41 (3), 2017: 25-30

https://journals-crea.4science.it/index.php/asr

International project reports

Marginal/peripheral populations of forest tree species and their conservation status: report for Continental region

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Received 02/09/2017 - Accepted 30/09/2017 - Published online 27/04/2018

Abstract - The report describes the geographical and ecological characteristics of the European continental region, which is the area that covers most of Central and Eastern Europe. Forest ecosystems and vegetational aspects, with particular emphasis to forest species growing at the edge of their distribution range, are also considered.

Keywords - Forest genetic resources; forest tree marginal populations; MaPs; marginality; Cost Action FP 1202 MaP FGR.

Geographical characteristics of the Region

Extension and borders

The European continental area covers most of Central and Eastern Europe, covering predominantly the regions with cold temperate and mountain climates (climate regions D and E of the Köppen-Geiger classification, see Peel et al. 2007). The definition is thus based on both phytogeographic and climatic criteria. The western limit is located in Germany (from Denmark border to Alps); for simplification, the whole territory of Germany was included in this report. It includes also most of the Alpine chain (except the Maritime Alps), the Jura Mountains, the interior parts of Slovenia and Croatia, the Pannonian lowland and the Carpathians. In the East, the cold climatic zone continues far into Russia but the report covers only Belarus and the western half of Ukraine and excludes steppe zones. In the North, Fennoscandia and the surroundings of the Baltic Sea (including the northern half of Poland) were also not considered, as they represent a region with predominantly boreal vegetation.

Orography

The most important mountain chains present in the region are located at its borders: at the eastern side the Ural Mountains (at the border between Europe and Asia), at the southern side the Balkan and Dinaric Mountains and the Alps, although, in the latter case, the region includes also the Po valley. The most important mountain chains fully included in the region are the Carpathians, which are shared by Austria, Czech Republic, Slovakia, Poland, Hungary, Ukraine and Romania. From the southeast, the region is bordered by a broad zone of lowland steppe, almost without forest vegetation. In the western part, there are not plateaus and lowlands, so that the transition with the adjacent temperate region occurs gradually.

Human presence

The western and southwestern parts of the considered area are among the most populated in Europe, where forest area was largely reduced in favor of agricultural use. Starting from the XVII century, original forests became gradually converted into Norway spruce and Scots pine plantations; later, clonal plantations of hybrid poplars replaced a large part of riparian forests. Along with these processes, major concentration of industrial districts has developed in this region. All this has of course determined deep environmental modifications, so that the original forest coverage is present only in a very few, small and scattered areas. Although the development in the eastern part of the continental area was similar, changes in forest cover and tree species composition have not been as extensive as in the West and large complexes of natural forests have locally been conserved (e.g., Bialowieza forest in Poland or UNESCO-protected complex of beech natural forests in the Eastern Carpathians).

Geographic barriers to gene flow

The region is someway isolated by mountain chains at the eastern and southern borders, while toward the western mountains there are no mountain chains capable to hinder plant migration.

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http://dx.doi.org/ 10.12899/asr-1532

However, the region is crossed by the Danube and the Po rivers including their tributaries, surrounded by large lowlands (the Hungarian plain, the Wallachian lowland, the Po valley) representing serious obstacles for the natural spread of some tree species (e.g., European beech). In addition, gene flow even by pollen from neighboring regions is restricted by natural boundaries: Baltic and Northern Sea in the north and steppe zone in the southeast.

Other barriers

Gene flow may become restricted on a local scale by additional mechanisms. As Central Europe has a very rugged topography, altitudinal differences may provoke shifts in flowering time (e.g., beech flowering is synchronized with leaf flushing and thus depends on temperature sum accumulation in the spring; if the distribution is not continuous, the populations at higher altitudes are phenologically isolated from those at lower elevations). Similar phenological shifts can be induced by local microclimates (e.g., populations in frost hollows) or be determined genetically (e.g., late-flushing Slovenian beech population Idrija, surrounded by generally early-flushing beechwoods). Translocated populations, especially if transferred over large distances, may also be asynchronous in flowering with neighbors of local origin. Genetic incompatibilities causing prezygotic or postzygotic isolation are usually relevant on the individual level and have not been documented at the population level.

Ecological aspects

Climatic characteristics of the region

In general, the continental climate is characterized by hot summers and colder winters, being far from the oceans, which contribute to keep climates milder in winter and cooler in summer. This is due to the lower heat capacity of soil and rock as compared to water; consequently, the former gain and lose heat faster. In the west, north and in northern side of the Alps are transient areas to neighbouring regions with Atlantic climate influence.

Continental climates are often relatively dry. This is because most of the moisture carried by air masses originating over oceans is lost as rainfall not far from the latter.

According to the updated Köppen climate classification (Peel et al. 2007), the continental/microthermal climate is characterized by an average temperature above 10°C in the warmest month and below -3°C in the coldest one. These conditions usually occur in the internal parts of continents as well as in the northernmost and easternmost coasts, normally at latitude above 40°N. In the austral hemisphere this climate is extremely rare, mainly because of the smaller land mass and in particular its concentration at latitude north of 40°S.

The continental climate (usually indicated as belonging to the group D of the Köppen classification, see Peel et al. 2007) has been subdivided in several types, of which three (typically the subtypes without dry season) occur in the continental area:

a) Hot summer continental climates: usually occur at latitudes between 30 and 40°N and the average temperature in the warmest month is higher than 22°C (Black Sea coast, Wallachian lowland, the northern margin of the Pannonian lowland).
b) Warm summer continental or hemiboreal climates: these climates occur immediately north of the previous one, generally between 40 and 50° N. (Belarus, Ukraine, most of Romania and Moldova, Hungary, the Czech Republic, Slovakia, Poland, Austria, eastern part of Germany, Switzerland, Alpine regions of Italy).)
c) Continental sub-arctic or boreal (taiga) climate: within the continental area, it occurs at higher elevations in the Alps, the Carpathians and the Herzynic ranges.

Soil characteristics

The paleographical development, specifically the tectonic processes in the tertiary and several glaciations in the quaternary, have led to today's surface conditions and influenced post-ice soil development. The glaciations of the Alps and Carpathians as well as the expansion of the northern icing to large parts of the continental area defined the starting positions for the resettlement by today's forests and strongly influenced it.

Possible future modifications due to climatic change

During the past two decades, the impacts of climate change on forests and the ability of forests to mitigate the consequences of ongoing climate change have been debated intensively. IPCC reports show that Europe has been warming faster than the global average over the last 30 years. For Central Europe and most parts of the continental area, with exceptions due to local conditions as in mountain regions (e.g. the Alps, the Carpathians), climate scenarios predict a significantly warmer climate (+2.6 °C), while annual precipitation is expected to remain more or less constant in the future (+4 %) (IPCC 2013, Mellert et al. 2016). Winter precipitation patterns in Europe are expected to increase in areas north of 45°N latitude. In the summer, the abovementioned models predict a reduction in precipitation in the temperate zones of central and Western Europe. Furthermore, warmer and drier conditions

may cause prolonged droughts and extend the fire season with increased forest fire risk (IPCC 2007). Precipitation will decrease in spring and partially in summer in South Germany (Beierkuhnlein and Foken 2008) and probably in most parts of the continental area.

Vegetational aspects

Diffusion of forests

Although during the last glacial period the continental area of Europe was not completely devoid of trees, most temperate species are generally newcomers. Very few reliably dated long pollen records are available from Central Europe but mostly they indicate that temperate trees like beech or silver fir were generally absent during the Late glacial period, or even if higher pollen percentage at the beginning of Holocene indicate their presence, they disappeared and recolonized the area again (Willis et al. 2000). High mountain ranges (the Alps, the Carpathians) in some cases hindered migration and prevented the spread of genetic lineages from southern refugia (e.g., oaks from the Apennine peninsula blocked by the Alps; Petit et al. 2002) or, in opposite, served to lead migration trails (the Carpathians for silver fir or common ash; Liepelt et al. 2009, Gömöry et al. 2012). Pollen records and macrofossils document that boreal species such as Norway spruce, Scots pine or silver birch were present in the continental area during the glacial period and their ranges substantially shrank during the Holocene. In some cases, e.g., *Pinus cembra*, the reduction of the range size was substantial and it has survived as glacial relics only in small populations at high elevations. The time of arrival differed between species, but around 5000 BP the current species pool of forests of the European continental area was more or less complete.

Prevalent forest types

In the western part of the continental area beech forests naturally occurs over a wide area and up to a height of 800 to 900 m, single trees up to 1200 m elevation. Oak or azonal forests grow only on warmer sites with low precipitation of the lower areas and along the rivers. Mixed forests with silver fir and Norway spruce are typical for mountain areas. In the high plains of the low mountain ranges (i.e. Harz, Bavarian Forest, Bohemian Forest) and the Alps spruce forests dominate. By human influence, spruce forests also spread outside their natural range and reached in some regions more than 40% of the forest area. Silver fir has been widely depleted and damaged due to game animals and grazing. In areas with continental climate or sandy soil conditions, especially in the Northeast, Scots pine is increasing and dominates forests. Today the spread of beech is strongly promoted by forest management.

Most common and/or representative species

In the southern slopes of the Alpine chain, broadleaves can be found at lower altitudes (mainly *Castanea sativa*, *Quercus petraea*, *Fraxinus excelsior*, *Acer pseudoplatanus*, *Sorbus aria*, *Laburnum anagyroides*, *Prunus avium*, *Populus tremula*, to which *Fagus sylvatica* in fresh ad wetter areas and *Quercus pubescens* in driest parts should be added). At higher altitude, broadleaves reduce their diffusion and are gradually substituted by conifers. The most important species are *Betula pendula*, *Sorbus aucuoparia* and *Alnus viridis* for the former, and *Pinus sylvestris*, *Picea abies* (mainly in central-eastern part of the chain) and *Abies alba* for the latter. At the highest altitudes there are *Larix decidua* (which diffusion was in the past strongly encouraged by humans), *Pinus cembra*, *Pinus mugo* (eastern part), *Pinus uncinata* (western part) and *Juniperus communis*.

Major threats to forests

The most important threats to forests of the European continental area are generally the same occurring all over the world. Deforestation due to urbanization has strongly reduced the surface and the quality of forests, mainly in plain areas close to rivers. Habitat fragmentation is a problem often underestimated, that however can play an important role in forest degradation, reducing the efficacy of protection measures and limiting genetic flow. Other factors that threaten the integrity of European continental forests are forest fires, mainly in parts closer to the Mediterranean region, incorrect forest management, use of inappropriate reproductive material in reforestation, and the diffusion of allochthonous species.

Furthermore, several countries of the region belonged to traditional industrial centers of Europe and the other became rapidly industrialized after the Second World War. The rapid increase of heavy industry and especially coal power plants led to serious pollution by sulphur dioxide and locally by heavy metals and subsequent extensive forest decline. Since 1990s, the situation improved considerably, but new threats appeared, mainly tropospheric ozone produced by road transport.

Among biotic factors, bark beetle outbreaks have become a major threat, especially in Norway spruce forests.

In Germany, Austria, Poland and other countries a relevant species with respect to climate change is *Picea abies*, in which low elevation populations

(mostly outside its natural distribution) are effected in warm summers and become susceptible to bark beetle attacks. In the Northern Alps, the height limit of spruce stands threatened by the bark beetle increased from 900 m to 1600 m a.s.l.

In general, the climatic warming endangers low elevation populations and favors those at higher elevations. However, in some cases species have already reached the highest elevations and can therefore not move further, e. g. *Pinus cembra* or *Alnus viridis*.

Although no statistics are available by climatic regions, for Central and Eastern Europe 1.1% of forest area is reported to be damaged by insects and diseases (Forest Europe 2015). For some tree species, pathogens contribute to large-scale decline on local or regional scales (*Armillaria* in conifers, *Phytophtora* in oaks) and sometimes even endanger further persistence of the species (*Ophiostoma* sp. in elms, *Hymenoscyphus albicans* in ash).

Expected modifications due to climatic change

Climate warming may lead to Northward and upward migrations of tree species at their expanding edges (Ewald 2012), while increasing drought could severely affect tree growth (Dobbertin 2005) and survival at low latitudinal and altitudinal limits of the distribution range (trailing, retreating or rear edge), especially in regions with limited precipitation amounts (Mellert et al. 2016).

Peripheral populations face increasing extinction risk but can also be seen as the source of migrants for colonization of new areas at leading edges and of genetic novelty for reinforcing standing genetic variation throughout the distribution range (Fady et al. 2016, Alleaume-Benharira et al. 2006)

Beech leading edge will shift north and northeast into Scandinavian and Baltic countries. In regions where beech already prevails, this highly competitive species will gain a more dominant role and will be able to displace other tree species with cool temperate climate requirements (e.g. *Picea abies*) or other light demanding species.

Due to the novel environmental conditions, thermopilous tree species at the leading edge (e.g *Sorbus tomentosa*, *Sorbus domestica*, *Quercus pubescens*) could colonize new sites and ecological niches and thus gain higher importance in continental forests. Fragmentation of population diffusion area could also be a dramatic consequence of climatic change.

In mountainous areas of Central Europe (Alps, Carpathians, Herzynian range) there is still a certain space for altitudinal shift of vegetation belts. Species at the upper tree limit (namely *Picea abies*) may be able to colonize alpine grasslands. However, this process will strongly depend on the availability of source populations, which at present are largely damaged by bark-beetle outbreaks and locally by ancient (SO_2) or novel (tropospheric ozone) industrial pollution.

Forest species at the edge of their distribution range

Species

The region is climatically very heterogeneous, as it includes the hot Danube lowlands as well as high mountain chains; this rugged orography contributes to range fragmentation and sometimes large discontinuities in tree distributions. The Pannonian lowland forms a gap in distribution of many tree species, low precipitation along with high summer temperatures induce a xeric distribution limit (e.g., *Prunus avium*, *Fraxinus excelsior*). On the other hand, most temperate species (e.g., *Abies alba*, *Fagus sylvatica*) or genetic lineages (e.g., central-European lineage of *Picea abies*) achieve their northern limits north of the Carpathians (www.euforgen.org/maps).

In the western range the leading edge of *Abies alba* is limited by the low mountains in Northern Bavaria and Thuringia and the Vosges Mountains in France. But also some thermopile species such as *Sorbus domestica* and *Quercus pubescens* are limited by low temperatures in the continental area. Endemic species are *Pinus cembra* in the higher elevation of the Alps and Carpathians and *Betula nana* and *Betula humilis* which lost their connection to the main distribution area of the boreal-region.

Other MaPs of the following species occur in the western part: *Acer pseudoplatanus*, *Castanea sativa*, *Pinus cembra*, *Populus nigra*, *Pyrus pyraster*, *Quercus petraea*, *Sorbus torminalis*, *Tilia platyphyllos*, *Ulmus laevis* and more. There are also high elevation species which have reached the altitudinal limit i.e. *Alnus viridis.*

Kind of marginality occurring in the area

Most of the marginal populations present in the European continental area are located at the rear edge of the species distribution areas, so that they can be considered marginal from both the geographical and ecological points of view. Many conifers do not extend south of the Alpine chain, for instance *Larix decidua*, *Picea abies*, *Pinus cembra*. Other species are also present in the Northern Apennines, although with small and fragmented populations (*Pinus sylvestris*, *Fraxinus excelsior*).

Most of the mentioned species in Central Europe are at the leading edge. Some occur in ecological niches at high elevation as *Pinus cembra* or *Alnus viridis*.

Table 1 - Overview of important marginal and peripheral populations identified by the FP1202 experts for the continental area.

Species	Country									Total
	DE[1]	CH	CZ	PL	SK	HU	UA	SI	IT[1]	
Abies alba	1	1		28	2		11		3	46
Pinus sylvestris			4				3		6	13
Pinus nigra								1		1
Pinus mugo							3			3
Pinus cembra								1	3	4
Picea abies				31	2			3		36
Larix decidua										0
Fagus sylvatica	1	5		46	1	17		1	4	75
Quercus petraea					2	8				10
Quercus pubescens		1								1
Quercus cerris		1								1
Quercus ilex								1		1
Castanea sativa								1		1
Fraxinus excelsior									5	5
Fraxinus ornus		1								1
Acer opalus		1								1
Sorbus torminalis								2		2
Total	**2**	**10**	**4**	**105**	**7**	**25**	**17**	**10**	**21**	**201**

[1] *The segment of the country belonging to the continental area*

Genetic information available on marginality

Due to limited knowledge on how to identify and describe marginal populations only a few genetic investigations have been carried out on this topic, mostly at the rear edge in Southern Europe.

At the northern distribution limit of Silver fir in Franconia (Bavaria) to the Ore Mountains, most populations show a typical low genetic diversity (Eckert et al. 2008). At the range wide scale, allelic richness decreases towards the front edge in zoochorous trees due to recurrent founder events during colonization (Comps et al. 2001); this applies also to peripheral populations of European beech in northern and eastern Poland (Gömöry et al. 2003). Isolated populations located at the fragmented range periphery may also display increased differentiation (*Pinus cembra*; Wojnicka-Poltorak et al. 2015). *Abies alba* shows low genetic diversity at the leading edge along North-Bavaria to the Ore Mountains in Saxony.

Concerning rear edge of the species distribution area, the situations appear different according to the considered species, in particular biological and demographic aspects. MaPs of Scots pine from Apennines showed low internal genetic variability and high differentiation towards populations from the Alps (Belletti et al. 2012), while in wild cherry the situation was reversed (high internal genetic diversity and low differentiation) (De Rogatis et al. 2013). Still different is the case of silver fir (high genetic variability and high differentiation) (Belletti et al. 2017).

Most important marginal populations

Within the FP1202 COST action, experts from the participating countries identified marginal populations, which are important from the point of view of gene resources conservation, nature conservation and other aspects; the list for the continental area is provided in Tab. 1. Of course, as national priorities and subjective opinions played a significant role in the choice of these populations, imbalances in terms of both tree species and countries are apparent. Nevertheless, there is a certain general tendency: the highest number of populations was identified for major temperate species such as *Abies alba* and *Fagus sylvatica*, whereas in some countries (Switzerland, Italy, Slovenia) more emphasis is given to rare species such as *Pinus cembra*, *Fraxinus ornus* or *Sorbus torminalis*.

Forest ecosystem and protected areas

Measures of environmental protection

Concerning nature conservation, the region includes 110 national parks with a total area of 29,357 km2, each containing also forest land (Tab. 2). The level of protection of forest resources within these national parks varies depending on country and park category.

In addition to national parks, there is a wide variety of other protected areas, such as strict nature reserves, wilderness areas, protected landscapes,

Table 2 - Overview of national parks and their area within the continental area (https://www.iucn.org/theme/protected-areas/).

Country	Number of parks	Total area (km²)
Austria	7	2,521
Belarus	4	2,222
Czech Republic	4	1,190
Germany[1]	10	1,554
Hungary	10	4,819
Italy[1]	24	2,184
Poland	23	3,149
Slovakia	9	3,690
Slovenia	1	838
Switzerland	1	170
Ukraine	17	7,020
Total	110	29,357

[1] *The segment of the country belonging to the continental area*

Table 3 - Overview of genetic conservation units[1] in the continental area.

Country	Number GCU (in situ)	Number of tree species	Marginal or scattered tree populations	Number of tree species
Austria	276	27	50	17
Belarus	no information	no information	no information	no information
Czech Republic	32	21	9	6
Germany[2]	127	22	34	13
Hungary	6	2	0	0
Italy[2, 3]	58	10	1	1
Poland	605	28	261	24
Slovakia	122	17	14	9
Slovenia	35	22	11	10
Switzerland	3	3	0	0
Ukraine	85	11	8	2
Total	**1349**	**45**	**388**	**34**

[1] *EUFGIS database, 12/2016*
[2] *The segment of the country belonging to the continental area*
[3] *Alpes/Latitude above 45.5o*

etc. Even though the IUCN provides definitions of individual categories of protected areas, there is no unanimity about their purpose, ways of management, size and other aspects even among European countries, and sometimes the same term is used in different countries for different concepts. Nevertheless, they always leave broad possibilities for natural processes to shape gene pools of forest tree populations.

In most European countries, a part of forest areas is managed primarily for some protection function: protection against soil erosion and avalanches, protection of water resources and others. Usually, management measures in such forests are not intensive and silvicultural treatments relying on natural regeneration are applied. In addition, certification systems such as the Forest Stewardship Council and Program for the Endorsement of Forest Certification are widely applied and contribute to sustainable management of commercial forests and protection of natural resources.

In recent years, special activities concerning the conservation of biodiversity and genetic diversity have been carried out at a national and international level. These efforts were initiated and intensified because of evident high losses in genetic diversity and because the worldwide destruction of forested areas contributes to a significant reduction of biological diversity.

In terms of practical implementation and legal frameworks, European countries have organized the conservation of forest genetic resources. One of the initiatives is the European Information System on Forest Genetic Resources (EUFGIS) that serves as a documentation platform linking national inventories on forest genetic resources in Europe. This supports the countries in their efforts to conserve forest genetic resources as part of sustainable forest management, as agreed in the context of Forest Europe, the pan-European forest policy process.

The countries of the continental area announced 1,349 in situ genetic conservation units (GCU) of 45 different tree species to EUFGIS (Tab. 3).

Management of these units aims to maintain and enhance the long-term evolutionary potential of tree populations. This means that management measures and silvicultural techniques are applied, as needed, to favor genetic processes within target tree populations. The monitoring of the units is carried out by visiting them regularly to observe that they still serve their purpose.

Measures for protection/exploitation/valorisation of already existing MaPs

For a part of important marginal and peripheral populations identified by the FP1202 expert information is available about their current protection within the framework of nature conservation units (strict reserves national parks or other types of protected landscapes, Natura 2000 sites), their inclusion in gene conservation units (within or outside the Euforgen program) as well as their use as sources of forest reproductive materials (Tab. 4). Even when for a substantial part of the populations this auxiliary information was not provided and there is a certain imbalance among species, a general pattern is visible: Most populations are not protected (except protection under the Natura 2000 program, where, however, protection is usually not very strict) and are not conserved within the framework of national or international forest gene conservation programs. On the other hand, a majority of the identified populations serve as seed stands, which means that they benefit from at least temporary conservation and their gene pools are secured for further use.

Table 4 - Status of protection and use of important marginal and peripheral populations identified by the FP1202 experts for the continental area.

Species	Protection			Natura 2000		GCU		Seed stand		EUFGIS	
	reserve	park	no protection	yes	no	yes	no	yes	no	yes	no
Abies alba	3	10	27	22	19	9	30	32	8		41
Pinus sylvestris	2	7	2	2	9		11	1	6	1	10
Pinus nigra			1	1			1		1		1
Pinus mugo	1	2			3		3		3		3
Pinus cembra		1	1		1		2		2		2
Picea abies	3	1	32	29	7	4	32	28	8	3	33
Larix decidua	1	1		2		2			2	2	
Fagus sylvatica		1	49	21	31	2	50	46	6	1	73
Quercus petraea	2				2		2		2		2
Quercus ilex	1			1		1		1		1	
Castanea sativa			1				1	1			1
Fraxinus excelsior		2	3		5		5		5		5
Sorbus torminalis			2	1	1	2		2		2	
Total	**13**	**25**	**118**	**79**	**78**	**20**	**137**	**111**	**43**	**10**	**171**

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