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

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Vanessa Py-Saragaglia, Marie-Claude Bal, Cécile Brun, Sandrine Buscaino, Sylvie Guillerme, et al.. Knowledge and conservation of Old-Growth Forests: a key issue to face global changes. The case study of Strâmbu-Băiuț - Maramureș (Eastern Carpathians, Romania). Quaderni Storici, 2020, Disassembling landscape. Applied Environmental archaeology and historical ecology, 164, pp.369-404. 10.1408/99412 . hal-03049790

HAL Id: hal-03049790

<https://hal.science/hal-03049790v1>

Submitted on 9 Apr 2021

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

THE CASE STUDY OF STRÂMBU-BĂIUȚ -
MARAMUREȘ (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 Maramureș 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 conservation¹ and provide many crucial ecosystem services². Forests constitute the second largest carbon sink on the planet behind oceans³. They assimilate carbon from atmospheric CO₂ 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 temperatures⁴ 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 Change⁵ and the scientific community have been tackling this issue⁶, 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 China⁷.

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 diversity⁸. Faced with the enthusiasm for tree plantations, Luysaert *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 other¹⁰. 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 adaptation¹¹. 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 areas¹². 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 Challenge¹³ involve vast tree monocultures for commercial purposes, implying regular harvesting and the release of carbon by the decomposition of plantation waste and products¹⁴. 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 erosion¹⁶.

In Europe, recent inventories show that «natural forests» represent less than 1% of European forest and only 0.2% has remained in central Europe¹⁷. Those remaining forest stands face major anthropogenic threats such as unsustainable resource uses, lack of global conservation plans, illegal logging, invasive species and pollution¹⁸. Moreover, global warming-induced changes in the natural forest disturbance regime (pests, diseases) and in both its resilience and adaptive capacity remain uncertain¹⁹. 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 phenomenon²¹) 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 centuries²². 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 project²³.

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 Arange²⁵ 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 communities²⁷. Even «primary forests» of the Amazon have been shaped by local indigenous communities, whose practices have possibly contributed to their hyperdiversity²⁸. 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 $\delta^{15}\text{N}$. 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 debate³⁰. 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 issues³¹.

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

The term «natural forest» used by Lewis *et al.* (2019)³² remains confusing. In the scientific literature³³ related to temperate forests, this term refers to «primary forest» or «pristine forest». It describes a large wooded area (>100 km²) 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 years³⁴. Recent interdisciplinary studies including paleoenvironmental, archaeological and micro-historical approaches have revealed that sites often described as «primeval», such as the Białowieża Forest³⁵ in Poland or the Fiby Urskog in Sweden³⁶, turn out to have had a more active management history³⁷.

The term «primary forest» defined by the Food and Agricultural Organization³⁸ (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 «subnat-

ural 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 stand⁴⁰. 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 debated⁴¹. 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 composition⁴². They also led to species gain or loss as well as almost irreversible changes in soils⁴³ and disturbance regime⁴⁴.

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 community⁴⁵ 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 ongoing⁴⁶.

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 populations⁴⁸. 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 forcing⁴⁹. 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 impact⁵⁰. 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 Europe⁵². 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 Europe⁵³. 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 understood⁵⁵. 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 regime⁵⁶. 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 Pyrenees⁵⁷.

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 conservation⁵⁸. 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 likewise⁵⁹. 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 forest⁶⁰.

Therefore, the so-called «natural forests» require crucial integrative research efforts taking the *longue durée* into consideration⁶¹. Improving knowledge, conservation and/or sustainable management on OGFs requires a deep interdisciplinary research framework from a historical ecology perspective⁶².

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 documents⁶³. 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 ecosystems⁶⁴.

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 time⁶⁵. Moreover, pollen dispersion modelling (using referential of modern pollen rain) and the combined study of plant macrofossils⁶⁶, charcoals⁶⁷ and even ancient DNAs⁶⁸ allow detailing changes in vegetation cover at various spatial and temporal scales⁶⁹. However, these studies rarely combine other parameters such as oral testimonies, archaeological findings in forests, soil charcoal analysis and historical sources⁷⁰. 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 trees⁷¹. 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 management⁷². This research topic has focused on ancient woodland indicator species (plants), their ecological characteristics and their regional to sub-continental variations⁷³. It has also focused on (i) phytosociological anomalies related to archaeological sites⁷⁴, and on (ii) indicator plant species of land use changes (clearing and agriculture) that may irreversibly alter their physicochemical characteristics and dormant seed stocks⁷⁵. 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' diversity⁷⁶. 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 diversity⁷⁸. Meanwhile LiDAR technologies has enabled the development of large-scale archaeological survey within woodland, but also characterization of their structural and biodiversity patterns⁷⁹.

Temporal continuity in forest cover is often interconnected with its spatial continuity in shaping local species communities⁸⁰. 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 practices⁸¹. 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 regions⁸². 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 rain⁸³. 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 areas⁸⁴. The following sections gather preliminary results from our transdisciplinary experience based on the implementation of new integrated research strategies and methods⁸⁵. 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-Băiuț 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 in-

tact forest landscapes», holding the second largest share of old-growth and primary forests within the EU⁸⁶. To protect them, several inventories of Romanian OGFs have followed each other since 2005⁸⁷ 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).

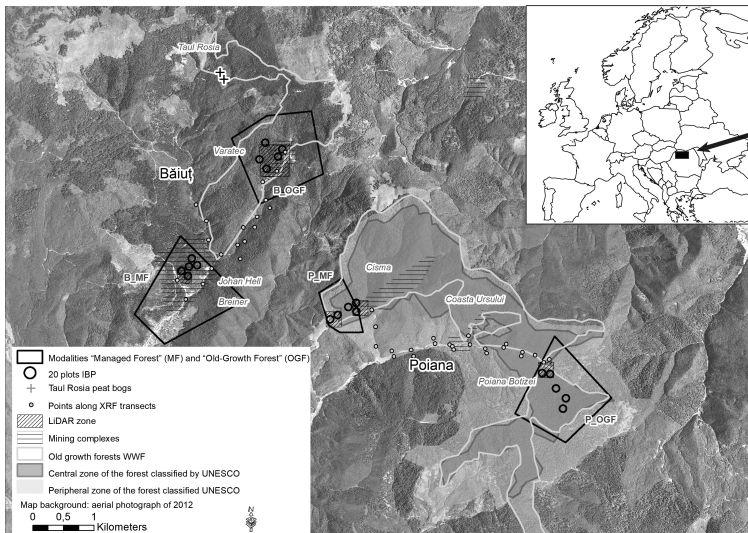


FIG. 1. Map of the study area with (i) in the insert top right, the location of the study area in the region of Maramureș, North-West of Romania (black rectangle), and (ii) in the main map the detailed location of the two valleys studied and both forest stand modalities (black polygons), MF and OGF.

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 area⁸⁸ 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 dynamics⁸⁹ 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 filled⁹².

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 measures⁹³, 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 communities⁹⁴. According to several authors⁹⁵, 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 process⁹⁶) leading to a breakdown of the forest management (Ministerial Conference on the Protection of Forests in Europe, 2007⁹⁷). 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 Maramureş 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 context⁹⁸. 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 collectivization⁹⁹. 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 list¹⁰¹), and its rich traditions, customs and folklore¹⁰². The County is still considered as a conservatory of traditional techniques, especially regarding woodworking¹⁰³: wood carving, carpentry with ancient tools, tar-pitch impregnation, wooden tiled roof etc.

At first glance, the Maramureş 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 complex¹⁰⁴. 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 peasant¹⁰⁵. 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 Maramureş also hosts the Baia Mare metallogenic district, one of the most important polymetallic mining districts in Romania with a remarkable geological diversity¹⁰⁷. This district comprises four main mining sectors, which are from west to east: Ilba-Nistru, Săsar-Dealul Crucii (Baia Mare), Herja-Băiut and Borşa¹⁰⁸. The Strâmbu-Băiut forest (administrative district) extends over the Herja-Băiut 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 (Poi-ana Botizii and Cisma) and three in the Băiut valley (Breiner, Johan Hell Mine and Văratec) (Figure 1). The Băiut metallogenic field consists of intermediate Pb-Zn-Cu epithermal deposits hosting common sulfides, Ag-minerals and native gold¹⁰⁹. Mining and smelting activities have prospered at least from the 14th century to 2006¹¹⁰. 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 soils¹¹¹. In Băiut, 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 (Lăpuş and Someş watersheds) after each thunderstorm¹¹² are still impacting pasture areas, orchards and vegetable gardens¹¹³. 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 century¹¹⁴ 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 Băiut 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-Băiut 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 years¹⁵.

5. *Towards a new transdisciplinary definition of formerly managed sub-natural forest hosting wildlife*

The Strâmbu-Băiut 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 con-

textualised 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 (14th-15th 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 perimeter¹¹⁶. 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 times¹¹⁷ 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 study¹¹⁸ 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 level¹¹⁹.

Interdisciplinary approach applied to a spatio-temporal multi-level study

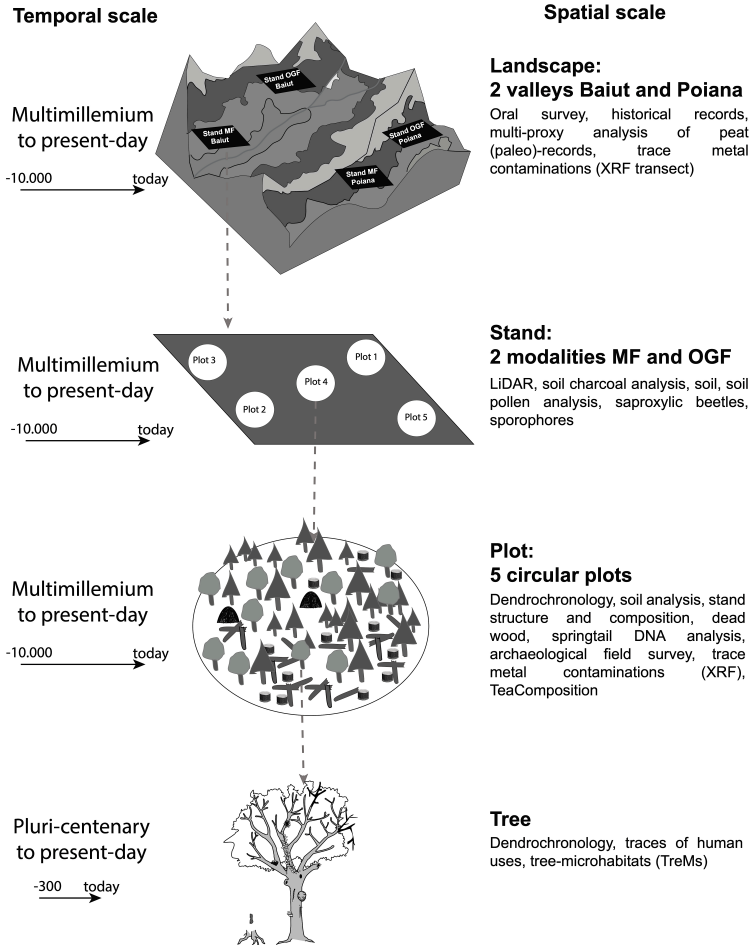


FIG. 2. Interdisciplinary and integrated multilevel approach applied to the valley of Băiuț and Poiana Botizi, at various spatio-temporal scales.

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 scale¹²¹. 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 level¹²².

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, IBP¹²³). 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 strategies¹²⁴.

The ecological monitoring of soils is based (i) on the systematic description of humus forms¹²⁵ 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 Protocol¹²⁶. 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 extracted¹²⁷. 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 relascope¹²⁸ 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 history¹²⁹.

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 lives¹³⁰.

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-Băiț (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 matrix¹³¹. 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 pentri-onalis* 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 dead-wood (*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 years¹³². 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 process¹³⁴. 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 understood¹³⁵.

The current forest distribution and species composition involve the complexity of past communities' uses and their spatial organization. The transition from the spruce-beech forest¹³⁶ 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-Băiului 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

* This work is part of the FORET EXIL project coordinated by V. Py-Saragaglia and supported by the French National Centre for Scientific Research (CNRS) and the Mission for Cross-cutting and Interdisciplinary Initiatives (MITI) in 2017 and 2018. It is also part of the SAFE NATURE project coordinated by C. Brun and funded by the House of Human and Social Sciences of Toulouse (MSHS-T) in 2018, and the URGENSES project coordinated by S. Ladet and funded by the INRAE-SAD department in 2018-2019. The project continues in new study areas (Northern Carpathians and French Northern Pyrenees) thanks to the support of the French National Research Agency (ANR) in the frame of the BENDYS project (ANR-19-CE03-0010) led by V. Py-Saragaglia (2020-2023). The authors would like to thank L. Burnel (DYNAFOR lab., INRAE) for his support for fieldwork and tree-ring core study. They would also like to thank M. Dušátko, from the Czech University of Life Science of Praha (CULS Prague), for his contribution to dendrochronological analysis (beech cores), and E. Maire (GEODE Lab.) for his contribution to the satellite imagery analysis and field investigation. They acknowledge the

efficient cooperation of the *Ocolul Silvic Strâmbu Băiuț* (Romsilva) and in particular F. Mârzac, and of the WWF Romania, especially C. Ardelean.

¹ L. GIBSON et al., *Primary forests are irreplaceable for sustaining tropical biodiversity*, in «Nature», 478 (7369) (2011), pp. 378-81.

² MILLENIUM ECOSYSTEM ASSESSMENT, *Ecosystems and Human Well-Being: Synthesis*, Washington DC. 2005, pp. 39-45: <http://www.maweb.org/documents/document.356.aspx.pdf>. [Last access: 06/11/2020].

³ M. REICHSTEIN, N. CARVALHAIS, *Aspects of Forest Biomass in the Earth System: Its Role and Major Unknowns*, in «Surveys in Geophysics», 40 (2019), pp. 693-707.

⁴ K. KARHU et al., *Temperature sensitivity of soil respiration rates enhanced by microbial community response*, in «Nature», 513 (7516) (2014), pp. 81-4.

⁵ IPCC, 2018. Report: <https://www.ipcc.ch/sr15/> [Last access: 06/11/2020].

⁶ Y. PAN et al., *A large and persistent carbon sink in the world's forests*, in «Science», 333 (6045) (2011), pp. 988-93; IPCC, 2018, cit.; S.L. LEWIS et al., *Regenerate natural forests to store carbon*, in «Nature», 568 (2019), pp. 25-8; G. POPKIN, *The forest question*, in «Nature», 565 (2019), pp. 280-2.

⁷ POPKIN, *The forest question* cit.

⁸ A. PAQUETTEAND, C. MESSIER, *The role of plantations in managing the world's forests in the Anthropocene*, in «Frontiers in Ecology and the Environment», 8/1 (2010), pp. 27-34; B.G. MACKEY et al., *Green carbon: the role of natural forests in carbon storage*, Canberra 2008; C. LIAO et al., *Ecosystem carbon stock influenced by plantation practice: implications for planting forests as a measure of climate change mitigation*, in «PloS one», 5/5 (2010); X. LIU et al., *Tree species richness increases ecosystem carbon storage in subtropical forests*, in «Proceeding of the Royal Society Biological Sciences», 285 (1240) (2018).

⁹ S. LUYSSAERT et al., *Old-growth forests as global carbon sinks*, in «Nature», 455 (2008), pp. 213-5.

¹⁰ C. SAGAN et al., *Anthropogenic Albedo Changes and Earth's Climate*, in «Science», 206 (4425) (1979), pp. 1363-8; G.L. POTTER et al., *Climate Change Due to Anthropogenic Surface Albedo Modification*, in W. BACH, J. PANKRATH, J. WILLIAMS (eds), *Interactions of Energy and Climate*, Dordrecht 1980, pp. 317-26; G. BALA et al., *Combined climate and carbon-cycle effects of large-scale deforestation*, in «Proceedings of the National Academy of Sciences USA», 104 (16) (2007), pp. 6550-5; R.A. PIELKE et al., *Land use/land cover changes and climate: modeling analysis and observational evidence*, in «WIRES Climate Change», 2 (2011), pp. 828-50; M.U.F. KIRSCHBAUM et al., *Implications of albedo changes following afforestation on the benefit of forests as carbon sinks*, in «Biogeosciences», 8 (2011), pp. 3687-96; N. UNGER, *Human land-use-driven reduction of forest volatiles cools global climate*, in «Nature Climate Change», 4 (10) (2014), pp. 907-10; K. NAUDTS et al., *Europe's forest management did not mitigate climate warming. Forest management*, in «Science», 351 (6273) (2016), pp. 597-9; S.R. PANGALA et al., *Large emissions from floodplain trees close the Amazon methane budget*, in «Nature», 552 (7684) (2017), pp. 230-4; C.E. SCOTT et al., *Impact on short-lived climate forcers increases projected warming due to deforestation*, in «Nature Communications», 9 (157) (2018).

¹¹ S. LUYSSAERT et al., *Trade-offs in using European forests to meet climate objectives*, in «Nature», 562 (7726) (2018), pp. 259-62.

¹² LEWIS et al., *Regenerate natural forests to store carbon* cit.

¹³ www.bonnchallenge.org [Last access: 06/11/2020].

¹⁴ LEWIS et al., *Regenerate natural forests* cit.

¹⁵ Ivi.

¹⁶ D.B. LINDENMAYER et al., *General management principles and a checklist of strategies to guide forest biodiversity conservation*, in «Biological Conservation», 131 (2006), pp. 433-45;

J.E.M. WATSON *et al.*, *The exceptional value of intact forest ecosystems*, in «Nature Ecology and Evolution», 2 (2018), pp. 599-610.

17 J. PARVIAINEN, *Virgin and natural forests in the temperate zone of Europe*, in «Forest Snow and Landscape Research», 79/1-2 (2005), pp. 9-18; F.M. SABATINI *et al.*, *Where are Europe's last primary forests?*, in «Diversity and Distribution», 24 (2018), pp. 1426-39.

18 F. ACHARD *et al.*, *Detecting intact forests from space: hot spots of loss, deforestation and the UNFCCC*, in C. WIRTH, G. GLEIXNER, M. HEIMANN (eds), *Old-Growth Forests. Ecological Studies (Analysis and Synthesis)*, vol 207, Berlin-Heidelberg 2009, pp. 417-27.

19 R. SEIDL *et al.*, *Searching for resilience: Addressing the impacts of changing disturbance regimes on forest ecosystem services*, in «Journal of Applied Ecology», 53/1 (2016), pp. 120-9; R. SEIDL *et al.*, *Forest disturbances under climate change*, in «Nature Climate Change», 7 (2017), pp. 395-402; M. SAULNIER *et al.*, *Climatic drivers of Picea growth differ during recruitment and interact with disturbance severity to influence rates of canopy replacement*, in «Agricultural and Forest Meteorology», 287 (107981), 2020.

20 S. TRUMBORE *et al.*, *Forest health and global change*, in «Science», 349 (6250), 2015, p. 814-8.

21 C.I. MILLAR, N.L. STEPHENSON, *Temperate forest health in an era of emerging mega disturbance*, in «Science», 349 (6250) (2015), pp. 823-6.

22 See., e.g.: L. LARRIEU *et al.*, *Impact of sylviculture on dead wood and on the distribution and frequency of tree microhabitats in Montane Beech-Fir forests of the Pyrenees*, in «European Journal of Forest Research», 131/3 (2012), pp. 773-86; L. LARRIEU *et al.*, *Development over time of the tree-related microhabitat profile: the case of lowland beech-oak coppice-with-standards set-aside stands in France*, in «European Journal of Forest Research», 136/1 (2016), pp. 37-49; L. LARRIEU *et al.*, *Post-barvesting dynamics of the deadwood profile: the case of lowland beech-oak coppice-with-standards set-aside stands in France*, in «European Journal of Forest Research», 138/2 (2019), pp. 239-51; Y. PAILLET *et al.*, *Quantifying the recovery of old-growth attributes in forest reserves: A first reference for France*, in «Forest Ecology and Management», 346 (2015), pp. 51-64.

23 www.remoteforests.org [Last access: 09/11/2020].

24 TRUMBORE *et al.*, *Forest health and global change* cit.

25 Advanced multifunctional forest management in European mountain ranges: www.arange-project.eu [Last access: 03/11/2020].

26 S. LABONNE *et al.*, *Forêts de montagne et changement climatique: impacts et adaptations*, in «Sciences Eaux et Territoires», 28/2 (2019), pp. 38-43.

27 K.J. KIRBY, C. WATKINS (eds), *Europe's changing woods and forests. From wildwood to managed landscapes*, Wallingford 2015.

28 C. LEVIS *et al.*, *Persistent effects of pre-Columbian plant domestication on Amazonian forest composition*, in «Science», 355 (6328) (2017), pp. 925-31; G. ODONNE *et al.*, *Long term influence of early human occupations on current forests of the Guiana Shield*, in «Ecology», 100 (10), e02806 (2019).

29 E. DAMBRINE *et al.*, *Present forest biodiversity patterns in France related to former Roman agriculture*, in «Ecology», 88/6 (2007), pp. 1430-9.

30 See, e.g.: S. ROSTAIN, *Amazonie. Un jardin sauvage ou une forêt domestiquée*, Errance 2016.

31 P. SZABÓ, R. HÉDL, *Advancing the integration of history and ecology for conservation*, in «Conservation Biology», 25/4 (2011), pp. 680-7; P. SZABÓ, *Traditional woodland management, forest legislation, and modern nature conservation in east-central Europe*, in A. DOWLING, R. KEYSER (eds), *Conservation's Roots: Managing for Sustainability in Preindustrial Europe, 1100-1800*, New York & Oxford 2020, pp. 304-26.

32 LEWIS *et al.*, *Regenerate natural forests* cit.

33 E. CATEAU *et al.*, *Ancientness and maturity: Two complementary qualities of forest ecosystems*, in «Comptes Rendus Biologies», 338 (2015), pp. 58-73; J.-J. DUBOIS, *Les réserves*

biologiques en France: de la dynamique dirigée à la dynamique spontanée, in P. ARNOULD, E. GLON (dir.), *La nature a-t-elle encore une place dans les milieux géographiques?*, Paris 2019, pp. 45-67.

³⁴ See, e.g.: K.J. KIRBY, C. WATKINS, *Evolution of Modern Landscapes*, in *Europe's changing woods and forests* cit., pp. 46-58; L. MARQUER et al., *Quantifying the effects of land use and climate on Holocene vegetation in Europe*, in «Quaternary Science Reviews: the international multidisciplinary research and review journal», 171 (2017), pp. 20-37.

³⁵ M. LATAŁOWA et al., *Białowieża Primeval Forest: A 2000-year Interplay of Environmental and Cultural Forces in Europe's best preserved Temperate Woodland*, in *Europe's Changing Woods and Forests* cit., pp. 243-64.

³⁶ R. BRADSHAW, G. HANNON, *The disturbance dynamics of Swedish boreal forest*, in A. TELLER, P. MATHY, J.N.R. JEFFERS (eds), *Responses of forest Ecosystems to Environmental Changes. European symposium on Terrestrial Ecosystems: Forests and woodland*, London 1992, pp. 528-35; A. UOTILA et al., *Assessing the naturalness of boreal forests in eastern Fennoscandia*, in «Forest Ecology and Management», 161 (2002), pp. 257-77; T. JOSEFSSON et al., *Long-term human impact and vegetation changes in a boreal forest reserve: implications for the use of protected areas as ecological references ecosystems*, in «Ecosystems», 12 (2009), pp. 1017-36.

³⁷ This idea has been reported synthetically in KIRBY, WATKINS, *Evolution of Modern Landscapes* cit.

³⁸ FRA 2015, *Forest Resources Assessment Working Paper. Terms and definitions*, Rome, 2012, p. 7.

³⁹ CATEAU et al., *Ancientness and maturity* cit.

⁴⁰ Ivi.

⁴¹ F.W.M. VERA, *Grazing Ecology and Forest History*, Wallingford 2000; H.J.B. BIRKS, *Mind the gap: How open were European primeval forests?*, in «Trends in Ecology and Evolution», 20/4 (2005), pp. 154-6; F.J.G. MITCHELL, *How open were European primeval forests? Hypothesis testing using palaeoecological data*, in «Journal of Ecology», 93 (2005), pp. 168-77; K.J. KIRBY, C. WATKINS, *The forest landscape before farming*, in *Europe's changing woods and forests* cit., pp. 33-45; I.D. ROTHERHAM (ed.), *Trees, Forested landscapes and grazing animals. An European perspective on woodlands and grazed treescapes*, Routledge 2017.

⁴² See, e.g.: T. GIESECKE et al., *The pace of Holocene vegetation change – testing for synchronous developments*, in «Quaternary Science Reviews», 30 (2011), pp. 2805-14.

⁴³ M. HERMY, K. VERHEYEN, *Legacies of the past in the present-day forest biodiversity: a review of past land-use effects on forest plant species composition and diversity*, in «Ecological Research», 22 (2007), pp. 361-71; J. PLUE et al., *Persistent changes in forest vegetation and seed bank 1,600 years after human occupation*, in «Landscape Ecology», 23 (2008), pp. 673-88.

⁴⁴ See, e.g.: W. TINNER et al., *Long term forest fire ecology and dynamics in southern Switzerland*, in «Journal of Ecology», 87/2 (1999), pp. 273-89; M. LINDNER et al., *Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems*, in «Forest ecology and management», 259/4 (2010), pp. 698-709; D. PURESWARAN et al., *Forest insects and climate change*, in «Current Forestry Reports», 4/2 (2018), pp. 35-50; U. BÜNTGEN et al., *Extending the climatological concept of 'Detection and Attribution' to global change ecology in the Anthropocene*, in «Functional Ecology», 2020.

⁴⁵ E.g. A. ECKELT et al., *Primeval forest relict beetles of Central Europe: a set of 168 umbrella species for the protection of primeval forest remnants*, in «Journal of Insect Conservation», 22/1 (2018), pp. 15-28; SABATINI et al., *Where are Europe's last primary forests?* cit.

⁴⁶ <https://whc.unesco.org/en/list/1133/> [Last access: 04/11/2020].

⁴⁷ J.E.M. WATSON et al., *The exceptional value of intact forest ecosystems*, in «Nature Ecology and Evolution», 2 (2018), pp. 599-610.

⁴⁸ D. MAGRI, *Patterns of post glacial spread and the extent of glacial refugia of European beech (*Fagus sylvatica*)*, in «Journal of Biogeography», 35 (2008), pp. 450-63.

49 D. GALOP, G. JALUT, *Differential human impact and vegetation history in two adjacent Pyrenean valleys in the Ariège basin, southern France, from 3000 bp to the present*, in «Vegetation History and Archaeobotany», 3 (1994), pp. 225-44; D. GALOP *et al.*, *Palynologie et histoire des activités humaines en milieu montagnard. Bilan provisoire des recherches et nouvelles orientations méthodologiques sur le versant nord des Pyrénées*, in «Archéologie du Midi Médiéval», 21 (2003), pp. 159-70; V. PY-SARAGAGLIA *et al.*, *Late Holocene history of woodland dynamics and wood use in an ancient mining area of the Pyrenees (Ariège, France)*, in «Quaternary Internationals», 458 (2017), pp. 141-57; M. SAULNIER *et al.*, *A study of late Holocene local vegetation dynamics and responses to land use changes in an ancient charcoal making woodland in the central Pyrenees (Ariège, France), using pediaanthracology*, in «Vegetation History and Archaeobotany», 29 (2020), pp. 241-58.

50 M. RALSKA-JASIEWICZOWA *et al.*, *Some problems of forest transformation at the transition to the oligocentric/Homo sapiens phase of the Holocene interglacial in northern lowlands of central Europe*, in «Vegetation History and Archaeobotany», 12 (2003), pp. 233-47.

51 T. GIESECKE *et al.*, *Patterns and dynamics of European vegetation change over the last 15,000 years*, in «Journal of Biogeography», 44 (2017), pp. 1441-56.

52 GIESECKE *et al.*, *Patterns and dynamics* cit.

53 S. FĂRCAȘ *et al.*, *Holocene vegetation history in the Maramureș Mountains (Northern Romanian Carpathians)*, in «Quaternary international», 293 (2013), pp. 92-104.

54 SABATINI *et al.*, *Where are Europe's last primary forests?* cit.

55 I. TANȚĂU *et al.*, *Holocene vegetation history in the upper forest belt of the Eastern Romanian Carpathians*, in «Palaeogeography, Palaeoclimatology, Palaeoecology», 3099 (2011), pp. 281-90; A. FEURDEAN *et al.*, *Tree and timberline shifts in the northern Romanian Carpathians during the Holocene and the responses to environmental changes*, in «Quaternary Science Review», 134 (2016), pp. 100-13.

56 R. GRINDEAN *et al.*, *Linking vegetation dynamics and stability in the old-growth forests of Central Eastern Europe: Implications for forest conservation and management*, in «Biological Conservation», 229 (2019), pp. 160-9.

57 J.M. SAVOIE (dir.), *Vieilles forêts pyrénéennes de Midi-Pyrénées. Deuxième phase. Évaluation et cartographie des sites. Recommandations. Rapport final. École d'ingénieurs de Purpan/DREAL Midi-Pyrénéens*, 2015: https://www.cen-mp.org/wp-content/uploads/2020/01/Savoie_VieillesFor%C3%AAts_Pyr%C3%A9n%C3%A9s_2015.pdf [Last access 22/11/2020]; SABATINI *et al.*, *Where are Europe's last primary forests?* cit.

58 V. GIURGIU *et al.*, *Les forêts vierges de Roumanie*, Louvain-la-Neuve 2001.

59 I.-A. BIRIȘ, P. VEEN (eds), *Inventory and strategy for sustainable management and protection of virgin forests in Romania (PIN-MĂTRA/2001/018)*, ICAS and KNNV, 2005. Web source datasets digital maps: *Pădurilevirgine din România*, Report and maps: <http://www.mmediu.ro/articol/proiect-pin-matrapadurile-virgine-din-romania/2068> [Last access: 12/10/2020]; I.-A. BIRIȘ *et al.*, *Ancient beech forests of Romania – the preliminary identification of potential nomination areas for the World Heritage List*, Project Report, ICAS, Bucharest, 2012; ID., *et al.*, *24000 ha of primary beech forests, the Romanian proposal in UNESCO World Heritage*, in «Bucovina Forestieră», 16/1 (2016), pp. 107-16; ID., *Status of Romania's Primary Forests. For Greenpeace Romania*, Bucharest 2017: <https://storage.googleapis.com/planet4-romania-stateless/2019/07/dd70c748-dd70c748-the-status-of-romaniaspriary-forests.pdf> [Last access: 12/10/2020]; A. SMALYCHUK, U. GRÄBENER (eds), *Natural forests of Ukrainian Carpathians*, Lviv 2018.

60 J. BRUNET *et al.*, *Biodiversity in European beech forests-a review with recommendations for sustainable forest management*, in «Ecological Bulletins», (2010), pp. 77-94.

61 W. BALÉE, *Brief review of historical ecology*, in S. ROSTAIN, G. DE SAULIEU, M. SALPETEUR (dir.), *Ecologie historique*, in «Les Nouvelles de l'archéologie», 152 (2018), pp. 7-10.

62 See, e.g.: M. BÜRGI, U. GIMMI, *Three objectives of historical ecology: the case of litter collecting in Central European forests*, in «Landscape Ecology», 22 (2007), pp. 77-87; D. MORENO, C. MONTANARI, *Il lato «oscuro» del paesaggio: (per) una ecologia storica del paesaggio rurale*

italiano, in C. TEOFILI, R. CLARINO (a cura di), *Riconquistare il paesaggio. La Convenzione Europea del Paesaggio e la Conservazione della Biodiversità in Italia*, Roma 2008, pp. 159-75; T.C. RICK, R. LOCKWOOD, *Integrating paleobiology, archaeology, and history to inform biological conservation*, in «Conservation Biology», 27 (2013), pp. 45-54.

⁶³ See, e.g.: O. RACKHAM, *Trees and Woodland in the British Landscape*, London 1976; ID., *Ancient Woodland: Its History, Vegetation and Uses in England*, London 1980; G.F. PETERKEN, *A method for assessing Woodland Flora for Conservation Using Indicator Species*, in «Biological Conservation», 6/4 (1974), pp. 239-45; J.-P. MÉTAILLÉ, *La forêt paysanne dans les Pyrénées centrales*, in «Revue Géographique des Pyrénées et du Sud-Ouest», 55/2 (1984), pp. 231-8; D. MORENO, *Dal documento al terreno. Storia e archeologia dei sistemi agro-silvo-pastorali*, Bologna 1990.

⁶⁴ E. SARATSI, et al. (eds), *Woodland Cultures in Time and Space: tales from the past messages for the future*, Athens 2009; C. WATKINS, *Methods and approaches in the study of woodland history, in Europe's Changing Woods* cit., pp. 18-32; S. BURRI, *Towards an interdisciplinary approach on ancient forests*, in S. PARADIS-GRENOUILLET, C. ASPE, S. BURRI, (eds), *Into the woods. Overlapping perspectives on the history of ancient forests*, 2018 (<https://www.quae.com/produit/1539/9782759229079/into-the-woods>) [Last access: 12/10/2020].

⁶⁵ See, e.g.: G.E. HANNON et al., *6000 years of forest dynamics in Suserup Skov, a semi-natural Danish woodland*, in «Global ecology and biogeography», 9 (2000), pp. 101-14; ID. et al., *Dynamic early Holocene vegetation development on the Faroe Islands inferred from high-resolution plant macrofossil and pollen data*, in «Quaternary Research», 73/2 (2010), pp. 163-72; LATAŁOWA et al., *Białowieża Primeval Forest cit.*; L. MARQUER et al., *Pollen-based reconstruction of Holocene land-cover in mountain regions: Evaluation of the Landscape Reconstruction Algorithm in the Videssos valley, northern Pyrenees, France*, in «Quaternary Science Reviews», 228, 106049 (2020).

⁶⁶ H.H. BIRKS, H.J.B. BIRKS, *Future uses of pollen analysis must include plant macrofossils*, in «Journal of Biogeography», 27 (2000), pp. 31-5.

⁶⁷ HANNON et al., *6000 years of forest dynamics* cit.

⁶⁸ H.J.B. BIRKS, H.H. BIRKS, *How have studies of ancient DNA from sediments contributed to the reconstruction of Quaternary floras?*, in «New Phytologist», 209 (2016), pp. 499-506.

⁶⁹ See, e.g.: R.H.W. BRADSHAW, *Modern pollen representation factors for woods in south-west England*, in «Journal of Ecology», 69 (1981), pp. 45-70; M.-J. GAILLARD et al., *Modern pollen/land-use relationships as an aid in the reconstruction of past land-uses and cultural landscapes: an example from south Sweden*, in «Vegetation History and Archaeobotany», 1 (1992), pp. 3-17; A. BROSTRÖM et al., *Pollen productivity estimates of key European plant taxa for quantitative reconstruction of past vegetation: a review*, in «Vegetation History and Archaeobotany», 17 (2008), pp. 461-78; N. ROBERTS et al., *Europe's lost forests: a pollen-based synthesis for the last 11,000 years*, in «Scientific Reports 8», 716 (2018).

⁷⁰ LATAŁOWA et al., *Białowieża Primeval Forest cit.*; M. ZANON et al., *European Forest Cover During the Past 12,000 Years: A Palynological Reconstruction Based on Modern Analogs and Remote Sensing*, in «Frontiers in Plant Science», 9 (253) (2018): <https://www.frontiersin.org/articles/10.3389/fpls.2018.00253/full>.

⁷¹ K.J. KIRBY, C. WATKINS (eds), *The Ecological History of European Forests*, Wallingford 1998; *Into the woods* cit.; L. BERGÈS, J.-L. DUPOUEY, *Historical ecology and ancient forests: progress, conservation issues and scientific prospects, with some examples from the French case*, in «Journal of Vegetation Science», (2019), pp. 1-17.

⁷² CATEAU et al., *Ancientness and maturity* cit.; T. SLACH et al., *Chapter 3: Ancient coppice woodlands in the Czech Republic*, in *Into the woods* cit.

⁷³ See, e.g.: M. HERMY et al., *An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation*, in «Biological Conservation», 91 (1999), pp. 9-22.

⁷⁴ G. DECOCOQ, *Utilisation de la flore et de la végétation actuelles en prospection archéologique*, in P. RACINET, J. SCHWERDROFFER (dir.), *Méthodes et initiations d'Histoire et d'Archéologie*, Pornic 2004.

75 HERMY, VERHEYEN, *Legacies of the past in the present-day forest* cit.; PLUE *et al.*, *Persistent changes in forest vegetation* cit.

76 J.-L. DUPOUEY *et al.*, *Irreversible impact of past land use on forest soils and biodiversity*, in «Ecology», 83 (11) (2002), pp. 2978-84; E. DAMBRINE *et al.*, *Present forest biodiversity patterns in France related to former Roman agriculture*, in «Ecology», 88/6 (2007), pp. 1430-9.

77 See, e.g.: V. PY *et al.*, *Interdisciplinary characterisation and environmental imprints of mining and forestry in the upper Durance valley (France) during the Holocene*, in «Quaternary International», 353 (2014), pp. 74-97; A. RAAB *et al.*, *Pre-industrial charcoal production in Lower Lusatia (Brandenburg, Germany): Detection and evaluation of a large charcoal-burning field by combining archaeological studies, GIS-based analyses of shaded-relief maps and dendrochronological age determination*, in «Quaternary International», 367 (2015), pp. 111-22; S. PARADIS-GRENOUILLET, S. BURRI, R. ROUAUD (dir.), *Charbonnage, charbonniers, charbonnières. Confluence de regards autour d'un artisanat méconnu*, Aix-en-Provence 2018: <https://www.frontiersin.org/articles/10.3389/fevs.2019.00051/full>.

78 P.G. OGUNTUNDE *et al.*, *Effects of charcoal production on soil physical properties in Ghana*, in «Journal of Plant Nutrition and Soil Science», 171/4 (2008), pp. 591-6; G. MASTROLONARDO *et al.*, *Long-term effect of charcoal accumulation in bearth soils on tree growth and nutrient cycling*, in «Frontiers in Environmental Science», 7 (51) (2019).

79 B.J. DEVEREUX *et al.*, *The potential of airborne lidar for detection of archaeological features under woodland canopies*, in «Antiquity» 79 (2005), pp. 648-60; J. WU, *LiDAR application in forestry: a brief review and demonstration to BC forestry*, Undergraduate Research, University of British Columbia, Vancouver 2015.

80 B. NORDÉN *et al.*, *Effects of ecological continuity on species richness and composition in forests and woodlands: a review*, in «Ecoscience», 21/1 (2014), pp. 34-45.

81 Ivi

82 SABATINI *et al.*, *Where are Europe's last primary forests?* cit.

83 M. KLOPCIC, A. BONČINA, *Stand dynamics of silver fir (Abies alba Mill.)-European beech (Fagus sylvatica L.) forests during the past century: a decline of silver fir?*, in «Forestry», 84/3 (2011), pp. 259-71.

84 J. KNORN *et al.*, *Forest restitution and protected area effectiveness in post-socialist Romania*, in «Biological Conservation», 146 (2012), pp. 204-12; Id. *et al.*, *Continued loss of temperate old-growth forests in the Romanian Carpathians despite an increasing protected area network*, in «Environmental Conservation», 40 (2013), pp. 182-93.

85 WATKINS, *Methods and approaches* cit.; BURRI, *Towards an interdisciplinary approach* cit.; R. CEVASCO, D. MORENO, *Historical ecology in Modern Conservation in Italy*, in *Europe's changing woods and forests* cit., pp. 227-42.

86 M. SCHICKHOFER, U. SCHWARZ, *Inventory of Potential Primary and Old-Growth Forest Areas in Romania (PRIMOFARO). Identifying the largest intact forests in the temperate zone of the European Union*, Report commissioned by Euro Natur Foundation, 2019.

87 BIRIȘ, VEEN (eds), *Inventory and strategy* cit.; BIRIȘ *et al.*, *Ancient beech forests* cit.; EAD., *24000 ha of primary beech forests, the Romanian proposal in UNESCO World Heritage* cit.; BIRIȘ, *Status of Romania's Primary Forests* cit.

88 KNORN *et al.*, *Forest restitution and protected area* cit.

89 See, e.g.: TANȚĂU *et al.*, *Holocene vegetation history* cit.; FĂRCAȘ *et al.*, *Holocene vegetation history* cit.; FEURDEAN *et al.*, *Tree and timberline shifts* cit.; GRINDEAN *et al.*, *Linking vegetation dynamics* cit.

90 C.C. GIURESCU, *A history of the Romanian Forest*, in «Bibliotheca Historica Romanae», 63 (1980); I. CSUCSUJA, *Istoria pădurilor din Transilvania, 1848-1914*, Cluj-Napoca 1998; F. IORAȘ, I.V. ABRUDAN, *The Romanian forestry sector: privatisation facts*, in «International Forestry Review», 8 (2006), pp. 361-7; C. MUNTEANU *et al.*, *Legacies of 19th century land use shape contemporary forest cover*, in «Global Environmental Change», 34 (2015), pp. 83-94; C. PALAGHI-

ANU, I. DUTCĂ, *Afforestation and reforestation in Romania: History, current practice and future perspectives*, in «Reforesta», 4 (2017), pp. 54-68; M. VASILE, *Formalizing commons, registering rights: the making of the forest and pasture commons in the Romanian Carpathians from the 19th century to post-socialism*, in «International Journal of the Commons», 12/1 (2018), pp. 170-201.

⁹¹ GIURESCU, *A history of the Romanian Forest* cit.

⁹² P. SZABÓ, *Woodland and Forests in Medieval Hungary*, Oxford 2005; ID., *The extent and management of woodland in medieval Hungary*, in J. LASZLOVSKY, B. NAGY, P. SZABÓ, A. VADAS (eds), *The Economy of Medieval Hungary*, Leiden & Boston 2018, pp. 219-37.

⁹³ L. DOGARU, *Forest legislation's role in the protection of Romanian forests*, in «Law review», 8/2 (2018), pp. 66-75.

⁹⁴ M.M. HOWARD, *The Weakness of Civil Society in Post-communist Europe*, Cambridge 2003.

⁹⁵ M. NIJNIK et al., *Analysing the development of small-scale forestry in Central and Eastern Europe*, in «Small-Scale Forestry», 8/2 (2009), pp. 159-74; P. GRIFFITHS et al., *Using dense time-series of Landsat images to assess the effects of forest restitution in post-socialist Romania*, in «Remote Sensing of Environment», 118 (2012), pp. 199-214; KNORN et al., *Forest restitution* cit.

⁹⁶ IORAȘ, ABRUDAN, *The Romanian forestry sector* cit.

⁹⁷ E.B. BARBIER et al., *The forest transition: towards a more comprehensive theoretical framework*, and E.F. LAMBIN, P. MEYFROIDT, *Land use transitions: socio-ecological feedback versus socio-economic change*, in «Land Use Policy», 27/2 (2010), pp. 98-107 and pp. 108-18.

⁹⁸ T. PAPAHAĞI, *Graiul și folklorul Maramureșului*, București 1925; C. KARNOUOH, *Vivre et survivre en Roumanie communiste. Rites et discours versifiés chez les paysans du Maramureș*, Paris 1998; R. NAGY, *Stratégies de vie sur une frontière. Le cas du Maramureș: enjeux et valorisations identitaires*, in «Cultures & Conflits», 72 (2008), pp. 45-55.

⁹⁹ NAGY, *Stratégies de vie sur une frontière* cit.

¹⁰⁰ M. MESNIL, *Evolution du phénomène d'art populaire dans deux régions de Roumanie. Etude ethnographique*, Mémoire de licence en sciences sociales, Bruxelles 1968; C. KARNOUOH, *Maisons et jardins: essai sur la signification du terme «stătu» dans le dialecte roumain du Maramureș*, in «Langages & société», 6 (1978), pp. 27-41; G. KLIGMAN, *Nunta mortului. Ritual, poetică și cultură populară în Transilvania*, Iași 1998 (first edition 1988); I. IANȘ ET AL., *Atlasul României*, București 2006.

¹⁰¹ A. ILIEȘ ET AL., *The patrimony of wooden churches, built between 1531 and 2015, in the Land of Maramureș, Romania*, in «Journal of Maps», 12/1 (2016), pp. 597-602.

¹⁰² M. DĂNCUȘ, *Vernacular architecture and other values of folk culture to be found in the collections of the Maramureș Ethnographic Museum*, Cluj-Napoca 2010.

¹⁰³ A. BĂRCĂ, D. DINESCU, *The wooden architecture of Maramureș*, București 1997.

¹⁰⁴ NAGY, *Stratégies de vie sur une frontière* cit.

¹⁰⁵ M. MESNIL, *Un mythe ethnographique: le pays du Maramureș. Parcours d'un(e) ethnographe dans la Roumanie de Ceaușescu*, in S. DORONDEL, S. ȘERBAN (eds), *Between east and west. Studies in anthropology and social history*, București 2005, pp. 91-106; NAGY, *Stratégies de vie sur une frontière* cit.

¹⁰⁶ S. LAGNEAUX ET AL., *Between communism and capitalism, resourcefulness in everyday life*, in «Analele Universității București. Istorie», 57 (2008), pp. 135-47.

¹⁰⁷ M. KOVACS, A. FÜLÖP, *Baia Mare Geological and Mining Park – a potential new Geopark in the north western part of Romania*, in «Geologia», 54/1 (2009), pp. 27-32.

¹⁰⁸ N.J. COOK, M. CHIARADIA, *Sources of base metal mineralization in the Baia Borsaore field, NW Romania: constraints from lead isotopes*, in H. PAPUNEN (ed.), *Mineral Deposits*, Rotterdam 1997, pp. 813-6; M. KOVACS, A. FÜLÖP, *Baia Mare metallogenetic district*, in «Acta Mineralogica-Petrographica, Field Guide Series», 19 (2010), pp. 5-13.

- 109 R. KOVÁCS, C.G. TÁMAŞ, *Cu₃(As,Sb)₄ minerals from the Baia Mare metallogenic district, Eastern Carpathians, Romania – a case study from the Cisma ore deposit*, in «Geological Quarterly», 62/2 (2020), pp. 263-74.
- 110 L. ZSAMBOKI, *One thousand year of mining of non-ferrous ores in Hungary (896-1918), in History of mineral exploration in Hungary until 1945*, in «Annals of the history of Hungarian geology», special issue 2 (1989), pp. 9-24; M. BORCOŞ, G. UDUBAŞA, *Chronology and characterization of mining development in Romania*, in «Romanian Journal of Earth Sciences», 86/1 (2012), pp. 17-26; B. WEISZ, *Mining towns privileges in Angev in Hungary*, in «Hungarian Historical Review», 2/2 (2013), pp. 288-312; Z. BATIZI, *Mining in medieval Hungary*, in J. LASZLOVSKY, B. NAGY, P. SZABÓ, A. VADAS (eds), *The Economy of Medieval Hungary*, Leiden & Boston 2018, pp. 166-81.
- 111 I. CHIRA *et al.*, *Spatial distribution of heavy metals in the soils of Băiuţ area, Maramureş county, Romania*, in «Carpathian Journal of Earth and Environmental Sciences», 9/1 (2014), pp. 269-78.
- 112 E.g.: 2018 Băiuţ accident: www.romania-insider.com/pollution-lapus-romania [Last access. 12/11/2020].
- 113 CHIRA *et al.*, *Spatial distribution of heavy metals* cit.
- 114 M. BULEARCĂ *et al.*, *The Romanian extractive industry, from its early beginnings up to year 1948*, in «Procedia Economics and Finance», 8 (2014), pp. 106-12.
- 115 E. SHOROHOVA *et al.*, *Stump decomposition rates after clear-felling with and without prescribed burning in southern and northern boreal forests in Finland*, in «Forest Ecology and Management», 263 (2012), pp. 74-84; T. KAHL *et al.*, *Wood decay rates of 13 temperate tree species in relation to wood properties, enzyme activities and organismic diversities*, in «Forest Ecology and Management», 391 (2017), pp. 86-95.
- 116 WEISZ, *Mining towns privileges in Angevin Hungary* cit.
- 117 ZSAMBOKI, *One thousand year of mining* cit.
- 118 These analyses of peat records are still in hand and it is therefore too early to draw final conclusions on this issue.
- 119 M. SEGNANA *et al.*, *Holocene vegetation history and human impact in the eastern Italian Alps: a multi-proxy study on the Coltrondo peat bog, Comelico Superiore, Italy*, in «Vegetation History and Archaeobotany», 29 (2020), pp. 407-26.
- 120 ECKELT *et al.*, *Primeval forest relict* cit.
- 121 SAULNIER *et al.*, *A study of late Holocene local vegetation dynamics* cit.
- 122 D.A. DAVIDSON *et al.*, *Analysis of pollen in soils: processes of incorporation and distribution in five soil profiles types*, in «Soil Biology and Biochemistry», 31 (1999), pp. 643-53.
- 123 L. LARRIEU, P. GONIN, *L'indice de biodiversité potentielle (IBP): une méthode simple et rapide pour évaluer la biodiversité potentielle des peuplements forestiers*, in «Revue forestière française», 40 (2008), pp. 727-48.
- 124 V. PY-SARAGAGLIA *et al.*, *Chapter 10. Long-term Forest Evolution and Woodland Uses in an Ancient Charcoal-production forest of the French Eastern Pyrenees: an interdisciplinary approach with high spatio-temporal resolution*, in *Into the woods* cit. pp. 441-519.
- 125 B. JABIOL *et al.*, *L'humus sous toutes ses formes*, 2ème ed., Paris 2007.
- 126 J.A. KEUSKAMP *et al.*, *Tea bag index: a novel approach to collect uniform decomposition data across ecosystems*, in «Methods in Ecology and Evolution», 4 (2013), pp. 1070-5.
- 127 S. MENNICKEN *et al.*, *Effects of past and present-day landscape structure on forest soil microorganisms*, in «Frontiers in Ecology and Evolution», 8 (118) (2020): <https://www.frontiersin.org/articles/10.3389/fevo.2020.00118/full> [Last access: 12/11/2020].
- 128 W. BITTERLICH, *The Relascope Idea. Relative Measurements in Forestry*, Farnham Royal 1984.
- 129 SAULNIER *et al.*, *Climatic drivers of Picea growth* cit.

¹³⁰ http://www.rosilva.ro/comunicate_de_presa/padurar_din_cadrul_directiei_silvice_maramures_ucis_in_timp_ce_incerca_sa_prevena_o_taiere_ilegala_la_ocolul_silvic_strambu_baiut_p_543.htm [Last access: 12/11/2020].

¹³¹ S. GUILLERME et al., *Landscapes of Non-woodland Trees: landscapes which reveal the challenges of sustainable development*, in Y. LUGINBHÜL, P. HOWARD, D. TERRASSON (eds), *Landscape and sustainable development, the French perspective*, Dorchester 2015, pp. 17-26.

¹³² G. PIOVESAN et al., *Structure, dynamics and dendroecology of an old-growth Fagus forest in the Apennines*, in «Journal of Vegetation Science», 16/1 (2005), pp. 13-28; D. PANTIC et al., *Analysis of the Growth Characteristics of A 450-Year-Old Silver Fir Tree*, in «Archives of Biological Sciences», 67/1 (2015), pp. 155-60.

¹³³ A. BOURAS, *La civilisation de clairières. Enquête sur la civilisation de l'arbre en Roumanie. Ethnoécologie, technique et symbolique dans les forêts des Carpates*, Besançon 2018.

¹³⁴ BOURAS, *La civilisation de clairières* cit.

¹³⁵ M. BÜRGI, *Close-to-nature Forestry*, in *Europe's Changing Woods* cit., pp. 107-15.

¹³⁶ GRINDEAN et al., *Linking vegetation dynamics and stability* cit.