Chapter 6
Silviculture of Mixed Forests: A European Overview of Current Practices and Challenges

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Abstract Currently, about 70% of the forest land in Europe is covered by stands composed of two or more tree species. The similar situation can be found outside Europe too. While forest management of monocultures is well described,

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multispecies forests still need a better understanding to develop appropriate forest practice. Managing mixed forests can be more complex than managing monocultures because of the need to optimize the provision of multiple benefits according to the societal demands including sustaining biodiversity and ecosystem functioning.

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In this chapter we are going to present (1) the most important and well-described tree species combinations found in each participating countries taking biogeographical region in Europe into account, (2) the main management objectives of those mixtures, (3) the silvicultural approaches that are available for the particular

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mixed-species forests and (4) the main challenges experienced in mixed-species forest management. We synthesized information about management of mixed-species forests based on questionnaires received from both European countries and few countries from outside Europe participating in COST Action 'EuMIXFOR'. The survey revealed that (i) the main management objective in the analysed mixtures is valuable timber production followed by protection of soil and water and protection of forests against disturbances, (ii) the uniform shelterwood is the most widespread regeneration method followed by the clear-cutting and the irregular shelterwood system, (iii) the crown thinning followed by low thinning is the most frequent thinning method, and (iv) the main challenge of management is high game pressure and the lack of management rules covering mixture growth and taking into account both species functional traits and site conditions.

Abbreviations

Latin Names of Tree Species

Aa	*Abies alba* Mill.
Aad	*Arbutus andrachne* L.
Ac	*Abies cilicica* Ant. and Kotschy Carriére
Ach	*Austrocedrus chilensis* (D.Don) Pic.Serm. and Bizzarri
Ad	*Arceuthos drupacea* Labill.
Ag	*Alnus glutinosa* Gaertn.
An	*Abies nordmanniana* (Steven) Spach
Ap	*Acer platanoides* L.
Aps	*Acer pseudoplatanus* L.
*A*spp	*Acer* spp.
Au	*Arbutus unedo* L.
Bpe	*Betula pendula* Roth
Bpu	*Betula pubescens* Ehrh.
*B*spp	*Betula* spp.
Ca	*Cedrus atlantica* (Endl.) Manetti ex Carrière
*Ca*spp	*Carpinus* spp.
Cb	*Carpinus betulus* L.
Cl	*Cedrus libani* A. Rich.
Co	*Carpinus orientalis* Mill.
*Cr*spp	*Crataegus* spp.
Cs	*Castanea sativa* Mill.
Cse	*Cupressus sempervirens* L.
*E*spp	*Eucalyptus* spp.
Fa	*Fraxinus angustifolia* Vahl
Fe	*Fraxinus excelsior* L.
Fon	*Fraxinus ornus* L.
Fot	*Fagus orientalis* Lipsky

Fs	*Fagus sylvatica* L.
*J*spp	*Juniperus* spp.
Ld	*Larix decidua* Mill.
*L*spp	*Larix* spp.
Nan	*Nothofagus alpina* (Poepp. and Endl.) Oerst.
Nd	*Nothofagus dombeyi* (Mirb.) Oerst.
No	*Nothofagus obliqua* (Mirb.) Oerst.
Oc	*Ostrya carpinifolia* Scop.
Pa	*Picea abies* [L.] Karst
Pb	*Pinus brutia* Ten.
Pce	*Pinus cembra* L.
Pco	*Pinus contorta* Dougl. ex Loud.
Ph	*Pinus halepensis* Mill.
Pm	*Pseudotsuga menziesii* (Mirb.) Franco
*Pm*spp	*Pinus mugo* spp. Turra
Pn	*Pinus nigra* Arn.
Po	*Picea orientalis* (L.) Peterm.
Pp	*Pinus pinea* L.
Ppr	*Pinus pinaster* Aiton
*Pr*spp	*Prunus* spp.
Psi	*Picea sitchensis* (Bong.) Carrière
*P*spp	*Pinus* spp.
Psy	*Pinus sylvestris* L.
Qce	*Quercus cerris* L.
Qco	*Quercus coccifera* L.
Qfa	*Quercus faginea* subsp. *baetica* (Webb) Maire
Qfr	*Quercus frainetto* Ten.
Qi	*Quercus ilex* L.
Qp	*Quercus petraea* (Matt.) Liebl.
Qpu	*Quercus pubescens* Willd.
Qpy	*Quercus pyrenaica* Willd.
Qr	*Quercus robur* L.
Qrt	*Quercus rotundifolia* Lam.
Qs	*Quercus suber* L.
*Q*spp	*Quercus* spp.
Tc	*Tilia cordata* Mill.
*T*spp	*Tetraclinis* spp.
*T*spp	*Tilia* spp.
Um	*Ulmus minor* Mill.

Silvicultural Systems

CC	Clear-cutting system
CO	Coppice system
CS	Coppice-with-standard system
GS	Group selection system

IH Individual tree harvesting
IS Irregular shelterwood system
PCF Patch clear felling
SE Selection system
SH Shelterwood system
SS Single tree selection system

Types of Regeneration

AP Artificial regeneration by planting
AS Artificial regeneration by direct seeding
NR Natural regeneration from seeds
VR Vegetative regeneration

Release Treatments

B Brushing
C Cleaning
L Liberation
W Weeding

Thinning Methods

CRT Final crop thinning
CT Crown thinning (thinning from above)
FT Free style of thinning
IT Intermediate thinning (mixture of crown and low thinning)
LT Low thinning (thinning from below)
SVT Selective thinning (the most competitive trees in relation to crop tree are cut regardless their position in the stand)

Other Intermediate Treatments

FE Fertilization
PF Prescribed fire
PR Artificial pruning
SLC Salvage cutting
SNC Sanitation cutting

All Tables

L Limited
N No treatment
NA Not applicable
ND Not documented (lack of information)
Y Yes

6.1 Introduction

Timber production was the main objective of forest management in Europe during the last century (Bengtsson et al. 2000; Farrell et al. 2000; Gamborg and Larsen 2003; Puettmann et al. 2009). More recently, the increasing recognition of the important role of forests in providing non-timber goods and services such as soil protection, water quality improvement, wildlife habitat, biodiversity, climate change mitigation, recreational opportunities as well as many others has revitalized interest in forest management practices which favour structural diversification of the stands and the development of mixed forests (Battles et al. 2001; Decocq et al. 2004; MEA 2005a; Rametsteiner et al. 2009; Bravo-Oviedo et al. 2014; Shua et al. 2015). Research has also increased our understanding of how biodiversity influences the functioning of ecosystems and affects the provision of ecosystem goods and services (MEA 2005a, b; Hooper et al. 2005; Balvanera et al. 2006; Leuschner et al. 2009; Gamfeldt et al. 2013). Evidence suggests that certain species combinations show complementary resource use, with positive consequences for productivity (Yachi and Loreau 1999; Pretzsch and Schütze 2009; Pretzsch et al. 2015b; Riofrío et al. 2016, 2017; Pretzsch and Forrester 2017), (higher) carbon storage capacity (He et al. 2013), ecosystem health and vitality (Jactel et al. 2005, 2009; Balvanera et al. 2006), resistance and resilience (Loreau et al. 2001; Griess et al. 2012), reducing economic risks (Knoke et al. 2008; Griess and Knoke 2013) and for providing insurance against environmental fluctuations (Schütz et al. 2006; Metz et al. 2016; Jactel et al. 2017). However, when the mixture leads to even-aged, mixed-species coniferous stand, the mixture is not necessarily more productive than single-species stands of the component species of the mixture (Chen et al. 2003). In the face of climate change (IPCC 2014), fostering mixed-species forests, with species adapted to various climatic conditions, is considered as one of the most important measures to use in climate-adopted forest management of many forests in Europe (Bolte et al. 2009; Brang et al. 2014). In spite of the lack of the common forest policy in the EU (Dobšinská et al. 2015), diversity of tree species was one of the quantitative indicators of sustainable forest management in Europe adopted by 7th Ministerial Conference in Madrid (SFM 2015). Furthermore, heterogeneity of species composition belongs to ecological attributes which make forests a complex adaptive system (Puettmann et al. 2013; Bauhus et al. 2013). However, despite the important benefits described above, managing mixed forests can be more complex than managing monocultures because of the need to optimize the provision of multiple benefits according to the societal demands (Corona 2014) including sustaining biodiversity and ecosystem functioning (Dieler et al. 2017).

Currently, about 70% of the forest land in Europe is covered by stands composed of two or more tree species (FOREST EUROPE 2015), and a considerable number of former monocultures are undergoing conversion towards more diverse structures. The reasons for conversion and the methods used differ on the basis of geographical and local situations (O'Hara 2001).

A range of silvicultural systems have been proposed to develop mixed-species stands, many of which are associated with the ideas of close-to-nature forestry or systemic forestry (Schütz 1999; Jacobsen 2001; Gamborg and Larsen 2003; Brang 2005; Mlinšek 2006; Bauhus et al. 2013; Brang et al. 2014; Puettmann et al. 2015; O'Hara 2016; Nocentini et al. 2017). Therefore, the effective implementation of these silvicultural systems requires knowledge of the ecology of mixed forests and an understanding of their role in different forest ecosystems. To date, studies have concentrated on different mixtures of species, management practices and specific growing conditions. One of the most important attempts to summarize knowledge about silviculture and management of mixed-species forests in Europe was the book by Olsthoorn et al. (1999). Lately, Pretzsch et al. (2017) have raised issues related to the processes undergoing in mixed-species forests and presented the problems of their modelling, stability, silviculture options and economics. Consequently, the knowledge gained is local, and a wider perspective on sustainable management of mixed forests has yet to be developed (Bravo-Oviedo et al. 2014).

Within the framework of the EuMIXFOR COST Action (http://www.mixedforests.eu), the opportunity came to gather information on the state of the art of current silvicultural approaches used in mixed-species forests in the wide range of countries by biogeographical region (http://www.eea.europa.eu/publications/report_2002_0524_154909) in Europe (Fig. 6.1) and also in the non-European participating countries in the Action. This chapter is going to address the following questions: (1) What are the main mixed tree species combinations found in each participating country and how does this vary by biogeographical region? (2) What are the main management objectives for those mixtures? (3) What silvicultural approaches (regeneration methods, intermediate treatments) are available for the particular mixed-species forests? (4) What are the main challenges (constraints) experienced in mixed tree species forest management?

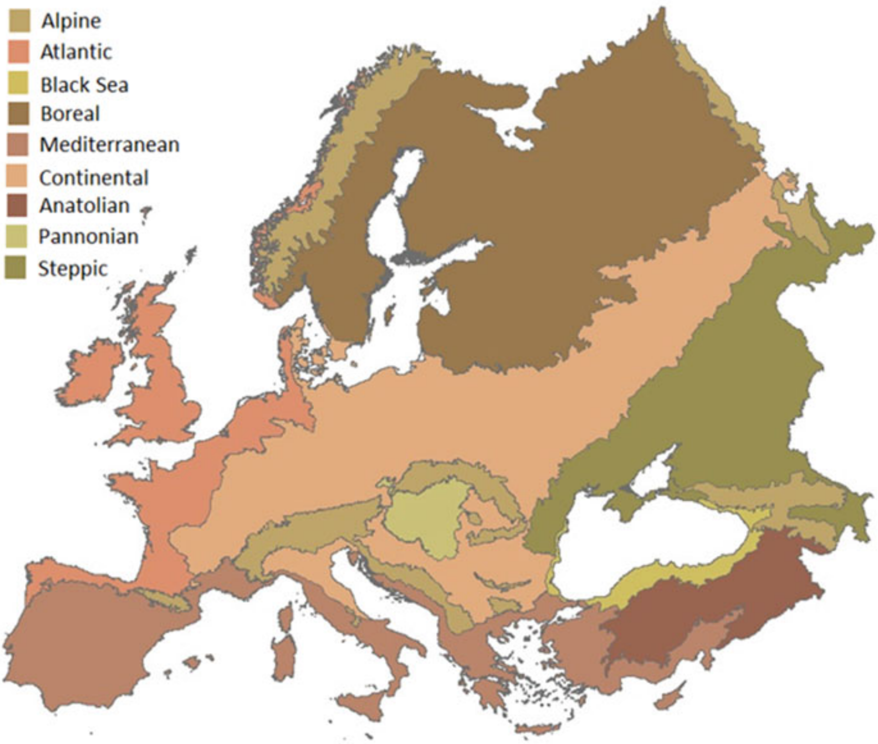

Fig. 6.1 Biogeographical regions in Europe

6.2 Material and Methods

A questionnaire was developed to characterize the silviculture of mixed forests in the participating countries. The two most important and well-described species mixtures were to be selected by biogeographical region (BR) of Europe in each country. 'Most important' means the most widely distributed tree species mixture, whereas 'well-described' refers to the knowledge of the silvicultural treatments and forest management practised in these mixed forest types. We decided to focus on only two types of mixtures because of the difficulty of collecting information about all mixture types in Europe and the impossibility to synthesize such a large range of data. For countries outside Europe, the selection of the mixtures was performed regardless of the biogeographical regions known from Europe. The questionnaire was divided into four main sections: (1) general information on mixture types, (2) management aims and silvicultural treatments, (3) challenges and (4) conversion processes.

The first section presented data on the two types of the most common mixture by biogeographical region and by country. Required information included the criteria applied to define the mixture (volume, stem number, canopy cover, biomass) and the mixed tree species forest types with the dominant species reported first followed by the dominated species. The second section compiled the description of silvicultural practices for the selected mixtures, including the management objectives in order of descending priority; the regeneration methods (vegetative or generative), natural or artificial by seeding or planting; the duration of regeneration period; the silvicultural system (terminology followed Matthews 1991); and the tending operations like weeding, brushing, liberation, precommercial (cleaning) and commercial thinning (methods – from above, from below, mechanical, selection, selective, free style, final crop thinning; intensity as a percentage of the removed growing stock and frequency). Other intermediate treatments like pruning, fertilization, salvage and sanitation cutting and potential for tree species diversification were indicated. The third section was focused on the barriers and gaps in knowledge regarding mixed forests' silviculture, and required improvements were presented. Finally, the last section collected information on conversion processes from pure stands towards mixed forests, but they will not be considered in the chapter.

The questionnaire was sent to 40 countries (30 European, 4 near neighbour and 6 international partner ones), participating in COST Action, and replies were received from 23 European and 4 non-European ones (Algeria, Argentina, Chile, Morocco). Among the national respondents were mostly scientists dealing with silviculture and working at universities or forest research institutes.

The qualitative analysis of the questionnaire was conducted by using the expert judgment of the respondent and the research team in charge of the analysis. The analysis is presented by biogeographical region to facilitate the comparison of silvicultural regimes for the same, or similar, mixtures in different countries within the same biogeographical region (BR). The regions less represented were grouped (Anatolian, Pannonian and Steppic, Sect. 6.3.7). The countries outside Europe were analysed in a separate group (see Sect. 6.3.8). The analysis covers the management objectives pursued, the description of silvicultural treatments and the management challenges according to the respondents. To facilitate the analysis, some generalizations were required. For simplicity reasons, most of the results are presented in a tabular form with the tables covering sections 1–3 of the questionnaire: (1) the type of mixture and its management objective, (2) the silvicultural prescription describing the practices and (3) the management challenges.

6.3 Results

6.3.1 Alpine Biogeographical Region

6.3.1.1 Mixture Types and Management Objectives

The Alpine BR was represented by 11 countries (Fig. 6.2). The most widespread species forming mixtures in the Alpine BR are *Abies alba*, *Fagus sylvatica* and *Picea abies*, whose shares in mixed stands differ significantly between countries (Fig. 6.3). Additionally, other species like *Larix decidua*, *Pinus cembra* and *Pinus mugo* are

Fig. 6.2 Countries in the Alpine BR participating in the survey (*AT* Austria, *BA* Bosnia and Hercegovina, *BG* Bulgaria, *HR* Croatia, *DE* Germany, *IT* Italy, *PL* Poland, *RS* Serbia, *SK* Slovakia, *ES* Spain, *UA* Ukraine)

Fig. 6.3 *Abies alba* Mill.-*Fagus sylvatica* L. mixed forest in the Alpine BR (Southwest Bulgaria) (Source: T. Zlatanov)

present in mixed mountain forests (Table 6.1). In six countries the mixture is defined according to the percentage of tree species in volume, in five countries by canopy cover and in one country by basal area. In 12 mixture types, out of the 21 listed in the Alpine BR, the main management objective is valuable timber (sawtimber) production. For nine of the mixtures, the protection of soils and water or mitigation of erosion or avalanches was indicated as the most important. As a second or third management, objectives were protection (12), timber production (9), biodiversity conservation (7) and recreation and aesthetic (5) (Table 6.1).

6.3.1.2 Silvicultural Prescriptions

The uniform or irregular shelterwood systems are the prevailing regeneration methods in mixed forests of the Alpine BR, usually followed by natural regeneration (Table 6.2). Single tree or group selection systems are the second most widespread applied regeneration method. These systems also rely upon natural regeneration. Shelterwood system was reported for five mixtures. Only in Austria is an individual tree harvesting or clear-cutting system in small areas (up to 0.5 ha) applied. The regeneration period in most countries is rather long and can range from 20 to 60 years. Again only in Austria, the regeneration period is rather short being around 5 years, if planting method is used. Rotation age ranges from 80 in Ukraine to 180 years for *Pinus cembra-Larix decidua* mixture in Italy. Consequently, the target

Table 6.1 Management objectives in the Alpine BR

Mixture type[a]	Country	Management objectives according to the relevance		
		I	II	III
Pa-Fs-Aa[4]	Austria	Valuable timber	Protection (water)	–
Ld-Pa-Pce[4]	Austria	Protection (erosion)	Timber	–
Fs-Aa[2]	Bosnia and Hercegovina	Valuable timber	Protection (soil, water)	–
Fs-Aa-Pa[2]	Bosnia and Hercegovina	Valuable timber	Protection (soil, water)	–
Fs-Aa[2]	Bulgaria	Valuable timber	Protection (water)	Partly recreation/ biodiversity conservation
Pa-Aa[2]	Bulgaria	Valuable timber	Protection (water)	Partly recreation/ biodiversity conservation
Aa-Fs[2]	Croatia	Valuable timber	Protection (soil, water)	–
Aa-Fs-Pa[2]	Croatia	Valuable timber	Protection (soil, water)	–
Pa-Aa,[1] *Fs-Aa,*[1] *Fs-Aa-Pa*[1]	Germany	Valuable timber	Protection (avalanches, rock-fall, landslides and water)	Partly recreation/ biodiversity conservation
Pce-Ld[4]	Italy	Protection (soil, water)	Timber production	Biodiversity conservation
Pa-Aa-Fs[4]	Italy	Protection	Timber production	Biodiversity conservation
Aa-Fs[4]	Poland	Protection (soil, water)	Valuable timber	Aesthetics (around spa)
Pa-Aa-Fs[4]	Poland	Protection (soil, water)	Valuable timber	–
Pa-Aa-Fs[2]	Serbia	Protection (soil, water)	Valuable timber	–
Pa-Aa[2]	Serbia	Protection (soil, water)	Valuable timber	–
Pa-Aa-Fs[2]	Slovakia	Valuable timber	Protection (soil, water)	Aesthetics (recreation)
Fs-Aa[2]	Slovakia	Valuable timber	Protection (soil, water)	–
Fs-Aa[4]	Spain	Valuable beech and fir timber	Protection against soil erosion and, natural hazards; aesthetics	Biodiversity
Pa-Aa-Fs[2]	Ukraine	Protection (soil, water)	Valuable timber	–
Fs-Aa-Pa[2]	Ukraine	Protection (soil, water)	Aesthetics	Valuable timber

[a]The mixture was defined according to the percentage of tree species in [1]basal area, [2]volume, [3]stem number and [4]canopy cover

Table 6.2 Silvicultural prescriptions in the Alpine BR

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Pa-Fs-Aa	Austria	CC, IH	NR or AP/5	100–140	Y	CT	Depending on the stage of development	Depending on the stage of develop-ment /1–3	SLC, SNC	Y
Ld-Pa-Pc	Austria	IH	NR or AP/20–50	NA	N	NA	NA	NA	SLC	L
Fs-Aa	Bosnia and Hercegovina	SS	NA	NA	NA	NA	NA	NA	SLC, SNC	ND
Fs-Aa-Pa	Bosnia and Hercegovina	SS	NA	NA	NA	NA	NA	NA	SLC, SNC	ND
Fs-Aa	Bulgaria	IS	NR/40–60	120–130/ 50	N	FT	20–25	3	NA	L
Pa-Aa	Bulgaria	IS	NR/30–50	120–130/ 50	N	LT	20–25	3	NA	N
Aa-Fs	Croatia	IS	NR/>20	100/50	Y	CT	20	Depending on the stage of development	SLC, SNC	L
Aa-Fs-Pa	Croatia	IS	NR/>20	100/50	Y	CT	20	Depending on the stage of development	SLC, SNC	L
Pa-Aa, Fs-Aa,	Germany	SS, GS	NR/30–60	Around 100/45	Y (if needed)	CT	Depending on the stage	Depending on the stage	SLC	L

(continued)

Table 6.2 (continued)

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Fs-Aa-Pa				(*Pa*,*Aa*); 120–140/ 60(*Fs*)			of development	of development		
Pce-Ld	Italy	IS, GS	NR/≥20	150–180/ 60	NA	FT (SVT)	20–25	Depending on the stand age	NA	N
Pa-Aa	Italy	IS	NR/≥20	120–150/ 60	NA	FT (SVT)	25–30	Depending on the stand age	NA	N
Aa-Fs	Poland	IS	NR/40–50	100/50	Y (W,C)	CT	20	5–7 up to age 60/3–4 than 10/4–5	SLC, SNC	L
Pa-Aa-Fs	Poland	IS	NR/40	100/50	Y (W,C)	CT and LT (*Pa*, >60 years)	20	5–7 up to age 60/3–4 than 10/4–5	SLC, SNC	L
Pa-Aa-Fs	Serbia	SE	NR/NA	NA	NA	NA	NA	NA	SLC, SNC	L
Pa-Aa	Serbia	SE	NR/NA	NA	NA	NA	NA	NA	SLC, SNC	L
Pa-Aa-Fs	Slovakia	SH	NR/30–40	90–120/ 50	Y (C)	CT	15–20	7–10/5–7 (usually 1 per 10 years)	SLC, SNC	Y
Aa-Fs	Slovakia	SH	NR/30–40	100–120/ 50	Y (C)	CT	15–20	7–10/5–7 (usually 1 per 10 years)	SLC, SNC	Y

Fs-Aa	Spain	SH/SS	NR/20–30	120–150/ 45	NA	CT	30	Depending on the stage of development	SNC	L
Pa-Aa-Fs	Ukraine	SH	NR/≥20	80–100/ 30–35	Y (W,C)	CT, IT, LT (depending on age)	15–25	5–7–10–15/ 1–3	SLC, SNC	Y
Fs-Aa-Pa	Ukraine	SH	NR/≥20	100–120/ 40	Y (W,C)	CT, IT, LT (depending on age)	15–35	4–7–10–15/ 1–3	SLC, SNC	Y

diameter at breast height (DBH) is set from 30–35 to 50–60 cm in most mixtures and countries. Release treatments are applied in 11 mixtures, and mostly they involve weeding and cleaning. In most cases thinning from above is used, and 15–25% of growing stock is removed in each intervention. The frequency and number of interventions mostly depend on the development stage of the stand. In some mixtures, the period between interventions ranges from 5 years in younger stands to 15 years in older ones. Salvage and sanitation cuttings are performed almost in all mixtures. In the case of the selection system, there is no regeneration period, rotation age, release treatments or thinning. For about half of the listed mixtures, limited potential for tree species diversification was indicated. However, for mixtures growing in relatively harsh climatic conditions (Italy, Bulgaria), the potential for tree species diversification is not considered. Only Slovakia and Ukraine identified possibilities to enrich species composition.

6.3.1.3 Challenges of Management

The most common challenge of management of mixed-species stands in the Alpine region is a high browsing pressure from ungulates and other animals which was indicated in eight mixtures, including six cases on the first place (Table 6.3). Climate change impact was identified as almost important as game pressure, but mostly as a second or further factor. Problems with European silver fir in mixed stands (decline, growing in mixture, regeneration) and the loss of selection structure were also often mentioned. In some mixtures, very important challenges are prevention against pest and disease attack, regeneration, growing and wind damages of *Picea abies* and gaps of knowledge in effective ways of regeneration. Another group of factors influencing management includes steep terrain, poor road infrastructure, difficult and dangerous access because of wartime minefields and insufficient education of forest managers.

6.3.2 Atlantic Biogeographical Region

6.3.2.1 Mixture Types and Management Objectives

Six countries belonging to the Atlantic BR responded to the survey (Fig. 6.4). The Atlantic region is very diverse in terms of most important mixed forest species composition (Table 6.4). Mixtures are mainly dominated by coniferous species (*Pinus sylvestris*, *Picea abies*, *Picea sitchensis*, *Abies alba*, *Pseudotsuga menziesii*, *Pinus contorta*, *Larix* spp.), but also broadleaved species like *Fagus sylvatica*, *Quercus robur*, *Acer pseudoplatanus*, *Fraxinus excelsior*, *Betula pendula* and *Quercus petraea* are very important (Fig. 6.5). More mixtures (six) are defined according to the species share of the basal area than by stem numbers (four types in Great Britain and Ireland).

Table 6.3 Challenges of management in the Alpine BR

Mixture type	Country	Challenges according to the relevance				
		I	II	III	IV	V
Pa-Fs-Aa	Austria	Steep terrain	High game pressure	Taming beech regeneration	–	–
Ld-Pa-Pc	Austria	Steep terrain	High game pressure	–	–	–
Fs-Aa	Bosnia and Hercegovina	Losing selection structure	The residue after the war (mines)	Poor road infrastructure	Climate change impacts	Education of forest managers
Fs-Aa-Pa	Bosnia and Hercegovina	Losing selection structure	Phytosanitary problems of spruce	Poor road infrastructure	Climate change impacts	Education of forest managers
Fs-Aa	Bulgaria	Climate change impacts	Education of forest managers	–	–	–
Pa-Aa	Bulgaria	Climate change impacts	Prevention of pest and disease attack	Education of forest managers	–	–
Aa-Fs	Croatia	*Aa* decline	Losing selection structure	The residue after the war (mines)	Poor road infrastructure	Climate change impacts
Aa-Fs-Pa	Croatia	*Aa* decline	Losing selection structure	The residue after the war (mines)	Poor road infrastructure	Climate change impacts
Fs-Aa, *Fs-Aa-Pa*, *Pa-Aa*	Germany	High ungulate pressure	Soil degradation because of past over-use	Gaps in knowledge in effective ways of regeneration	–	–
Pce-Ld	Italy	High elevation and steep slopes make management very difficult	Regeneration system considering the ecological preferences of the two species	–	–	–

(continued)

Table 6.3 (continued)

Mixture type	Country	Challenges according to the relevance				
		I	II	III	IV	V
Pa-Aa	Italy	Relatively high ungulate pressure, management system ensuring suitable natural regeneration	–	–	–	–
Aa-Fs	Poland	High game pressure	Difficulties to obtain natural regeneration of *Aa* beneath the canopy of *Aa*	Spring ground frost (beech)	–	–
Pa-Aa-Fs	Poland	High game pressure	Difficulties to obtain natural regeneration of *Aa* beneath the canopy of *Aa*	Spring ground frost (*Fs*)	Wind damages among spruce	–
Pa-Aa-Fs	Serbia	Prevention of pest and disease attack	Gaps in knowledge in effective ways of regeneration	Climate change impacts	–	–
Pa-Aa	Serbia	Prevention of pest and disease attack	Losing selection structure	Climate change impacts	–	–
Pa-Aa-Fs	Slovakia	High ungulate pressure (esp. conifers)	Dieback of *Pa*	–	–	–
Fs-Aa	Slovakia	High ungulate pressure (esp. conifers)	–	–	–	–
Fs-Aa	Spain	Phytosanitary problems of fir	More knowledge about fir decay and possible interactions with other species is needed	Climate change impact	–	–
Pa-Aa-Fs	Ukraine	Preservation of natural regeneration during harvesting	Lack of care for plants at a young age	Reduction of soil fertility because of water erosion	Education of forest managers	–
Fs-Aa-Pa	Ukraine	Lack of natural regeneration of *Pa* under the canopy of mature plants	Loss of natural beech regeneration due to the intensive development of grass and damage by frost	Development of model of mixed stands	Planting spruce after felling and tending treatment	Education of forest managers

Fig. 6.4 Countries in the Atlantic BR participating in the survey (*BE* Belgium, *DK* Denmark, *DE* Germany, *GB* Great Britain, *IE* Ireland, *ES* Spain)

The most important management objective, in the first place according to relevance, in almost all listed mixtures is valuable timber (sawtimber) production, except for *Quercus robur*/*Quercus petrae*-*Betula pendula*/*Betula pubescens* mixture in Great Britain, where restoration of native woodlands is the predominant aim followed by biodiversity, production of valuable timber and firewood and landscape. Other aims like biodiversity, water protection, wildlife (game) habitat, recreation, property value, protection against soil erosion, natural hazards and aesthetics, multifunctionality and nursing of oak by pine and of beech by conifers are listed as lesser important ones.

6.3.2.2 Silvicultural Prescriptions

Various regeneration methods used in Atlantic BR are a reflection of the variability of species combinations in the region (Table 6.5). The methods range from clear-cutting in Denmark and Ireland, through patch clear felling and uniform and irregular shelterwood system, up to single tree and group selection system in Germany, Belgium and Denmark as well if possible. Both natural regeneration and planting occur with regeneration periods of up to 20 years or even longer to 30–40 in

Table 6.4 Management objectives in the Atlantic BR

Mixture type[a]	Country	Silvicultural objective according to the relevance				
		I	II	III	IV	V
Fs-Qr[1]	Belgium	Valuable beech and oak timber	Multifunctionality	–	–	–
Qr-Aps-Fe[1]		Valuable beech, maple, ash and oak timber				
Psy-Qr-Bpe[1]	Belgium	Valuable pine, oak and birch timber	–	–	–	–
Psi-Aa[1]	Denmark	Profitable timber production	Wildlife (game) habitat	Recreational purposes	Protection of soil	–
Pa-Pm[1]	Denmark	Profitable timber production	Wildlife (game) habitat	Property value	Recreational purposes	Protection of soil
Fs-Pa[1]	Germany	Valuable timber and fuelwood	Biodiversity	Partly drinking water protection	Recreation	–
Psi-Psy (Pco/Lspp)[3]	Great Britain	Production of sawtimber along with pulp and chipwood	–	–	–	–
Qr(Qp)-Bpe(Bpu)[3]	Great Britain	Restoration of native woodlands	Biodiversity	Production of valuable timber (lowland Britain)	Timber production and firewood (in upland Britain)	Landscape (in lowland Britain)
Qr-Psy(Ld)[3]	Ireland	Valuable oak and pine timber	Nursing of the oak by the pine	–	–	–
Fs-Psy(Ld)[3]	Ireland	Valuable beech timber and intermediate conifer timber	Nursing of beech by the conifer	–	–	–
Psy-Fs[1]	Spain	Valuable beech and pine timber	Protection against soil erosion and natural hazards; aesthetics	Biodiversity	–	–

[a]The mixture was defined according to the percentage of tree species in [1]basal area, [2]volume, [3]stem number and [4]canopy cover

Fig. 6.5 *Fagus sylvatica* L.-*Quercus robur* L. mixed forest in the Atlantic BR (Southern Germany) (Source: Ch. Ammer)

Germany. Rotation age and target DBH depend mostly on tree species and site conditions. In all mixtures, release treatments are applied through weeding or cleaning in a few cases. Thinning from above and final crop tree thinning are dominant methods of treatments. In some mixtures thinning from below or selective thinning is performed. The intensity of thinning is at the most removal of 30% of growing stock with frequency ranging from 3 to 15 years depending on the stage of stand development. In Belgium, Denmark and Ireland (broadleaf), artificial pruning is applied to increase timber quality. In other countries, salvage and sanitation cuttings are used to improve stand condition. The potential for tree species diversification is indicated for most of the mixtures.

6.3.2.3 Challenges of Management

The lack of management rules for mixtures was considered the most significant challenge, reported as the primary challenge for five types (Table 6.6). The second most important challenge is high game pressure. Less common challenges are improved growth and yield models for mixed stands and low interest of owners in forest management. Other issues vary according to mixture species composition and are mostly indicated only once.

Table 6.5 Silvicultural prescriptions in the Atlantic BR

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Fs-Qr *Qr-Ap-Fe*	Belgium	GS	AP, NR/10	100–120(*Fs*)/60 120(*Qr*)/60 100(*Ap*)/50 100(*Fe*)/50	Y	CRT	ND	5–10/5–10	PR	ND
Psy-Qr-Bpe	Belgium	SH	NR (AP)/5	60(*Bpe*)/50 100(*Psy*)/50 120(*Qr*)/60	Y	CRT	ND	5–10/5–10	PR	ND
Psi-Aa	Denmark	CC, SH, IS or GS	NR, AP/1–20	35–50(*Psi*), 60–100(*Aa*)/ 35–40(*Psi*), 50–60(*Aa*)	Y	CT later SVT or NO (*Psi*) and SVT (*Aa*)	10–15	3–10/5–8	SLC, SNC	Y
Pa-Pm	Denmark	CC, SH, IS or GS	NR, AP/1–20	40–80 (*Pa*) 60–100 (*Pm*)/ 35–40(*Pa*), 50–90(*Pm*)	Y	CT later SVT	15	3–10/5–8	PR, SLV SNC	Y
Fs-Pa	Germany	SS, GS	NR/30–40	80/45(*Pa*); 120/60(*Fs*)	Y (if needed)	CT	Depending on the stage of development	Depending on the stage of development// 1 per 10 years	SLC	Y

Psi-Psy (Pc/Lspp)	Great Britain	PCF	AP/–	40–60/30–50	Y (W,C)	LT	20	5/2	NA	L
Qr(Qp)-Bpe(Bpu)	Great Britain	PCF, CS, IS, GS	NR (AP)/ 5–10	100–150/60–80	Y (W,C)	CT (IT)	15–20	10–15/4–7	NA	Y
Qr-Psy (Ld)	Ireland	CC	AP (NR)/–	[a]	Y (W)	CRT	50–100(*Psy*) 0–30(*Qr*)	Depending on the stage of development	PR	ND
Fs-Psy (Ld)	Ireland	CC	AP (NR)/–	[a]	Y (W)	CRT	50–100(*Psy*) 0–30(*Fs*)	Depending on the stage of development	PR	ND
Psy-Fs	Spain	SH	NR/≥20	120–130	Y (if needed)	LT/CT in some areas	20–30	Depending on the stage of development	SLC, SNC	L

[a]Plantations are too young to determine

Table 6.6 Challenges of management in the Atlantic BR

Mixture type	Country	Challenges according to the relevance			
		I	II	III	IV
Fs-Qr / *Qr-Ap-Fe*	Belgium	Lack of management rules for mixtures	Low timber quality of the broadleaved species	–	–
Psy-Qr-Bpe	Belgium	Lack of management rules for mixtures	–	–	–
Psi-Aa	Denmark	High game pressure (*Aa*)	Windfall and bark beetle (*Psi*)	–	–
Pa-Pm	Denmark	Frost damage (*Pm*)	Inter-tree competition	High game pressure (*Pm*)	–
Fs-Pa	Germany	Unknown behaviour of tree species response to climate change	High browsing pressure	Regionally high N-inputs from agriculture	–
Psi-Psy (Pc/Lspp)	Great Britain	Duration of nurse tree keeping in mixtures	Improved growth and yield models for mixed stands	Long-term impacts of 'nursing' mixtures on timber properties of spruce	Integrating the mixture effect into decision support tools that are used to guide species choice under a climate change scenario
Qr(Qp)-Bpe(Bpu)	Great Britain (both types)	Devising cost-effective methods for the control of animal browsing	Achieving adequate natural regeneration of the species to be used in mixture	Appropriate thinning regimes for use in mixtures	Improved growth and yield models for mixed stands
Qr-Psy (Ld)	Ireland	Knowledge how to grow mixtures	Low interest of owners in forest management	–	–
Fs-Psy (Ld)	Ireland	Knowledge how to grow mixtures	Low interest of owners in forest management	–	–
Psy-Fs	Spain	Knowledge how to grow mixtures	–	–	–

6.3.3 *Black Sea Biogeographical Region*

6.3.3.1 Mixture Types and Management Objectives

The Black Sea BR is represented only by two countries (Fig. 6.6) with four types of mixed-species stands (Table 6.7). Oaks (*Quercus frainetto*, *Quercus cerris*, *Quercus petraea*) are the main tree species in Bulgaria, while in Turkey species composition is more varied (Fig. 6.7). In mixed stands consisting of oaks (Bulgaria), species proportion is based on their share in volume, whereas in mixed stands in Turkey, this is based on canopy cover. The most significant management objective is valuable timber production followed by firewood production and protection (soil).

Fig. 6.6 Countries in the Black Sea BR participating in the survey (*BG* Bulgaria, *TR* Turkey)

Table 6.7 Management objectives in the Black Sea BR

Mixture type[a]	Country	Silvicultural objective according to the relevance	
		I	II
Qfr-Qce[2]	Bulgaria	Firewood	Protection (soil)
Qp-Qrf[2]	Bulgaria	Valuable timber production	Protection (soil)
Fot-Cs(Tspp/Caspp/Aspp)[4], *Fot-An*[4]	Turkey	Valuable timber production	–

[a]The mixture was defined according to the percentage of tree species in [1]basal area, [2]volume, [3]stem number and [4]canopy cover

Fig. 6.7 *Carpinus betulus* L.-*Tilia rubra* and *T. tomentosa* Moench-*Acer campestre* L.-*Acer platonoides* L.-*Cestanea sativa* Mill. mixed forest in Black Sea BR (Duzce, the north-western region of Turkey) (Source: O. Yildiz)

6.3.3.2 Silvicultural Prescriptions

The irregular shelterwood system prevails in the oak forests in Bulgaria (Table 6.8). The mixed stands of Turkey are managed by clear-cutting or single tree selection system followed by natural generative or vegetative regeneration with up to 30 years of regeneration period (Bulgaria). Rotation age ranges between 80 and 100 years. Only in Turkey release treatments in the form of cleaning or liberation are performed. Intermediate, low or free style of thinning is applied with 20–25% of intensity. In Turkey salvage and sanitation cuttings are performed. The mixtures are considered to have the potential for tree species diversification.

Table 6.8 Silvicultural prescriptions in the Black Sea BR

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Qf-Qc	Bulgaria	IS	NR, VR/30	80/ND	N	LT or FT	20–25	2	NA	Y
Qp-Qfr	Bulgaria	IS	NR, VR/30	80/ND	N	LT or FT	20–25	2–3	NA	Y
Fot-Csa (Tspp/ Cspp/ Aspp)	Turkey	CC with seed trees	NR/NA	80/ND	Y (C)	IT	20–25	2	SLC, SNC if needed	Y
Fot-An	Turkey	SS	NR/NA	100(*Fot*, *An*)/55 (*Fot*), 50 (*An*)	Y (C,L)	IT (*Fot*)/ SVT (*An*)	20–25	2	SLC, SNC if needed	Y

Table 6.9 Challenges of management in the Black Sea BR

Mixture type	Country	Challenges according to the relevance	
		I	II
Qf-Qc	Bulgaria	Decreased vitality at some places due to many rotations of coppice management	Lack of successful transformation to seed-originated stands due to insufficient care of newly regenerated seedlings
Qp-Qfr	Bulgaria	Decreased vitality at some places due to many rotations of coppice management	Lack of successful transformation to seed-originated stands due to insufficient care of newly regenerated seedlings
Fot-Csa (Tspp/ Cspp/ Aspp)	Turkey	Management focuses on other objectives (e.g. diversity)	Lack of information on the growing different mixtures
Fot-An	Turkey	Management focuses on other objectives (e.g. diversity)	Lack of information on the growing different mixtures

6.3.3.3 Challenges of Management

Since mixed oak stands in Bulgaria are very often derived from vegetative reproduction, decreasing vitality of some stands is observed due to many rotations of coppice management (Table 6.9). In Turkey, the management of the mixtures should be focused not only on valuable timber production but also on maintaining and enhancing tree species diversity. Other challenges are the lack of successful transformation to seed-originated stands due to the insufficient care of newly regenerated seedlings (Bulgaria) and lack of information on the growing of different mixtures (Turkey).

6.3.4 Boreal Biogeographical Region

6.3.4.1 Mixture Types and Management Objectives

Four countries from the Boreal BR responded to the survey (Fig. 6.8). In Northern Europe where the Boreal BR dominates, the main tree species are *Pinus sylvestris*, *Picea abies* and *Betula pendula* (Fig. 6.9) which are growing either in pure stands or in various mixture combinations (Table 6.10). The share of each species in stand composition is mainly based on a percentage of volume or basal area (only Estonia). The predominant management aim is the production of valuable *Pinus sylvestris*, *Picea abies* and also *Betula pendula* timber. Additional important aims in mixtures of Estonia are sustainable bioeconomy and sustainable forest ecosystems, biodiversity and resilience with habitat and species protection. In Sweden, the management is focused also on volume (more on quantity, less on quality of timber) production, nature (habitat and species) protection and recreation. The last mentioned objective is also of importance in Lithuania.

Fig. 6.8 Countries in the Boreal BR participating in the survey (*EE* Estonia, *LV* Latvia, *LT* Lithuania, *SE* Sweden)

Fig. 6.9 *Pinus sylvestris* L.-*Picea abies* (L.) Karst mixture forest in the Boreal BR (Latvia) (Source: Z. Libiete-Zalite)

Table 6.10 Management objectives in the Boreal BR

Mixture type[a]	Country	Silvicultural objective according to the relevance	
		I	II
Psy-Bpe[1]	Estonia	Sustainable bioeconomy – valuable pine and birch timber	Sustainable forest ecosystems biodiversity and resilience – habitat and species protection
Pa-Bpe[1]	Estonia	Sustainable bioeconomy – valuable spruce and birch timber	Sustainable forest ecosystems biodiversity and resilience – habitat and species protection
Pa-Bspp[2]	Latvia	High-quality pine and spruce sawlogs, veneer logs	–
Psy-Pa[2]	Latvia	High-quality pine and spruce sawlogs	–
Psy-Pa[2]	Lithuania	Valuable timber production	Recreation
Pa-Bpe[2]	Lithuania	Valuable timber production	–
Pa-Psy[2]	Sweden	Volume production (spruce), valuable timber production (pine)	Recreation
Pa-Bpe[2]	Sweden	Volume production	Nature protection – habitat and species protection

[a]The mixture was defined according to the percentage of tree species in [1]basal area, [2]volume, [3]stem number and [4]canopy cover

6.3.4.2 Silvicultural Prescriptions

The main regeneration method adopted in the region is the clear-cutting system followed by artificial regeneration (Table 6.11). Usually, the main species (*Pinus sylvestris*, *Picea abies*) are planted, but sometimes seeding is also used if possible after the cutting, while *Betula pendula* is naturally regenerated. In the case of natural regeneration, the regeneration period is very short (1–10 years). The rotation age ranges from 70 to 120 years (*Pinus sylvestris*, *Picea abies*) and 40–70 (*Betula pendula*) with target DBHs varying between 27 and 40 cm (*Pinus sylvestris*, *Picea abies*) and 16–31 cm (*Betula pendula*). In Swedish mixtures, the target DBH of *Pinus sylvestris* and *Picea abies* is larger (30–40 cm) than in other countries in the region and depends on site conditions. In all mixtures, release treatments in the form of cleaning or weeding are applied. The most widespread thinning methods in the listed mixed stands are from below and from above followed by intermediate and free style of thinning. The intensity of thinning in four mixtures (Latvia, Sweden) is variable and in the other four does not exceed 20 (Estonia) or 25% (Lithuania). The frequency of thinning in Latvia depends on stand basal area, whereas in other countries, it ranges between 5 and 20 years. Salvage or sanitation cuttings are the main other treatments applied in almost all mixtures. Pruning is usual in Estonia and Latvia with the aim of obtaining valuable timber production. In Sweden fertilization is used as another effective treatment.

6.3.4.3 Challenges of Management

Among the most important challenges identified (Table 6.12) are high game pressure (Sweden) and limited management pathways for one stand in one rotation (Estonia). Next significant issues of mixed forest management listed first are too high rotation

Table 6.11 Silvicultural prescriptions in the Boreal BR

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Psy-Bpe	Estonia	CC	AS, AP, NR/ 5–10	90–120(*Psy*), 60–70(*Bpe*)/ 28(*Psy*), 16–26(*Bpe*)	Y (C)	CT, LT, FT	20	10–20/1–3	PR, SLC, SNC	Y
Pa-Bpe	Estonia	CC	AS, AP, NR/ 5–10	90–120(*Pa*), 60–70(*Bpe*)/ 28(*Pa*), 16–26(*Bpe*)	Y (C)	CT, LT, FT	20	10–15/1–2	PR, SLC, SNC	L
Psy-Pa	Latvia	CC	AP(*Psy*,*Pa*), NR(*Pa*)/5	101(*Psy*), 81 (*Pa*)/27–39 (*Psy*), 27–31 (*Pa*)	Y (W)	LT	Various	Depending on stand basal area	PR, SNC	L
Pa-Bspp	Latvia	CC	AP(*Pa*), NR (*Pa*), NR (*Bspp*)/5	81(*Pa*), 71 (*Bspp*)/27–31 (*Pa*), 22–31 (*Bspp*)	Y (W)	LT	Various	Depending on stand basal area	PR, SNC	L
Psy-Pa	Lithuania	CC	AP/3	101(*Psy*), 71 (*Pa*)/NA	Y (C)	CT, IT	10–25	5–15/3–4	SNC	Y
Pa-Bpe	Lithuania	CC	AP(*Pa*), NR (*Bpe*)/3	71(*Pa*), 61 (*Bpe*)/NA	Y (C)	CT, IT	10–25	5–10/4–5	SNC	Y
Pa-Psy	Sweden	CC	AP, NR/1–5	70–120/ (30–40 if any)	Y	LT (CT)	Various	15/1–5	SLC, FE	L
Pa-Bpe	Sweden	CC	AP, NR/1–10	70–120(*Pa*), 40(*Bpe*)/30 (*Pa*)	Y	LT (CT)	Various	10/1–3	SLC	L

Table 6.12 Challenges of management in the Boreal BR

Mixture type	Country	Challenges according to the relevance I	II	III
Psy-Bpe	Estonia	Limited management pathways for one stand in one rotation	Lack of information on growing different mixtures	Lack of management models for mixtures
Pa-Bpe	Estonia	Limited management pathways for one stand in one rotation due to high rotation age for spruce	Lack of information on growing different mixtures	Lack of management models for mixtures
Psy-Pa	Latvia	Too high rotation age for spruce	Root rot (*Pa*)	–
Pa-Bpe	Latvia	Conflicting composition	Root rot (*Pa*)	Incorrect estimation of standing spruce volume (second storey) affecting decision making
Psy-Pa	Lithuania	Problems to get natural regeneration of *Psy*	Game pressure on *Psy*	*Ips typographus* damage
Psy-Bpe	Lithuania	*Pa* must be planted in clear-cuts and later promoted by thinnings	*Bpe* often compete with less valuable *Populus tremula* and *Alnus incana*	*Ips typographus* damage
Pa-Psy	Sweden	High game pressure	Gaps in knowledge of interactions between browsers and plants	Education of forest managers
Pa-Bpe	Sweden	High game pressure	Gaps in knowledge of interactions between browsers and plants	Education of forest managers

age for spruce and conflicting composition (Latvia), problems to get natural regeneration of *Pinus sylvestris* and promotion of artificial regeneration of *Picea abies* (Lithuania). Other challenges of lesser priority (pointed out in two mixtures) are gaps in knowledge of interactions between browsers and plants, lack of management models for mixtures, *Ips typographus* damages and education of forest managers.

6.3.5 Continental Biogeographical Region (BR)

6.3.5.1 Mixture Types and Management Objectives

The number of countries belonging to the Continental BR that replied to the survey was as big as in the case of the Alpine BR (Fig. 6.10). Mixed forests in the Continental BR are mainly dominated by broadleaved (*Quercus*, *Fagus*, *Fraxinus*,

Fig. 6.10 Countries in the Continental BR participating in the survey (*AT* Austria, *BE* Belgium, *BG* Bulgaria, *CZ* Czech Republic, *DK* Denmark, *HR* Croatia, *DE* Germany, *IT* Italy, *PL* Poland, *RS* Serbia, *UA* Ukraine)

Carpinus, *Tilia*, *Acer*) and coniferous tree species (*Pinus sylvestris*, *Picea abies*) (Table 6.13, Fig. 6.11). The species share in the mixtures is based on the percentage of volume (nine mixtures), canopy cover (seven) and basal area (six).

The silvicultural objectives are very diverse. Valuable timber production, which is indicated in 14 mixtures as the main objective, is common in this region followed by the protection of soil, water and biodiversity (which is the main goal in five types). Firewood production is reported by Bulgaria and Serbia. Recreation, landscape and other social functions are important management aims in the Czech Republic, Denmark and Italy. One of the significant management aims of two mixtures in Denmark is the creation of wildlife (game) habitat. Other goals like multifunctionality, hunting, fuelwood production, property value, protection of groundwater, non-wood forest products and conversion to high forest were mentioned by respondents only once.

Table 6.13 Management objectives in the Continental BR

Mixture type[a]	Country	Silvicultural objective according to the relevance				
		I	II	III	IV	V
Pa-Fs[4]	Austria	Valuable timber	Protection (water)	–	–	–
Psy-Pa[4]	Austria	Valuable timber	–	–	–	–
Fs-Qp(Qr)[1]	Belgium	Valuable beech and oak timber	Multifunctionality	–	–	–
Fs-Aps-Fe-Qr[1]		Valuable beech, maple, ash and oak				
Pm-Pa[1]	Belgium	Valuable timber	–	–	–	–
Qp-Qce[2]	Bulgaria	Firewood	Protection (soil)	–	–	–
Qr-Cb[2]	Croatia	Valuable oak timber	–	–	–	–
Qp-Cb[2]	Croatia	Valuable oak timber	–	–	–	–
Psy-Qp-Cb-Tc[2]	The Czech Republic	Valuable timber production	Aesthetics in special purpose forests (recreation, social functions)	Biodiversity	Protection (soil, water)	–
Pa-Fs[2]	The Czech Republic	Valuable timber production	Protection (soil, water)	Recreation and other social functions	Biodiversity	–
Fs-Aps(Fe)[1]	Denmark	Wildlife (game) habitat	Profitable timber production	Recreational purposes and landscape aesthetics	Protection of groundwater	Biodiversity
Fe-Ag[1]	Denmark	Protection of biodiversity	Wildlife (game) habitat	Property value	Recreational purposes and landscape aesthetics	Profitable timber production

Psy-Qr[1]	Germany	Valuable timber	Biodiversity	Partly drinking water protection	Recreation	–
Qr-Cb-Fspp-Um-Aspp[4]	Italy	Biodiversity conservation	Recreation	Timber production	Non-wood forest products	–
Oc-Fon-Qpu[4]	Italy	Protection	Fuelwood production	Biodiversity conservation		
Psy-Qr(Qp)[4]	Poland	Valuable timber production (*Ps*)	Protection (soil, water)	–	–	–
Fs-Qr(Qp)[4]	Poland	Valuable timber production	Protection (soil, water)	–	–	–
Qr-Fa[2]	Serbia	Protection (soil, water)	Valuable timber production	–	–	–
Qce-Qfr[2]	Serbia	Protection (soil, water)	Valuable timber production	Firewood	Conversion to high forests	–
Psy-Qr[2]	Ukraine	Valuable oak and pine timber	–	–	–	–
Qr-Cb[2]	Ukraine	Valuable oak timber	–	–	–	–

[a]The mixture was defined according to the percentage of tree species in [1]basal area, [2]volume, [3]stem number and [4]canopy cover

Fig. 6.11 *Pinus sylvestris* L.-*Quercus petraea* (Matt.) Liebl. mixture forest in the Continental BR (Germany) (Source: L. Steinacker)

6.3.5.2 Silvicultural Prescriptions

A range of regeneration methods is used in the Continental BR (Table 6.14). The most common is the uniform shelterwood system which is used in 13 mixtures followed by clear-cutting (seven mixtures), irregular shelterwood (five mixtures), group selection (four mixtures), single tree selection (one mixture) and coppice-with-standard (one mixture) method. Natural regeneration is the primary method employed in mixtures, but artificial planting, seeding and vegetative reproduction are also applied. The regeneration period ranges from 1 year up to 40 years in the shelterwood method. The rotation age is variable and depends on species and site conditions. The shortest one (25–30 years) refers to *Ostrya carpinifolia-Fraxinus ornus-Quercus pubescens* mixture in Italy regenerated by vegetative reproduction. The second shortest rotation age (60–70 years) is applied to *Pseudotsuga menziesii-Picea abies* mixture in Belgium. The longest one (160–240 years) refers to *Pinus sylvestri-Quercus robur* mixture in Germany. The target diameter depends on tree species and site conditions and ranges from 35–40 cm in *Pinus sylvestris-Quercus robur* mixture (Ukraine) to 80 cm mostly for oak in few mixed types. Release treatments in the form of weeding, cleaning, brushing and liberation are performed in almost all mixtures. Only mixed types in Italy, Bulgaria and one in Belgium are not the subjects of this intervention. The most widespread thinning method is crown thinning (from above) followed by other methods like free, selective, low (from below) and intermediate thinning. The intensity of thinning depends on the stage of stand development in many mixtures. It can reach even 40% of growing stock during

Table 6.14 Silvicultural prescriptions in the Continental BR

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Pa-Fs	Austria	SH or GS	NR or AP/5	90/50	Y (L,W)	FT, SVT	Depending on the stage of development	Depending on the stage of develop-ment/4	SLC, SNC	Y
Psy-Pa	Austria	CC or SH	NR or AP/5	90/50	Y (L,W)	FT, SVT	Depending on the stage of development	Depending on the stage of develop-ment/4	SLC, SNC	Y
Fs-Qp (Qr)	Belgium	SS, GS	NR/NA	150/80	N	SNT	Around increment	12(3,6,9)/NA	PR, FE	Y
Fs-Aps-Fe-Qr										L
Pm-Pa	Belgium	CC	AP/NA	60–70/50	Y (C)	CT	40 (first thinning) down to 20–25(last entry)	3–6/10	PR	L
Qf-Qc	Bulgaria	IS	NR, VR/30	80/-	N	LT or FT	20–25	2	NA	Y
Qr-Cb	Croatia	SH	NR (AP, AS)/10–20	120/ 70–80	Y (W,B, C)	CT	20–30	1 per 10 year	SLC, SNC	Y
Qp-Cb	Croatia	SH	NR (AP, AS)/10–20	120/ 50–60	Y (W,B, C)	CT	20	1 per 10 year	SLC, SNC	Y
Ps-Qp-Cb-Tc	The Czech Republic	SH	NR, AP/ 20–30	100–130/ 40–50	Y (W,B, C)	CT	≤20	3–7/ND	SLC, SNC	ND

(continued)

Table 6.14 (continued)

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Pa-Fs	The Czech Republic	SH	NR, AP/ 30–40	120/ 40–50	Y (W,B, C)	LT (*Pa*), CT	≤15	5–10/ND	SLC, SNC	ND
Fs-Aps (Fe)	Denmark	CC, SH, IS or GS	NR or AP/1–30	80(*Aps*)-120(*Fs*)/ ≥57 (*Fs*), > 47 (*Aps*)	L	CT	10–15	3–15/8–18	ND	Y
Fe-Ag	Denmark	CC, SH, IS or GS,	NR, VR or AP/0–15	ND	L	CT	15–20	3–15/3–20	SLC, SNC	Y
Psy-Qr	Germany	SH	NR/20–30	120/60 (*Psy*); 160–240/ 70(*Qr*)	Y (if needed)	CT	Depending on the stage of development	Depending on the stage of develop-ment/1 per 10 years	PR(*Psy*)	Y
Qr-Cb-Fspp-Um-Aspp	Italy	IS	NR/10–30	120/60	NA	CT	20–30	Depending on the stage of develop-ment/1 per 15 years	PR	Y
Oc-Fon-Qpu	Italy	CS	VR (NR)/ 10–30	25–30/ ND	NA	NA	NA	NA	NA	Y

Psy-Qr (Qp)	Poland	CC, SH	AP, NR(*Qr/Qp*)/11–20	90–110 (*Psy*), 140–160 (*Qr/Qp*)/ 50–60 (*Psy*), 60–80 (*Qr/Qp*)	Y (W,C)	CT, LT for *Psy*>=60 years	20	5–7 up to age 40 years/3–4 then 8-10/4-8 (*Qr/Qp*)	SLC, SNC	Y
Fs-Qr (Qp)	Poland	SH	NR/10–30	100–120 (*Fs*), 140–160 (*Qr/Qp*)/ 60(*Fs*), 60–80 (*Qr/Qp*)	Y (W,C)	CT	20–25	5–7 up to age 40 years/3–4 then 8-10/4-8 (*Qr/Qp*)	SLC, SNC	L
Qr-Fa	Serbia	SH	NR/20	120–140/ 60–80	Y (W,C,B, L)	CT	15–20	1 per 10 years	PR, SNC	L
Qc-Qf	Serbia	SH	NR /10–20	80–100/-	Y (W,C,B, L)	CT	15–20	1 per 10 years	PR, SNC	Y
Psy-Qr	Ukraine	CC (IS)	NR, AP/10	80–90/ 35–40	Y (W,B, C)	CT, IT, LT (depending on age)	15–20	5–7–10–15–25/1–2	SLC, SNC, PR, FE	Y
Qr-Cb	Ukraine	CC	AP, AS/10	100–110/ 40–45	Y (W,B, C)	CT, LT (depending on age)	10–15–25–45	5–7–10–20/ 1–2	SNC, FE	Y

the first entry in the mixture *Pseudotsuga menziesii-Picea abies* (Belgium). However, in most mixed types, the intensity is not higher than 25–30% of growing stock. The frequency of thinning also depends on the stage of stand development and amounts from 3 to 7 years in younger stands up to 15 or even 25 (Ukraine) years in older mixtures. Other intermediate treatments like salvage and sanitation cuttings are performed in almost all mixtures. In Belgium, Germany, Italy, Serbia and Ukraine, artificial pruning is applied in order to achieve better timber quality. Fertilization is indicated in the case of three mixtures, one in Belgium and two in Ukraine. The potential for tree species diversification is considered to exist or to be limited in almost all mixtures.

6.3.5.3 Challenges of Management

The challenges indicated by respondents in questionnaires are very variable, and there is no single one that dominates (Table 6.15). The most common challenges listed in the first ranked column are (1) obtaining and maintaining natural regeneration, especially of *Quercus robur*, which is threatened by other expansive tree species (*Carpinus*, *Fagus*), (2) steep terrain making forest operations difficult, (3) lack of management rules and models for mixtures and (4) high game pressure. The remaining challenges listed in Table 6.15 occur once or twice at the most, and they are so different that it is difficult to aggregate them.

6.3.6 Mediterranean Biogeographical Region

6.3.6.1 Mixture Types and Management Objectives

Seven countries (Fig. 6.12) laying in the Mediterranean BR provided information in the questionnaire. Mixed tree species configurations occurring in the Mediterranean BR are mostly composed of *Quercus*, *Pinus* and *Carpinus* species and to a lesser extent *Fagus*, *Abies*, *Cedrus*, *Fraxinus*, *Castanea* and others (Table 6.16, Figs. 6.13). The share of each listed species in the mixtures is based on the percentage of canopy cover in most cases. Only in Bosnia and Hercegovina mixtures are characterized by species share in volume. The most important silvicultural objective in this region is the protection of soil and water (five mixtures) followed by valuable timber production (two mixtures), the protection against wildfire (two mixtures), biodiversity (two mixtures) and cork production (one mixture). Among other lesser objectives are timber and fuelwood production, ecological stability, social function, conversion to high forests, recreation, biodiversity conservation, aesthetic value and some very specific aims like resin and cone or nut production.

Table 6.15 Challenges of management in the Continental BR

Mixture type	Country	Challenges according to the relevance					
		I	II	III	IV	V	VI
Pa-Fs-Aa	Austria	Steep terrain	High game pressure (browsing of *Aa*)	Taming beech regeneration	–	–	–
Ld-Pa-Pc	Austria	Steep terrain	High game pressure on *Ld*	–	–	–	–
Fs-Qp (Qr) *Fs-Aps-Fe-Qr*	Belgium	Lack of management rules for mixtures	Beech outcompete other species	–	–	–	–
Pm-Pa	Belgium	Lack of management rules for mixtures	–	–	–	–	–
Qp-Qc	Bulgaria	Decreased vitality at some places due to many rotations of coppice management	Lack of successful transformation to seed-originated stands due to insufficient care of newly regenerated seedlings	–	–	–	–
Qr–Cb	Croatia	Natural regeneration of *Qr*	Weed control	High game pressure	–	–	–
Qp-Cb	Croatia	High harvest in private forests	Increase of *Fs* at the expense of *Qp*	–	–	–	–
Ps-Qp-Cb-Tc	The Czech Republic	Regeneration of light-demanding species	Natural regeneration in drought periods	High game pressure	Wood processing industry of non-conifers species	Insufficient knowledge of mixed stand management	Silviculture of valuable admixtures
Pa-Fs	The Czech Republic	Spruce stability and health	Ecophysiology of thinning	High game pressure	–	–	–
Fs-Aps (Fe)	Denmark	Inter-tree competition, mixture management	–	–	–	–	–

(continued)

Table 6.15 (continued)

Mixture type	Country	Challenges according to the relevance					
		I	II	III	IV	V	VI
Fe-Ag	Denmark	Ash dieback	–	–	–	–	–
Psy-Fs	Germany	Unknown behaviour of tree species response to climate change	High browsing pressure	Role of pests in a warmer climate	High establishment costs for oak regenerations	–	–
Qr-Cb-Fspp-Um-Aspp	Italy	Hornbeam control to allow growth of oak regeneration	Valorization of sporadic tree species	Relatively high pressure from ungulates	Increase the provision of non-wood forest products	–	–
Oc-Fo-Qpu	Italy	Lack of management in steep slopes	Silvicultural abandonment can produce serious problems of stand stability	Technological innovation for wood valorization	Relatively high pressure from ungulates	Increase the provision of non-wood forest products	–
Psy-Qr (Qp)	Poland	High game pressure	–	–	–	–	–
Fs-Qr (Qp)	Poland	High game pressure	Strong competition caused by *Fs* at naturally regenerated stands	–	–	–	–
Qr-Fa	Serbia	Obtaining natural regeneration	Dead trees or groups of trees	High game pressure	Weed control	Climate change impacts	–
Qc-Qf	Serbia	Coppice origin, conversion	High harvest in private forests	Decreased vitality at some places due to many rotations of coppice management	–	–	–
Ps-Qr	Ukraine	Preservation of *Qr* natural regeneration	Dominance of artificial regeneration	Negative impact of fast-growing species	–	–	–
Qr-Cb	Ukraine	Lack of natural regeneration of *Qr* and dominance of *Cb*	Insufficient care for plants at a young age	Management models for mixtures	–	–	–

Fig. 6.12 Countries in the Mediterranean BR participating in the survey (*BA* Bosnia and Hercegovina, *HR* Croatia, *GR* Greece, *IT* Italy, *PT* Portugal, *ES* Spain, *TR* Turkey)

6.3.6.2 Silvicultural Prescriptions

Apart from Bosnia and Hercegovina where no interventions are foreseen in Mediterranean forests, the main regeneration system used is the shelterwood system with natural regeneration sometimes supplemented by artificial planting or seeding. The clear-cutting is applied in four mixtures (Italy, Portugal and Turkey) (Table 6.17). Coppicing methods are also common in this region (Italy, Greece). In Portugal management of *Quercus suber-Pinus pinea* mixed stands is based on the irregular shelterwood system; however, cork oak is protected by law. The regeneration period is commonly 20 years with some exceptions that can reach up to 30 (or 40) years in Italy. Rotation age differs substantially between mixtures being from 30 years (*Quercus* spp.) to 140 years (*Fagus sylvatica-Abies alba*) in Italy. The target DBH like rotation age is also diverse ranging from 10–15 cm (Italy) to 50 cm (Greece, Italy, Portugal and Turkey). Both the rotation age and the target DBH strongly depend on tree species and on the regeneration method. Release treatments like weeding, cleaning and brushing are performed in almost all mixtures except Bosnia and Hercegovina and one type in Italy. Among thinning methods, the most common one is thinning from below used in five mixtures. Intermediate, crown and selective thinning are less frequent. Thinning intensity ranges from 10% to 15% (Croatia,

Table 6.16 Management objectives in the Mediterranean BR

Mixture type[a]	Country	Silvicultural objective according to the relevance			
		I	II	III	IV
Qpu-Co[2]	Bosnia and Hercegovina	Protection against wildfire	–	–	–
Qpu-Oc[2]	Bosnia and Hercegovina	Protection against wildfire	–	–	–
Qpu-Co[4]	Croatia	Protection (soil, water)	Social functions	Conversion to high forests	–
Qi-Fon[4]	Croatia	Protection (soil, water)	Social functions	Conversion to high forests	–
Fs-Psy-Pa[4]	Greece	Biodiversity	High productivity	Ecological stability	Aesthetic value
Qi(Qco/Au/Aad)-Ph (Pp/Cse)[4]	Greece	Biodiversity	Ecological stability	–	–
Fs-Aa[4]	Italy	Protection (soil, water)	Biodiversity conservation	Timber production	–
Qspp(*Qi*/*Qp*/*Qce*)-Mediterranean *Pspp* (*Ph*/*Pp*/*Ppr*)[4]	Italy	Protection (soil, water)	Fuelwood production (*Qspp.*)	Recreation (coastal pinewoods)	–
Qs-Pp[4]	Portugal	Cork production (*Qs*)	Cone production (pine nuts) and wood	–	–
Cs-Pm[4]	Portugal	Valuable timber (*Cs*); Timber of small, medium and large dimensions (*Pm*)	*Pm* promotes well-shaped *Cs*	–	–
Psy(*Ppr*)-*Qpy*[1]	Spain	Protection (soil, water)	Timber (*Psy* and *Ppr*), biomass production (*Qpy*)	Resin (*Ppr*)	Biodiversity
Pb-Cl[4]	Turkey	Valuable timber production	Fuelwood	–	–
Cl-Ac-Jspp[4]					

[a]The mixture was defined according to the percentage of tree species in [1] basal area, [2] volume, [3] stem number, [4] and canopy cover

Fig. 6.13 *Quercus suber* L.-*Pinus pinea* L. mixture forest in the Mediterranean BR (Portugal) (Source: S. Barreiro)

Italy) of the growing stock to up to 30–40% in the terms of the number of trees for *Pseudotsuga menziesii* in mixture *Castanea sativa-Pseudotsuga menziesii* (Portugal). The frequency of thinning is mostly one entry per 10 years or depends on commercial profitability or the stage of stand development. In the majority of mixtures, salvage and sanitation cuttings are applied. In Portugal, artificial pruning of the main species in both mixtures and fertilization in *Quercus suber-Pinus pinea* may be used. The potential for tree species diversification is indicated as limited in six mixtures, and no such possibility is considered in two cases and foreseen possible in three mixtures.

6.3.6.3 Challenges of Management

The commonest challenge identified in the region is gaps in the knowledge on the management of mixed stands (Table 6.18). This was the highest-ranked challenge in the case of four mixtures (Greece, Portugal and Spain) and received a lower rank in two other mixtures. High game pressure is the second-ranked challenge in two mixtures (Croatia) as the major issue and as a minor problem in one other case (Italy). Other important challenges are species interactions in the condition of the closed canopy (two mixtures in Bosnia and Hercegovina), a shift from timber-oriented management to other objectives like biodiversity protection (two mixtures in Turkey) and lack of technical, management guidelines (Portugal). The remainder of the challenges reported had lower rankings.

Table 6.17 Silvicultural prescriptions in the Mediterranean BR

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Qpu-Co	Bosnia and Hercegovina	NA	NA	NA	NA	NA	NA	NA	NA	ND
Qpu-Oc	Bosnia and Hercegovina	NA	NA	NA	NA	NA	NA	NA	NA	ND
Qpu-Co	Croatia	SH	NR (AP, AS)/10–20	80/40	Y (W,B, C)	CT	10–15	1 per 10 years	SLC, SNC	L
Qi-Fo	Croatia	SH	NR (AP, AS)/10–20	80/40	Y (W,B, C)	CT	10–15	1 per 10 years	SLC, SNC	L
Fs-Psy-Pa	Greece	SH, CO	VR/10–20	80/50	Y (C)	SVT	15–20	1 per 10 years	NA	L
Qi(Qc/Au/Aa)-Ph(Pp/Cse)	Greece	CO	VR/10–20	80/50	N	SVT	15–20	1 per 10 years	NA	L
Fs-Aa	Italy	SH, IS, (SS, GS)	NR/20–40	90–140/ 40–50	Y (in public property)	LT or SVT	15–25	Depends on commercial profitability	NA	Y
Qspp(*Qi*/*Qp*/ *Qc*)-Mediterra- nean *Pspp*(*Ph*/ *Pp*/*Ppr*)	Italy	CC, SH, CS	NR, AP/10–30	30 (*Qspp*), 80–100 (*Pspp*)/ 10–15	N	LT in pine	10–15	Depends on commercial profitability	NA	L

Qs-Pp	Portugal	IH	AP/NA	120 (*Pp*)/NA	Y (W,C)	LT, SVT	20–30 (*Qs-Pp*) (trees removed)	1 per 10 years/4–5 (*Qs*); 1 per 5–10 years/ 2–4 (*Pp*)	PR (*Qs*,*Pp*), FE (*Qs-Pp*), SNC (*Pp*)	N
Cs-Pm	Portugal	CC	AP/NA	40–45 (*Cs*,*Pm*)/ 40–45 (*Cs*) 40–50 (*Pm*)	N	IT	30–40 (*Pm*); 20–40 (*Cs*) (trees removed)	1 per 7–10 years/3 (*Pm*); 1 per 7 years/4 (*Cs*)	PR (*Cs*,*Pm*), SLC, SNC	N
Psy/Ppr-Qpy	Spain	SH	NR/≥20	100–120	Y (if needed)	LT	20–35	Depending on stage of development	SLC, SNC	L
Pb-Cl	Turkey	CC	NR (Pb), AS (*Cl*)/NA	60/45 (*Pb*), 120/50 (*Cl*)	Y	LT	20–25	2	SLC, SNC if needed	Y
Cl-Ac-Jspp	Turkey	CC	NR/NA	120/50	Y	IT	20–25	2	SLC, SNC if needed	Y

Table 6.18 Challenges of management in the Mediterranean BR

Mixture type	Country	Challenges according to the relevance			
		I	II	III	IV
Qpu-Co	Bosnia and Hercegovina	Species interaction in condition of closed canopy	–	–	–
Qpu-Oc	Bosnia and Hercegovina	Species interaction in condition of closed canopy	–	–	–
Qpu-Co	Croatia	High game pressure	Tourism	Climate change impacts	
Qi-Fo	Croatia	High game pressure	Tourism	Climate change impacts	
Fs-Psy-Pa	Greece	Gaps in management knowledge	–	–	–
Qi(Qc/Au/Aa)-Ph(Pp/Cse)	Greece	Gaps in management knowledge	–	–	–
Fs-Aa	Italy	Management limited due to mixture occurrence in protected areas	Silviculture of pure beech/fir stands towards multispecies forests with distinctive valorization of sporadic tree species	Relatively high pressure from ungulates	–
Qspp(*Qi*/*Qp*/*Qc*)-Mediterranean *Pspp*(*Ph*/*Pp*/*Ppr*)	Italy	Small size properties, lack of specific management rules	Fire prevention and fostering more fire-resilient stands	Valorization of sporadic tree species	Increase the provision of non-wood forest products
Qs-Pp	Portugal	Lack of knowledge about how both species grow in the mixture	Lack of technical, management guidelines	–	–
Cs-Pm	Portugal	Small size properties	Lack of technical, management guidelines	Reduction of interest in the demand for chestnut wood	Low interest of owners in forest management

(continued)

Table 6.18 (continued)

Mixture type	Country	Challenges according to the relevance			
		I	II	III	IV
Psy(Ppr)-Qpy	Spain	Knowledge how to grow mixtures	Fire occurrence	Climate change impacts	–
Pb-Cl	Turkey	Management focuses on other objectives (e.g. diversity)	Lack of information on the growing different mixtures	–	–
Cl-Ac-Jspp	Turkey	Management focuses on other objectives (e.g. diversity)	Lack of information on the growing different mixtures	–	–

6.3.7 Anatolian, Pannonian and Steppic Biogeographical Region

6.3.7.1 Mixture Types and Management Objectives

The Anatolian, Pannonian and Steppic biogeographical regions are represented only by three countries that replied to the survey (Fig. 6.14). The dominant tree species in these regions are *Quercus* spp., *Pinus nigra*, *Pinus sylvestris* and *Juniperus* spp. (Table 6.19). The share of species in the mixtures is determined based on a percentage of canopy cover and volume. The most important management objective in the region is valuable timber production (first ranked in three mixtures in Slovakia and Ukraine; lower ranking in two mixtures in Turkey). The next is the protection of soils and water which was indicated in two mixtures in Turkey as the highest priority and of lower importance in three mixtures in Slovakia and Ukraine.

6.3.7.2 Silvicultural Prescriptions

The clear-cutting is the dominant regeneration system in the regions (Table 6.20). In Slovakia, the shelterwood system is applied in *Quercus petraea-Carpinus betulus* mixtures followed by natural regeneration with the regeneration period lasting 30–40 years. In Turkey, the coppice system is used for *Quercus* spp.-*Juniperus* spp.-*Prunus* spp. mixture with vegetative renewal. In the clear-cutting methods, regeneration relies on artificial planting or seeding. Rotation age differs significantly depending on the tree species. It ranges from 30 years for the coppice and clear-cutting systems in Turkey (Anatolian and Steppic) to 150 years in Slovakia (Pannonian) for the shelterwood method. Likewise, the target DBH varies from

Fig. 6.14 Countries in the Anatolian, Pannonian and Steppic BRs participating in the survey (*SK* Slovakia, *TR* Turkey, *UA* Ukraine)

Table 6.19 Management objectives in the Anatolian, Pannonian and Steppic BRs

Mixture type[a]	Country[b]	Silvicultural objective according to the relevance I	II
Pn-Jspp-Qspp[4]	Turkey (A)	Protection (soil, water)	Timber production
Qspp-Jspp-Prspp[4]			
Qp-Cb[2]	Slovakia (P)	Valuable oak timber production	Protection (soil, water)
Pn-Jspp-Ad[4]	Turkey (S)	Protection (soil, water)	Valuable timber production
Jspp-Qspp-Ad-Prspp-Crspp[4]			
Qr-Ap-Tc[2]	Ukraine (S)	Valuable timber production	Protection (soil)
Psy-Qr[2]	Ukraine (S)	Valuable oak and pine timber	Protection (soil)

[a]The mixture was defined according to the percentage of tree species in [1] basal area, [2] volume, [3] stem number and [4] canopy cover
[b]*A* Anatolian, *P* Pannonian, *S* Steppic

Table 6.20 Silvicultural prescriptions in Anatolian, Pannonian and Steppic BRs

Mixture type	Country[a]	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/ target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Pn-Jspp-Qspp	Turkey (A)	CC	AP/NA	120/50	Y (L,W)	IT	20	1	SLC, SNC if needed	Y
Qspp-Jspp-Prspp	Turkey (A)	CO	VR/NA	30/20	Y (L)	CRT	20	1	SLC, SNC if needed	Y
Qp-Cb	Slovakia (P)	SH	NR/30–40	130–150/ 55–60	Y (W)	CT, CRT	14–18	5–7(10)/ 5–7	SLC, SNC	L
Pn-Jspp-Ad	Turkey (S)	CC	NR, AS/NA	30/20	Y (L)	CRT	20	1	SLC, SNC if needed	Y
Jspp-Qspp-Ad-Pspp-Cspp	Turkey (S)	CC	AP/NA	30/20	Y (L)	CRT	20	1	SLC, SNC if needed	Y
Qr-Ap-Tc	Ukraine (S)	CC	AP, AS/10	100–110/ 25–30	Y (W)	CT, IT, LT (depending on age)	5–7–10–20	5–7–10–15–25/ 1–2	SLC (if needed), SNC, FE	Y
Psy-Qr	Ukraine (S)	CC	AP/10	80–90/ 30–35	Y (W)	LT	7–10-15	5–7–10–15–20/ 1–2	PR, SLC, FE	Y

[a] *A* Anatolian, *P* Pannonian, *S* Steppic

20 cm (Turkey) to 60 cm (Slovakia). Release treatments (weeding, liberation) are performed in all listed mixtures. The most widespread methods of thinning are final crop thinning and crown thinning (from above). Thinning from below, intermediate thinning or thinning method depending on age are indicated in some countries. The intensity of thinning does not exceed 15–20% of the growing stock. The frequency of thinning depends on the stage of stand development and ranges from 5 to 20 (or 25) years. In Turkey thinning is performed only once in the rotation. In all mixtures, salvage and sanitation cuttings are applied. Additionally, in Ukraine, some fertilization and artificial pruning are allowed. The potential for tree species diversification is reported in almost all mixtures except for *Quercus petraea-Carpinus betulus* type in Slovakia which is pointed as limited.

6.3.7.3 Challenges of Management

The transformation from timber-oriented management to management focused on other objectives like protection of biodiversity is the main challenge in Turkey (Table 6.21). Other important challenges involve the protection and maintenance of natural regeneration of mixed stands, especially of *Quercus robur* and *Quercus petraea*. Less significant challenges include damage to vegetation by fire, the dominance of artificial over natural restoration, the negative impact of fast-growing species, the improvement of care for plants after planting, the need for improved felling practices in order to ensure natural regeneration of species and foresters' inadequate knowledge about the management of mixed stands.

6.3.8 Mediterranean and Temperate Forest Ecosystems Outside Europe

6.3.8.1 Mixture Types and Management Objectives

Only four countries from outside Europe have responded to our questionnaire (Fig. 6.15). More accurate characteristics of mixed-species forests in South America are presented in Chap. 8 of this book (Loguercio et al. 2018). Species composition of the listed mixed forests in these countries strongly depends on the region (climatic conditions) (Table 6.22, Figs. 6.16 and 6.17). The two main objectives of the management in these forests are the protection of soil and water (Algeria) and valuable timber production (Chile, Morocco). Also, valuable cork production, conservation of *Austrocedrus chilensis* because of *Phytophthora austrocedri* disease and multipurpose management are highly ranked objectives. The remaining aims are very varied and cover, among others, social function, aesthetic value and recreation, ecosystem protection, biodiversity, ecological stability, timber and cork production and restoration of degraded forests.

Table 6.21 Challenges of management in Anatolian, Pannonian and Steppic BRs

Mixture type	Country[a]	Challenges according to the relevance				
		I	II	III	IV	V
Pn-Jspp-Qspp	Turkey (A)	Management focuses on other objectives (e.g. diversity)	–	–	–	–
Qspp-Jspp-Pspp	Turkey (A)	Management focuses on other objectives (e.g. diversity)	–	–	–	–
Qp-Cb	Slovakia (P)	Problems with natural regeneration of *Qp* (wild boar)	The loss of *Qp* seedlings/saplings due to strong competition of *Cb*	–	–	–
Pn-Jspp-Ad	Turkey (S)	Management focuses on other objectives (e.g. diversity)	–	–	–	–
Jspp-Qspp-Ad-Pspp-Cspp	Turkey (S)	Management focuses on other objectives (e.g. diversity)	–	–	–	–
Qr-Ap-Tc	Ukraine (S)	Complexity of natural conditions for natural regeneration of mixed stands	Damages to vegetation because of fires	The loss of a significant part of the trees of *Qr* at the age up to 10 years	Improvement of care for plants	Inadequate knowledge of the foresters on mixed stands management
Psy-Qr	Ukraine (S)	Problems with the preservation of *Qr* natural regeneration	Dominance of artificial over natural restoration	Negative impact of fast-growing species	Improvement of major felling practice in order to ensure a natural regeneration of species	–

[a]*A* Anatolian, *P* Pannonian, *S* Steppic

Fig. 6.15 Non-European countries participating in the survey (*DZ* Algeria, *AR* Argentina, *CL* Chile, *MA* Morocco)

6.3.8.2 Silvicultural Prescriptions

The most common regeneration methods are the uniform and irregular shelterwood systems (Table 6.23). For *Quercus rotundifolia* in Morocco, the coppice system is also applied. Natural regeneration or artificial planting is the commonest in the listed mixtures. The regeneration period is mostly between 15 and 25 years, but in Algeria, it is longer up to 40 years. The rotation age ranges from 40 years for *Quercus rotundifolia* managed by coppicing in Morocco to 70 years in *Nothofagus obliqua-Nothofagus alpina* mixture leaving old-growth remnants (125 years) to be incorporated into the following generation where it seems to be economically promising by irregular shelterwood in Chile. The target DBH is described in four mixtures and is from 45 cm for *Nothofagus dombeyi* in *Austrocedrus chilensis-Nothofagus dombeyi* type (Argentina) and *Nothofagus obliqua-Nothofagus alpina* type (Chile) to 80 cm in Morocco. In all mixture types, some release treatments (weeding, brushing, cleaning) are performed. The main thinning methods are crown and intermediate thinning, but also free thinning and thinning similar to salvage cuttings are used. The intensity of thinning in most mixtures depends on stand age and stand density, and precise details are not available. Similarly, the frequency of thinning depends on stand age and density in Argentina or is from 10 (Chile) to 20 (Morocco) years. Among other intermediate treatments, the most common intervention is artificial pruning which is performed in Morocco and could be possible in Argentina. Salvage and sanitation cuttings are used only in Algeria and in *Austrocedrus chilensis-Nothofagus dombeyi* types in Argentina. In mixtures indicated in Algeria, no thinning is applied. The potential for tree species diversification was marked for mixtures in Algeria and Chile. In other mixed types, this aspect is not reported or there are no such possibilities.

Table 6.22 Management objectives in some specific mixtures in the Mediterranean and temperate forest ecosystems outside Europe

Mixture type	Country	Silvicultural objective according to the relevance				
		I	II	III	IV	V
Qs-Ph-Qi-Qfa	Algeria	Protection (soil, water)	Restoration of forest *Qs* because not natural regeneration	Valuable cork production	Social functions	Aesthetic value and recreation
Ca-Qs-Qi-Ph	Algeria	Protection (soil, water)	Restoration of degraded forest of degraded *Ca* because not natural regeneration	Biodiversity conservation	Social functions	Aesthetic value and recreation
Ach-Nd	Argentina	Conservation of *Ach* because of *Phytophthora austrocedri* disease	Restoration of degraded *Ac* forests	Timber production of *Ac* and *Nd*	–	–
Na-No-Nd	Argentina	Multipurpose management	Valuable timber production	Ecosystem protection (soil, water, biodiversity)	Aesthetic value preservation	Scientific research
No-Na with temperate rainforest species	Chile	Valuable timber production	Biodiversity	Ecological stability	–	–
Ca-Qrt	Morocco	Valuable cedar timber and oak timber as fuelwood	–	–	–	–
Qrt-Qs	Morocco	Valuable cork	Valuable oak timber	–	–	–

Fig. 6.16 *Nothofagus dombeyi* (Mirb.) Oerst.-*Austrocedrus chilensis* (D.Don) Pic.Serm. & Bizzarri mixture forest in the sub-Antarctic temperate region of Argentina. (Source: G. Loguercio)

Fig. 6.17 *Cedrus atlantica* (Endl.) Manetti ex Carrière-*Quercus rotundifolia* Lam. mixture in the Medal Atlas forest, humid bioclimate, Morocco. (Source: B. Belghazi)

Table 6.23 Silvicultural prescriptions in some specific mixtures in the Mediterranean and temperate forest ecosystems outside Europe

Mixture type	Country	Silvicultural system	Type of regeneration/ regeneration period [years]	Rotation [years]/target DBH [cm]	Release treatments	Thinning			Other intermediate treatments	Potential for tree species diversification
						Method	Intensity of growing stock removal [%]	Frequency [years]/ number of entries		
Qs-Ph-Qi-Qfa	Algeria	IS	AP, NR/≥40	NA	Y (C)	NA	NA	NA	SNC	Y
Ca-Qs-Qi-Ph	Algeria	IS	AP, NR/≥40	NA	Y (C)	NA	NA	NA	SNC	Y
Ach-Nd	Argentina	Combination GS for *Nd* and SLC for *Ach*	NR/–	Regulated by SLC (*Ach*)/ 45(*Nd*)	Y (C)	CRT (*Nd*) SLC (*Ach*)	Depending on stand age and density	Depending on stand age and density	PR(*Nd*) if needed, SLC	ND
Na-No-Nd	Argentina	SH	NR/20	100/–	Y	CT	Depending on stand age and density	Depending on stand age and density	NA	N
No-Na with temperate rainforest species	Chile	IS	NR, VR/≥15	70 (125 for old-growth incorporated into next generation)/ 45–50	Y (C)	CT, FT	Depending on natural density (maintaining 35% of rel. density)	10/3 (*No-Na*); 10/3 (others)	NA	Y
Ca-Qrt	Morocco	SH(*Ca*), CO (*Qrt*)	NR, AP(Ca)/ ≥20	120(*Ca*), 40 (*Qrt*)/80(*Ca*)	Y (W,B, C)	IT	Depending on stand age and density	40 then each 20 (*Ca*)	PR(*Ca*)	ND
Qrt-Qs	Morocco	SH(*Qs*), CO (*Qrt*)	NR, AP(Qs)/ 20–24	120(*Qs*), 40 (*Qrt*)/80(*Qs*)	Y (W,B, C)	IT	Depending on stand age and density	Each 20 (*Qs*)	PR(*Qs*)	ND

6.3.8.3 Challenges of Management

The most significant challenge for these mixtures is to control overgrazing which is mentioned in all mixtures (Algeria, Argentina, Chile and Morocco) (Table 6.24). Two others given the highest rank are conservation of *Austrocedrus chilensis* against *Phytophthora* through natural regeneration (Argentina) and the problem with regeneration due to bamboo competition (Chile). From the remaining challenges, illegal cutting practice (Algeria, Morocco), problems with the preservation of *Quercus suber* natural regeneration (Algeria), lack of application of management plans (Morocco), lack of knowledge on how yield and growth of the main tree species might be affected by climate change (Morocco) and damages to vegetation by fire (Algeria) are often reported.

6.4 Discussion and Conclusion

Although not all countries replied to the questionnaire, the response level reached 58% which is a high level for this type of survey (Baruch and Holtom 2008). Furthermore, the response allows us for the first time to assess the state of silviculture in mixed stands across most of Europe including all nine biogeographical regions, as well as allowing comparison with a few countries outside the continent. However, we are aware that this study may have some limitations like some bias in the mixture selection (as it should be well-described), possible bias due to the fact that in many cases the information was provided by researchers and difficulties to cover all the possible particularities in silvicultural treatments.

Forests in Europe cover a large bioclimatological range from the Boreal to the Mediterranean regions and from floodplain to mountain areas up to the alpine tree line (FOREST EUROPE 2015). As a consequence, species composition and the type of mixtures in European forests are very varied. Mixed forests dominated by conifers are prevalent in the Alpine (*Abies alba*, *Picea abies*), Atlantic (*Pinus sylvestris*, *Picea abies*, *Picea sitchensis*) and Boreal (*Picea abies*, *Pinus sylvestris*) regions, while broadleaves are prevalent in the Black Sea, Continental, Mediterranean, Pannonian and Steppic regions. The mixed stands in the Alpine region are mainly composed of *Abies alba*, *Picea abies* and *Fagus sylvatica* in different configurations and proportions so that the management of these mixtures is similar in many cases. Similarly, mixtures in the Boreal BR consist mostly of three tree species: *Picea abies*, *Pinus sylvestris* and *Betula pendula*. By contrast, species diversity in the remaining BRs is much higher so that it is rather difficult to indicate dominant species. The mixtures can be defined according to various stand parameters like basal area, volume, stem number, canopy cover and biomass (Dirnberger et al. 2017; del Río et al. 2018), but the most common definitions used in all BRs are volume and canopy cover. That is the reason for some difficulties in comparing different types of mixed stands within and between BRs.

Table 6.24 Challenges of management in some specific mixtures in the Mediterranean and temperate forest ecosystems outside Europe

Mixture type	Country	Challenges according to the relevance			
		I	II	III	IV
Qs-Ph-Qi-Qfa	Algeria	Overgrazing	Problems with the preservation of *Qs* natural regeneration	Illegal cutting practice	Damages to vegetation because of fires
Ca-Qs-Qi-Ph	Algeria	Overgrazing	Problems with the preservation of *Ca* natural regeneration	Illegal cutting practice	Damages to vegetation because of fires
Ach-Nd	Argentina	Conservation of *Ach* against *Phytophthora* through natural regeneration, overgrazing by domestic cattle	Growth relationships in mixed stand to regulate composition	Production of quality timber (*Nd*)	–
Na-No-Nd	Argentina	Overgrazing by domestic cattle	Large crown cover of remnant trees after harvesting	Dense understory of *Chusquea culeou*	–
No-Na with temperate rainforest species	Chile	Overgrazing, problem with regeneration due to bamboo occurrence	Little experience in satisfactory regeneration of valuable tree species	More information about strip width and gap size is needed	–
Ca-Qrt	Morocco	Overgrazing	Lack of application of the management plan	Illegal cutting practice	Lack of knowledge on yield and growth of the main tree species considering climate change
Qrt-Qs	Morocco	Overgrazing	Lack of application of the management plan	Illegal cutting practice	Lack of knowledge on yield and growth of the main tree species considering climate change

Despite the increasing attention paid to the ecological role of forests, when considering the highest-ranked management objectives, timber production, and in particular valuable timber production, represents the major driver of mixed forest management in Europe and in selected mixtures outside Europe (Fig. 6.18). Protection of soil and water as well as protection of forests against disturbances (e.g. fire,

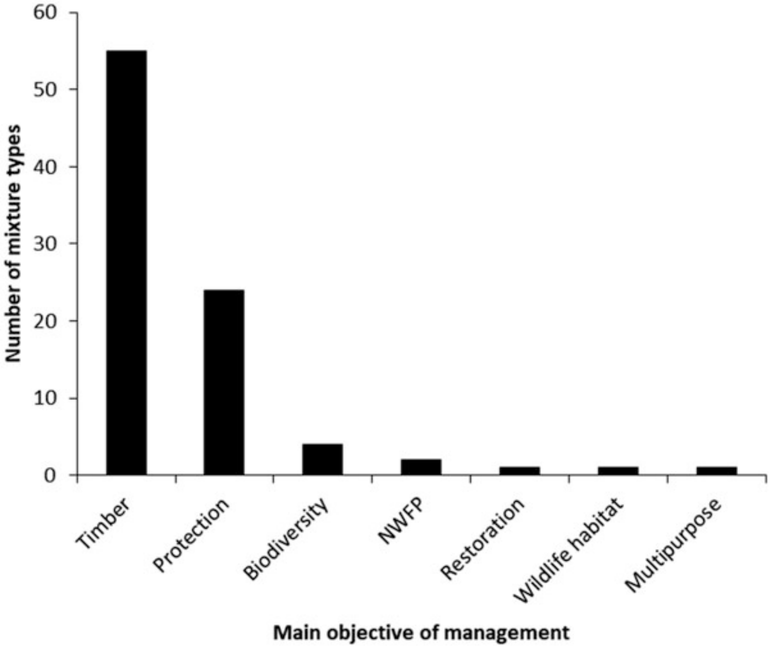

Fig. 6.18 The main management objectives in the studied mixture types (*NWFP* non-wood forest products (nuts, cork))

diseases, avalanches, rockfalls and landslides) is the second most important management goal followed by other aims like biodiversity, non-wood forest products (nuts, cork), restoration of native woodlands, wildlife habitat and multipurpose management (Biber et al. 2015). The outdoor recreation activities and nature-based tourism, which are not clearly mentioned by respondents in the survey, have rapidly expanded from protected areas into commercial forests (Tyrväinen et al. 2014), and in many European countries, they are recognized as the most valuable forest ecosystem service provided. Setting up aesthetic value of forests, Ribe (1989) highlights such their attributes as openness and visibility, amount of light in the stand and its stratification, but at the same time, he also suggests that there is a slight overall preference for species diversity. In fact, most often mixed forests are preferred by visitors over monocultures which is grounded on the recreational value of this forest type (Gundersen and Frivold, 2008; Schraml and Volz 2009; Edwards et al. 2012; Carnol et al. 2014; Giergiczny et al. 2015). Thus forest managers should recognize these new challenges and deal with them proactively rather than reactively (Tyrväinen et al. 2014, 2017). Consequently, this should lead sometimes to modification of the applied forest management regimes.

Still, in Europe, much attention is evidently paid to valuable timber production as the means of covering the costs of all other treatments in forests while providing a certain level of profit to the landowner. Since timber quality coming from mixed

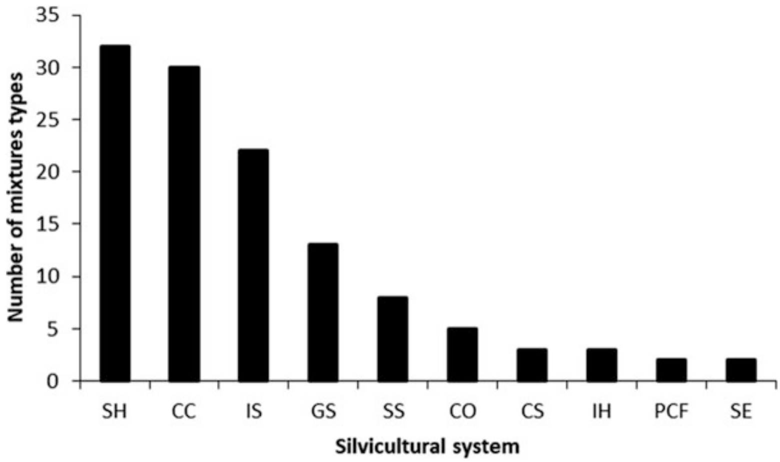

Fig. 6.19 The silvicultural systems applied in the studied mixture types (*CC* clear-cutting, *CO* coppice, *CS* coppice-with-standard system, *GS* group selection, *IH* individual tree harvesting, *IS* irregular shelterwood, *PCF* patch clear felling, *SE* selection, *SH* shelterwood, *SS* single tree selection)

stands is generally lower than from pure stands (Röhrig et al. 2006), much more effort is required to obtain valuable timber from a multispecies stand. If uncertainty and reduced financial risk (production risk) are taken into consideration, mixed stands can show advantages in comparison to the pure stands (Griess and Knoke 2013; Knoke 2017).

The silvicultural systems mentioned by respondents in the questionnaires were varied covering almost all techniques used in the temperate region (Matthews 1991). Just as site conditions, ownership, cultural, economic and social conditions vary, so forest management should differ and be adjusted to local conditions (Spiecker 2003). The uniform shelterwood is the most widespread regeneration system (Fig. 6.19) applied mostly in Continental, Alpine and Mediterranean BRs followed by the clear-cutting system (Boreal, Atlantic BRs) and the irregular shelterwood system (Alpine, Continental BRs). The use of specific regeneration methods entails the application of natural or artificial regeneration. Both the uniform and irregular shelterwood systems are based on the use of natural regeneration, while the clear-cutting system depends upon planting (artificial regeneration). Some complementary artificial planting may be used to enrich natural regeneration and vice versa: this can be a means of creating some valuable admixtures. Other local regeneration methods are carried out according to the type of mixture and the main silvicultural objectives. We found in our study that single tree or group selection systems that are mostly used in forests composed of shade-tolerant species are usually combined with valuable timber production. Among less representative but locally important regeneration methods is coppicing in the Mediterranean, Atlantic and Anatolian BRs (less frequent in Continental BR and Morocco too) where it has a long and well-established tradition.

From the point of view of the potential of species diversification in listed mixtures, temporal and spatial separation of species regeneration within a stand is a very powerful way to increase species heterogeneity of forest stands (Bauhus et al. 2017). This is a fundamental assumptions of the irregular shelterwood system that fosters the regeneration of tree species with various functional traits (Bagnaresi et al. 2002; Raymond et al. 2009; Klopcic and Boncina 2012; Pretzsch et al. 2015a; Raymond and Bédard 2017) at the same time taking care of the value increment (growth potential, high-quality timber) of mature trees (Paluch 2006; Skrzyszewski et al. 2017). Even in Scandinavian conditions (Boreal BR) where clear-cutting is a dominant regeneration method, some possibilities exist to enhance species diversification (Holmström et al. 2016).

The Boreal BR should be considered an outlier in this survey as, in the countries belonging to this region, an intensive silviculture, focused on timber production, is still the dominant approach. In this case, the main regeneration method employed is clear-cutting followed by artificial regeneration, although some differences are evident in the case of broadleaved natural regeneration (mostly *Betula* spp.). In this BR intensive interventions such as fertilization, mechanical soil preparation and weeding are common. A further example of intensive silviculture, however, is shown in a contrasting climatic condition, in a few mixtures of the Mediterranean BR. Here forest types like cork oak- and chestnut-dominated forests are under a strict management (including fertilizing practices) to guarantee productive purposes. In general such practices as fertilization, soil liming and chemical control are associated with a high interest in productivity goals.

The most frequent thinning method in all studied regions is crown thinning (from above), especially in Continental and Alpine BRs (Fig. 6.20). This method concentrates on the selection of the best crop trees in the main canopy of the stand and elimination of one or two most competitive trees from the same strata. Low thinning

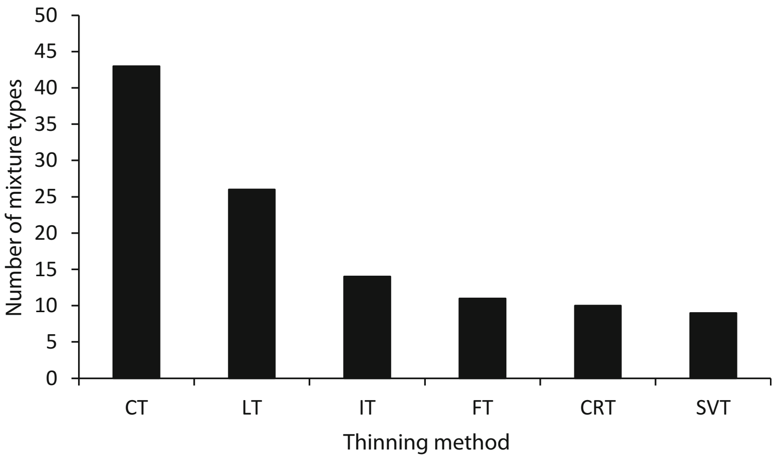

Fig. 6.20 Number of mixture types according to indicated thinning methods in all BRs (*CRT* final crop thinning, *CT* crown thinning, *FT* free style of thinning, *IT* intermediate thinning, *LT* low thinning, *SVT* selective thinning)

(from below) which is the second most common method, especially in Boreal BR where it is used in 75% of the mixtures, operates in the lower stand strata removing suppressed and intermediate trees without paying attention to the trees in the upper layer. The frequency of occurrence of other methods (free, intermediate, crop tree and selective thinning) is similar. Differences in growth pattern and rates, tree allometry, species interactions and crown shape between mono- and multispecies stands are evident (Pretzsch and Forrester 2017; Pretzsch 2017), and application of thinning methods developed in monospecific stands in mixed-species forests can be inaccurate and even flawed (Bauhus et al. 2017). An alternative solution for mixed stands could be the use of the thinning method, called crop tree thinning, indicated in a few mixtures, focusing on individual trees in the stand considering the species proportion, spatial and temporal mixing pattern, relative growth rates of neighbouring trees and species-specific target diameters (Bauhus et al. 2017).

The replies to the questions on challenges let us identify how important was an effective sustainable management of the mixtures. Indeed, management aspects are the most important of the challenges listed. The second aspect, in order of importance, is the problem of regeneration, first, if we consider that many described mixtures are managed by adopting artificial regeneration, at the place of or integrating the natural one. Considering the third aspect of improving knowledge about the dynamics and growth of mixtures, we can say that studies are needed to better understand the functioning of each one of the mixtures described. With such additional knowledge, it will be possible to develop more site-specific management guidelines. Regional topics included the serious impact of environmental (biotic and abiotic) factors on forest stability and functionality as in the Mediterranean area, in consequence of wildfires and climate change, or over a wider region for the game pressure.

Considering only those challenges given the highest ranking, the main issue is high browsing pressure from game animals (also including domestic animals), which threatens target species composition of regeneration (Klopcic et al. 2010; Bernard et al. 2017). Regeneration is threatened by animals during both seedling (browsing, trampling, fraying) and sapling stages (bark stripping). A lot of measures and efforts need to be made in order to ensure the survival of appropriate species composition of regeneration (Hothorn and Müller 2010; Beguin et al. 2016). The second most important challenge is the lack of management rules covering mixture growth and taking into account both species functional traits and site conditions. There is an urgent need to fill this gap in our knowledge of mixed forest management (Pretzsch and Zenner 2017; Coll et al. 2018), especially in the face of predicted environmental changes (IPCC 2014). Problems to get natural regeneration of specific tree species (*Picea abies*, *Pinus sylvestris*, *Quercus petraea*, *Quercus robur*) in the some site and stand conditions (hornbeam or bamboo occurrence) are the third of the highest-ranked challenge. A significant challenge, surprisingly listed in only a few cases, is climate change impacts on growth and performance of tree species, although the establishment of mixtures is seen as a promising tool to adapt forest ecosystems to climate change (Ammer 2017).

Responses to the survey indicated that potential for tree species diversification exists in analysed mixtures (43 mixed types) however depending on climatic conditions. The largest potential is in Continental, Black Sea, Anatolian, Steppic and Atlantic BRs. In 26 listed mixtures, the potential was determined as limited (ten in Alpine BR) due to unfavourable site conditions, and in six ones (Alpine, Mediterranean, one in Argentina), such possibilities do not exist. The secondary temperate forests of Chile have a great potential for diversification with the incorporation of semi-tolerant and tolerant rainforest species. This potential for tree species diversification is very important in the light of enhancing forests' adaptability to predicted environmental (climatic) changes (Bolte et al. 2009; Seppälä et al. 2009; Lindner et al. 2010; Park et al. 2014; Vilà-Cabrera et al. 2018).

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References

Ammer C (2017) Unraveling the importance of inter- and intraspecific competition for the adaptation of forests to climate change. In: Canovas FM, Lüttge U, Matyssek R (eds) Progress in botany, vol 78. Springer, Cham, pp 345–367

Bagnaresi U, Giannini R, Grassi G, Minotta G, Paffetti D, Pini Prato E, Proietti Placidi AM (2002) Stand structure and biodiversity in mixed, uneven-aged coniferous forests in the eastern Alps. Forestry 75(4):357–364

Balvanera P, Pfister AB, Buchmann N, He JS, Nakashizuka T, Raffaelli D, Schmid B (2006) Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol Lett 9:1146–1156

Baruch Y, Holtom BC (2008) Survey response rate levels and trends in organizational research. Hum Relat 61:1139–1160

Battles JJ, Shlisky AJ, Barrett RH, Heald RC, Allen-Diaz BH (2001) The effects of forest management on plant species diversity in a Sierran conifer forest. For Ecol Manag 146:211–222

Bauhus J, Puettmann KJ, Kühne C (2013) Close-to-nature forest management in Europe: does it support complexity and adaptability of forest ecosystems. In: Messier C, Puettmann KJ, Coates KD (eds) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge, New York, pp 187–213

Bauhus J, Forrester DI, Pretzsch H, Felton A, Pyttel P, Benneter A (2017) Silvicultural option for mixed-species stands. In: Pretzsch H, Forrester DI, Bauhus J (eds) Mixed-species forests. Springer, Berlin

Beguin J, Tremblay J, Thiffault N, Pothier D, Côté SD (2016) Management of forest regeneration in boreal and temperate deer-forest systems: challenges, guidelines, and research gaps. Ecosphere 7(10):1–16

Bengtsson J, Nilsson SG, Franc A, Menozzi P (2000) Biodiversity, disturbances, ecosystem function and management of European forests. For Ecol Manag 132:39–50

Bernard M, Boulanger V, Dupouey JL, Laurent L, Montpied P, Morin X, Picard JF, Saïd S (2017) Deer browsing promotes Norway spruce at the expense of silver fir in the forest regeneration phase. For Ecol Manag 400:269–277

Biber P, Borges JG, Moshammer R, Barreiro S, Botequim B, Brodrechtová Y, Brukas V, Chirici G, Cordero-Debets R, Corrigan E, Eriksson LO, Favero M, Galev E, Garcia-Gonzalo J, Hengeveld G, Kavaliauskas M, Marchetti M, Marques S, Mozgeris G, Navrátil R, Nieuwenhuis M, Orazio C, Paligorov I, Pettenella D, Sedmák R, Smreček R, Stanislovaitis A, Tomé M, Trubins R, Tuček J, Vizzarri M, Wallin I, Pretzsch H, Sallnäs O (2015) How sensitive are ecosystem services in European forest landscapes to silvicultural treatment? Forests 6:1666–1695

Bolte A, Ammer C, Löf M, Madsen P, Nabuurs GJ, Schall P, Spathelf P, Rock J (2009) Adaptive forest management in central Europe: climate change impacts, strategies and integrative concept. Scand J For Res 24(6):473–482

Brang P (2005) Virgin forests as a knowledge source for central European silviculture: reality or myth? For Snow Landsc Res 79(1/2):19–32

Brang P, Spathelf P, Larsen JB, Bauhus J, Bončina A, Chauvin C, Drössler L, Carlos García-Güemes C, Caroline Heiri C, Kerr G, Lexer MJ, Mason B, Mohren F, Mühlethaler U, Nocentini S, Svoboda M (2014) Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. Forestry 87:492–503

Bravo-Oviedo A, Pretzsch H, Ammer C, Andenmatten E, Antón C, Barbati A, Barreiro S, Brang P, Bravo F, Brunner A, Coll L, Corona P, den Ouden J, Drössler L, Ducey MJ, Kaynas BY, Legay M, Löf M, Lesiński J, Mason B, Meliadis M, Manetti MC, Morneau F, Motiejunaite J, O'Reilly C, Pach M, Ponette Q, Río M, Short I, Skovsgaard JP, Souidi Z, Spathelf P, Sterba H, Stojanovic D, Strelcova K, Svoboda M, Valsta L, Verheyen K, Zlatanov T (2014) European mixed forests: definition and perspectives. For Syst 3:518–533

Carnol M, Baeten L, Branquart E, Grégoire J-C, Heughebaert A, Muys B, Ponette Q, Verheyen K (2014) Ecosystem services of mixed species forest stands and monocultures: comparing practitioners' and scientists' perceptions with formal scientific knowledge. Forestry 87:639–653

Chen HYH, Klinka K, Mathey A-H, Wang X, Varga P, Chourmouzis C (2003) Are mixed-species stands more productive than single-species stands: an empirical test of three forest types in British Columbia and Alberta. Can J For Res 33:1227–1237

Coll L, Ameztegui A, Collet C, Löf M, Mason B, Pach M, Verheyen K, Abrudan I, Barbati A, Barreiro S, Bielak K, Bravo-Oviedo A, Ferrari B, Govedar Z, Kulhavy J, Lazdina D, Metslaid M, Mohren F, Pereira M, Peric S, Rasztovits E, Short I, Spathelf P, Sterba H, Stojanovic D, Valsta L, Zlatanov T, Ponette Q (2018) Knowledge gaps about mixed forests: what do European forest managers want to know and what answers can science provide? For Ecol Manag 407:106–115

Corona P (2014) Forestry research to support the transition towards a bio-based economy. Ann Silvic Res 38:37–38

Decocq G, Aubert M, Dupont F, Alard D, Saguez R, Wattez Franger A, De Foucalt B, Delelis-Dusollier A, Bardat J (2004) Plant diversity in a managed temperate deciduous forest: understorey response to two silvicultural systems. J Appl Ecol 41:1065–1079

Del Río M, Pretzsch H, Alberdi I, Bielak K, Bravo F, Brunner A, Condés S, Ducey MJ, Fonseca T, von Lüpke N, Pach M, Peric S, Perot T, Souidi Z, Spathelf P, Sterba H, Tijardovic M, Tomé M, Vallet P, Bravo-Oviedo A (2018) Characterization of mixed forests. In: Bravo-Oviedo A, Pretzsch H, del Río M (eds) Dynamics, silviculture and management of mixed forests. Springer, Dordrecht, pp 27–71

Dieler J, Uhl E, Biber P, Müller J, Rötzer T, Pretzsch H (2017) Effect of forest stand management on species composition, structural diversity, and productivity in the temperate zone of Europe. Eur J For Res 136:739–766

Dirnberger G, Sterba H, Condés S, Ammer C, Annighöfer P, Avdagić A, Bielak K, Brazaitis G, Coll L, Heym M, Hurt H, Kurylyak V, Motta R, Pach M, Ponette Q, Ruiz-Peinado R, Skrzyszewski J, Šrámek V, de Streel G, Svoboda M, Zlatanov T, Pretzsch H (2017) Species proportions by area in mixtures of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.). Eur J For Res 136:171–183

Dobšinská Z, Rathke J, Weber N (2015) Synthesis report COST ACTION FP 1207, WG1 Forest-related policy targets and measures. IUFRO occasional paper no. 29

Edwards D, Jay M, Jensen FS, Lucas B, Marzano M, Montagné C, Peace A, Weiss G (2012) Public preferences across Europe for different forest stand types as sites for recreation. Ecol Soc 17 (1):27

Farrell EP, Führer E, Ryan D, Andersson F, Hüttl R, Piussi P (2000) European forest ecosystems: building the future on the legacy of the past. For Ecol Manag 132:5–20

FOREST EUROPE (2015) State of Europe's forests 2015

Gamborg C, Larsen JB (2003) 'Back to nature' – a sustainable future for forestry? For Ecol Manag 179:559–571

Gamfeldt L, Snäll T, Bagchi R, Jonsson M, Gustafsson L, Kjellander P, Ruiz-Jaen MC, Fröberg M, Stendahl J, Philipson CD, Mikusiński G, Andersson E, Westerlund B, Andrén H, Moberg F, Moen J, Bengtsson J (2013) Higher levels of multiple ecosystem services are found in forests with more tree species. Nat Commun 4:1340

Giergiczny M, Czajkowski M, Żylicz T, Angelstam P (2015) Choice experiment assessment of public preferences for forest structural attributes. Ecol Econ 119:8–23

Griess VC, Knoke T (2013) Bioeconomic modelling of mixed Norway spruce – European beech stands. Economic consequences of considering ecological effects. Eur J For Res 132:511–522

Griess VC, Acevedo R, Härtl F, Staupendahl K, Knoke T (2012) Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce. For Ecol Manag 267:284–296

Gundersen VS, Frivold LH (2008) Public preferences for forest structures: a review of quantitative surveys from Finland, Norway and Sweden. Urban For Urban Green 7:241–258

He Y, Qin L, Li Z, Liang X, Shao M, Tan L (2013) Carbon storage capacity of monoculture and mixed-species plantations in subtropical China. For Ecol Manag 295:193–198

Holmström E, Ekö PM, Hjelm K, Karlsson M, Nilsson U (2016) Natural regeneration on planted clearcuts – the easy way to mixed Forest? Open J For 6:281–294

Hooper DU, Chapin SJ, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J, Wardl DA (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol Monogr 75:3–35

Hothorn T, Müller J (2010) Large-scale reduction of ungulate browsing by managed sport hunting. For Ecol Manag 260:1416–1423

IPCC (2014) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change (Core Writing Team, Pachauri RK, Meyer LA (eds)), IPCC, Geneva, 151 p

Jacobsen MK (2001) History and principles of close to nature forest management: a central European perspective. Naconex 3:56–58

Jactel H, Brockerhoff E, Duelli P (2005) A test of the biodiversity-stability theory: meta-analysis of tree species diversity effects on insect pest infestation, and re-examination of responsible factors. In: Scherer-Lorenzen M, Körner C, Schulze E-D (eds) Forest diversity and function: temperate and boreal systems, Ecological Studies, vol 176. Springer, Berlin, pp 235–262

Jactel H, Nicoll BC, Branco M, Gonzalez-Olabarria JR, Grodzki W, Långström B, Moreira F, Netherer S, Orazio C, Piou D, Santos H, Schelhaas MJ, Tojic K, Vodde F (2009) The influences of forest stand management on biotic and abiotic risks of damage. Ann For Sci 66:701

Jactel H, Bauhus J, Boberg J, Bonal D, Castagneyrol B, Gardiner B, Gonzalez-Olabarria JR, Koricheva J, Meurisse N, Brockerhoff EG (2017) Tree diversity drives forest stand resistance to natural disturbances. Curr For Rep 3:223–243

Klopcic M, Boncina A (2012) Recruitment of tree species in mixed selection and irregular shelterwood forest stands. Ann For Sci 69:915–925

Klopcic M, Jerina K, Boncina A (2010) Long-term changes of structure and tree species composition in Dinaric uneven-aged forests: are red deer an important factor? Eur J For Res 129:277–288

Knoke T (2017) Economics of mixed forests. In: Pretzsch H, Forrester DI, Bauhus J (eds) Mixed-species forests. Springer, Berlin

Knoke T, Ammer C, Stimm B, Monsandl R (2008) Admixing broadleaved to coniferous tree species: a review on yield, ecological stability and economics. Eur J For Res 127:89–101

Leuschner C, Jungkunst HF, Fleck S (2009) Functional role of forest diversity: pros and cons of synthetic stands and across-site comparisons in established forests. Basic Appl Ecol 10:1–9

Lindner M, Maroschek M, Netherer S, Kremer A, Barbati A, Garcia-Gonzalo J, Seidl R, Delzon S, Corona P, Kolström M, Lexer MJ, Marchetti M (2010) Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For Ecol Manag 259:698–709

Loguercio GA, Donoso PJ, Müller-Using S, Dezzotti A, Urretavizcaya MF, Navarro CO, Martin M, Schlegel B, Müller-Using B, Mujica R, González-Peñalba M, Attis Beltrán H, Caselli M (2018) Silviculture of temperate mixed forests from South America. In: Bravo-Oviedo A, Pretzsch H, del Río M (eds) Dynamics, silviculture and management of mixed forests. Springer, Cham, pp 271–317

Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime JP, Hector A, Hooper DU, Huston MA, Raffaelli D, Schmid B, Tilman D, Wardle DA (2001) Biodiversity and ecosystem functioning: current knowledge and future challenges. Science 294(5543):804–808

Matthews JD (1991) Silvicultural systems. Oxford University Press, Oxford

Metz J, Annighöfer P, Schall P, Zimmermann J, Kahl T, Schulze ED, Ammer C (2016) Site-adapted admixed tree species reduce drought susceptibility of mature European beech. Glob Chang Biol 22:903–920

Millennium Ecosystem Assessment (MEA) (2005a) Ecosystems and human wellbeing: biodiversity synthesis. World Resource Institute, Washington, DC

Millennium Ecosystem Assessment (MEA) (2005b) Ecosystems and human wellbeing: synthesis. Island Press, Washington, DC

Mlinšek D (2006) Close to nature forestry as the only true culture of a man's activity. In: Diaci J (ed) Nature-based forestry in central Europe. Alternatives to industrial forestry and strict preservation, vol 126. Studia Forestalia Slovenica, Ljubljana, pp 91–103

Nocentini S, Buttoud G, Ciancio O, Corona P (2017) Managing forests in a changing world: the need for a systemic approach. A review. For Syst 26(1):eR01

O'Hara K (2001) The silviculture of transformation – a commentary. For Ecol Manag 151:81–86

O'Hara K (2016) What is close-to-nature silviculture in a changing world? Forestry 89(1):1–6

Olsthoorn AFM, Bartelink HH, Gardiner JJ, Pretzsch H, Hekhuis HJ, Franc A (1999) Management of mixed-species forest: silviculture and economics. IBN Sci Contrib 15:1–389

Paluch J (2006) Tree value increment as a cutting control criterion in complex cutting systems. Sylwan 150(12):54–63 (in Polish)

Park A, Puettmann K, Wilson E, Messier C, Kames S, Dharf A (2014) Can boreal and temperate forest management be adapted to the uncertainties of 21st century climate change? Crit Rev Plant Sci 33(4):251–285

Pretzsch H (2017) Individual tree structure and growth in mixed compared with monospecific stands. In: Pretzsch H, Forrester DI, Bauhus J (eds) Mixed-species forests. Springer, Berlin, pp 271–336

Pretzsch H, Forrester DI (2017) Stand dynamics of mixed-species stands compared with monocultures. In: Pretzsch H, Forrester DI, Bauhus J (eds) Mixed-species forests. Springer, Berlin

Pretzsch H, Schütze G (2009) Transgressive overyielding in mixed compared with pure stands of Norway spruce and European beech in Central Europe: evidence on stand level and explanation on individual tree level. Eur J For Res 128:183–204

Pretzsch H, Zenner EK (2017) Toward managing mixed-species stands: from parametrization to prescription. For Ecosyst 4:19

Pretzsch H, Biber P, Uhl E, Dauber E (2015a) Long-term stand dynamics of managed spruce-fir-beech mountain forests in Central Europe: structure, productivity and regeneration success. Forestry 88(4):407–428

Pretzsch H, del Río M, Ammer C, Avdagic A, Barbeito I, Bielak K, Brazaitis G, Coll L, Dirnberger G, Drössler L, Fabrika M, Forrester DI, Godvod K, Heym M, Hurt V, Kurylyak V, Löf M, Lombardi F, Matović B, Mohren F, Motta R, den Ouden J, Pach M, Ponette Q, Schütze G, Schweig J, Skrzyszewski J, Sramek V, Sterba H, Stojanović D, Svoboda M, Vanhellemont M, Verheyen K, Wellhausen K, Zlatanov T, Bravo-Oviedo A (2015b) Growth and yield of mixed versus pure stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) analysed along a productivity gradient through Europe. Eur J For Res 134:927–947

Pretzsch H, Forrester DI, Bauhus J (eds) (2017) Mixed-species forests. Ecology and management. Springer, Berlin, p 653

Puettmann KJ, Coates KD, Messier C (2009) A critique of silviculture. Managing for complexity. Island Press, Washington, DC

Puettmann KJ, Messier C, Coates KD (2013) Managing forests as complex adaptive systems. Introductory concept and application. In: Messier C, Puettmann KJ, Coates KD (eds) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge, New York, pp 3–16

Puettmann KJ, Wilson SM, Baker SC, Donoso PJ, Drössler L, Amente G, Harvey BD, Knoke T, Lu Y, Nocentini S, Putz FE, Yoshida T, Bauhus J (2015) Silvicultural alternatives to conventional even-aged forest management – what limits global adoption? For Ecosyst 2:8

Rametsteiner E, Eichler L, Berg J, Aggestam F, Zane EB, Plumet C (2009) Shaping forest communication in the European Union: public perceptions of forests and forestry. ECORYS, Tender no. AGRI-2008-EVAL-10

Raymond P, Bédard S (2017) The irregular shelterwood system as an alternative to clearcutting to achieve compositional and structural objectives in temperate mixed wood stands. For Ecol Manag 398:91–100

Raymond P, Bédard S, Roy V, Larouche C, Tremblay S (2009) The irregular shelterwood system: review, classification, and potential application to forests affected by partial disturbances. J For 107(8):405–413

Ribe RG (1989) The aesthetics of forestry: what has empirical preference research taught us? Environ Manag 13(10):55–74

Riofrío J, del Río M, Bravo F (2016) Mixing effects on growth efficiency in mixed pine forests. Forestry 90:381–392

Riofrío J, del Río M, Pretzsch H, Bravo F (2017) Changes in structural heterogeneity and stand productivity by mixing Scots pine and Maritime pine. For Ecol Manag 405:219–228

Röhrig E, Bartsch N, von Lüpke B (2006) Waldbau auf ökologischer Grundlage. Eugen Ulmer, Stuttgart, p 479

Schraml U, Volz K-R (2009) Do species matter? Valuable broadleaves as an object of public perception and policy. In: Spiecker H (ed) Valuable broadleaved forests in Europe. 211–236. S. Brill, Leiden/Boston/Köln, pp 213–236

Schütz J-P (1999) Close-to-nature silviculture: is this concept compatible with species diversity? Forestry 72:359–366

Schütz J-P, Götz M, Schmid W, Mandallaz D (2006) Vulnerability of spruce (*Picea abies*) and beech (*Fagus sylvatica*) forest stands to storms and consequences for silviculture. Eur J For Res 125:291–302

Seppälä R, Buck A, Katila P (2009) Adaptation of forests and people to climate change. A Global Assessment Report, IUFRO World Series Volume 22. Helsinki, p 224

SFM (2015) Madrid ministerial declaration, 25 years together promoting sustainable forest management in Europe, 7th Forest Europe Ministerial conference, Madrid 20–21 October 2015

Shua K, Wende S, Wagner S, Feger K-H (2015) Soil chemical and microbial properties in a mixed stand of spruce and birch in the Ore Mountains (Germany) – a case study. Forests 6:1949–1965

Skrzyszewski J, Pach M, Krzysztof R, Szafron M, Stenka Z (2017) Modelling the basal area increment in mature silver fir stands. Sylwan 161(6):467–475 (in Polish)

Spiecker H (2003) Silvicultural management in maintaining biodiversity and resistance of forests in Europe – temperate zone. J Environ Manag 67:55–65

Tyrväinen L, Mäntymaa E, Ovaskainen V (2014) Demand for enhanced forest amenities in private lands: the case of the Ruka-Kuusamo tourism area, Finland. Forest Policy Econ 47:4–13

Tyrväinen L, Plieninger T, Sanesi G (2017) How does the forest-based bioeconomy relate to amenity values? In: Winkel G (ed) Towards a sustainable European forest-based bioeconomy – assessment and the way forward. What Science Can Tell Us 8. EFI, pp 92–100

Vilà-Cabrera A, Coll L, Martínez-Vilalta J, Retana J (2018) Forest management for adaptation to climate change in the Mediterranean basin: a synthesis of evidence. For Ecol Manag 407:16–22

Yachi S, Loreau M (1999) Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. Proc Natl Acad Sci USA 96:1463–1468