategy (European Commission, 2019) and potentially the forthcoming new CAP. Indeed, without knowing what exists and where it is cultivated, it is rather difficult for national governments to properly plan and implement the systematic conservation and sustainable use of landraces. From what presented in this work, it clearly appears that different political and socio-economic backgrounds, as well as actions for *in situ* conservation, have had strong impact on conserved materials and data availability; this must carefully be considered when comparing conservation levels in different countries.

Italy was the first country in Europe to protect genetic resources and landraces issuing National and Regional Laws with the declared goals of promoting *in situ* or on-farm conservation and developing the economic interest for food products obtained by local resources (Hammer et al., 2018; Negri, 2012). These acts favored the knowledge of *in situ* landraces and an initial catalogue for Italy was released in 2013 by the University of Perugia within the frame of the EU funded project PGR Secure (Negri et al., 2013) that served the development of the first national *in situ* landrace conservation strategy (Torricelli et al., 2016). The great amount of collected information has been allowing continuous integration and helps monitoring the wealth of landraces *in situ* in the country (Giupponi et al., 2021). Concerning Italy, beside what reported here, it is also worth to mention the richness in landraces of olive (htt

Table 2
Number of landrace cultivation sites (LrCSs) and of different species (spp.) by country (row) and biogeographical regions (column).

Country	Alpine		Atlantic		Boreal		Continental		Macaronesia		Mediterranean		Stepp	
	LrCSs	spp.	LrCSs	spp.	LrCSs	spp.	LrCSs	spp.	LrCSs	spp.	LrCSs	spp.	LrCSs	spp.
Austria	972	22	0	0	0	0	3517	21	0	0	0	0	0	0
Croatia	5	2	0	0	0	0	8	1	0	0	11	6	0	0
Czech Republic	1	1	0	0	0	0	195	8	0	0	0	0	0	0
Denmark	0	0	8	2	0	0	95	20	0	0	0	0	0	0
Estonia	0	0	0	0	17	10	0	0	0	0	0	0	0	0
Finland	4	2	0	0	209	20	0	0	0	0	0	0	0	0
Germany	0	0	20	5	0	0	194	10	0	0	0	0	0	0
Greece	290	43	0	0	0	0	284	37	0	0	4114	93	0	0
Italy	654	46	0	0	0	0	957	61	0	0	3823	91	0	0
Portugal	0	0	539	26	0	0	0	0	3	2	2508	45	0	0
Romania	3	3	0	0	0	0	120	21	0	0	0	0	5	3
Spain	51	10	29	5	0	0	0	0	0	0	286	38	0	0
Sweden	4	2	0	0	128	11	5	4	0	0	0	0	0	0
United Kingdom	0	0	264	25	0	0	0	0	0	0	0	0	0	0
TOTAL	1984	–	860	–	354	–	5375	–	3	–	10,742	–	5	–

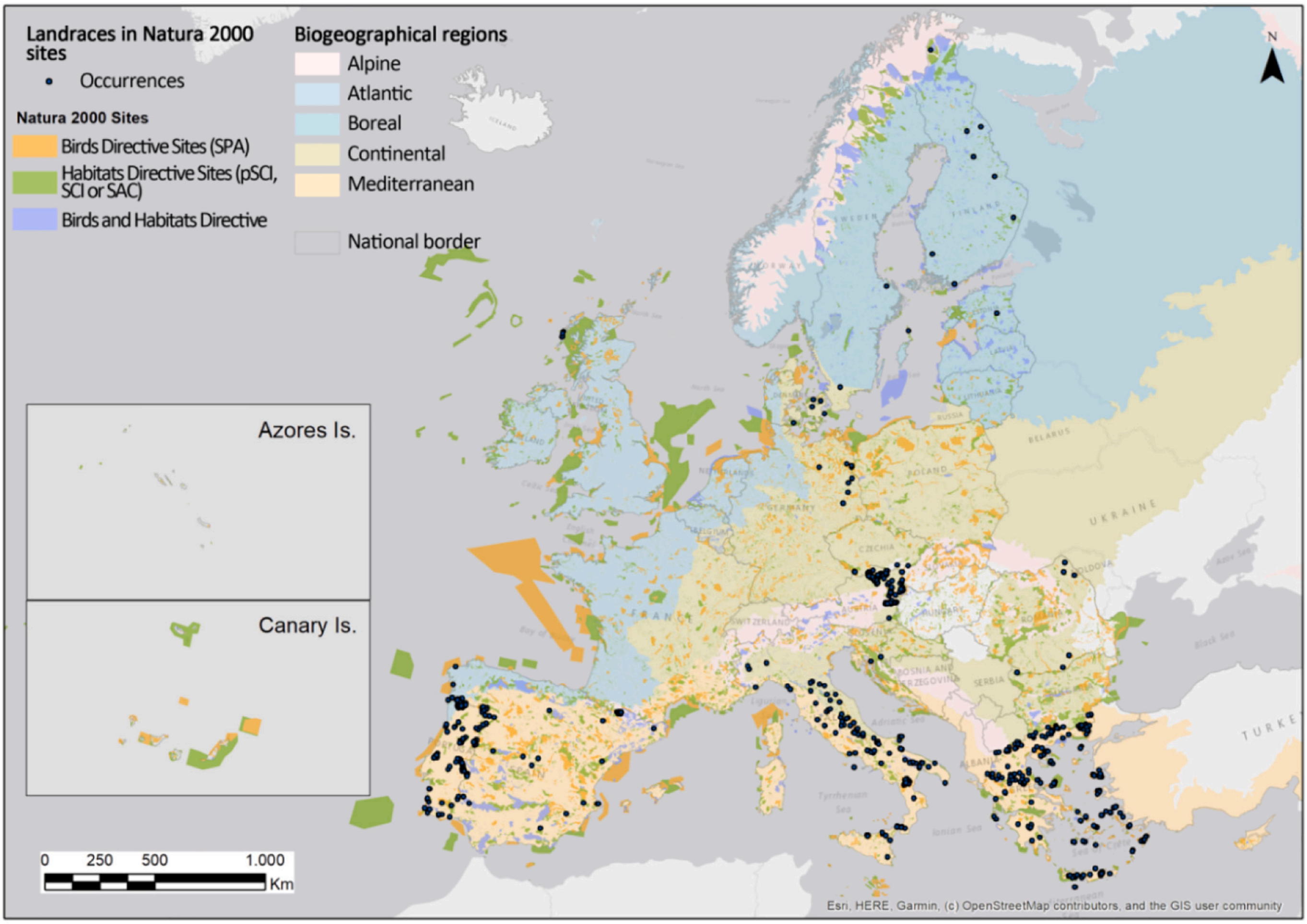

Fig. 4. Geographical location of the 3829 landrace cultivation sites (LrCSs) occurring in Natura 2000 protected areas; multiple sites with the same geographic coordinates appear as a single locality.

p://www.oleadb.it/) and grapevine, where still thousands of local genotypes and accessions remain not registered (Palliotti A., personal communication). In Greece, the development of a national inventory is still in progress; the database used in this study refers to recent genebank collecting missions, reports and publications (Ralli et al., 2010); it also integrates data from the national 'Catalogue of Conservation Varieties' and the 'Catalogue of Extensive Crops Threatened by Genetic Erosion' resulting in a fairy complex dataset in which, however, some species as olive and grape are also underestimated (Ralli P., personal communication). Data from Portugal were collected in a similar manner: details on sites where landraces are cultivated were derived merging information found in publications together with those in collecting missions. In Spain, the availability of a first national catalogue of traditional knowledge and uses of agro-diversity dates 2018 (Tardío et al., 2018) while a proper inventory of georeferenced landraces still lacks. It is known that many more landraces are being cultivated in the country in comparison with the available data; for example, data from the autonomous community of Asturias is not available even if landraces have been reported to be present *in situ* (Caballero et al., 2007). An inventory of English and Welsh vegetable landraces was initially developed by Kell et al. (2009) starting from UK seedbank data, searching national lists of old varieties and then including information of actual cultivation from groups of national landrace growers. Interestingly, a quite different approach was used in Austria, where only landraces framed into the Rural Agricultural Policy of EU, and financially supported, were inventoried and served this work; this limits the knowledge of other landraces still in cultivation. In Germany data were primarily collected at the regional level and those here analysed were provided by the federal states of Brandenburg and Nordrhein-Westfalen, in which special programs for the promotion of plant genetic resources are currently ongoing. The first national inventory of *in situ* conserved landrace of Finland was developed within framework of PGR Secure project (Heinonen, 2014). In this country special efforts have been put to evaluate landrace trueness-to-type through the application of socio-historic, pomological and molecular methods (Heinonen and Bitz, 2019); however, there is still an incomplete ecogeographical coverage of some species especially herbaceous. For Czech Republic, due to past policies aimed at increasing productivity and standardization, there is general lack of the century lasting tradition in keeping landrace *in situ*. In this country the inventory of landraces and obsolete cultivars except fruits was published based on literature sources from 1941 to 2000 including comparison to the national PGR documentation system (Holubec, 2017). The Research and Breeding Institute of Pomology Holovousy Ltd. (RBIPH) is currently working to put tree landraces back in cultivation (Paprštein et al., 2015) and provided data included in this study. While individual attempts had been made before 2000, a formal and nationwide inventory for Sweden was only launched in 2002 (Weibull et al., 2009) and data of this study derived from the latest update of this inventory. As for Romania, Croatia and Estonia traditional, low input farming is still an important component of agriculture where landraces of major species are continuously cultivated. While the compilation of national inventories is still in progress, it is likely that here analysed inventory significantly underrepresents the actual inter- and intraspecific diversity that exists in farmers' fields that are particularly

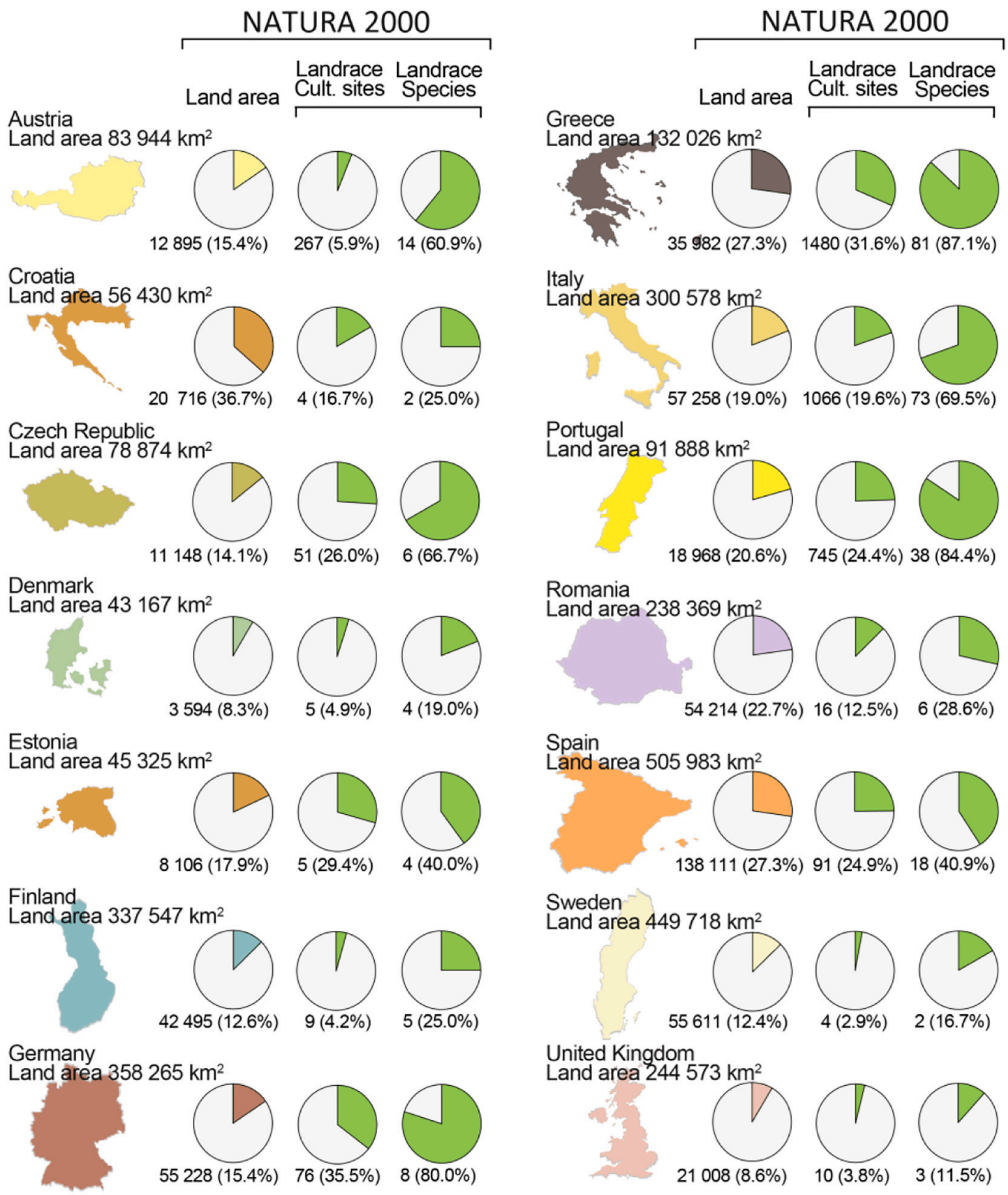

Fig. 5. Absolute number and corresponding percentage (in bracket and as pie graphs) of i) land area (km^2), ii) landrace cultivation sites and iii) landrace species occurring in Natura 2000 protected areas in each of the 14 countries covered by this study. The total land area is also reported for each country; countries are not drawn using a common scale.

difficult to be reached (Străjeru et al., 2009). As for the EU countries not covered by this study, in spite of widespread request of information, they did not provide access to national data. Hopefully, this study will favour future integrations as well as iterations needed to provide an even more accurate picture of landrace cultivation in Europe.

As for the collected data, landraces of garden, open-field and tree crop species used for human nutrition are prevalent on-farm in Europe; common bean, potato, tomato, onion, maize, rye, spelt and the trees apple, pear, cherry, grape and olive are among those of main interest. In addition to these species, of great strategic and economic value for Europe, we also got evidence that landraces of neglected and underutilised crops - such as saltwort, einkorn and emmer - and of many minor vegetables can still be found on-farm. Beside the proof that ancient food uses still exist in some parts of Europe, these data suggest that facilitating registration of landraces of neglected and underutilised species as conservation varieties may help in increasing seed availability of species overlooked by seed companies. Interestingly, cultivation records of forage landrace species like alfalfa and species belonging to the genus *Trifolium* as well as species traditionally linked to medicinal (*e.g.*, poppy), aromatic (*e.g.*, garden thyme) and ornamental (Osage orange) uses can still be found *in situ* across countries and biogeographical regions in Europe.

Considering number of landraces, species and cultivation sites at the same time, our results show that different models of *in situ* conservation exist in Europe. We got evidence that in Italy, Greece, Portugal and Spain a high number of landraces of different crop species are cultivated in a high number of sites evenly distributed across their respective territories, that seems the natural consequence of the tight connection between landraces and communities. However, it is also known that in these countries an important portion of landraces is often maintained by

Table 3
List of crop species and landrace cultivation sites (LrCSs) occurring in protected sites of the Natura 2000 network.

Species	LrCSs	Species	LrCSs	Species	LrCSs
Abelmoschus esculentus	19	*Cynara scolymus*	2	*Panicum miliaceum*	2
Allium ampeloprasum	1	*Daucus carota*	5	*Papaver somniferum*	30
Allium cepa	35	*Diospyros kaki*	26	*Petroselinum crispum*	25
Allium porrum	10	*Elettaria cardamomum*	2	*Phaseolus coccineus*	25
Allium sativum	57	*Eriobotrya japonica*	10	*Phaseolus vulgaris*	429
Allium schoenoprasum	2	*Eruca sativa*	4	*Pimpinella anisum*	4
Amaranthus retroflexus	3	*Eruca vesicaria*	3	*Pisum sativum*	19
Anethum graveolens	18	*Fagopyrum esculentum*	48	*Prunus armeniaca*	12
Apium graveolens	16	*Ficus carica*	18	*Prunus avium*	52
Arachis hypogaea	5	*Foeniculum vulgare*	3	*Prunus cerasus*	12
Arbutus unedo	2	*Fragaria vesca*	1	*Prunus domestica*	28
Avena nuda	2	*Gossypium hirsutum*	1	*Prunus dulcis*	19
Avena sativa	23	*Hedysarum coronarium*	1	*Prunus fruticosa*	1
Avena strigosa	6	*Helianthus annuus*	13	*Prunus persica*	24
Beta vulgaris	14	*Hordeum vulgare*	23	*Prunus × eminens*	1
Brassica napus	3	*Humulus lupulus*	1	*Punica granatum*	13
Brassica nigra	2	*Juglans regia*	10	*Pyrus communis*	306
Brassica oleracea	99	*Lablab purpureus*	5	*Raphanus sativus*	5
Brassica rapa	29	*Lactuca sativa*	57	*Rheum × rhabarbarum*	2
Calendula officinalis	1	*Lagenaria siceraria*	18	*Salsola soda*	1
Camelina sativa	7	*Lathyrus clymenum*	1	*Secale cereale*	112
Capsicum annuum	100	*Lathyrus ochrus*	13	*Sesamum indicum*	12
Capsicum chinense	2	*Lathyrus sativus*	14	*Setaria italica*	4
Capsicum frutescens	13	*Lens culinaris*	38	*Sinapis arvensis*	1
Castanea sativa	23	*Linum usitatissimum*	2	*Sinapis nigra*	1
Ceratonia siliqua	1	*Luffa acutangula*	1	*Solanum lycopersicum*	181
Chaenomeles japonica	1	*Lupinus albus*	6	*Solanum melongena*	46
Cicer arietinum	42	*Maclura pomifera*	1	*Solanum tuberosum*	43
Cichorium endivia	3	*Malus baccata*	1	*Sorbus domestica*	17
Cichorium intybus	2	*Malus domestica*	256	*Sorghum bicolor*	11
Citrullus lanatus	51	*Malus pumila*[a]	7	*Spinacia oleracea*	13
Citrus ×limon	1	*Malus sylvestris*	3	*Thymus vulgaris*	1
Citrus ×sinensis	2	*Matricaria recutita*	1	*Trifolium pratense*	6
Coriandrum sativum	26	*Medicago sativa*	2	*Trifolium squarrosum*	1
Cornus mas	3	*Mentha pulegium*	1	*Triticum aestivum*	51
Corylus avellana	23	*Mentha spicata*	1	*Triticum turgidum* L. subsp. *dicoccon*	12
Crataegus laevigata	1	*Mespilus germanica*	2	*Triticum monococcum*	12
Cucumis melo	222	*Morus alba*	2	*Triticum aestivum* L. subsp. *spelta*	132
Cucumis sativus	35	*Morus nigra*	17	*Triticum turgidum*	28
Cucurbita ficifolia	6	*Nicotiana tabacum*	1	*Vicia ervilia*	3
Cucurbita maxima	56	*Ocimum basilicum*	17	*Vicia faba*	54
Cucurbita moschata	43	*Olea europaea*	23	*Vicia sativa*	3
Cucurbita pepo	110	*Onobrychis viciifolia*	3	*Vigna unguiculata*	67
Cuminum cyminum	3	*Origanum majorana*	2	*Vitis vinifera*	23
Cydonia oblonga	1	*Origanum vulgare*	7	*Zea mays*	179
Cynara cardunculus	5	*Oryza sativa*	1	*Ziziphus jujuba*	3

[a] *Malus domestica* synonym.

elderly farmers (Negri, 2003; Sordi et al., 2008) and are at high risk of erosion (Hammer et al., 1999; Katsiotis et al., 2009). These features seem to be common to other countries like Romania, Croatia and Estonia but still incomplete knowledge of materials and cultivation sites limits our ability to compare these systems on a solid data basis. Differently, other *in situ* conservation systems seem to be characterised by the use of a limited number of local varieties, sometimes alloctonus, grown in in many sites, as suggested by data from Austria and Germany. As consequence of some critical aspects peculiar to each system, these models can have positive as well as negative effects on the level of diversity conserved *in situ*. In fact, whether the link to cultural identity determines the maintenance of a high number of local varieties (Perales and Brush, 2005), often scarce economic interest, coupled with limited marketability and adoption by new farmers, can compromise the survival of landraces in the medium and long term (Casañas et al., 2017; Maxted et al., 2009; Raggi et al., 2021). On the other hand, the presence of few local varieties of high marketability in many sites, that in some cases cover quite large areas, can dramatically reduce the level of landrace diversity *in situ* but guarantee the survival of the landrace on the long term. Whatever system is pursued, knowledge of landraces cultivation sites, and of farmers carrying out their activities in those sites, is of paramount importance in planning and developing future landraces conservation activities (ECPGR, 2017).

Landraces have an important cultural value for farmers and local communities owing to their tastes, shapes and colours and or use in particular dishes or occurrences; cultural differences among people of the European melting pot sustained and continue to sustain the cultivation of numerous landraces in the Region in spite of the wide and aggressive diffusion of modern cultivars. A vast literature exist on the main causes behind landrace conservation (Maxted et al., 2020 and references therein) which discussion is behind the scope of this investigation where opportunities and challenges related to current EC policies are of main interest. Indeed, maintenance of a such large number of landraces of different species as well as the knowledge of cultivation sites was supported by different financing activities promoted by the EC to cope with renewed interest on landraces (European Commission, 2014b). As example, the last three National Rural Development Programmes (NRDP) in Italy have guaranteed economic support for landraces *in situ* and favored the implementation of regional laws providing funds for landrace *ex situ* and *in situ* conservation. Even though only some countries have taken the opportunity of including the abovementioned activities within their NRDPs, actions in favour of landrace conservation have also being carried out through the European Agricultural Fund for Rural Development (EAFRD). The EC has also financed

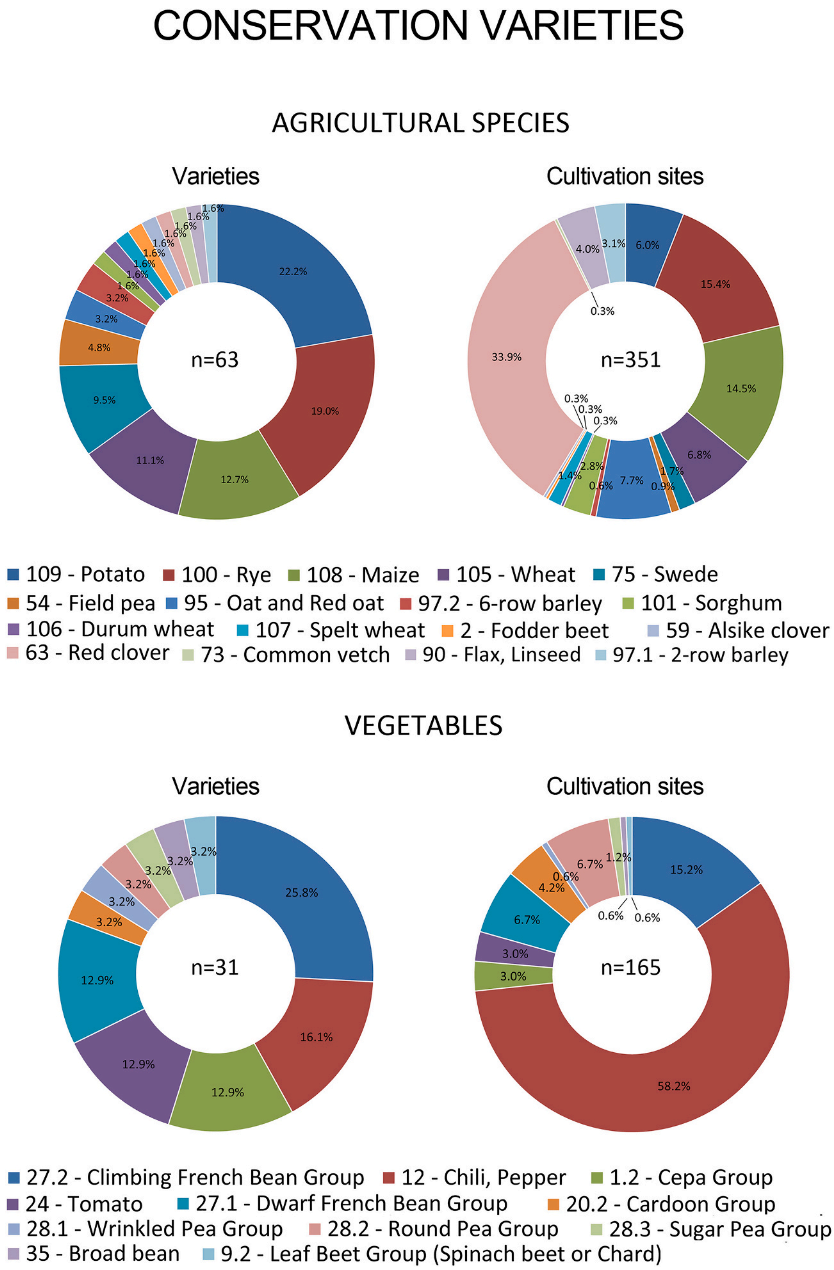

Fig. 6. Percentage of varieties (left) and of cultivation sites (right) of a single (*e.g.,* tomato) or a group of species (*e. g.* Climbing French Bean) recorded for vegetables (top) and agricultural species (bottom). In each diagram, *n* corresponds to the total number of conservation varieties and cultivation sites, respectively. Numerical percentages are only reported for values ≥3%.

the development of projects, including research project, aimed at increasing knowledge, conservation and sustainable use of landraces. In this context, a wide circulation of different types of heterogeneous materials has been stimulated in different European countries (*e.g.*, France, Italy, Hungary and Spain) where initiatives toward *in situ* conservation have also been directly developed through the establishment of collaborative approaches. These collective initiatives, which are recognized by the current EU policies, have taken various forms and names (*e.g.*, community seed or gene banks, farmer seed houses, seed-saver groups and farmer networks) give support to different activities including participatory plant breeding, local seed production, exchange and commercialisation (Chable et al., 2020 and references therein). For example, it is well known that in France an intense activity in diffusing landraces of cereals and other open field crops across the country has been carried out since years by different farmers, local seed groups, and networks as recently reviewed by Mazè et al. (2021). However, France - as well as other countries - is not covered here as data of landrace cultivation sites were not retrieved.

In recent years the EC also adopted measures regarding seed legislation, which are aimed to enhance *in situ* conservation and use of landraces by facilitating access to seeds (European Commission, 2008, 2009, 2010, 2014a). At present, 377 and 161 landraces belonging to agricultural and vegetable species, respectively, are commercialised under the above-mentioned Directives and Decisions; of these, 63 agricultural and 32 vegetable resulted in cultivation. According to our data, while a relatively high proportion of conservation varieties listed in the EU Plant variety database is cultivated (about 20%), their extent *in situ* is still limited when compared to the whole dataset. This suggests that there is still room for increasing both registration and cultivation of these materials (Spataro and Negri, 2013).

As from what observed in this study for the first time, about 20% of landrace cultivation sites are in Natura 2000 which also shows how EU policies - mainly aimed at protecting the wild part of nature - also had significant impact in protecting landraces. In fact in protected areas, where organic or low input agricultural techniques are encouraged (European Commission, 2018), landraces are material of election. Landrace cultivation in protected areas, that appears common in Greece and Italy, increases the value of the Natura 2000 network, potentially becoming an important asset for the European 'Green Deal' and the 'Farm to Fork' strategy; many CAP supportive policies are already linked to farming systems occurring in Natura 2000 sites (European Commission, 2018). It should also be noted that the EC is currently redrafting the CAP (to be implemented in 2023) and the current draft foresees specific measure to support *in situ* conservation of PGRFA including landraces; these provisions are also being applied in non-EU countries, as UK (UK Parliament, 2020). Such widespread support for landrace cultivation will certainly require detailed information on materials and cultivation sites, like those presented in our study, to facilitate payments.

Other considerations must account the effect that different pedoclimatic conditions have on landrace diversity. Indeed, we got evidence that in some cases landraces of the same crop species are cultivated in all the main European biogeographical regions: *A. cepa*, *Beta vulgaris*, *Brassica napus* and *Brassica rapa, C. pepo, Daucus carota, P. sativum* and *Vicia faba* for garden and *Hordeum vulgare, Avena sativa, S. cereale* and *T. aestivum* subsp. *aestivum* open field species. Based on this evidence, the 'Predictive Characterization'- an approach for the identification of germplasm of interest in connection with a particular trait - could be applied to identify germplasm of interest in connection with tolerance/resistance to environmental stress (Thormann et al., 2014) certainly favouring a more extensive use of these resources in breeding purposes as well as for their introduction in cultivation in new sites. Optimal *in situ* conservation occurs when a high number of landraces of many different crop species is present in similarly high number of cultivation sites representative of the different agro-ecologies. Our results suggest that a well-balanced combination of these features exists in Italy, Greece and Portugal that arise as virtuous examples to follow to attain landraces sustainable conservation through use and to boost the creation of a complete European inventory. Overall, results also tell us that some key actions are needed to take forward conservation of European landrace diversity; among these increase the systematic knowledge of landrace cultivation sites in different countries covered by our study appears to be quite urgent being well established that uncharacterized diversity remains unused. To promote landrace characterization on-farm and support custodian farmers are other actions that can increase the wealth of cultivated diversity. The development a European network of people, sites and stakeholders of landrace *in situ* conservation appears to be the logical step to facilitate the achievement of such objectives bringing different actors on a common ground of cooperation and discussion.

5. Conclusions

Recognizing that landrace *in situ* conservation in Europe is an extraordinarily complex puzzle, some of its main features are now clarified. Our study highlights a gap among countries in Europe where only a few hold systematic knowledge of landrace diversity. This gap appears as the natural consequence of different national policies, cultural and socio-economic contexts where actions promoting *in situ* conservation took place. As such, differences among countries in the extent of *in situ* landraces certainly reflect real dissimilarities as well as quite diverse levels of documentation. Overall, results of this study show that coordinated actions of single stakeholders as well as of national institutions, often supported by the EC, can significantly improve knowledge, access and sustainable use of landraces. Principles and methods of this work will hopefully inspire similar studies in other regions of the world.

Declaration of competing interest

The authors have no competing interests.

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- Lorenzo Raggi: conceptualization, methodology, formal analysis, investigation, data curation, writing – original draft, writing– review & editing, visualization
- Ciro L. Pacicco: methodology, formal analysis, visualization
- Leonardo Caproni, Clara Álvarez-Muñiz, Külli Annamaa, Anna M. Barata, Diana Batir-Rusu, María J. Díez, Maarit Heinonen, Vojtech Holubec, Shelagh Kell, Hrvoje Kutnjak, Helene Maierhofer, Gert Poulsen, Jaime Prohens, Parthenopi Ralli, Filomena Rocha, María L. Rubio Teso, Dan Sandru, Pietro Santamaria, Maria Scholten, Sarah Sensen, Olivia Shoemark, Salvador Soler, Silvia Străjeru, Imke Thormann, Jens Weibull: data providing, writing– review & editing
- Nigel Maxted: data providing, writing– review & editing, team building, funding acquisition
- Valeria Negri: research planning and conceptualization, data providing, methodology, investigation, writing – original draft, writing– review & editing, supervision, funding acquisition

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Appendix A. Supplementary data

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