Knowledge and conservation of Old-Growth Forests: a key issue to face global changes. The case study of Strâmbu-Băiuț - Maramureş (Eastern Carpathians, Romania)

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KNOWLEDGE AND CONSERVATION OF OLD-GROWTH FORESTS: A KEY ISSUE TO FACE GLOBAL CHANGES

THE CASE STUDY OF STRÂMBU-BĂIUȚ - MARAMUREŞ (EASTERN CARPATHIANS, ROMANIA)*

Over the last three decades, worldwide forests have become increasingly the focus of societal and scientific interest. The critical ecosystem services they provide are considered as key elements to mitigate harmful effects of global changes. Most of recent studies highlighted the highest effectiveness of the so-called «primary», «natural» and «old-growth forests» in this struggle due to their specific features (biodiversity and carbon storage capacity). However, in Europe, these forests which represent less than 1% of total forest cover are threatened by unsustainable human activity. Mainly based on pure ecological investigations, most of recent studies have rarely integrated human dimensions so far. Several outstanding issues remain to be addressed about the real nature of the «remaining natural European forests». Tackling this issue is crucial to know which forest must be conserved and how. In order to improve (i) knowledge about and (ii) conservation and /or sustainable management of such forests, we carried out an integrative and innovative research combining natural, social and human science approaches on a recently classified UNESCO primary beech forest located in the Maramureş county (Eastern Carpathians, Romania). First results highlighted that far from being untouched, this current high-value forest results from a long-term co-evolution with local communities. It implies a deeper understanding of the complex interaction between ecological and anthropogenic legacies is mandatory to improve and grant the preservation and sustainability of old-growth forests.
Keywords: Old-Growth forests, Eastern Carpathians, historical ecology, biocultural diversity conservation.

1. *Forests facing global change: a major societal and environmental issue*

Forests have received a tremendous societal and scientific focus over the last three decades. They are placed at the forefront of terrestrial biodiversity conservation[1] and provide many crucial ecosystem services[2]. Forests constitute the second largest carbon sink on the planet behind oceans[3]. They assimilate carbon from atmospheric CO_2 through photosynthesis, store it in their living tissues, slowly release it with the decomposition of organic matter in litter and soil or store it in deep soil and dead wood. However, each disturbance, such as deforestation, fires, or increased soil microorganism activity favoured by higher temperatures[4] could release massive amounts of carbon in various environmental compartments. The 2015 Paris climate agreement has aimed at reducing the unbridled rise in atmospheric carbon concentrations and since, the Intergovernmental Panel on Climate Change[5] and the scientific community have been tackling this issue[6], leading to an increasing number of projects on forests. Most of governmental actions aim at planting trees over unprecedented large areas in the European Union, the United States and China[7].

All forests are however unequal in terms of carbon storage. Numerous studies on the carbon storage ability of «natural forests», managed woodlands and plantations have highlighted the crucial role of management practices and tree diversity[8]. Faced with the enthusiasm for tree plantations, Luyssaert et al. (2008)[9] demonstrated on the contrary that «primary forests» (i.e. debated «natural forests», see section 2) «can continue to accumulate carbon, contrary to the long-standing view that they are carbon neutral». According to the same authors, «primary forests» in the boreal and temperate regions of the northern hemisphere alone sequester about 1.3±0.5 gigatons C per year. Scientists are also still debating the relative cooling and warming effects of forests, both able to counterbalance the other[10]. Recent modelling of European forest management scenarios points to the limited capacity of managed forests to offset global warming, and warns on the risks the European Union would take by mainly basing its policy on forest management adaptation[11]. It has also been suggested that the only way to significantly increase the planet's carbon sequestration capacity to meet global climate commitments (1.5°C) would be to restore and protect «natural forests», primarily in the tropics where the albedo is more limited than in boreal areas[12]. In other words, the forest should do what it does with no further human intervention. However, almost half of forest plantation commitments of the Bonn Challenge[13] involve vast tree monocultures for commercial purposes, implying regular harvesting and the release of carbon by the decomposition of plantation waste and products[14]. Using modelling of several forest restoration scenarios, Lewis *et al.* (2019)[15] highlighted that «natural forests» have a 40-time higher carbon storage capacity than monoculture tree plantations, and a 3-time higher capacity than the current mix of natural forest restoration, agroforestry and plantations. «Rewilding forests» would therefore be the only way to mitigate climate change and biodiversity erosion[16].

In Europe, recent inventories show that «natural forests» represent less than 1% of European forest and only 0.2% has remained in central Europe[17]. Those remaining forest stands face major anthropogenic threats such as unsustainable resource uses, lack of global conservation plans, illegal logging, invasive species and pollution[18]. Moreover, global warming-induced changes in the natural forest disturbance regime (pests, diseases) and in both its resilience and adaptive capacity remain uncertain[19]. In this context, it is essential to know whether we can prepare forests for future climate conditions and if any management or conservation policies can contribute to their adaptation and resilience. Trumbore et al. (2015)[20] have hypothesized that it is crucial to strengthen the monitoring both the health and dynamics of forests (independently of the natural dieback phenomenon[21]) in order to detect hotspots of decline and identify their causes. In addition, in-depth and interdisciplinary studies of the complex relationships between human (e.g. logging, biomass collection), abiotic (climatic, atmospheric and biogeochemical stresses) and biotic (defaunation, herbivory modification, diseases and invasive species) factors are mandatory to understand the evolution of these forests from a holistic perspective. Understanding the mechanisms for the recovery or rapid decline of forest functions in stands subject to increasing local and global disturbances should be based on field survey and laboratory experiments. They also should be combined with long-term surveys because «natural forest» features may respond only after a few decades to several centuries[22]. Such dataset could provide crucial information to improve the accuracy of current and future process-based models forecasting potential declines in forest health worldwide, and could join larger projects such as the Remote primary forest project[23].

While numerous projects aim at finding promising mitigation strategies, Trumbore et al. (2015)[24] argue that miracle solutions may not apply to all forests. The European project Arange[25] tackles the problem by focusing on forest management in seven mountain regions of the European Union. The study compares current and alternative regional/national management practices integrating the effects of climate change. Instead of proposing a single solution for adapting forests to climate change, Arange suggests experimenting «slight modifications» in current management practices at the scale of each stand by integrating the «particular ecological conditions in which it is evolving»[26]. But readjusting current practices in order to «adapt the forests of tomorrow» also involves looking back and observing phenomena at the stand and landscape levels.

Today's forests are inherited but also result *pro parte* from the management systems implemented by successive local communities and/or central administration/authority. Forests and woodlands have always provided services for successive and different communities[27]. Even «primary forests» of the Amazon have been shaped by local indigenous communities, whose practices have possibly contributed to their hyperdiversity[28]. Former land-use can also drive present-day biodiversity. For example, in European temperate forests, Dambrine *et al.* (2007)[29] highlighted a strong correlation between present-day forest plant diversity patterns and the location of a Roman farm linked to an increase in soil pH, available P, and $\delta^{15}N$. However, they have not considered the successive occupations and woodland uses throughout time. Indeed, very few works tackle this local historical complexity and its impact on «natural forest» features, as if the subject were incidental to the ongoing debate[30]. The diachronic evolution of forests is therefore determined by the socio-ecosystems responses to a combination of multiple natural and anthropogenic stressors. Thus, to know what should be protected and how, it is crucial to understand the past trajectories of «natural forests» and to disentangle the main natural and anthropogenic drivers that led to their current state. But the legacy of the past remains both poorly understood in current forest stands, and little (if not) considered in conservation issues[31].

2. *«Old-Growth Forest» vs «Natural Forest» concept*

The term «natural forest» used by Lewis et al. (2019)[32] remains confusing. In the scientific literature[33] related to temperate forests, this term refers to «primary forest» or «pristine forest». It describes a large wooded area (>100 km^2) grown by spontaneous colonization without human intervention since the end of the last Ice Age (ca. 10,000 yrs). In Europe, numerous palaeoecological and historical ecology studies have shown that primary forests probably completely disappeared during the last 2000 years, especially during the last 500-350 years[34]. Recent interdisciplinary studies including paleoenvironmental, archaeological and micro-historical approaches have revealed that sites often described as «primeval», such as the Białowieża Forest[35] in Polandor the Fiby Urskog in Sweden[36], turn out to have had a more active management history[37].

The term «primary forest» defined by the Food and Agricultural Organization[38] (i.e. naturally regenerated forests of native species without visible indications of human activities) actually refers to «Old-Growth Forest» (OGF). Cateau et al. (2015)[39] defined OGF as «subnatural forest», i.e. never-exploited «secondary forest» or only marginally exploited, developed over a long period of time without significant anthropogenic disturbance. The required duration without human pressure varies from 100 to 500 years depending on the characteristics of the original stand[40]. In theory, these forests have reached a high stage of maturity: many large and old living trees, many types of Tree-related Microhabitats – TreMs –, high volume of dead wood at different decay stages, natural dynamic equilibrium with stands dominated by *dryades* (long-lived and shade-tolerant tree species) and a high level of biodiversity.

However, this «natural state» does not imply that the forest is close or similar to its pre-anthropogenic state. Besides, the structure of the forests (open and closed tree cover) before widespread farming is still debated[41]. At least from the Neolithic period (7000BP) onwards, biomass removals linked to land clearing, agro-sylvo-pastoral practices, commercial forestry, and mid-Holocene climate fluctuations modified the extent and distribution of forests as well as their structure and composition[42]. They also led to species gain or loss as well as almost irreversible changes in soils[43] and disturbance regime[44].

Besides the diversity of definitions and criteria, the myth of the European pristine forest, which is said to have remained in tatters in Boreal areas or in the remotest valleys of the Carpathians, Dinaric or the Balkan Mountains, still persists within the scientific community[45] as well as in people's mind. The UNESCO has even registered the «ancient and primeval beech forests of the Carpathians and other regions of Europe» as a «transnational and transboundary property» that spans over twelve countries in the world heritage list. It assumes that «primeval European beech forests» have spread across the whole continent from a few isolated Glacial refugia in the Alps, Carpathians, Dinarides, Mediterranean and Pyrenees, over a «short period» of a few thousand years in a process that would be still ongoing[46].

However, without compromising the high heritage value of UNESCO «primeval forests»[47], we draw attention on local scientific results which have identified more refugia, and a diffused post-glacial spread of beech from scattered stands of small populations[48]. For example, in the Northern Pyrenees, decades of paleoenvironmental works have revealed that beech was preceded by silver fir and that its post-glacial expansion is mainly due to anthropogenic forcing[49]. The central-European *Corylus* decline at ca. 3500 BP correlates with the expansion of *Fagus* in Western Europe and is also the result of human impact[50]. In northern Europe (>47°N), the expansion of silver fir (ca. 6000 BP) has also preceded beech (ca. 5000 BP)[51]. Moreover, beech Glacial refugia in southern regions (Iberian Peninsula, south-western France, Apennine and Balkans peninsulas) have probably contributed little to the beech post-glacial colonization of Europe[52]. Beech populations in the Balkan, Iberian Peninsulas and Northern Pyrenees have remained small until ca. 5000-4000 BP. They expanded from the mid-Holocene in parallel with populations in central Europe[53]. However, the early post-glacial spread of the beech as well as Norway spruce at the sub-continental scale is not yet fully understood.

In the case of the Carpathians, present patches of fir-beech OGF are probably the last remnants of the «biogeographical» fir-beech mountain forest called «mountainous beech forest» in Sabatini et al. (2018)[54]. It has developed non-uniformly in the North-Eastern Carpathians during the late Holocene (beech: 5000-4500 BP, fir: 3000 BP) under the complex influence of climatic and anthropogenic factors that are still not fully understood[55]. The «spruce-beech forest» established ca. 2800 BP in the Rodna Mountains (Northern Romania) was replaced by a forest co-dominated by beech, silver fir and Norway spruce, ca. 1750 cal BP, i.e. a crucial period in terms of human disturbances and fire regime[56]. While the largest remaining mountain fir-beech stands are located in the Danube-Carpathian region, they have almost disappeared in western Europe, except in some remote mountain areas such as in the Northern Pyrenees[57].

Today, OGFs of the Carpathians show a large declination from pure to mixed beech with silver fir and/or Norway spruce bringing the question of the reference state for conservation[58]. Some of these OGFs have been registered to the UNESCO World Heritage Site List as «primeval beech forests» because they are composed of very large and tall living-trees as well as a large amount of dead wood. They host an exceptionally specialised forest biodiversity including plants, fungi and animals likewise[59]. Such a diversity raises questions about forest history, as an increase of tree-species diversity could also result from complex dynamics at a local-scale, leading to a multi-aged and multi-layered forest[60].

Therefore, the so-called «natural forests» require crucial integrative research efforts taking the *longue durée* into consideration[61]. Improving knowledge, conservation and/or sustainable management on OGFs requires a deep interdisciplinary research framework from a historical ecology perspective[62].

3. *OGFs' knowledge and conservation need the construction of a true interdisciplinarity based on new approaches*

In Europe, the first historical ecology studies on forest ecosystems have mainly focused on managed open woodlands («peasant forest» and «culturally modified trees») used over centuries by local communities (e.g. wooden pastures, open coppice stands). They relied on flora and fauna surveys, field observation of trees, archaeological remains and historical documents[63]. Over the last 30 years, the development of new methods and interdisciplinary approaches involving (paleo)ecology, geography and history across Europe has greatly improved our knowledge of long anthropogenic processes of forest ecosystems[64].

At a regional scale, paleoecological studies have made considerable progress in the spatiotemporal data resolution using small peat bogs, ponds and lakes as archives of vegetation changes over time[65]. Moreover, pollen dispersion modelling (using referential of modern pollen rain) and the combined study of plant macrofossils[66], charcoals[67] and even ancient DNAs[68] allow detailing changes in vegetation cover at various spatial and temporal scales[69]. However, these studies rarely combine other parameters such as oral testimonies, archaeological findings in forests, soil charcoal analysis and historical sources[70]. Integrating not only clues of past local and regional history, but also present-day forest traits (structure, composition, dead-wood diversity, etc.) and tree-growth patterns should provide a much finer resolution of changes in vegetation and human activities at the landscape and stand levels.

Over the last 20 years, forest historical ecology has grown on the theme of «ancient forests» and the biodiversity-related ancient woodlands and veteran trees[71]. An ancient forest is not necessarily an OGF. It involves a secular to multi-secular continuity of a woodland state, but regardless of current or past management, i.e. it can consist of young trees or coppices related to stand rejuvenation through management[72]. This research topic has focused on ancient woodland indicator species (plants), their ecological characteristics and their regional to sub-continental variations[73]. It has also focused on (i) phytosociological anomalies related to archaeological sites[74], and on (ii) indicator plant species of land use changes (clearing and agriculture) that may irreversibly alter their physicochemical characteristics and dormant seed stocks[75]. Biogeochemical analysis of soils has also been used to identify past human land use (e.g. agriculture) and their long-term legacy in ancient woodlands' diversity[76]. Numerous studies have characterized the impact of industrial harvesting (e.g. mining, smelting, charcoal manufacturing, etc.) on the evolution of woodland (composition and structure)[77], but few have focused on their impact on soils diversity[78]. Meanwhile LiDAR technologies has enabled the development of large-scale archaeological survey within woodland, but also characterization of their structural and biodiversity patterns[79].

Temporal continuity in forest cover is often interconnected with its spatial continuity in shaping local species communities[80]. The forest succession initiated following a disturbance is partly driven by the landscape context through the quantity and diversity of colonizers. However, our knowledge about the involved mechanisms and species sensitivity to ecological continuity still needs improvement to be able to recommend sustainable forest management practices[81]. Finally, despite these significant advances in forest studies, we note that only a few holistic studies involve the combination of close examination of the current OGF (or «natural forest») features with approaches including historical depth such as, oral testimonies (by interviewing elderly people), analysis of written and archaeological records, palaeoecological archives (forest soils, peat bogs, lakes) and tree-ring width of larger living-trees, to understand how the forest has been used over the last few decades, centuries and millennia. To tackle this issue, we decided to focus on European fir-beech forests (*Abies alba* Mill. and *Fagus sylvatica* L.) as they currently constitute the largest patches of «primary forest» in temperate European regions[82]. About 2000 years ago, these have formed the main forest cover at the mountain level where climatic conditions are favoured by regular clouds, fog and rain[83]. We have implemented an exploratory research in the core area of the Northern Romanian Carpathians: the Maramureş region (Transylvania). The region hosts some of the last remaining «primeval forests» which are also endangered even in protected areas[84]. The following sections gather preliminary results from our transdisciplinary experience based on the implementation of new integrated research strategies and methods[85]. This experience contributes to improving interdisciplinary knowledge about «primary forests», which are generally considered and studied as a «natural landscape» unaffected by human influence.

4. *The Strâmbu-Băiuţ case study: a «pristine forest» at the heart of the mining region of Maramureş? An overview of forest history and uses*

Romania is considered by scholars and NGOs (i.e. WWF, Euronatur, Greenpeace, etc.) as the «prime harbour of the EU's last intact forest landscapes», holding the second largest share of old-growth and primary forests within the EU[86]. To protect them, several inventories of Romanian OGFs have followed each other since 2005[87] and have led to the registration of twelve OGFs on the UNESCO world heritage list as «Primeval beech forests of the Carpathians and other regions of Europe» in 2017.

The Strâmbu-Băiuț forest is one of the three classified OGFs located in the County of Maramureș, an historical region of Transylvania (Eastern Carpathians, North Romania), at the borders with Ukraine and Hungary, thanks to the work started in 2010 by Romsilva and WWF Romania and the financial support of the EEA GRANTS for the project *Pădurile seculare de la Strâmbu-Băiuț – Ultimii giganți ai Maramureșului* (Fig. 1).

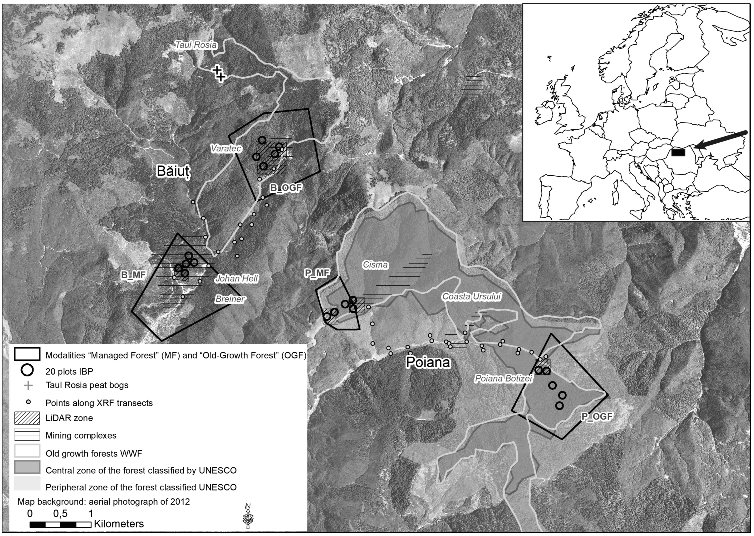

FIG. 1. Map of the study area with (i) in the insert top right, the location of the study area in the region of Maramureș, North-West of Romania (black rectangle), and (ii) in the main map the detailed location of the two valleys studied and both forest stand modalities (black polygons), MF and OGF.

Strâmbu-Băiuț is described by managers as having a primary, complex and heterogeneous structure, with individuals reaching their physiological age limit and a great compositional diversity with a natural mixture of species dominated by beech. At least since 2010, the anthropogenic forcing (forest management and biomass collection) has been considered «minimal» over *ca.* 580 ha (UNESCO core zone), which extends over two valleys of the

Comuna Băiuț (Băiuț and Poiana Botizii) in the Țibleșului Mountains within the Gutâi Mountains (Figure 1). The interest of focusing on this forest of high conservation value is multiple. Firstly, it is located in the heart of the Maramureș region where the remained OGFs are confined to a restricted area[88] compared to the Ukraine (Uholka) or the Southern Carpathians (Gemenele, Semenic, Nera) where OGFs are extended on several thousands of hectares. Secondly, while most of the Maramureș' OGFs are located in protected areas, they are nevertheless subject to anthropogenic disturbances with recent rise in tensions between illegal loggers and managers.

So far, the Maramureș forest history remains poorly known. Recent paleoenvironmental studies provide the first milestones of their Holocene dynamics[89] while historical studies mainly focus on contemporary periods, especially on legal and administrative issues and on recent history legacies on current woodlands (e.g. effects of post-socialist restitutions)[90]. A real gap remains between medieval and modern times. Even in the main forest historical synthesis of G. Giurescu (1980)[91], the Maramureș County is barely considered because this region was first part of the medieval Hungarian Kingdom, then of the autonomous principality of Transylvania before being incorporated back to the Austro-Hungarian Empire and eventually joined to Romania in 1918. For this same reason, the same gap exists in Hungarian historiography and must be filled[92].

As elsewhere in Europe in the 18th century, early forest laws (1781 Austro-Hungarian forest law for Transylvania) organized forest management in state, common and freeholder's forests and woodlands to meet the needs of timber (conifer and mixed high forest) and/or of fuel (wood and charcoal) for industries (coppices) as well. Such regulation often conflicted with and aimed to reduce traditional domestic uses and agro-sylvo-pastoral common rights (as grazing in forest): such practices being accused of damaging the integrity of forests. The last Romanian Forest Code (2008, republished in 2018) includes the preservation of the forest ecosystem biodiversity through sustainable management measures[93], according to the European Union provision. Despite legislation, the OGF governance experienced a major decline throughout the three decades following the fall of the Communist regime. Their protection entered into competition with national and international timber economy, other land uses and subsistence activities of poor local communities[94]. According to several authors[95], this decline is mainly due to the change of forest ownership with the restitution of large areas of state-owned forest to previous owners (about 800

000 small holdings at the end of the restitution process[96]) leading to a breakdown of the forest management (Ministerial Conference on the Protection of Forests in Europe, 2007[97]). The restitution process also hindered the implementation of sustainable silvicultural practices and the governance of biodiversity.

Due to its geographical border position and history (see above), the Maramureș has remained quite isolated and distinctive from the rest of Romania. Historically, the County has enjoyed a relative internal autonomy (more informal than official) contributing to create a specific cultural context[98]. During the 20th century (after 1918), the County was characterized by an acute mobilization of the Romanian popular traditions (Romanian being the majority people alongside Hungarian, Ukrainian and Romani people), as the outcome of both a strong cultural pressure exerted by its border position and a hostility (and/or lack of interest) towards collectivization[99]. This particular context has contributed to the preserved authenticity of this countryside that might explain its status of «archaic ethnographic zone»[100]. This preserved authenticity is truly reflected in its traditional rural landscape (hay meadows, haystacks, mountain pastures, wooden architecture as traditional houses and churches, including several registered in the UNESCO world heritage list[101]), and its rich traditions, customs and folklore[102]. The County is still considered as a conservatory of traditional techniques, especially regarding woodworking[103]: wood carving, carpentry with ancient tools, tar-pitch impregnation, wooden tiled roof etc.

At first glance, the Maramureș seems to have been little affected by the external influences and centralizing powers. However, from a socio-economical point of view, the reality is more complex[104]. These timeless peasant characteristics have been idealized to lend themselves to tourism. It has led to a real staging of traditions and folklore since the 1970's. However, as the land and climate do not enable intensive agriculture, livestock rearing, forestry work and woodworking have remained the main occupations of these mountain populations. Additionally, metal mining has been an important activity, although rarely mentioned in order to avoid undermining the cultural purity of the perfect peasant[105]. Faced with the prolonged shock of the post-communist «transition period» (i.e. from eastern socialism to western liberal capitalism) and the Romania's adhesion in the EU, local communities have been compelled to adapt a complex, historically-rooted, plural activity also called «multi-strategy of resourcefulness»[106]. This has led them to diversify their economic strategies: «peasant-workers», loggers, charcoal burners, miners, etc. and mainly cross-border and pendular labour migration. The increased commodification of traditions, authenticity and unspoiled nature storytelling is part of this diversification process (e.g. green and rural tourism and craft trades).

The Maramureș also hosts the Baia Mare metallogenic district, one of the most important polymetallic mining districts in Romania with a remarkable geological diversity[107]. This district comprises four main mining sectors, which are from west to east: Ilba-Nistru, Săsar-Dealul Crucii (Baia Mare), Herja-Băiuț and Borșa[108]. The Strâmbu-Băiuț forest (administrative district) extends over the Herja-Băiuț sector which is located about 45 km east of Baia Mare. This mining sector is developed on several areas including two within the UNESCO central area (Poiana Botizii and Cisma) and three in the Băiuț valley (Breiner, Johan Hell Mine and Văratec) (Figure 1). The Băiutmetallogenic field consists of intermediate Pb-Zn-Cu epithermal deposits hosting common sulfides, Ag-minerals and native gold[109]. Mining and smelting activities have prospered at least from the 14th century to 2006[110]. Indeed, the mines have been gradually shut down between 2004 and 2006 with respect to European Union conditions imposed to Romania prior its adhesion.

Historical intensive mining activities have resulted in trace metal (TM) pollution in rivers and soils[111]. In Băiuț, waste dumps are still found at the heart of the UNESCO area. Acid mine drainage releasing harmful TM (Pb, Cu, Zn, Ni, Cd, As) into lands and rivers (Lăpuș and Someș watersheds) after each thunderstorm[112] are still impacting pasture areas, orchards and vegetable gardens[113]. This situation raises the question of TM accumulation and distribution in OGF soils and their effect on soil and vegetation biogeochemical processes. Furthermore, long term large-scale mining activities have direct impact on forests including local deforestation and removal of topsoil for mining surveys, open-cast mining and waste storage. Firstly, the development of settlements near mining sites may open up forest to other activities (i.e. agriculture, animal husbandry, hunting and logging). Secondly, forests constitute a vital resource for metal mining activities over time. Wood is called upon at all stages of the ore processing chain, from extracting ores (e.g. timbering, propping, buildings, fire-setting etc.) until its transformation into metal (reduction, smelters). Indeed, charcoal was the preferred fuel for supplying forges and smelting ores, involving massive wood harvesting over vast forest areas at least until the 19th century[114] and their effective management over a long time to meet every need.

Despite this crucial aspect, close relationships between mining and forestry have never been investigated in the Băiuț area and more broadly in the Baia Mare mining district. However, this specific context (historical, socio-economic and cultural) implies a past and relatively recent intense pressure on local forest resources, which does not correspond to the primary features highlighted by managers in the Strâmbu-Băiuț forest. That is probably due to the fact that the management and/or conservation of the OGFs has been widely discussed by ecologists and managers who mainly focus on the present-day aspects of forests and absence of obvious anthropogenic signs without integrating historical, archaeological and more broadly, socio-economical parameters. However, timber harvesting legacies (stumps, slashes) remain for only about 50 years[115].

5. *Towards a new transdisciplinary definition of formerly managed subnatural forest hosting wildlife*

The Strâmbu-Băiuț forest constitutes a particularly interesting case study to explore the «hidden legacies» of human activities in a present-day exceptional «wilderness forest ecosystem». Furthermore, an overview of the two valleys suggests different socio-environmental trajectories that need to be investigated. Consequently, we have decided to examine both space (from the landscape to the tree level) and time (from the last millennia to present-day), using an interdisciplinary and integrated multilevel approach (Fig. 2). In each observation level, we have developed several approaches, allowing each scientist to participate in the observations and in the sampling of each other's discipline and therefore strengthening interdisciplinary practices.

The research employed a methodology focused on several steps; they are identifiable in four different analytical scales: landscape, stand, plot and tree level.

At *landscape level*, in order to investigate the co-evolution between forest ecosystem and human communities over the last millennium, we perform a regressive approach from living memories back to medieval times. Firstly, we have conducted a preliminary social survey based on thirty semi-structured interviews on a wide panel of randomly-selected stakeholders (various ages, genders, professional and touristic activities). They were questioned about present and past activities in connection with forest, agriculture, biodiversity and mines, how they use the forests and forest produce (as well as how formerly they have been used), and their connection to the forest. The oral testimonies collected about practices and perceptions spatially and temporally contextualised and have contributed to explore the collective memories. They provided a better understanding of both perceptions and practices related to mining heritage (buildings, underground works, workshops and factories, TM contaminations), forests, their biodiversity and their ecosystem services. This qualitative social approach with local stakeholders has been supported by the combined study of contemporary records and local literature focusing on the pastoralism-mining-forestry trilogy. Secondly, a review of both Romanian and Hungarian literature about medieval and modern forest and mining activities is ongoing. We also performed a first inventory of the available medieval and modern written records preserved at the Arhivele Naționale ale României – Maramureș (Baia Mare) and at the Magyar Nemzeti Levéltár (Budapest). A preliminary study based on late medieval royal diplomas (14^{th}-15^{th}centuries) shows a close relationship between forest use and conservation with non-ferrous ore mining in the Baia Mare district. Ore extraction privileges granted by the Hungarian kings, renewed in 1347 and confirmed again in 1376, were completed by rights on the surrounding forest in a perimeter of three miles. As this area was no longer sufficient for supplying timber for the mines and buildings, the king extended these rights to other royal forests (the *Sylva nigra* and other unnamed forests), located outside this perimeter[116]. Such forests provided timber but also charcoal used as fuel for ore smelting, as stated by a 1329 royal diploma. These texts reveal the early awareness of central authorities on the strategic importance of wood resources for supporting mining and metallurgy. The continuous ore exploitation – with variable intensity in Baia Mare (*Rivulus Dominarum*, then *Nagybánya*), Baia Sprie (*Medius Mons,* then *Felbőbánya*), Cavnic (*Kapnikbánya*) or smaller districts such as Băiuț (*Erzsébetbánya*) and the related smelting facilities until contemporary times[117] raises the issue of forest management strategies that further investigation of Hungarian archives will try to tackle.

To characterize present-day TM contaminations linked to the mining wastelands, two large transects (n=42) extending from the OGF forest patches to the heart of the two villages were analysed using field portable X-ray fluorescence (on the A horizon of forest soils and alluvium of river banks) (Figure 2). Surface measurements were also carried out on the two Tăul Roșia peat bogs (c. 1100 m asl), located north of the Băiuț OGF (Figure 1). These small peat bogs were also cored to perform a multi-proxy study[118] including pollen and non-pollen palynomorphs, microscopic charcoal particles and TM analyses in order to reconstruct the long-term vegetation history and anthropogenic disturbances at the landscape level[119].

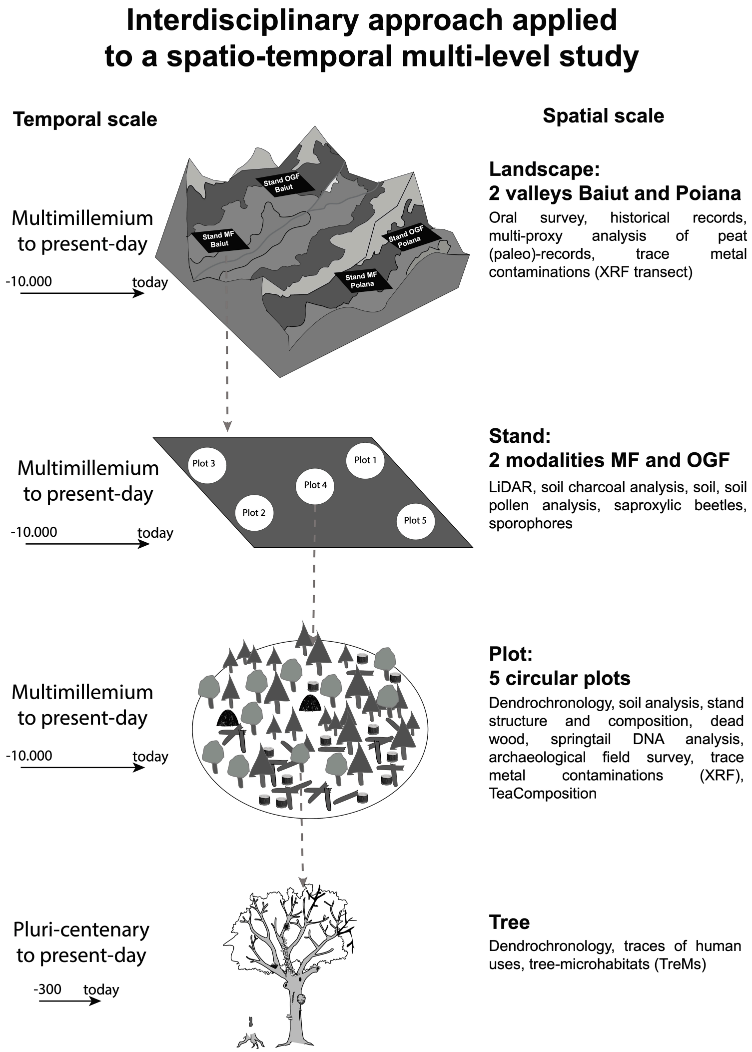

FIG. 2. Interdisciplinary and integrated multilevel approach applied to the valley of Băiuț and Poiana Botizi, at various spatio-temporal scales.

Stand level. We have selected two forest stand modalities in each valley: «Managed Forest» (MF) and «OGF» allowing the comparison of both modalities in term of biodiversity, «naturality» and complex historical trajectories (Figg. 1, 2). The MF modality was defined by the presence of obvious recent traces of logging operations. The OGF modality corresponds to patches with, at first glance, few evident traces of recent human perturbation and features suggesting a low anthropogenic pressure. To evaluate the biological quality of forests, we have looked for «relict» OGF saproxylic beetle species that are bio indicators of low-disturbance forests (by sight-search oriented on substrates favourable to certain species of the «relict» list following Eckelt et al. (2018)[120].

In each stand modality, we used soil charcoal analysis (2 sampling points per modality) to study the occurrence of fire disturbances and characterize the evolution of forest composition since the early Holocene at the stand scale[121]. In addition, as acid soils (pH below 5.5) may preserve fossil pollen, we have performed a soil sampling (every 10 cm) for palynological analysis in order to supplement the vegetation history at the stand level[122].

In each stand modality, we have selected five 1-ha circular plots, partly randomly and partly according to the possibilities of LiDAR drone flights (Figure 1, 2). Indeed, the number of points extracted from LiDAR to detect archaeological remains are limited by the conifers-dominated forest. The LiDAR survey is also applied to test its accuracy in explaining and predicting biodiversity indices (or indicators). Finally, LiDAR allows the spatial distribution analysis of clearings to compare patterns of both modalities.

Plot level. In each plot we firstly performed a rapid habitat assessment including 10 factors describing the full 1-ha plot present-day forest stands and their potential capacity to host biodiversity (Index of Biodiversity Potential, IBP[123]). Additionally, we have carried out a systematic archaeological survey focusing on Charcoal Kiln (CK) sites. The study of the spatial distribution of CKs and the analysis of remaining charcoals (anthracology/dendroanthracology, radiocarbon dating) allow reconstructing charcoaling practices and woodland cover changes related to management strategies[124].

The ecological monitoring of soils is based (i) on the systematic description of humus forms[125] and on the sampling of the A horizon for pH and C/N analyses, (ii) on the analysis of trace elements (including TM) using portable X-ray fluorescence, and (iii) on the measure of the decomposition rate of organic matter and carbon capture using the Tea Composition Protocol[126]. The analysis of the litter and its decomposition rate is indicative of the long-term carbon storage. The humus form characterization (organic and A horizons) is used to control the relevance of comparisons of the decomposition rates of tea bags between plots or modalities.

In order to describe the soil microfauna and fungi diversity as well as to study their interactions (connection of trophic networks) into both modalities, soil environmental DNA was extracted[127]. To complete the DNA reference base to increase the quality of taxonomic assignment, plots were surveyed for basidiocarp in the deadwood and soil compartments.

Tree level. Using a relascope[128] from the plot centre, we have sampled the stand and accurately described all the dead and living trees belonging to the fixed-angle plot, recording tree-species, diameter at breast height (dbh) and tree-related microhabitats it bears. In addition, for deadwood items, we have assessed position (standing vs lying), volume and decay stage.

Tree-ring width analysis (3 firs and 3 beeches per plot) have been performed to evaluate individual tree age and to (well-)assess the effects of both climate and disturbance on individual tree growth. All individual chronologies have then been averaged at both the plot and stand scale in order to estimate the mean tree age at the plot/stand scale, to characterize the large-scale climate-tree growth relationships and to reconstruct the disturbance history[129].

Our preliminary study of the Strâmbu-Băiuț forests confirms the paradoxical situation highlighted in the previous sections. An overview of the two valleys' forests effectively demonstrates a remarkable density of maturity features in several stands, but paradoxically, it also shows a relatively high-level forestry activity occurring in areas away from or in the periphery of the UNESCO zone. Forest stands are currently harvested in two ways: small or larger clear-cuts and light thinning cuts. Timber is mainly harvested using mechanized skidding machines, but the villagers still use the traditional wood extraction methods with horses. In both investigated forest sites, the stands at the origin of the present-day forests seem to have been managed mainly by selective cutting. Indeed, clear-cut is a recent practice, implemented since Maramureș forests have been solicited by the major European wood industrialists and harvested by companies from other territories. This represents a threat insofar as these new players do not perceive these forests as their own but as a simple resource to be exploited. Despite of the UNESCO classification, a strong pressure remains on protected stands and managers try to control it risking of their own lives[130].

On the one hand, commercial forestry benefits the local economy since the mines stopped; on the other, pastoralism has been maintained in the two valleys (sheep, cows, horses, goats), but in a less developed way in Băiuț than in Poiana. In Poiana, humid grasslands of the bottom of the valley (Fig. 3) and dry grasslands of mountainsides are farmed by mowing or grazing. Small herds graze trimmed mountain pasture areas in summer (Fig. 4), but during the last 30-50 years, the volume and intensity of this activity were probably most important. In Poiana, the mining legacy is subtler and large areas of mining waste are far from the village, which has preserved its rural authenticity (Fig. 5). The UNESCO forest site is mainly located in the southern half of Poiana valley offering a showcase closer to the ideal natural image (Fig. 6).

FIG. 3. Mowing meadow near Poiana (credit: S. Guillerme).

FIG. 4. Herd grazing in the mountains near Strâmbu-Băiuț (credit: S. Guillerme).

FIG. 5. Poiana, a village that has maintained a strong agricultural economy (credit: S. Guillerme).

FIG. 6. UNESCO protected forest site (credit: S. Guillerme).

The highest concentrations of trace metals (mainly Pb and As) are measured contaminant in both valley bottoms and near mining wastes. Trace metal concentrations remain high in forest soils, but values are decreasing in the areas furthest from the mines. The on-going multi-proxy study of the peat records suggests evidence of TM atmospheric pollution prior to the modern times, which may confirm long mining history in the region (A. Petras, PhD research) and its possible legacy on in present-day forest soils. The numerous remains of CK terraces (n=80) detected in both modalities of each forest site, including in the UNESCO core zone, provides evidence for past fuelwood harvesting to supply former smelters. The spatial distribution of the CKs (mainly concentrated in Băiuț MF and Poiana OGF) could result from a former organization of forest neighbourhoods, which is also suggested by oral testimonies (some areas were deemed to have been used formerly by charcoal burners). For this reason, during the social interviews forest has not been considered as an isolated component of the landscape, but within a wider land-use system, as part of the same agrarian matrix[131]. This working assumption however requires a detailed chronological control and further investigation in historical archives as well as in people's memory.

The Băiuț MF modality excluded from the UNESCO area do not show any significant difference in structure, composition and litter decomposition compared to the OGF modalities of each site (with the exception of the density of trees with trunk cavities). Despite recent and former logging operation evidence which are sometimes very abundant (as operational longshoring corridors and CK remains), the MF modalities show specific features of forests spared from human activities for several centuries. They have a high level of naturalness and present a strong stakes of biodiversity conservation (i.e. abundant and diversified dead wood with large diameter, high density of large and very large trees, numerous and diversified TreMs, fungi associated with dead wood such as *Fomesfomentarius*, *Phellinus hartigii*, *Polyporus squamosus*, *Sparassis nemecii*, *Hericium flagellum*, *Climacodonse ptentrionalis* and *Fomitopsis pinicola*. Furthermore, this subnatural forests indicator species list will be complemented by DNA data. In addition, a higher species diversity has been evidenced in the Băiuț OGF which stretches over the Văratec mining complex. The MF modality of Poiana, located in the vicinity of the Cisma mining area, is the second site with a high fungi diversity. Similarly, the saproxylic beetle inventory highlights the biological quality of the forests of both valleys, including the Băiuț MF, with the presence of remarkable species such as *Peltis grossa*, *Eurythyrea austriaca*, *Platydema dejeani* and *Ceruchus chrysomelinus*. The presence of these species raises questions about past forest management that were not detrimental to the saproxylic diversity. This suggests a stable, local or landscape-level, presence of standing fir deadwood (*Eurythyrea austriaca*, *Peltis grossa*) and large-diameter lying dead wood on the ground in an advanced decay stage (*Ceruchus chrysomelinus*) despite timber harvesting.

Interestingly, the preliminary dendrochronological findings show that the formation of the largest trees did not go back before the very beginning of the 19th century in Băiuț stands. The tree age is rather typical of managed forests, although the oldest trees' age is probably underestimated due to recurring heart rot. Moreover, the tree age does not vary significantly in each modality: fir trees have an average age of 135 and 169 years in MFs and OGFs, respectively; for beech, average age were 149 and 146 in MFs and OGFs, respectively. Several phases of disturbance were detected in the tree-ring sequences and would explain their relative youth (wind disturbance, harvesting). Indeed, beech and fir have a life expectancy of up to 400-500 years[132]. Phases of decline and regeneration where trees older than 500 years are expected to be present, have not been observed. The spatial mosaic of phases related to the sylvigenetic cycle is thus incomplete.

The examination of the OGF modalities evidences subtle traces of past timber harvest, including in the UNESCO core area. The remnants from former logging operations such as slash, sections of abandoned logs, stumps at different decay stages and remains of logging corridors are preserved in different places. In Poiana OGF numerous «testing notches» are also detected, mainly on living silver fir trunks but also on beech and sycamore (*Acer pseudoplatanus* L.) (Fig.7).

FIG. 7. «Testing notches» in a living tree trunk (credit: S. Guillerme).

This suggests that trees have been tested to exploit lumber and other wood products during the last decades, i.e. during the period of forest predation's rise in Romanian OGFs (see section 4). According to Bouras (2018)[133], this practice consisting of «test trees» using notches (called *încercarea* in Romanian) has only become widespread recently in Romania, where it is considered to be illegal. It provides the advantage to evaluate the wood quality by observing its colour and fibres on the removed piece, without cutting down the entire tree. However, it weakens the tree by exposing the sapwood on 20x10-cm windows. The development of this aggressive practice mainly used by craftsmen specialized in the manufacture of staves, wooden tiles, and even musical instruments, is mostly linked to both the economic demise of local communities and pressure exerted by large forestry companies within the current globalization process[134]. Consequently, it can be assumed that this forest constituted, before its protection, a reserve of high-quality timber. Villagers interviewed in Poiana have mentioned the management of this forest under the control of the centralized forestry administration. The forest has been locally-managed by village manpower. Even school children have been asked to contribute during some «camps», with tasks such as picking wild berries. The Community status of the forest has probably contributed to its preservation during the post-communist restitution process. Some 50 years ago, the local community was still exchanging timber and wood products harvested from this forest on the Baia Mare market, for various foodstuffs and other consumer items that were not produced locally. The detection of several CKs dating from modern times (c. 18th century) evidence other uses linked to mining and metal working that may have been combined with timber harvest (carbonization of slashes). Today, this forest is considered by the local community as a part of their heritage. It is still used daily for many purposes such as berry and mushroom picking, dead-wood collection, hunting or hiking. However, such traditional uses conflict with new ones (like off-road motorcycle or four-wheel drive vehicle riding, large scale berries and mushroom harvest for international trade). For example, managers (*Ocolul Silvic Strâmbu Băiuț*) are trying to eradicate the extreme off-road motorcycle riding, a new practice attracting foreign tourists and offering a source of income for some villagers in the local community (mostly restaurants, bars or lodge owners) but damaging the forests.

The forest dominant species composition in both forest sites also involves different management strategies (selection of species) through time. Spruce, well represented in the MF and OGF modalities of Băiuț in a mixture with fir and beech, is not present in the Poiana OGF. This absence has been interpreted by managers as an indicator of naturalness, spruce being deemed to have been introduced in the 18th century by the Austrian-Hungarians. This standing view is probably based on the fact that the Austrian-Hungarians, belonging to the German classical school of forestry, carried out spruce plantations when they controlled and managed the region and the mines. Present-day spruce plantations have an azonal spatial distribution (spruce is the most subalpine *dryade* species). At the bottom of the Băiuț valley, 30 to 60-year-old spruce stands have been planted on former cultivated areas and grasslands. The

2017 storm, resulting in the fall of a huge number of trees, has evidenced they were highly vulnerable regarding extreme weather events. Some subalpine spruce stands remain at highest altitude, as in Tăul Roșia, and require further studies.

Our preliminary soil charcoal analysis results suggest clear differences between MF and OGF modalities in terms of fire disturbance intensity. The anthracomasses (> 0.8mm charcoal weight) obtained in the MF modalities are much higher than OGF modalities where charcoals are almost rare. This suggests different multi-secular (even multi-millenary) trajectories in terms of human land-use (e.g. charcoal making and sylvo-pastoral practices using fire). However, the taxonomic composition of charcoal assemblages from different soil horizons up to the substratum is largely dominated by *dryade* species (silver fir, spruce and beech) in both modalities. Some species naturally present in mixture (birch, maple cf. sycamore, hazelnut, willow, poplar cf. aspen) with *dryade* species are poorly represented (number of fragments and weight). This result suggests a continuity of forest cover probably from the early Holocene and, therefore, its pluri-millennia ancientness. Several radiocarbon dates will detail this chronology.

In conclusion, on the basis of these first observations, we confirm that the present-day forests classified as «primary» are inherited through centuries, and probably even millennia of interplay between local communities and forest ecosystem. The forests initially considered as OGFs do not differ significantly from the other managed forests under study, which are of equal heritage interest and also require an adapted conservation plan. As a result of our research, managers have recently (2018) extended the protected area over most of the Strâmbu-Băiuț forest district (3000 ha). Moreover, although the studied forests have many traits of «subnatural» stands, their history bears witness to management and exploitation carried out until the last decades. These forests therefore constitute a conceptual crevice because they do not correspond to «primary forest», «natural forest» or even OGF definitions, which assume no or few human interventions. Furthermore, they do not include the legacies of multi-millennial interactions between humans and forests. Nevertheless, these forests are linked to past sustainable management practices that have maintained a closed to semi-closed canopy until recently, therefore suggesting the continuity of the tree cover. These forests are thus characterized by a pluri-centuries ancientness and a continuity of different decaying wood habitats. These features, coupled with the evidences of former and recent timber harvesting imply the implementation of close-to-nature management practices yet to be understood[135].

The current forest distribution and species composition involve the complexity of past communities' uses and their spatial organization. The transition from the spruce-beech forest[136] into the one co-dominated by beech, silver fir and Norway spruce, requires more focus. Moreover, the combined effects of anthropogenic and climatic factors in removing spruce in some current stands call further examination. In spite of the UNESCO classification, these exceptional forests remain threatened, first and foremost because of pressure from illegal logging and secondly because of recent changes in forestry practices linked to the globalization process and local poverty growth, particularly since mines stopped. These aspects have to be considered in local and European conservation policies. Indeed, the adequacy between European conservation policies of endangered relic ecosystems and local communities' development and protection remains a very complex issue. The Strâmbu-Băiuț forest falls under the umbrella term «ancient forest», but would require the creation of a new concept integrating human and nature interplay. It could contribute to the consideration of socio-environmental issues in conservation policies and to reduce tension between «rewilding forest» and «biocultural diversity» as a driver of conservation or restoration.

This study demonstrates the interest value of changing scales, from continental to local, by placing remaining OGF stands in a historical perspective necessary to truly understand the complex local situations and contemporary issues in a globalized world. In this way, the local level can become the main operator of actions to protect and conserve forest biodiversity and the delivery of ecosystems goods and services.

6. *What's the future of European OGFs?*

Threats to European OGFs forests are numerous and growing while their role to mitigate harmful effects of global changes (above all, climate warming and biodiversity loss) is crucial. Moreover, most of OGFs are ancient and therefore combine properties due to both high level of maturity and ancientness. We are at a critical point for OGFs. Despite the increasing uncertainty about the future, we must contribute to preserve the remaining OGFs as well as the wildlife they host on a long-term scale. But we also need to offer local communities the possibility to still use these forests. Therefore, we are proposing six main challenges for social and natural scientists:

Challenge 1: There is an urgent need to stimulate and undertake interdisciplinary studies, explorative and innovative research methods closely associated with sustainable management strategies (and their effects) and conservation issues. We need a greater knowledge of the European OGFs at a local scale.

Challenge 2: It becomes crucial to deeply understand the close relationship between local communities and OGFs as well as how they belong to a unique socio-ecosystem, which interdependencies guaranties their preservation and sustainability.

Challenge 3: It becomes a fundamental issue to disseminate more practice-oriented publications and carry out awareness-raising and learning activities to managers, practitioners and local communities. It is probably the best way to stimulate innovative actions to preserve OGFs and closely-related biodiversity without totally prohibiting local and traditional uses (harvesting of wild plants, fungi and fruits, honey production, peripheral wood-pastures, etc.) and close-to-nature practices (e.g. emulating natural disturbances), which benefit wildlife.

Challenge 4: It is a priority to show and explain the long-term and vastly negative environmental impact of illegal logging and related trade due to strongly increasing international demand for woody biomass. In addition to economic and social impacts, they durably alter all ecosystem services provided by European OGFs at the local and global levels.

Challenge 5: There is a need to enhance OGFs' local and participative governance integrating local communities. By referring to local history and knowledges, conserving OGFs may be achieved through a combination of integrative protection strategies (rewilding) of sufficiently large forest areas and biodiversity-friendly management practices integrating the natural disturbance regimes on other forest sites. The aim being to ensure ecological, social and economic functions for local community needs only.

Challenge 6: We need to continue to fight against socio-environmental vulnerability of local communities, which has repercussions on forest ecosystem vulnerability.

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Notes

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