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EuMIXFOR Introduction: integrating scientific knowledge in sustainable management of Mixed Forests

The dynamics, structure and functioning of mixed forests are research topics of increasing importance. The higher resistance and resilience of mixed forests to natural and anthropogenic disturbances (Jactel *et al*., 2009)[1] combined with the higher biodiversity and carbon storage capacity which result in a higher potential for mitigation substantiate this timely research. To date, these features have been studied separately for different mixtures of species, management practices and specific growing conditions. Existing knowledge and technological breakthrough must now be integrated for a better understanding of these forests and their ability to face global changes, while securing the maintenance of multiple ecosystem services.

Despite the importance of mixed forests, much more scientific knowledge has been devoted to monocultures than to admixtures. There is a long history of management of pure stands (*i.e.* forests with one single tree species or monocultures), in contrast, mixed stands have often had their dominant species managed while the secondary ones were only inventoried, monitored or even removed if considered less economically valuable. The lack of general management rules applicable to mixed forests is not the only threat to their sustainability. The effects of rapid climate and socio-economic changes are expected to impact forest structure and functioning. In this changing context, maintaining the provision of ecosystem services from forests and reducing risks constitute the main challenges to forest managers and policy makers. In forestry, this could be achieved through the implementation of silvicultural strategies oriented to enhance diversity of and in forests. Thus, silviculture measures and management strategies specially devised for mixed-forests' emerge as a primary need.

The scientific interest on mixed forests has already produced reviews and case studies on silviculture and management of mixed-species stands (Kelty, 1992)[2], and a summary of practices in Western Europe has been presented by Olsthoorn *et al*. (1999)[3]. The linkage between biodiversity and functioning has been identified as a hot research topic on mixed forests (Scherer-Lorenzen *et al*., 2005)[4]. The promotion of mixed stands of well adapted species has been pointed as an important adaptation measure for European forests facing projected climate change (Kolström *et al.,* 2011)[5]. Recent studies have underlined the importance of species' diversity for most forest functions and services (Hector & Bagchi, 2007)[6]. Moreover, particular interest has been put in the relationship between species diversity and productivity (Morin *et al*., 2011[7], Zhang *et al*., 2012[8]), as the latter is a key variable for ecology, economy and sustainability (Scherer-Lorenzen *et al*., 2005)[9]. Many other studies describe an over-yielding of mixed versus pure stands due to continuous facili-

[1] Jactel H, Nicoll BC, Branco M, Gonzalez-Olabarria JR, Grodzki W, Långström B, Moreira F *et al.* 2009. The influences of forest stand management on biotic and abiotic risks of damage. Ann For Sci 66 (7): 701 (pp. 1-18).
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[6] Hector A, Bagchi R, 2007. Biodiversity and ecosystem multifunctionality, Nature 448:188-190.
[7] Morin X, Fahse L, Scherer-Lorenzen M, Bugmann H, 2011. Tree species richness promotes productivity in temperate forests through strong complementarity between niches, Ecology Letters, 14 (12): 1211-1219.
[8] Zhang Y, Chen HYH, Reich PB, 2012: Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis. Journal of Ecology 100(3): 742-749.
[9] Scherer-Lorenzen M, Körner Ch, Schulze ED (Eds), 2005. Forest diversity and function. Temperate and Boreal Systems. Springer, 399 pp.

tation or stress-release under episodic stress (Pretzsch *et al.,* 2010[10], Richards *et al*., 2010[11]), whereas the promotion of mixed forests can contribute to ease the negative effects of environmental change. This role has led to recent research on European mixed forests devoted, among others, to competition (Pretzsch, 2009)[12] or growth modelling (Porte & Bartelink, 2002)[13], whereas overseas the maximum density concept has been analyzed (Ducey & Knapp, 2010)[14] and the carbon sink capacity of mixed forests is currently under investigation (Woodall *et al.*, 2010)[15].

The recognition of mixed forests as a natural adaptive alternative to reduce global change risks has lead to the creation of the scientific network EuMIXFOR funded by COST Action framework for the period 2013-2017 (www.mixedforests.eu). The aim of the Action is to establish a long-lasting research network on mixed forests, which can contribute to increasing the knowledge, promoting the sustainable management, while at the same time, expanding, conserving and improving mixed forests on the basis of science, innovation and rural development within Europe and worldwide.

The objectives of the Action are established accordingly to three actors that operate on mixed forests: policy-makers, managers/owners and users, altogether linked by the scientific community. The specific objectives are: i) to provide a sound overview of the role that mixed forests can play in the provision of environmental services in the European bioregions (Boreal, Atlantic temperate, Continental temperate, Mountainous and Mediterranean) As well as a complete state of the art including a comparison with other regions worldwide; ii) to address how can mixed forests face environmental challenges affecting the needs of rural, peri-urban and urban populations, analyzing barriers to adaptive changes, threats and opportunities; iii) to identify objective-oriented silvicultural practices and decision tools (*e.g.* decision support systems) for the creation of an adequate sustainable management of heterogeneous forests in order to safeguard the present and future provision of ecosystem services while enhancing rural development; and iv) to establish different actions, such as standard protocols, common methodological approaches and experimental designs to create a research network in the public domain, to promote the knowledge transferred acquired through the field experiments conducted in mixed forests, and the dissemination of their main results, making it accessible to policy makers, managers/owners and users.

EuMIXFOR networking will promote the accomplishment of the above stated objectives by sharing experiences and research results. Parallel to these objectives, EuMIXFOR will yield (i) the compilation of past and recent research on mixed forests, (ii) experts opinions' on their experiences and perspectives regarding how mixed forests can provide ecosystem services in comparison to other forests, (iii) research information from mixed forest experiments to allow true knowledge sharing and (iv) identification of environmental and social challenges like climate change, pest outbreaks and human impact on mixed forests, (v) the perception of the economic and ecological role of mixed forests by end-users, (vi) the attitude of forest owners towards changing management practices face to economic and institutional changes that might affect the provision of goods and services.

This special section is an outcome of the first half of the Action where **Bravo-Oviedo *et al.***[16] provide a reference definition of mixed forest in order to harmonize research results and make comparable analyses and a brief review of research perspectives in mixed forests where the definition can be tested. **Dirnberger & Sterba**[17] analyze different methods for estimating spe-

[10] Pretzsch H, Block J, Dieler J, Dong P H, Kohnle U, Nagel J, Spellmann H, Zingg A, 2010. Comparison between the productivity of pure and mixed stands of Norway spruce and European beech along an ecological gradient. Ann For Science 67(7): 1-12.
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[14] Ducey MJ, Knapp R, 2010. A stand density index for complex mixed species forests in the northeastern United States. For Eco Manage 260: 1613-1622.
[15] Woodall CW, 2010. Carbon Flux of Down Woody Materials in Forests of the North Central United States. International Journal of Forestry Research 2010: 1-9.
[16] Bravo-Oviedo A, Pretzsch H, Ammer C, Andenmatten E, Barbati A, Barreiro S, Brang P, Bravo F, Coll L, Corona P *et al.,* 2014. European Mixed Forests: definition and perspectives. Forest Syst 23(3): 518-533.
[17] Dirnberger GF, Sterba H, 2014. A comparison of different methods to estimate species proportions by area in mixed stands. Forest Syst 23(3): 534-546.

cies proportion and come to the conclusion that the individual tree approach with leaf area gives the best fit with the most appropriate, regional maximum basal area equations. They also forewarn that the mixing effects on individual species can be seriously over- or under-estimated whereas the mixing effects on the total increment are only negligibly affected. On the other hand, **Sterba *et al.***[18] show how the species proportion must be described as a proportion by area considering the maximum density for the given species and point that wrong mixing effects could be introduced by inappropriate species proportion definitions. **Pretzsch & Schültze**[19] find that mixing Norway spruce and sessile oak modifies the size-structure dynamics of European beech and that mortality shifts from the smaller diameter classes further to the taller trees than when compared to pure stands. Using data from long term experiments, **Bielak *et al.***[20] show evidence of over-yielding of mixed compared with neighbouring pure stands, particularly under stress conditions, and substantiates the preference of Scots pine-Norway spruce mixtures. Another experimental design by **Mason**[21] demonstrates that facilitation between the larch and the spruce during the establishment phase is followed by competition for light once canopy closure occurred.

Finally, comparing land use cover change **Pereira *et al.***,[22] find an increasing land area occupied by mixed forests whereas the percentage of burnt area of this kind of forests is the lowest of all land cover classes.

We believe that the understanding and management of mixed forests is the current challenge in forestry. EuMIXFOR and this special section in *Forest Systems* aim at helping forest managers and researchers to face it.

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[18] Sterba H, Río M, Brunner A, Condés S, 2014. Effect of species proportion definition on the evaluation of growth in pure *vs.* mixed stands. Forest Syst 23(3): 547-559.
[19] Pretzsch H, Schültze G, 2014. Size-structure dynamics of mixed *versus* pure forest stands. Forest Syst 23(3): 560-572.
[20] Bielak K, Dudzińska, M Pretzsch H, 2014. Mixed stands of Scots pine (*Pinus sylvestris* L.) and Norway spruce [*Picea abies* (L.) Karst] can be more productive than monocultures. Evidence from over 100 years of observation of long-term experiments. Forest Syst 23(3): 573-589.
[21] Mason WL, 2014. Long-term development of nursing mixtures of Sitka spruce and larch species in an experiment in northern Scotland. Forest Syst 23(3): 590-597.
[22] Pereira MG, Aranha J, Amraoui M, 2014. Land cover fire proneness in Europe. 23(3): 598-610.