# Mapping Regions of Provenance for Italy

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# Mapping Regions of Provenance for Italy


## Abstract

In the follow-up of 1999/105/CE Directive on national level, the new map of regions of provenance for forest reproductive materials of Italy is adopted as reference for the national register of forest basic materials. The new map was outlined to match needs linked to the transposition of European legislation to the complexity of the Peninsula's environment and the national nursery system. The main objective in this technical note is to present the map units in relation to the distribution of main forest species. The map units of ecoregional meaning might facilitate new allocations for forest reproductive materials which are needed to increase genetic diversity. Furthermore, studies on genetic variability of forest species are required to understand the possible interactions between the ecological amplitude of forest species, their actual genetic diversity, and possible adaptation to future climate conditions.


**Keywords:** Forest reproductive material, region of provenance, ecoregional mapping.



## Introduction

The resilience and ecological and economic sustainability of plantations are linked to the phenotypic quality of forest reproductive materials (FRM) which derives from the interaction between the environment and the genetic component of which these characters are an expression. In this regard, the environmental conditions of origin or provenance can play a crucial role in shaping the genetic structure of forest populations controlling both phenotypic and adaptive traits (Konnert et al. 2015, Kettle et al. 2020). The rule of procuring seeds or seedlings from forests growing in the same geoclimatic zone or in regions with ecological characteristics like those where they will be planted has long been adopted all over the world (Alia et al. 2021, Eriksson et. al. 2017). This is the reason why in almost all countries, from those that have adopted the international scheme of OECD (2022) to the EU member states, official registers of seed stands have been established by meeting the phenotypic and genetic quality requirements suitable for use as sources of FRM. This does not always happen due to genetic factors, but in most cases, it is now experimentally established that one can count on a greater adaptive capacity of the reproductive materials coming from similar environmental conditions (Herbert et al. 1999, Mátyás 1996, Konnert et al. 2015).

To guarantee the best possible management of reproductive materials, region of provenance (RP) maps are usually enclosed into the official registers of forest basic materials (Liesebach and Schneck 2016). The international regulations to comply conventionally refer to the creation of RP maps based essentially on homogeneous territories from an ecological point of view. This approach has an evident prudential meaning, having to refer to a wide range of species common to many countries and of which only partial and often only local genetic, adaptive, and productive information is available. Thus, maps referring to each species, based not only on the ecological variability in the respective distribution areas, but also on the genetic structure of the species itself should be the final goal, whereas the overall basic information, at least for species considered most important, is integrated with outcomes from comparative experimental tests (Mátyás 1996), which allow a definitive proof of the performance of FRM to be used at least in certain contexts.

A region of provenance is defined by the 1999/105/CE Directive as an area or group of sub-areas, with approximately the same ecological conditions, in which populations of a species have shared phenotypic and even genetic characteristics. Maps of Provenance Regions indicate the region in which off-springs from those origins can be planted reducing the risk of failure. In addition, in a country rich in forest diversity to be protected such as Italy, provenance regions can be an efficient tool for protecting gene pools possibly adapted to marginal situations (Ducci et al. 2014, Ducci and Donnelly 2018) and therefore seed sources of interest for adaptation to the effects of climate change (Ducci et al. 2018, Marchi et al. 2016, Marchi and Ducci 2018).

As mentioned above, in a first phase a harmonisation of local-regional RP systems is needed by adopting a unique national map, based on ecological regions and shared for all the species included in Annex I of Legislative Decree 386/2003. In a following phase, species natural ranges with the relative registered seed stands can be uploaded on this cartographic basis: hence, new maps should be drawn up for each individual species, when possible integrated with data on the genetic structure to delimitate the provenance regions limits.

The follow-up of 1999/105/CE Directive in the European countries has led to different approaches for mapping regions of provenance. In some countries (e.g., Austria, United Kingdom, and Germany) RP maps for individual species were based on ecological zones at national level. In other smaller countries (e.g., Ireland, the Netherlands, Denmark) the entire national territory was considered as a unique RP. According to a third approach (e.g., France and Spain), only the species distribution range was recorded on maps and divided into provenance regions and RP were established for some main species based on genetic traits.

In Italy, the previous national legislation (Law 269/1973) provided the National Book of Seed Forests without a map of the regions of origin, but only required to use the FRM collected from a seed forest in the relative phytoclimatic zone, according to the classification of De Philippis (1937). Subsequently, in the need to implement Directive 1999/105/EC, since forestry matters became a regional competence, each region proceeded to draw up its own registers of basic forest materials and its own RP cartographies. This context has partly caused inhomogeneity of detail in the national cartography: for a certain period, the national map was insufficient to reflect the ecological variability of the Italian territory and therefore it was partially unable to meet the needs of the forest nursery sector.

New opportunities are emerging for the Italian nursery chain to mitigate and adapt to the effects of climate change thanks to new plantations (Konnert et al. 2015, Martini et al. 2022), and to face the consequent challenges deriving from emergencies of biotic and abiotic factors. Frequently repeated biotic and abiotic extreme events, as the huge bark beetle (*Ips typographus* L.) pullulation throughout Europe (Wermelinger 2004) or exceptional storms as Vaia on the Alps, or large forest fires in the Mediterranean Region during the last years (Motta et al. 2018, Ascoli et al. 2022), urge forestry activities to correctly manage the source of FRMs, starting from the use of RP maps ecologically coherent with the forest environmental conditions in the country.

There are different approaches to preserve or increase genetic diversity and to prepare forests for future climate conditions. Plants from mixture of provenances planted alongside the current population, using climate change predictions to guide the choice of provenances (Hubert and Cottrell 2007), will ensure high genetic diversity in the range of distribution of the species in a context of uncertainty of future climate conditions. The introduction of FRM from a single provenance, from a location with present climate like the one predicted for the site, provides a different approach by assuming that the translocated provenance would contain genes more suitable for survival in the future climate. Lastly, silvicultural practices based on natural regeneration can preserve genetic variability and phenotypic plasticity (Bonamour 2019) occurring in most forest tree species and create conditions where selection can operate on naturally regenerated seedlings, the stage at which tree species experience the most severe selection pressures: in this case, the key factor is to ensure a high genetic variability in the population.

In the last twenty years, the classification of Italian forests according to ecological and silvicultural criteria has been carried out at the regional level and has become the basis of close-to-nature forest management (Del Favero 2001). The basic management unit, the forest type, is represented by a characteristic composition of forest species that reflects local ecological and management factors. In another way, forest species are spread over the landscape as consequence of geographical, ecological, and anthropogenic factors forming, to some extent, homogeneous units which are repeated in the landscape whenever similar conditions occur.

At a more general, European, level, forest types have been recognized as an important reference for sustainable forest management and for ecological mapping (Barbati et al. 2014). Moreover, several studies on FRM and ecological mapping were carried out in Italy mainly on a local (regional) level, with some preliminary studies on unifying criteria for the country (Ducci and Vannuccini 2006, Ducci et al. 2008, Ducci et al. 2013b). Since the most recent ecoregional zoning study for Italy (Blasi et al. 2010) did not specifically take into account the results of previous studies on forest types and FRMs, the national technical commission responsible for the implementation of the 1999/105/CE Directive on national level proposed a new map of regions of provenance for FRM of Italy (Cagelli et al. 2021), which was adopted by ministerial decree (MIPAAF 2021a), as reference for the national register of forest basic materials

(MIPAAF 2021b). The new RP map was outlined to match needs linked to the transposition of European legislation to the national nursery system.

The main objective of this technical note is to present the evaluation of the new map of regions of provenance of Italy in relation to the distribution of main forest species. In the environmental context of the country, attention to the analysis of the tree component of the phytocoenoses could appear as a limitation in the evaluation process, as the actual presence of species might reflect anthropic factors rather than the potential expression of habitat (Pavari 1959a). Nevertheless, other biological, physical, and practical reasons justify the focus on forest tree species, which are the main physiognomic feature of the forest type on the geographical scale of ecoregional studies (Ozenda 1994).



## Materials and methods

The RP map for Italy was developed from an existing GIS shape layer made by the Ministry of the Environment which is part of the Nature Conservation System (NCS) of Italy (ISPRA 2013). The units of the layer (called physiographic types of landscape units), intended as geographically defined portions of territory that present a characteristic physiographic structure and land cover pattern (Amadei et al. 2000), were used in a GIS environment as a layer of polygons to be aggregated into the larger units of the RP map. As a result, from 37 map units of the NCS map, 19 units were established for the RP map (Fig. 1), each of them identified by a two-digit code related to 7 main landscape systems: Alpine (R11, R12, R13), Padan Valley (R21), Apennine (R31, R32, R33, R34, R35), Tyrrhenian (R41, R42), Adriatic and Ionian (R51, R52, R53, R54), Sardinian (61, 62) and Sicilian (R71, R72).

[Here Fig. 1]

The criteria adopted during the process of merging the original polygons into wider units were based on an evaluation of:

a) Forest zones recorded in studies on forest types at regional level (Piedmont, Lombardy, Veneto, Friuli-Venezia Giulia, Liguria, Marche, Basilicata, and

Sicily) and ecological subdivisions of phytogeographical studies (Ozenda 1994, Bohn et al. 2004).

b) Ecological zones proposed at regional (Tuscany, Marche, Abruzzo, Campania, Molise, Sardinia) and national level by FRM studies (Ducci and Pignatti 2004, Ducci and De Rogatis 2010, Camerano et al. 2012, De Dato et al. 2018, Marchi et al. 2013).

c) Expert decision on a provisional map as a result of several meetings with components of the above-mentioned national technical commission, and with regional representatives. Regions and autonomous provinces (Trento and Bolzano) are the official administrative bodies designated by law for the management of FRM in Italy.



The provisional map of landscape units of Italy was compared on GIS with the homogeneous data map of the potential natural vegetation of Europe, which represents the distribution of the main forest associations identified at a phytosociological level (Bohn et al. 2004). The resulting map was finally adapted considering the morphological trend of the territory (e.g., long ecologically homogeneous valleys were divided into different RP if the conditions were met).

Overall, the used procedure made it possible to obtain regions reflecting the distribution of forest vegetation. Secondly, the use of landscape units facilitated the geomorphological description of the different RP units (Cagelli et al. 2021), allowing a direct relationship between the FRM cartography and the NCS.

The ecological evaluation of the new regions of provenance considered the distribution of forest species in the whole country. Data from the national forest inventory (NFI) 6,993 plots, where forest species composition was sampled during the ground phase of the survey (Gasparini et al. 2022), were used to analyse the occurrence of forest species in the map units. NFI plots with data on forest species occurrence are distributed on the whole national territory on a sampling basis reflecting the real forest cover and tree species on the site, with an approximation of georeferencing of about 1 km, which was considered in line with the map resolution of data adopted in this study. Due to georeferencing issues (plots falling out of RP bounds), data analysis was performed on 6,973 NFI plots of the database (https://www.inventarioforestale.org/en/statistiche_infc/). GIS analyses were performed using QGis. Table 1 shows the 25 most frequent tree species included in the analysis and their occurrence in the RP, according to their grouping in three main phytogeographical zones defined as Temperate, Sub-Meridional and Meridional (Bohn et al. 2004). For the purposes of this analysis, the three zones are named according to the presence of the most distinctive vegetation domain, respectively referred as Alpine, Meso-Mediterranean and Thermo-Mediterranean (Ozenda 1994).

[Here Tab. 1]



The coherence between forest species occurrence and RP delimitation at national level was performed through the correspondence analysis (CA), an extension of principal component analysis (PCA) suited to explore relationships among categorical data. CA is used to analyse two-way contingency tables and is intended as geometric approach for visualizing the rows and columns of the table as points in a low-dimensional space, such that the positions of the row and column points are consistent with their associations in the table. The data table included the abovementioned 25 species (columns) and their occurrence (frequency) in the 19 RP (rows). CA transforms the data table in two sets of variables called factor scores, which give the best representation of the similarity structure of the rows and the columns of the table by plotting them as map (biplot graph). For interpret CA the total variance (often called inertia) of the factor scores was considered, which is proportional to the independence Chi-square statistic of the table, the eigenvalues (proportional to the amount of variance explained by the row/column), the contribution (of each row/column) to the factor score and the quality of representation (of each row/column) as squared cosine measure.

For the statistical analysis and data visualization FactoMineR (Lê et al. 2008) and Factoshiny R packages were used.

## Results

The correspondence analysis output (Fig. 2) evidenced that the first two dimensions express 55.17% of the total dataset variance (inertia), a relatively high value for the representation of data variability. This value is strongly greater than the reference value that equals to 34.41% (the reference value is the 0.95-quantile of the inertia percentages distribution obtained by simulating 3,643 data tables of equivalent size based on a uniform distribution), meaning that the variability explained by this plain is highly significant. By interpreting the decomposition of the total inertia, it is possible to restrict the analysis to the description of the first axes, which are carrying a real information, as the third and following axes express each less than 10% of the total variance.

[Here Fig. 2]



The dimension 1 opposes R62 and R61 (to the right of the graph, characterized by a strongly positive coordinate on the axis) to R11 (to the left of the graph, characterized by a strongly negative coordinate on the axis). The group in which R62 and R61 stand is sharing high frequency for the species *Quercus suber* L. and *Phillyrea latifolia* L., whereas R11 is sharing high frequency for *Pinus cembra* L. On the other side, the dimension 2 opposes again R62 and R61 (to the top of the graph) to R32, R33, R34 (to the bottom of the graph, characterized by a strongly negative coordinate on the axis), a group which is sharing a high frequency for the species *Quercus cerris* L., *Quercus pubescens* Willd. and *Acer* obtusatum (Waldst & Kit. ex Wild.) Gams.

The main contribution (value more than 0.05), beyond the abovementioned RP, is given for the dimension 1 by R13, R41, R42, R53, R54, R71 and R72, and for the second also by R21 and R31, whereas the contribution of R51 and R52 is always low (Tab. 2). From the point of the quality of the representation, squared cosine values are highlighted by different colours in the graph, whereas R21, R31, R35, R51, R52, R53, R54, R71 and R72 have the lowest values.

[Here Tab. 2]

The graph reflects the environmental gradient, showing the Alpine RP on the left side of the diagram, the Meso-Mediterranean in the middle and the Thermo-Mediterranean on the upper right side.

Dimension 1 accounts for most of the variance of *Quercus pubescens, Picea abies* Karst., *Quercus ilex, Larix decidua* Mill., *Pinus sylvestris* L., *Fraxinus excelsior* L., *Abies alba* Mill., whereas dimension 2 for the most of *Ostrya carpinifolia* Scop. and *Quercus suber* L.

**Discussion**

The analysis on the distribution pattern of main forest species over Italy reveals a coherent relation with the RP, according to main factors of drive for species distribution which, for the forest Mediterranean vegetation, have been considered to depend to a large extent on total precipitation in relation to temperature (Pavari 1959b). To some extent, the RP map units explain the variability in the distribution of forest species for the Alpine area, the Central-Apennine and Tyrrhenian area, and Sardinia (Ozenda 1994). On the other hand, this is not always the same case for other areas, for example, in the Po Valley, along the Adriatic coast and the southernmost areas, where low associations between RP and forest species distribution pattern are evident. In fact, these areas are often the most transformed by the anthropic past and present land uses, which changed species composition and reduced forest cover. As these areas reflect peculiar ecological conditions and host often small remnants of natural forest populations (Sartori and Bracco 1996), the delineation of RP also in these areas seems worthy of consideration, despite their weak association to a global pattern of species distribution.

As general interpretation of the CA graph, the species are ordered following their requirements for temperature on dimension 1, whereas on dimension 2, to some extent, with the precipitation pattern (e.g., highest conditions of precipitation the lover middle part of the diagram). Underlining the ecological behaviour of species, the group of Mediterranean species (*Quercus ilex*, *Arbutus unedo* L., *Pinus halepensis* Mill., *Quercus suber*, *Phillyrea latifolia* L., *Quercus trojana* Webb.) are placed at one extreme of the gradient, interpreted for the hottest and most arid climate conditions, those more tolerant to low temperatures (*Pinus cembra*, *Picea abies*, *Larix decidua*, *Pinus sylvestris*) placed at the opposite end. The remaining species are divided into two groups, the first has a Meso-Mediterranean character (*Quercus cerris*, *Quercus pubescens*, *Acer obtusatum*, *Quercus frainetto* Ten., *Pinus laricio* Poir.) in relation to the position of RP belonging to the Central and Southern Apennines (R33, R34, R35), the second a plain-subcontinental ecological character (*Quercus robur* L., *Robinia pseudoacacia* L.) or mountain-oceanic one (*Castanea sativa* Mill., *Fagus sylvatica* L., *Ostrya carpinifolia*, *Abies alba*), in relation to the position of RP belonging the Po Valley (R21) and the Northern Apennines (R31, R32).

As highlighted by Pavari (1959b), among the main forest species, holm oak (*Quercus ilex*) is associated with relatively arid and warm climate, being *Pinus halepensis* the expression of driest conditions and *Quercus suber* of warm-humid ones. In RP not far from the seas, even if local conditions enjoy a favourable microclimate, holm oak occurs in the Apennine inland areas (slopes exposed to the sea) and at relatively high altitudes. Downy oak (*Quercus pubescens*), the most represented species in the Italian forests, is associated with intermediate climates and Apennine regions well represented in the Meso-Mediterranean zone, while beech (*Fagus sylvatica*) is associated with more humid regions of the northern Apennines and esalpic (southern-external) areas. Finally, spruce (*Picea abies*) occurs in association with Alpine regions, which are colder and relatively humid. In a way, the results of the analysis reflect the relation between the distribution of the main forest species and the classification of forest climatic zones (phytoclimatic zones) widely used as reference for the Italian silviculture for nearly a century (Pavari 1959b).

Comparisons between RP in the three phytogeographical zones highlight the differences more in detail. In the northern zone, the Alpine area shows a forest species change proceeding northward (from the esalpic to the endalpic region), which strongly influence the occurrence of economically valued forest species (e.g., *Pinus cembra* L., *Larix decidua, Picea abies, Abies alba*). RP differences are more evident for the central Meso-Mediterranean zone, especially between the innermost Apennine part, where temperate broadleaved species are typical (e.g., *Fagus sylvatica, Castanea sativa, Quercus petraea* (Matt.) Liebl. and *Ostrya carpinifolia*), and the part facing the seas (Tyrrhenian Sea to the west and Adriatic Sea to the east).

Differences in forest species distribution are slighter in the southernmost part of the country, where sea proximity plays a relevant mitigation effect and mountains are often close to the coastline (Brullo et al. 2001). In these regions, forest species endemic to the Mediterranean flora (e.g., *Pinus laricio* and *Quercus trojana*, whereas some species are not included in the present analysis as for example *Pinus heldreichii* H. Christ., *Abies nebrodensism* (Lojac) Mattei, *Betula aetnensis* Raf., *Quercus macrolepis* (Kotschy) Hedge & Yalt. etc.) are often restricted to a local and limited distribution, and the distribution of more widespread forest species is strongly influenced by orography (e.g., *Quercus cerris, Ostrya carpinifolia, Fagus sylvatica, Castanea sativa* for mountain RP, *Pinus halepensis* and *Quercus ilex* for coastal ones). Finally, the geographic position of the two main islands, Sardinia and Sicily, matches with a typical occurrence of some forest species in the RP (e.g., *Quercus suber*, *Pinus halepensis, Arbutus unedo* and *Phillyrea latifolia*).

For many aspects, the RP map is in line with acknowledged floristic subdivisions used at European level (Meusel et al. 1992, Ozenda 1994, Bohn et al. 2004). Main units reflect floristic zones of Italy (Alpine, Padanian, Apennine, Tyrrhenian, Circum-Adriatic, Apulian, Calabrian, Sardinian, and Sicilian), defining the boundaries between the northern, central (sub-southern) and southern range of the Apennines. The reference to a European subdivision allows a link, which is desirable for the future, to other European maps concerning the RP in the countries bordering Italy and, more generally, belonging to the European Union.

In the practical management of FRMs, the developed RP map shows its effectiveness when linked to the national seed stand register, which was recently adopted by ministerial decree (MIPAAF 2021b). In fact, it allows an immediate view on the gaps in the availability of FRM for each RP (Fig. 3), considering as a desirable objective to have a sufficient number of stands to ensure genetic variability to be introduced into the nursery chain. From another point of view, the map refers to real distribution of species as in current conditions of climate, while in relation to climate scenarios, a focus on the future adaptation of forest species is needed (Ducci et al. 2013a).

[Here Fig. 3]

The success of a plantation mainly depends on the adaptation of FRMs to the environmental conditions at the planting site. Today, due to the long-life cycles of forest trees, the selection of new basic materials should be conducted taking into account climate projections for the next 30-100 years, i.e. when the trees planted now will be mature. Genomic-assisted selection of functional adaptive characters could give a valid contribution (Konnert et al. 2015), and identifying, in the range of a species, sub-regions of provenance with climatic characteristics similar to those of future projections would be crucial. However, scenarios are mere projections, and we are unable to forecast the evolution of climate in the next 200 years. On the other side, more genetic diversity selected within a RP can provide raw material for adaptation to assure resilience of forest ecosystems to climate change: high levels of genetic diversity increase the probability of genotype survival and adaptability of the population. At the rear edge of the geographical range of forest species local conditions might change drastically in the future due to climate changes. In these conditions, high levels of genetic diversity should be achieved, as well as FRM from these marginal populations might be better adapted to extreme climate conditions (drought, high temperatures) and become a valuable source of FRM for reforestation under climate change (St. Clair and Howe 2007, Mátyás 1994, Robson et al. 2011, Konnert et al. 2015, Fady et al. 2016, Fady et al. 2021, Picard et al. 2022).

From the side of governance of the process of management of FRMs, the map locates main ecological regions on a hierarchical approach, which might be a common reference for the establishment of so-called national Centres for Forest Biodiversity Conservation, already foreseen by law (MIPAAF 2018, MITE 2022), in charge for the conservation of forest genetic resources and for research on them by valorising the existing experimental networks to evaluate the adaptive behaviour of FRMs (e.g., provenance trials) and to select materials of higher quality. On the other side, the improvement of the RP map goes through a more comprehensive consideration of genetic aspects for forest species in relation to climate change adaptation, the match with the system of conservation units and future advances in the implementation of the European genetic forest strategy by sharing common criteria of management with other European countries (Alia et al. 2021, Vinceti et al. 2020).

## Conclusions

Ensuring legislative implementation of FRMs through the mapping of regions of provenance of forest reproductive material is of outmost importance. The units of ecoregional meaning here presented for Italy might facilitate new allocations for FRM which are needed to increase genetic diversity, an unavoidable issue to foster adaptation to future climatic conditions. Genetic diversity is a critical issue to foster adaptation to future climatic conditions and for future improvements in forest reproductive material and ecological mapping. The knowledge of the genetic resources of tree species may lead in future to the definition of new provenance maps for the single tree species (or for small groups of similar species) and, ultimately, to greatly simplify the procurement of reproductive materials and their management within the forestry nursery chain in Italy.



## References

Alia R., Aravanopoulos F., Fjellstad K. B., Bozzano M., Fady B., Gonzalez-Martinez S. C., Heinze B., Kandemir G. et. al. 2021 - *Forest genetic resources strategy for Europe*. EUFORGEN. 80 p.

Amadei M., Bagnaia R., Di Bucci D., Laureti L., Lugeri F.R., Nisio S., Salvucci R. 2000 - *Carta della Natura alla scala 1:250.000: Carta dei Tipi e delle Unità Fisiografiche di Paesaggio d'Italia* (Aggiornamento 2003). ISPRA.

Ascoli D., Ferlazzo S., Marchetti M., Motta R., Pompei E., Stefani A. 2022 - *Strategia Forestale Nazionale italiana e governo integrato degli incendi boschivi*. Forest@- Journal of Silviculture and Forest Ecology 19 (1): 31.

Barbati A., Marchetti M., Chirici G., Corona P. 2014 - *European forest types and forest Europe SFM indicators: tools for monitoring progress on forest biodiversity conservation*. Forest Ecology and Management 321: 145-157.

Blasi C., Capotorti G., Smiraglia D., Guida D., Zavattero L., Mollo B., Frondoni R., Copiz R. 2010 - *Contributo tematico alla Strategia Nazionale per la Biodiversità. Le Ecoregioni d'Italia*. MATT-DG per la Protezione della Natura e del Mare. [Online] Available: https://www.minambiente.it/.

Bohn U., Gollub G., Hettwer C., Neuhäuslova Z., Raus T., Schlüter H., Weber H. 2004 - *Map of the natural vegetation of Europe: scale 1:2,500,000*. Bundesamt für Naturschutz (German Federal Agency for Nature conservation).

Bonamour S., Chevin L.-M. Charmantier A., Teplitsky C. 2019 - *Phenotypicplasticity in response to climate change: the importance of cue variation*. Philosophical Transaction of the Royal Society of London B 374: 1-12.

Brullo S., Giusso Del Galdo G., Guarino R. 2001. *The orophilous communities of the Pino-Juniperetea class in the Central and Eastern Mediterranean area*. Feddes Repertorium 112: 261-308.

Cagelli L., Camerano P., Camoriano L., Ducci F., Pignatti G. 2021 - *Cartografia nazionale delle Regioni di Provenienza per il controllo del commercio e della distribuzione dei Materiali Forestali di Riproduzione.* [Online] Available: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/16635

Camerano P., Belletti P., Ferrazzini D., Pignatti G. 2012 - *Definizioni di Regioni di Provenienza. A che punto siamo?* Sherwood – Foreste e Alberi oggi: 179: 23 -27.

De Dato G., Teani A., Mattioni C., Marchi M., Monteverdi M.C., Ducci F. 2018 - *Delineation of seed collection zones based on environmental and genetic characteristics for* Quercus suber *L. in Sardinia, Italy*. iForest 11: 651-659.

Del Favero R. 2001 - *Tipologie forestali: analisi di un decennio di studi a scala regionale*. Monti e Boschi 52(6): 9-13.

De Philippis A. 1937 - *Classificazione ed indici del clima in rapporto alla vegetazione forestale italiana.* Firenze, Ricci, 1937. In "Selvicoltura generale". Piussi P. Torino, UTET, 1994. XVI-454 p.

Ducci F., Pignatti G. 2004 - *Regioni di provenienza di specie forestali*. Sherwood – Foreste e Alberi oggi 104: 29-34.

Ducci F., Vannuccini M. 2006 - *Definition of provenance regions for chestnut (*Castanea sativa *Mill.) and flowering ash (*Fraxinus ornus *L.) in Tuscany*. In "Euforgen - Noble Hardwoods Network, Report of VI (9-11 June 2002, Alter do Chao, Portugal) and VII Meeting (22-24 April 2004, Arezzo, Italy)". Bozzano M., Rusanen M., Rotach

P., Koskela J. (compilers). International Plant Genetic Resources Institute, Rome, Italy: 43 -51.

Ducci F., Vannuccini M., Carone G., Vedele S., Cilli S., Apuzzo S. 2008 - *Delimitazione di Regioni di Provenienza per la gestione dei Materiali Forestali di Base in Campania*. Annali CRA - Centro di Ricerca per la Selvicoltura 35: 133 - 142.

Ducci F., De Rogatis A. (eds.) 2010 - *Risorse Genetiche Forestali in Italia*. CRA -SEL, Arezzo, Italy. 180 p.

Ducci F., Fady B., Vendramin G.G. 2013a - *Some key issues for adaptation of Mediterranean forests to climate change. Biodiversity, forest genetic resources and climate change.* In "State of Mediterranean Forests", FAO. 163 p.

Ducci F., Reale T., Vitiello A. (eds.) 2013b - *Linee guida per la Vivaistica Forestale in Molise.* Regione Molise, Assessorato alle Politiche Agricole, Forestali ed Ittiche. Servizio Valorizzazione e Tutela della Montagna e delle Foreste. Ufficio Ricerche e Promozione delle Produzioni Forestali, Campobasso, Italy. 134 p.

Ducci F., Garavaglia V., Monteverdi M.C. 2014 - *Conserver les populations marginales d'essences forestieres en Europe*. Unasylva (65) 242: 51-55.

Ducci F., Cutino I., Monteverdi M.C., Proietti R. 2018 - *Marginal/peripheral populations of forest tree species and their conservation status: report for Mediterranean region.* Annals of Silvicultural Research 41 (3): 31-40.

Ducci F., Donnelly K. 2018 - *Forest tree Marginal Populations in Europe - Report on the state of knowledge on forest tree marginal and peripheral populations in Europe*. Annals of Silvicultural Research 41 (3): 1 -12.

Eriksson G., Varela M.C., Lumaret R., Gil L. 2017 - *Genetic conservation and management of* Quercus suber. Technical Bulletin. European Forest Genetic Resources Programme (EUFORGEN), Bioversity International, Rome, Italy. 43 p.

Fady B., Aravanopoulos F.A., Alizoti P., Mátyás C., von Wühlisch G., Westergren M., Belletti P., Cvjetkovic B., Ducci F., Huber G., Kelleher C. T., Khaldi A., Dagher Kharrat M.B., Kraigher H., Kramer K., Mühlethaler U., Peric S., Perry A., Rousi M., Sbay H., Stojnic S., Tijardovic M., Tsvetkov I., Varela M.C., Vendramin G.G., Zlatanov T. 2016 - *Evolution-based approach needed for the conservation and* *silviculture of peripheral forest tree populations*. Forest Ecology and Management 375: 66-75.

Fady B., Božič G., Ducousso A., Heinze B., Eliades N.-G., Sbay H., Dalibor B., Gömöry D., Kelleher C., Ladier J., Danusevicius D., Ducci F., Bou Dagher Kharrat M., Markiewicz P., Malvolti M. E., David-Schwartz R., Westergren M., Vendramin G. G., Myking T., Villani F. 2021 - *A dataset of 577 marginal and peripheral forest tree populations in Europe* [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4767651.

Gasparini P., Di Cosmo L., Floris A., De Laurentis D. 2022 (eds.) - *Italian National Forest Inventory. Methods and Results of the Third Survey*. Springer. 576 p.

Herbert R., Samuel S., Patterson G. 1999 - *Using Local Stock for Planting Native Trees and Shrubs*. Practice Note. 10 p. ISSN 1460-3810 © Crown Copyright. ISBN 0-85538-503-0

Hubert J., Cottrell J. 2007 - *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note, FCIN086. 12 p.

ISPRA 2013 - *Dati del Sistema Informativo di Carta della Natura alla scala 1:250.000*. [Online] Available: https://www.isprambiente.gov.it/it/servizi/sistema-carta-della-natura/cartografia

Kettle C.J., Atkinson R., Boshier D., Ducci F., Dawson I., Eküe M., Elias M., Graudal L., Jalonen R., Koskela J., Monteverdi M.C., Thomas E., Vinceti B. 2020 - *Priorities, challenges and opportunities for supplying tree genetic resources, 2020. Restoring the Earth - The next decade.* Unasylva 252 (71): 51-61.

Konnert M., Fady B., Gömöry, D., A'Hara S., Wolter F., Ducci F., Koskela J., Bozzano M., Maaten T., Kowalczyk J. 2015 - Use and transfer of forest reproductive material in Europe in the context of climate change. European Forest Genetic Resources Programme (EUFORGEN), Bioversity International, Rome, Italy. xvi and 75 p. ISBN 978-92-9255-031-8

Lê S., Josse J., Husson, F. 2008 - *FactoMineR: An R Package for Multivariate Analysis.* Journal of Statistical Software 25 (1): 1-18.

Liesebach M., Schneck V. 2016 - *Ist die Einteilung der forstlichen Herkunftsgebiete in Deutschland noch zeitgemäß?* Thünen Report 45: 15.

Marchi M., Chiavetta U., Castaldi C., Contu F., Di Silvestro D., Ducci F. 2013 - *Definizione di regioni di provenienza e seed zones per i materiali forestali di base e di moltiplicazione d'Abruzzo*. Forest@ 10: 103-112.

Marchi, M., Nocentini, S., Ducci F. 2016 - *Future scenarios and conservation strategies for a rear-edge marginal population of* Pinus nigra *Arnold in Italian central Apennines.* Forest Systems 25 (3): e072.

Marchi M., Ducci F. 2018 - *Some refinements on species distribution models using tree-level National Forest Inventories for supporting forest management and marginal forest population detection.* iForest 11: 291-299.

Martini S., Maltoni A., Monteverdi M.C., De Dato G., Salbitano F., Marchetti M., Mariotti B. 2022 - *Indagine sulla produzione vivaistica forestale pubblica in Italia*. Forest@ 19 (1): 18.

Mátyás C. 1994 - *Modeling climate change effects with provenance test data*. Tree Physiology 14 (7-9): 797–804.

Mátyás C. 1996 - *Climatic adaptation of trees: rediscovering provenance tests*. Euphytica 92: 45–54. https://doi.org/10.1007/BF00022827

Meusel H., Jäger E., Weinert E. 1992 - *Comparative chorology of the Central European flora*. Gustav Fischer, Jena, Stuttgart, New York. 258 p.

MIPAAF 2018 - *D. L.vo 03/04/2018 n. 34 - Testo unico in materia di foreste e filiere forestali (TUFF).* [Online] Available: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12774

MIPAAF 2021a - *D.M. N. 269708 del 11/06/2021 - Suddivisione del territorio italiano in Regioni di Provenienza.* [Online] Available: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/17155

MIPAAF 2021b - *D.D. N. 307490 del 06/07/2021 - Approvazione del Registro nazionale dei materiali di base*. [Online] Available: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/17154

MITE 2022 - *Decreto 31 marzo 2022. Individuazione dei Centri nazionali per lo studio e la conservazione della biodiversità forestale.* Gazzetta Ufficiale Serie Generale n. 141 del 18/06/2022. [Online] Available: https://www.gazzettaufficiale.it.

Motta R., Ascoli D., Corona P., Marchetti M., Vacchiano G. 2018 - *Selvicoltura e* schianti da vento. Il caso della "tempesta Vaia". Forest@ 15: 94-98.

OECD 2022 - *Rule 2. Delineation of regions of provenance.* In "OECD Scheme for the certification of forest reproductive material moving in international trade". 57 p. https://www.oecd.org/agriculture/forest/documents/FINAL%202022%20English_Forest-Rules_%202022.pdf

Ozenda P. 1994 - *Végétation du continent européen*. Delachaux et Niestlé. 271 p.

Pavari A. 1959a - *Su alcuni principi di ecologia forestale.* In "Scritti di ecologia, selvicoltura e botanica forestale". Accademia Italiana Scienze Forestali, Firenze: 29-61.

Pavari A. 1959b - *La restaurazione forestale dei terreni nudi nel bacino mediterraneo.* Scritti di ecologia, selvicoltura e botanica forestale. Accademia Italiana Scienze Forestali, Firenze: 91-116.

Picard N., Marchi M., Serra-Varela M.J., Westergren M., Cavers S., Notivol E., Piotti A., Alizoti P., Bozzano M., C. Gonzalez-Martínez S.C., Grivet D., Aravanopoulos F.A., Vendramin G.G., Ducci F., Fady B., Alía R. - 2022. *Marginality indices for biodiversity conservation in forest trees. Ecological Indicators*. Volume 143, October 2022: 109367 https://doi.org/10.1016/j.ecolind.2022.109367

Robson T.M., Alía R., Božic G., Clark J., Forstreuter M., Gömöry D., Liesebach M., Mertens P., Rasztovits E., Zitová M., von Wühlisch G. 2011 - *The timing of leaf flush in European beech (*Fagus sylvatica *L.) saplings.* In "Genetic Resources of European Beech (Fagus sylvatica L.) for Sustainable Forestry". Proceedings of the COST E52 Final Meeting. Monografías INIA, Seria Forestal 22: 61–81.

Sartori F., Bracco F. 1996 - *Present vegetation of the Po Plain in Lombardy*. Atti del Convegno su "Passato e presente della vegetazione nella Padania". Allionia 34: 113-135.

St. Clair B.J., Howe G.T. 2007 - *Genetic maladaptation of coastal Douglas fir seedlings to future climates*. Global Change Biology 13(7): 1441–1454.

Vinceti B., Manica M., Lauridsen N., Verkerk P.J., Lindner M., Fady B. 2020 – *Managing forest genetic resources as a strategy to adapt forests to climate change: perceptions of European forest owners and managers.* European Journal of Forest Research 139: 1107-1119.

Wermelinger B. 2004 - *Ecology and management of the spruce bark beetle* Ips typographus - *a review of recent research.* Forest Ecology and Management 202: 67–82. doi:10.1016/j.foreco.2004.07.018

## Tables

**Table 1** – Records of forest species relating to the occurrence in the phytogeographical zones and region of provenance (number of NFI plots).

| Species | Abbreviation | Phytogeographical zones/Region of provenance | | |
|---|---|---|---|---|
| | | Alpine | Meso-Mediterranean | Thermo-mediterranean |
| | | R11, R12, R13 | R21, R51, R31 R32, R33, R41 R42, R52 | R34, R35, R53 R54, R61, R62 R71, R72 |
| *Quercus pubescens* | Que_pub | 195 | 1221 | 530 |
| *Quercus cerris* | Que_cer | 12 | 937 | 438 |
| *Ostrya carpinifolia* | Ost_car | 365 | 889 | 147 |
| *Fagus sylvatica* | Fag_syl | 569 | 485 | 227 |
| *Castanea sativa* | Cas_sat | 329 | 489 | 141 |
| *Picea abies* | Pic_abi | 888 | 36 | 1 |
| *Quercus ilex* | Que_ile | 8 | 340 | 368 |
| *Larix decidua* | Lar_dec | 628 | 13 | 0 |
| *Acer pseudoplatanus* | Ace_pse | 264 | 226 | 69 |
| *Robinia pseudoacacia* | Rob_pse | 128 | 278 | 34 |
| *Pinus sylvestris* | Pin_syl | 313 | 93 | 0 |
| *Fraxinus excelsior* | Fra_exc | 287 | 73 | 32 |
| *Abies alba* | Abi_alb | 226 | 68 | 46 |
| *Quercus petraea* | Que_pet | 146 | 152 | 12 |
| *Arbutus unedo* | Arb_une | 0 | 96 | 80 |
| *Acer obtusatum* | Ace_obt | 1 | 205 | 74 |
| *Quercus suber* | Que_sub | 0 | 34 | 196 |
| *Pinus halepensis* | Pin_hal | 0 | 51 | 117 |
| *Quercus robur* | Que_rob | 25 | 76 | 15 |
| *Pinus laricio* | Pin_lar | 0 | 1 | 97 |
| *Phillyrea latifolia* | Phi_lat | 0 | 18 | 63 |
| *Alnus glutinosa* | Aln_glu | 63 | 72 | 22 |
| *Pinus cembra* | Pin_cem | 89 | 0 | 0 |
| *Quercus frainetto* | Que_fra | 0 | 11 | 63 |
| *Quercus trojana* | Que_tro | 0 | 0 | 24 |

**Table 2** – Results of the correspondence analysis in terms of contributions ($ctr_1$ and $ctr_2$) and squared cosines ($cos_1$, $cos_2$) for each region of provenance, with highest values in bold.

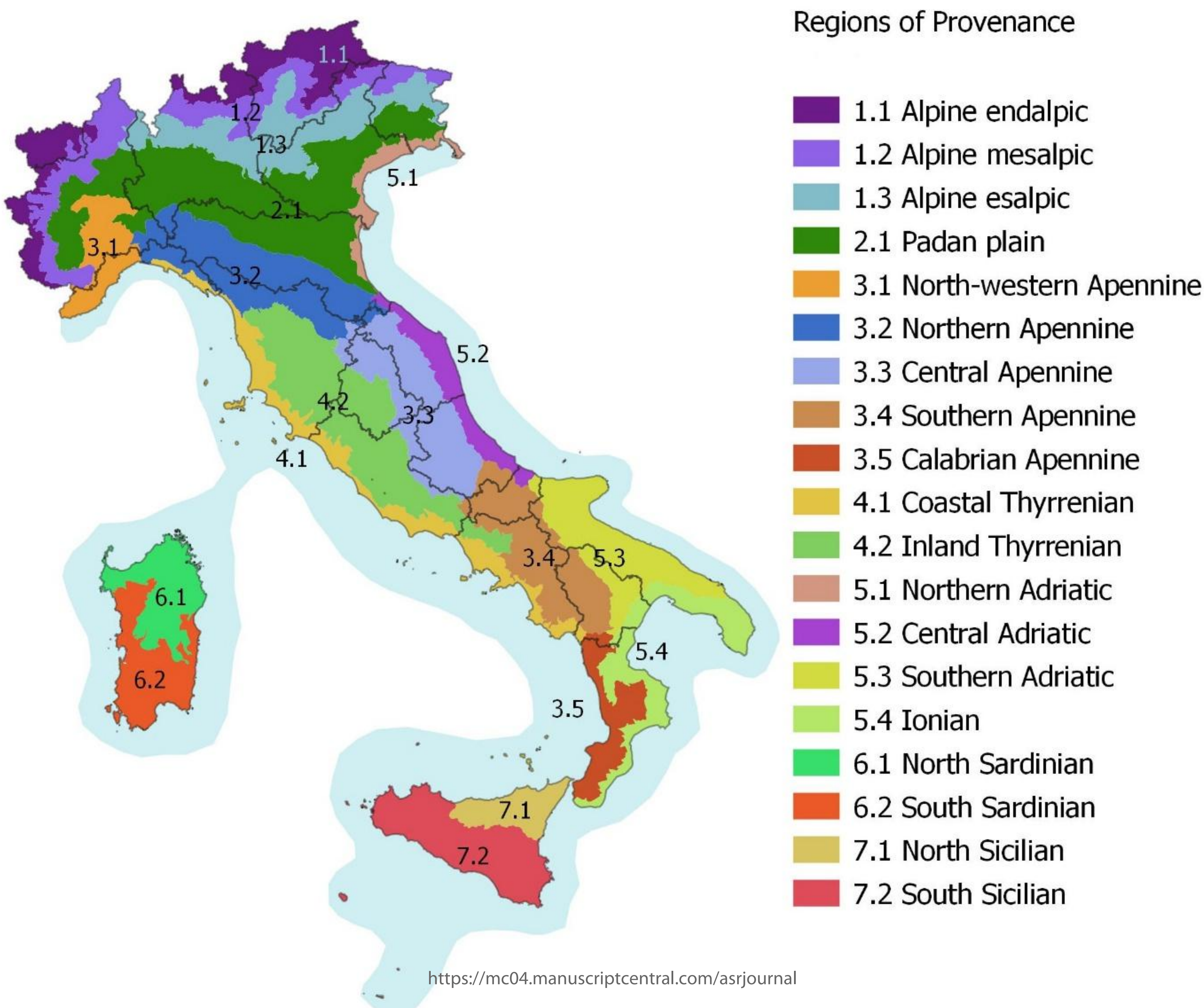
| | **$ctr_1$** | **$ctr_2$** | **$cos_1$** | **$cos_2$** |
|---|---|---|---|---|
| **R11** | **0.297** | **0.187** | **0.593** | **0.234** |
| **R12** | **0.178** | 0.016 | **0.770** | 0.042 |
| **R13** | **0.071** | 0.003 | **0.545** | 0.015 |
| **R21** | 0.001 | 0.006 | 0.007 | 0.026 |
| **R31** | 0.000 | 0.008 | 0.005 | 0.063 |
| **R32** | 0.002 | **0.079** | 0.024 | **0.629** |
| **R33** | 0.026 | **0.089** | **0.186** | **0.398** |
| **R34** | 0.025 | **0.062** | **0.180** | **0.286** |
| **R35** | 0.003 | 0.004 | 0.015 | 0.011 |
| **R41** | **0.045** | 0.016 | **0.551** | 0.121 |
| **R42** | **0.064** | 0.003 | **0.616** | 0.018 |
| **R51** | 0.002 | 0.000 | 0.198 | 0.017 |
| **R52** | 0.001 | 0.000 | 0.056 | 0.012 |
| **R53** | 0.019 | 0.000 | 0.089 | 0.000 |
| **R54** | 0.012 | 0.001 | **0.266** | 0.015 |
| **R61** | **0.127** | **0.286** | **0.357** | **0.502** |
| **R62** | **0.101** | **0.222** | **0.364** | **0.502** |
| **R71** | 0.006 | 0.000 | 0.156 | 0.004 |
| **R72** | 0.019 | 0.017 | 0.144 | 0.080 |

**Figures' caption list**

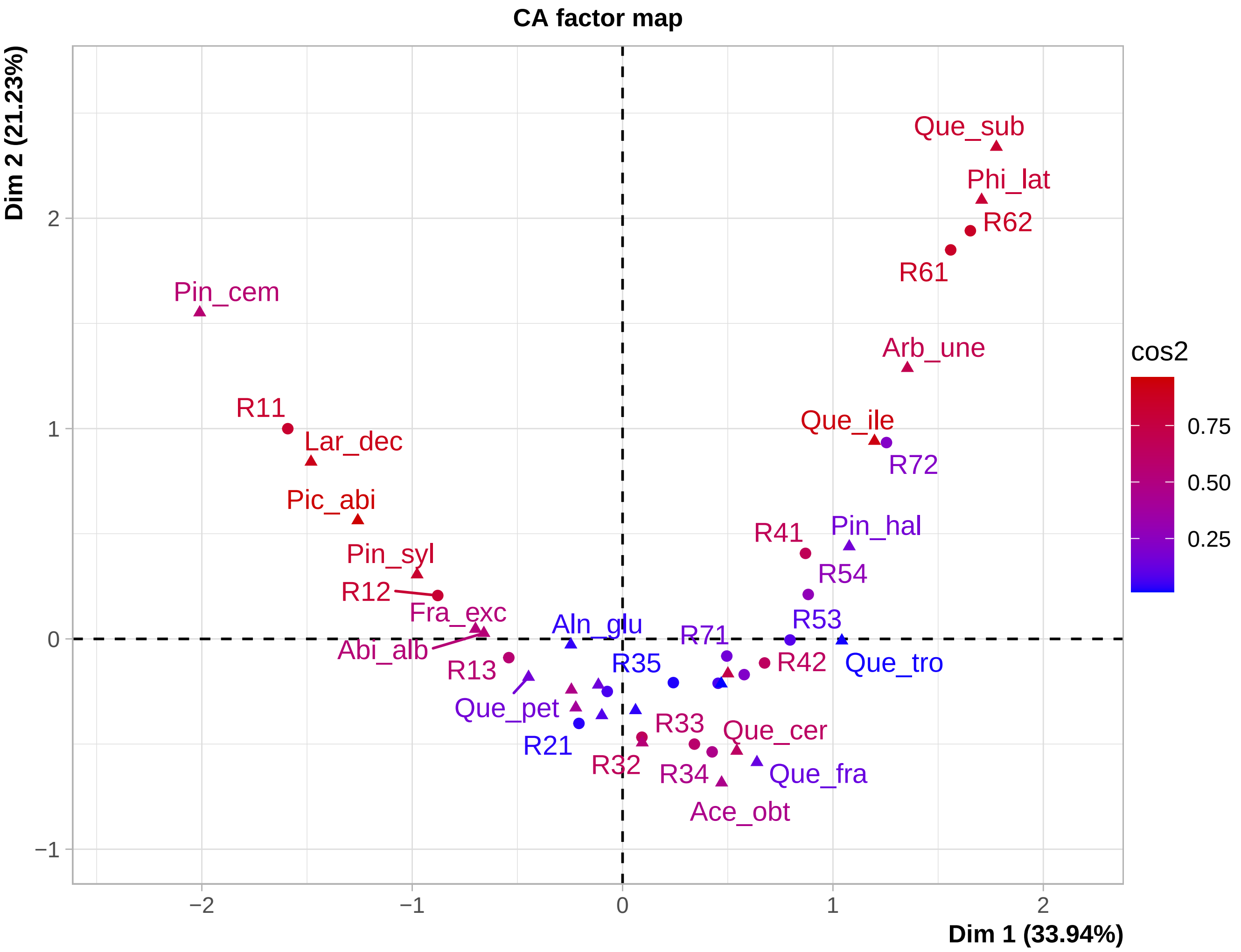
**Figure 1 –** Map of regions of provenance for FRM of Italy (MIPAAF 2021a).

**Figure 2 –** Correspondence analysis diagram with the joint projection of RP and species, colours from blue to red according to higher values of squared cosines. For abbreviations see Figure 1 (RP) and Table 1 (species).

**Figure 3 -** Visualization of the National Basic Materials Register (by coordinates of the forest reproductive material in the register) on the RP map, with colours of basic materials according to the type of material (yellow = source-identified, green = controlled, pink = qualified, blue = tested).



Regions of Provenance
1.1 Alpine endalpic
1.2 Alpine mesalpic
1.3 Alpine esalpic
2.1 Padan plain
3.1 North-western Apennine
3.2 Northern Apennine
3.3 Central Apennine
3.4 Southern Apennine
3.5 Calabrian Apennine
4.1 Coastal Thyrrenian
4.2 Inland Thyrrenian
5.1 Northern Adriatic
5.2 Central Adriatic
5.3 Southern Adriatic
5.4 Ionian
6.1 North Sardinian
6.2 South Sardinian
7.1 North Sicilian
7.2 South Sicilian


CA factor map
Dim 2 (21.23%)
Dim 1 (33.94%)
−2
−1
0
1
2
cos2
0.75
0.50
0.25
Que_sub
Phi_lat
R62
R61
Pin_cem
Arb_une
R11
Lar_dec
Que_ile
R72
Pic_abi
R41
Pin_hal
Pin_syl
R54
R12
Fra_exc
R53
Aln_glu
R71
Abi_alb
R42
Que_tro
R13
R35
Que_pet
R33
Que_cer
R21
R32
R34
Que_fra
Ace_obt