This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 289437

ARANGE Deliverable D5.2

Recommendations for multifunctional forest management strategies

30.07.2015

Matija Klopčič, Andrej Bončina, Adrian Enache, Manfred J. Lexer

with the contributions of

Thomas Cordonnier, Tomas Hlasny, Martin Kühmaier, Michael Maroschek, Marta Pardos, Karl Stampfer, Erik Wilhelmsson, Tzvetan Zlatanov

ARANGE - Grant no. 289437- Advanced multifunctional forest management in European mountain ranges

Document Properties

Document number	FP7-289437-ARANGE / D5.2
Document title	D5.2 Recommendations for multifunctional forest management strategies
Author(s)	Matija Klopčič, Andrej Bončina, Adrian Enache, Manfred J. Lexer
Date of last revision	15092015
Status	Final
Version	Version 1.2
Dissemination level	PU
Relation	WP5, based on WP1, WP2, and WP4

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 289437.

Keywords:

European mountain forests, forest management, silviculture, harvesting technology, climate change, ecosystem services, adaptation

Abstract:

Deliverable provides an overview on currently used silvicultural and harvesting systems, the evaluation of their efficiency and suitability for provisioning of portfolio of ecosystem services (ES), and recommendations and possible improvements regarding utilization of forest management systems in mountain forests, considering the interdependency of silvicultural systems and technically feasible harvesting systems. It consolidated all the results from the previous tasks within the ARANGE project, some information were gathered by questionnaires. The results showed that the performance and efficiency of currently used silvicultural and harvesting systems related to BAU forest management in regard to provisioning the demanded portfolio of ES were satisfactory in most CSAs. However, surprising was that no obvious relationship was detected between the demanded ES (i.e. management objectives) and the BAU forest management approaches. Nevertheless, current forest management practices in European mountain forests need adaptations and improvements in order to be more efficient in providing demanded ES and to cope climate change. To adapt stands to possible climate change, sufficient adaptations and modifications within the BAU forest management are feasible. In general, these changes should not alter the BAU forest management practices, but should only complement and adjust them to specific needs of ES demands or climate change adaptation. The recommendation of one single general multifunctional forest management approach in European mountain forests is not appropriate or reasonable. Forest management must be adapted to stand, site and climate conditions as well as to demands of forest owners and stakeholders for provisioning ES. Since the frame conditions as well as the environment (e.g. climate) are subjected to constant changes, forest management strategies need to be flexible and adaptive to be able to cope with them. However, time lags in decision making and in forest response to changes in management regimes limit the ability to follow such changes instantly. This conclusion does not invalidate the principles of the adaptive forest management approach but emphasizes the limitations of a command and control approach in forest management under uncertainty.

TABLE OF CONTENTS

1. Introduction

In the states of the European Union, mountain areas represent approximately 40% of total surface (Nordregio… 2004), and 41% of this area is covered by forests (Price et al. 2011), giving them a significant role in societal, economic as well as ecological aspects. Mountain forests provide goods and services essential to the livelihood of both highland and lowland communities, that is a wide variety of ecosystem services, from protection against rock fall, avalanches and torrential flows up to high quality drinking water, wildlife habitats, landscape scenic beauty, timber production and carbon sequestration (Forest Europe et al. 2011; Price et al. 2011). With an increasing societal demands for forest products and ecosystem services (European Commission 2013), the selection of suitable and effective silvicultural and harvesting systems for their provisioning is of the highest importance for multifunctional forest management.

Three historical characteristics of mountain forestry can be exposed if compared to the lowland forestry. First, there is a rich forestry tradition in many mountain regions and mountain forests across Europe. In many countries "the regular forestry" characterized by forest regulations, forest management plans, professional forestry experts ("Waldbereiters") etc., began in mountain regions as early as in the 15th and 16th centuries; the main aim at that time was to provide sustainable timber flows. Secondly, mountain areas were much less appropriate for agricultural use compared to the lowlands; therefore forest use was traditionally of high economic importance for local communities. Forests were a source of timber for sale, they enabled the development of mines, and iron and glass industry. In the middle ages the economic importance of (mountain) forests in Central Europe was so high that the government limited property rights of forest owners to ensure sufficient timber supply for industry (e.g. Maximilian order; Johann 2007). Finally, in mountainous regions people recognized the importance of non-timber forest functions very early. Protection against gravitational hazards was probably the most important forest function; it was provided through simple verbal or written regulations (e.g. "Bannbriefe") as early as the 14th century (Schüler 1992). The awareness on protection function of (mountain) forests increased in the following centuries; in Central Europe it was exposed especially after great floods at the end of the 19th century. Similarly, some other non-timber forest functions (services) seemed to appear on the agenda earlier in the mountain regions than in the lowlands; for example, in the era of romanticism mountain regions like the Alps became highly important for nature conservation purposes. The high dependence of communities in mountain regions on forests and ecosystem services has been reflected in many ways, also in specific cultural aspects such as wood-based architecture, wood-based handcrafting, cultural traditions related to forests or specific tree species, specific relation of people in regard to the forests, etc.

In the development of mountain forestry – from the beginnings up to now – silviculture has played a crucial role for providing desired ecosystem services from the forests. Frame conditions for forest management (i.e. demographic changes, innovations in harvesting technology, new possibilities and approaches in rural development and economy, environmental changes) have changed considerably in the past, resulting in changed and new demands towards mountain forests. Such changes may be expected to be present also in the future, possibly in even larger extent and intensity than in the past. Climate change is generally believed to happen in the future (Christensen et al. 2011), which will strongly affect also forests (Lindner et al. 2010). Therefore, the consortium of the ARANGE project was motivated to evaluate the effectiveness and suitability of currently practiced forest management systems (i.e. silvicultural system & harvesting technology) to provide the demanded ES portfolio in mountain forests across European mountain ranges, to assess their possibilities for adaptation to possible climate change, and to search for possible improvements in forest management in regard to both abovementioned goals. This deliverable provides an overview on currently used silvicultural and harvesting systems, the evaluation of their efficiency and suitability for provisioning of ES portfolios, and recommendations and possible improvements regarding utilization of forest management systems in mountain forests, considering the interdependency of silvicultural systems and technically feasible harvesting systems.

1.1 Abbreviations used in the deliverable

AM = alternative forest management
AS = aesthetics (ES)
BAU FM = business-as-usual forest management
BD = biodiversity conservation (ES)
BM = biomass for energy production (ES)
CS = carbon sequestration (ES)
CSA = case study area
CSR = case study responsible person
ES = ecosystem service
FM = forest management
FW = fuel wood production (ES)
GM = game management and hunting (ES)
HS = harvesting system
LS = livestock pasture (ES)
NW = non-wood forest products (ES)
PGH = protection against gravitational hazards (ES)
RC = recreation (ES)
RF = provisioning of reindeer fodder (ES)
TI = timber production (ES)
WT = regulation of water balance (ES)

2. Objectives

The main objectives of this deliverable are:

(i) to give an overview on silviculture systems and timber harvesting practices applied across the European mountain regions,

(ii) to assess in a generic way the suitability and effectiveness of various forest management strategies (i.e. silvicultural system & harvesting technology) applied in the analyzed mountain forests in regard to the desired ES under current and future climate conditions (considering several analytical aspects: i) topography and related options for harvesting technologies, ii) tree species composition of the forest, iii) the demanded ES portfolio, iv) the ownership), and

(iii) to discuss possible adaptation and improvements of the current silviculture and timber harvesting practices.

3. Methods

The deliverable D5.2 is based on consolidated results from previous tasks within the ARANGE project. It is based on deliverables and results of the tasks done within the ARANGE project; therefore the main method to develop D5.2 was analyzing published deliverables, publications, and other (also unpublished) results. We paid special attention to documents dealing with i) historical aspects of forest management, ii) currently applied forest management strategies, iii) modelling forest development in regard to different management strategies and climate scenarios, and iv) political and social aspects related to mountain forests and land use. In detail we investigated deliverables D1.3 ("Current and historical forest management in the case study areas"; Klopčič et al. 2013), D2.3 ("Analysis of historic & current forest management practices, forest dynamics and related ecosystem services"; Pardos et al. 2014), and D3.2 ("Mountain Forests and Land Use Scenarios – a review and scenario development"; Aggestam and Wolfslehner 2013). We also analyzed the available simulation outputs on forest stand development under BAU FM as well as under AMs (e.g. published and unpublished scientific papers, draft manuscripts, unpublished results).

In order to gain some more detailed information on demands towards forests, BAU FM and AM in the CSAs, a questionnaire on the most important key issues in the CSA was developed (Appendix 1). Each CSR completed the questionnaire based on his/her expert knowledge and documents, reports, and unpublished results obtained within the ARANGE project. The completed questionnaires provided information mainly for sections 5 and 6 of this deliverable.

In section 6 "Synthesis", a modified trade-off analysis between demands for ES and efficiency of BAU FM (i.e. silvicultural system) to provide demanded ES was applied to rank silvicultural systems in their ability and effectiveness in provisioning the desired portfolio of the main ES (timber TI, fuel wood FW, and biomass for energy production BM, carbon sequestration CS, biodiversity conservation BD, protection against natural gravitational hazards PGH). A 2-D scatterplot diagram was charted showing the relationship between weighted demands for ES (Equation 1) and weighted efficiency rate of BAU FM providing the entire portfolio of ES (Equation 2) for each BAU FM approach (i.e. silvicultural system).

$$D_{BAU} = \sum_i^n D_{ES(i)} \times W_{ES(i)} \quad \text{(Eq. 1),}$$

$$E_{BAU} = \sum_i^n E_{ES(i)} \times W_{ES(i)} \quad \text{(Eq. 2),}$$

where:

- i is representing the main (n) ES considered in ARANGE;
- D_{BAU} is the weighted demand for the entire portfolio of ES;
- $D_{ES(i)}$ is the average current demand for the i-th ES, calculated as an average between assessed demands of the forest owner(s) and stakeholders evaluated on a 1-10 scale (10 being highly demanded);

- $E_{ES(i)}$ is the expert assessment of effectiveness of the BAU FM in provisioning the i-th ES (on a scale 1-10, 10 being the most efficient), made by the CSRs;
- $W_{ES(i)}$ is the weight acquired from the average current demands for the i-th ES in European mountain forests, calculated as the average assessment of demands towards ES of forest owners and stakeholders across all CSAs.

4. Management approaches and silvicultural systems

4.1 Categorization of silvicultural systems

In the forests of European mountain ranges, several silvicultural systems are applied to implement multifunctional forest management (Table 4.1), some creating uneven-aged and the others even-aged forest stand structure. They are mainly based on natural regeneration, only some practice combination of natural and artificial (mainly planting) regeneration. Weeding is generally not practiced, while tending and thinning operations are frequently performed, but differ in type and intensity. The type of regeneration fellings is directly related to the name of the regeneration system, therefore only a number of fellings per time period (i.e. regeneration period) and approximate size of fellings are given in the Table 4.1 (if applicable and data available).

Table 4.1: Silvicultural systems applied in the analyzed European mountain forests.

Silvicultural system	Stand type*	Regeneration	Weeding	Tending	Thinning type / intensity	Regeneration felling	
						sequence	size of fellings
Single tree selection	UA	Natural	no	extensive**	extensive**	1/10-15 y	-
Group selection	UA	Natural	no	no	extensive**	1/10-15 y	0.05-0.2 ha
Patch cut system	UA/EA	Natural	no	intensive	random / intensive	3-4/20 y	0.1-0.5 ha
Irregular shelterwood	UA/EA	Natural	no	intensive	above+below/ intensive	3/20-30 y	0.3-several ha
Uniform shelterwood	EA	natural + artificial	yes	intensive	below/ intensive	3-4/15-30 y	several ha
Clear cutting	EA	artificial + natural	no	intensive	above+below/ extensive	1	>1 ha
Simple coppice	EA	Natural	no	intensive	Below+random/ intensive	1	Optional

* stand type: UA – uneven-aged, EA – even-aged

** both tending and thinnings in single tree selection and group selection systems are normally done simultaneously with regeneration (selection) fellings

4.1.1 Regeneration

Considering the type of regeneration when stands are rejuvenated, two main types can be recognized in the analyzed mountain forests: 1) natural and 2) combined natural and artificial regeneration. In most of the CSAs natural regeneration is used (Table 4.1), originated mainly from natural seed bank, only the simple coppice system uses a vegetative regeneration by sprouting from stumps. When a combination of natural and artificial regeneration is used, the latter is done by planting different tree species, *Picea abies* being mostly used, but also *Pinus sylvestris*, *Larix decidua*, *Fagus sylvatica* and *Fraxinus excelsior* are planted.

4.1.2 Weeding, tending and precommercial thinnings

Weeding is not the best distinguishing operations between silvicultural systems since weeding is conducted only within the uniform shelterwood system, in all other systems weeding is generally not performed.

Tending operations are a part of most silvicultural systems, however their intensity varies. Intensive tending operations are carried out in most of the systems; as an intensive tending operation, a removal of 30-80 % of individuals in one operation is understood. In the single tree selection system extensive tending operations are carried out since stand structure developed by such a system stimulate “indirect” tending in regeneration, therefore intensive measures are unnecessary.

Precommercial thinnings were not explicitly reported, but can be conducted in several systems and were reported in D1.3 either as a tending or thinning operation.

4.1.3 Thinnings

Thinning operations are being implemented within all silvicultural systems applied in the analyzed mountain forests, the main constraint for thinning not being applied are unfavorable site conditions (i.e. steep slopes, high rockiness). With single tree selection, group selection, and clear cutting systems extensive thinnings are applied, while in all other systems intensive thinnings are performed.

In the irregular shelterwood and clear cutting systems both thinnings from above and from below are practiced, in patch cut and coppice systems mainly random thinnings are executed, while in uniform shelterwood system thinnings from below are performed in the analyszed regions.

4.1.4 Regeneration fellings

Regeneration fellings characterize the silvicultural system. Regarding the size of regenerated forest area, two main categories can be recognized: 1) small-scale systems including single tree selection, group selection, patch cut system, and in some variations irregular shelterwood system, and 2) large-scale systems including some variations of irregular shelterwood system, uniform shelterwood system, clear cutting, and simple coppice system.

Regarding the sequence of operations silvicultural systems can be categorized into three groups: 1) systems with continuing regeneration (selection) fellings, including single tree selection and group selection systems, 2) systems with several (2-4) consecutive regeneration fellings in a prescribed time period (i.e. regeneration period), including patch cut system, irregular shelterwood system, and uniform shelterwood system, and 3) systems with a single regeneration felling including clear cutting system and simple coppice system.

Considering the pattern of regeneration felling silvicultural systems could be categorized into three categories: 1) systems of large-scale concentrated regeneration (> 1 ha), including clear cutting system, simple coppice system, uniform shelterwood system, and some variations of irregular shelterwood system, 2) systems of concentrated regeneration in small-scale groups (< 1 ha), including small-scale variations of irregular shelterwood system and patch cut system, but also some variations of group selection system, and 3) systems of diffused regeneration, including single tree selection and group selection systems.

4.1.5 Revised silvicultural systems in the forests of European mountain ranges

Based on facts given above, a revised categorization of silvicultural systems applied in European mountain forests can be done, distinguishing several silvicultural systems described below. However, in other mountain forest areas which had not been analyzed within the ARANGE project some other silvicultural system not listed here can be in use.

Single tree selection system is the most representative system creating uneven-aged stands. Within this silvicultural system, scattered individual trees of multiple age classes are selected to be harvested over the whole stand area. Such harvesting produces small canopy openings, which are especially conducive to the establishment and growth of shade-tolerant tree species. Harvest trees are selected by diameter and structure regulation. Created stands are always of uneven-aged structure. No significant needs for tending and thinning measures are expressed in these stands.

Group selection system is another silvicultural system creating uneven-aged stands. According to this concept small groups of trees are selected to be harvested over the whole area. This regeneration system produces canopy openings of sizes 0.1-0.2 ha (i.e. circular gaps approximately one tree height wide), in more extreme versions up to 0.5 ha (i.e. circular gaps approximately 2-3 tree heights wide). Several variants of group selection system could be found across mountain ranges in Europe. In steep mountainous regions of the Eastern Alps in Austria, this system is related to a sky-line based timber extraction, therefore selection cuts are flexible in size and executed as slit (5-40 m wide, up to 80 m long) or small patch cuts along the sky-line track which are spanned diagonally across the slope. In the Dinaric Mountains in Slovenia, group selection is executed as harvesting of small groups of trees on areas of 0.05-0.2 ha irregularly spaced in a stand. Usually there is only need for low-intensity tending and thinning measures in these stands. Due to a high similarity in conducting regeneration cuts, **patch cut system** was included into this category.

Irregular shelterwood system is silvicultural system which can create uneven-aged or even-aged stands, depending on the size of initial patches harvested to regenerate a stand. Regenerating a stand is usually performed on several regeneration areas in a stand of which number and size depend on the size of a stand to be regenerated, the planned harvesting intensity, and the presence of advanced regeneration. If no advanced regeneration is present, the seeding felling in the sense of a shelterwood system is performed and waited for natural regeneration to occur. Initial regeneration areas (patches) are usually 0.1-0.3 (0.5) ha large (size of 1-2 tree heights in diameter) and are enlarged afterwards in a series of secondary fellings, frequently in two harvesting operations (enlarging regeneration areas up to sizes between 0.5-1 ha). There are 1-3 initial patches per hectare, depending on the planned harvesting intensity and length of the regeneration period. The second regeneration felling is made by removing most of mature trees in the initial regenerated area (some could still be left as seed bearers) and some surrounding trees in the form of a ring around the regenerated area (to enlarge the regenerated area), while mature stand around this area could be additionally thinned to harvest mature trees and / or promote the growth of high quality stems. This could be continued with adding (asymmetrical) extensions to the initial gap area. In the final regeneration felling all mature trees in the stand (or part thereof) are removed. This procedure is continuously repeated until the intended forest area is regenerated.

Uniform shelterwood system is a system of successive regeneration fellings on a larger forest area and usually implies a uniform opening of the canopy, creating new even-aged stand. When the stand approaches the age at which it should be harvested and regenerated, the harvest is made in several steps. First step is the seeding cut, which removes a certain portion of trees evenly across a stand to open stand canopy and provide sufficient light to ensure germination and survival of seedlings. The seeding cut is followed by one or several secondary fellings to provide more light for the established regeneration layer. The last cut is the final felling of the residual stand, when the regeneration is already well established. To qualify as a uniform shelterwood system at least two regeneration cuts are required.

Clear cutting system prescribes successive forest areas (coupes) to be clear felled, some pre-existing poles or groups of saplings may be left if they are large enough to form self-contained crops. Afterwards, coupes are (usually artificially) regenerated. Created new stands are of even-aged structure.

Simple coppice system is a silvicultural system in which a (fixed) area of old crop (i.e. an annual coupe) is annually clear felled. The entire area of coppice stand is divided into the annual coupes in numbers equal to the number of years in the rotation period. A result of a simple coppice system is new even-aged coppice stand.

4.2 Silvicultural systems in the CSAs

Usually there is one "standard" silvicultural system practiced in a region. However, in the CSA 1 Montes Valsain, Spain, and CSA 4 Snežnik, Dinaric Mountains, Slovenia, more than one system are practiced side by side, either depending on stand types, objectives or owner type (Table 4.2).

Table 4.2: Silvicultural systems practiced in the CSAs

Silvicultural system	CSA 1 Iberian Mts.	CSA 2 E Alps	CSA 3 W Alps	CSA 4 Dinaric Mts	CSA 5 Scand. Mts.	CSA 6 Carpathians	CSA 7 Rhodope
Single tree selection s.		×		×			
Group selection s.	×		×	×			
Irregular shelterwood s.				×			×
Uniform shelterwood s.						×	
Clear Cutting s.					×		
Simple coppice system	×						

5. Key issues in the CSAs

The information on key issues in each CSA included in the ARANGE project were gathered by a questionnaire (Appendix 1) which was completed for each CSA by the corresponding Case Study Responsible person (CSR) and a team of (forestry) experts. The forest owners' and stakeholders' demands for ES were obtained from the completed questionnaires distributed among them in the frame of WP6, while the efficiency of the BAU FM in provisioning demanded ES were obtained as an expert knowledge of the CSRs based on their experiences and/or data. A standardised analysis of the completed questionnaires was applied across CSAs and figures 5.1.1-5.7.1 were plotted based on the described data.. The thorough analysis of efficiency gaps in harvesting systems were done, but only summarized results are shown in this chapter; the detailed results can be found in the Appendix 2. The abbreviations of ES are given in the Introduction.

5.1 Montes Valsain, Iberian Mountains, Spain

5.1.1 Effectiveness of BAU FM in providing ES

In the CSA Montes Valsain, Spain, two main BAU FM are applied, even-aged FM applying patch cut system in *Pinus sylvestris* dominated stands (hereinafter *Pinus* stands) and simple coppice FM in the *Quercus pyrennaica* dominated stands (hereinafter *Quercus* stands). The portfolios of ES in these two forest types also differ, therefore the analysis were done separately.

In the even-aged *Pinus* stands, the main owners' demands are TI, CS, PGH, RC, WT, and GM, although any was very highly demanded (Figure 5.1.1). The stakeholders' demands for provisioning ES are similar to those from the owners, though their demand for WT is much higher. In the coppice *Quercus* stands, the demands for provisioning ES are much less expressed (Figure 5.1.2). The demands for RC provisioning are on the same level as in *Pinus* stands, while all other ES are less demanded. However, LS is relatively highly demanded by the forest owners.

In *Pinus* stands, the BAU FM is relatively effective in provisioning all importantly demanded ES, but is less effective in *Quercus* stands.

Generally BAU FM is integrating ES on a stand spatial scale. In the *Pinus* stands, the most typical combinations of ES being provided simultaneously are: 1) CS, BD, WT, and GM, 2) CS, BD, PGH, RC, WT, and GM, and 3) TI, FW, BM, CS, BD, WT, and GM. In the *Quercus* stands, simultaneously provided ES are 1) TI, FW, BM, CS, and RC, 2) CS, BD, and RC, and 3) CS, BD, PGH, RC, and LS. The main FM approach to provide productive ES (TI, FW, BM in *Pinus* and *Quercus* stands) is the approach with allocations on a stand scale, to provide some ES (CS, BD, WT, and GM in *Pinus* stands, CS, BD, and RC in *Quercus* stands) a matrix approach is used, while for provisioning of PGH and RC in *Pinus* stands and PGH and LS in *Querus* stands the approach of allocations on a landscape scale is applied.

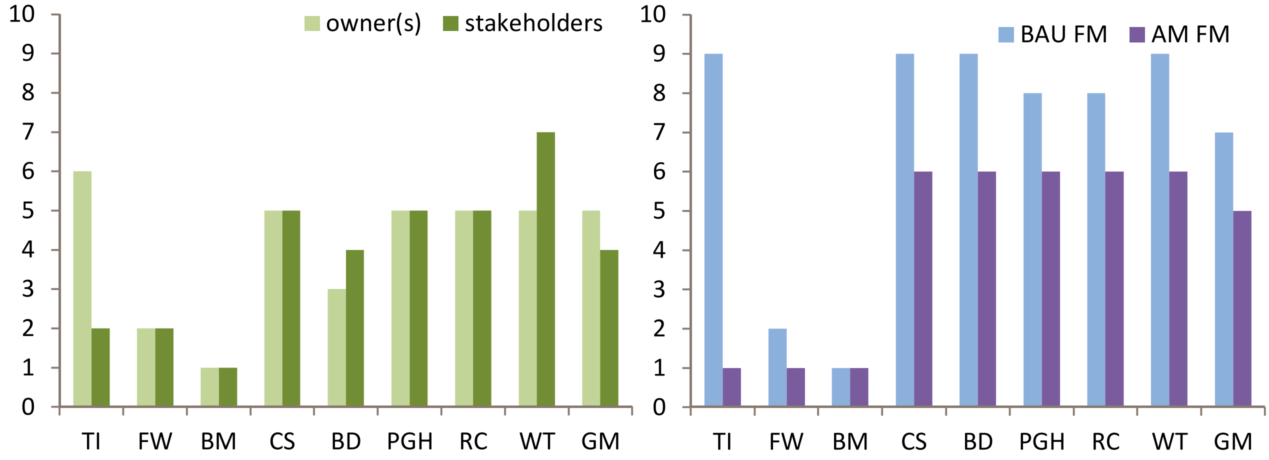

Figure 5.1.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) in the even-aged *Pinus sylvestris* stands (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RC – recreation, WT – regulation water balance, GM – game management and hunting)

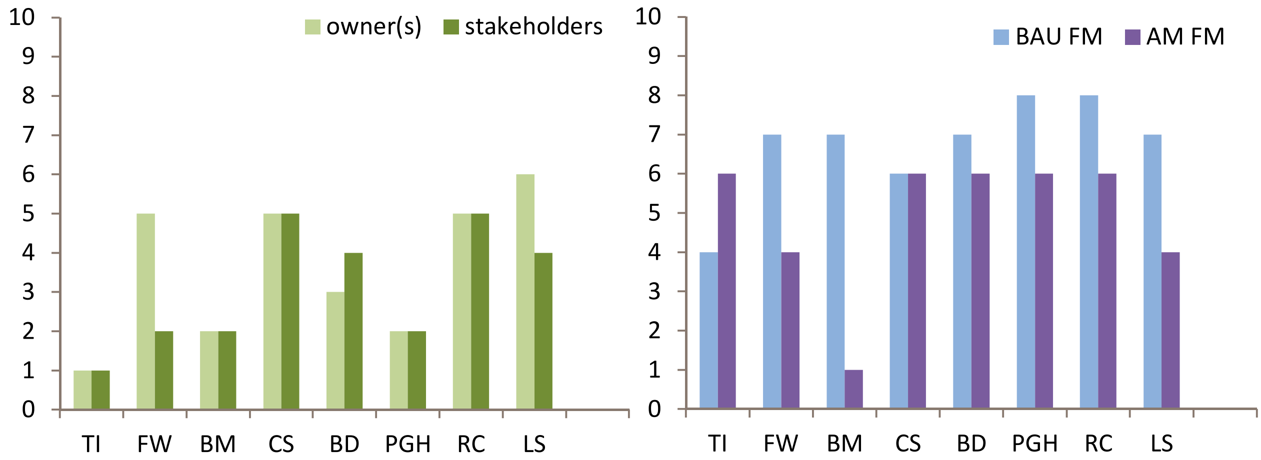

Figure 5.1.2: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) in the coppice *Quercus pyrennaica* stands (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RC – recreation, LS – livestock pasture)

Several conflicting ES if integrated at stand scale were listed. 1) TI, FW and BD could have been hypothetically simultaneously and effectively provided on a spatial scale of 20-100 ha, 2) TI, FW and RC on the same scale of 20-100 ha, while 3) TI, FW and GM, and 4) TI, FW, CS, RC, and GM on a scale of more than 1000 ha.

5.1.2 BAU FM and harvesting technologies

The harvesting operations are performed with mechanized systems (chain saw and processor for timber harvesting, skidder and forwarder for timber extraction) and the tree-length and cut-to-length harvesting methods are used in almost equal shares, 49% and 51% respectively. The road density is 34.7 m/ha and the mean extraction distance from tree to forest road is 520 m.

Although the road density is about two and a half times higher than the average across CSAs, the mean extraction distance is very high. With such a high road network density, the expected mean extraction distance would be in the range of 150 – 200 m. Thus, it seems that either the layout of the roads is not optimal or not all roads of the road network are used for harvesting operations for various reasons (e.g. damaged roads, public roads). Timber felling and processing is performed entirely by chainsaw and the timber extraction is done 100% by skidders. The productivity of the overall BAU HS (felling, processing and extraction) is very low (50% below the average across CSAs), especially due to the low productivity of felling and processing operations with chainsaw.

Although the CSR reported that BAU HS does not imply any constraints for implementation of the BAU FM, the performance and productivity of BAU HS can be improved by enhancing the road network infrastructure, with better trained forest workers (trainings), and utilization of more suitable and more efficient alternative HS (i.e. chain saw and harvesters for timber harvesting, a combination of skidder, forwarder and cable yarder for timber extraction).

5.1.3 BAU FM and climate change

In both *Pinus* and *Quercus* stands, climate change will have a moderately negative or neutral impact on the provisioning of most of ES in the CSA (Table 5.1.1).

In *Pinus* stands, the adaptation to climate change that could be achieved with BAU FM is considered sufficient. The main adaptation measure would be the enhancement of mixture and mixed tree species composition in stands around and above 1500 m. As a conclusion, in *Pinus* stands no urgent need for an application of alternative FM was expressed.

Table 5.1.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change (p – even-aged *Pinus* stands, Q – coppice *Quercus* stands)

ES	Sensitivity of BAU FM in providing ES under climate change conditions									
	strongly negative		moderately negative		neutral		moderately positive		strongly positive	
	P	Q	P	Q	P	Q	P	Q	P	Q
Timber			×	×						
Fuel wood				×	×					
Biomass for energy					×	×				
Carbon sequestration			×	×						
Biodiversity conservation			×	×						
Protection against gr. hazards			×	×						
Recreation					×	×				
Regulating water balance					×					
Game management and hunting					×					
Livestock pasture						×				

In *Quercus* stands, no possibility for adaptation compatible with BAU FM was recognized; therefore an alternative FM should be applied in these stands. The BAU FM needs a major change in silvicultural system. Current coppice stands need to be converted to high forests through an indirect gradual transformation.

5.1.4 Alternative FM

The simulated development of forest stands managed according to prescribed alternative forest management practices (AM) showed that there were no improvements in provisioning ES (with an exception being TI in the *Quercus* stands; Figure 5.1.1).

Since any of the prescribed and tested AM did not reveal significant improvements in provisioning ES in both *Pinus* and *Quercus* stands, none of the prescribed AM could be recommended. However, in the *Quercus* coppice stands the transformation of coppice system and coppice stands into high forests can be recommended according to the expert knowledge. Additional analyses need to be done in order to be able to recommend which silvicultural system (or their combination) should have been applied in order to gain best results for the forest owner(s) and stakeholders regarding the provisioning of demanded ES.

5.2 Vercors, Western Alps, France

5.2.1 Effectiveness of BAU FM in providing ES

In the CSA Vercors, France, the demands of the owner and the stakeholders are mainly for wood supply, being TI and FW, somewhat less BM (Figure 5.2.1). Beside the mentioned the demands of the stakeholders are additionally oriented towards biodiversity conservation (BD), recreation provisioning (RC) and game management (GM). The effectiveness of BAU FM (i.e. single tree selection system) in provisioning the demanded ES is on a relatively high level for TI and FW, and RC, less so for provisioning of BD, PGH, and GM, and the least for provisioning of BM and CS. All highly demanded and effectively provided ES are currently aimed for in the management plans, while CS and PGH are not.

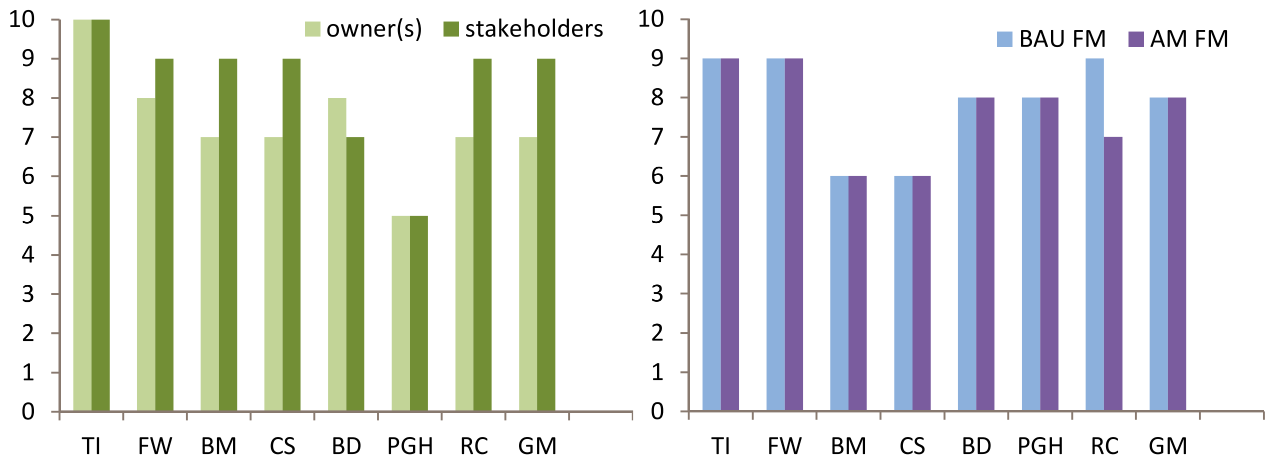

Figure 5.2.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RC – recreation, GM – game management and hunting)

BAU FM is generally aiming to integrate ES on a stand spatial level. The exceptions are BD and PGH, which are provided in allocated areas of larger spatial scale (i.e. landscape scale; BD, PGH) or stand scale (BD). The integrational approach is especially exposed for simultaneous provisioning of TI, BD, REC and GM.

In the CSA simultaneous provisioning of TI, BD and REC impose conflicts if integrated on a stand spatial scale. Hypothetically, if provided on a 5-20 ha spatial scale there would be no conflict.

5.2.2 BAU FM and harvesting technologies

The harvesting operations are performed with partly mechanized systems (chain saw for timber harvesting, skidder for timber extraction) using 100% tree length harvesting method. The road density is 14.7 m/ha and the mean extraction distance is 490 m. The technology was assessed as relatively suitable to implement the BAU FM in the CSA (rank 8/10).

The BAU HS productivity is 11% below the average across CSAs (13.0 vs. 14.6 m^3/h), but it is as high as the average value across CSAs that use partly mechanized systems. The productivity of the BAU HS is only 4% lower than the optimum for this type of HS, which means the road network is well developed in accordance with the skidding technology and forest workers are experienced using this technology.

However, the terrain and stand conditions allow utilization of more efficient HS. If compared to the BAU situation, the combination of chain saw and harvester for timber harvesting and skidder, forwarder and cable yarder for timber extraction would increase productivity and lower the harvesting costs, the number of accidents and the residual stand damage, but some negative points are also present with such a change (i.e. higher fuel consumption and $CO2_{eq}$ emissions). In addition to these, the CSR as the forestry expert exposed 1) denser forest road network would improve opening up the area, 2) trees could be cut into assortments at roadside for quality timber, 3) coordination between operators could have been more effective, 4) the application of group selection or small scale irregular shelterwood systems could be of interest in some locations.

5.2.3 BAU FM and climate change

Climate change will not have a high impact on the effectiveness of BAU FM in provisioning of ES in the CSA (Table 5.2.1). Only the effectiveness of BAU FM in TI, CS and RC provisioning will be moderately negatively affected.

The possibility to adapt BAU FM to climate change is sufficient; therefore there is no urgent need to apply any alternative FM. Reducing the harvesting diameter would reduce risks, the same would be by promotion of mixed stands and avoidance of unstable highly stocked stands. Additional BAU FM adaptation possibility would be controlling the competition by silver fir and the high dynamics of European beech. Regeneration in larger canopy gaps might also adapt BAU FM to climate change.

Table 5.2.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change

ES	Sensitivity of BAU FM in providing ES under climate change conditions				
	strongly negative	moderately negative	neutral	moderately positive	strongly positive
Timber		×			
Fuel wood			×		
Biomass for energy			×		
Carbon sequestration		×			
Biodiversity conservation			×		
Protection against gr. hazards			×		
Recreation		×			
Game management and hunting			×		

5.2.4 Alternative FM

Although there is no urgent need to change BAU FM into AM, the latter could improve the provisioning of ES in the CSA both under current climate and conditions of possible climate change. The most suitable AM would be patch cut/group selection silvicultural system with mean DBH of harvested trees being 45 cm. Applying variable group selection or small-scale irregular shelterwood systems would increase both the resilience and the flexibility of ES provisioning, but not necessarily the level of ES provisioning. Such AM would necessitate promoting dead trees and large trees retention measures to compensate for a decrease of harvesting DBH.

Under climate change conditions described AM would enhance provisioning of TI, BD, and PGH. Under current climate conditions the AM would provide the RC on lower level as BAU FM, while provisioning of the other ES would remain on the same level (Figure 5.2.1).

5.3 Montafon, Eastern Alps, Austria

5.3.1 Effectiveness of BAU FM in providing ES

In Montafon, Austria, the demands of the owners for provisioning of ES are oriented mainly towards timber production (TI; Figure 5.3.1), less so towards fuel wood (FW) supply and protection against gravitation hazards (PGH). The supply of biomass for energy (BM) and carbon sequestration (CS) are practically undemanded and also not recognized as aims in the forest management plans. On the other hand, stakeholders have much lower demands for wood supply, but higher for biodiversity conservation, protection against gravitational hazards, but especially for provisioning of recreation and game management and hunting.

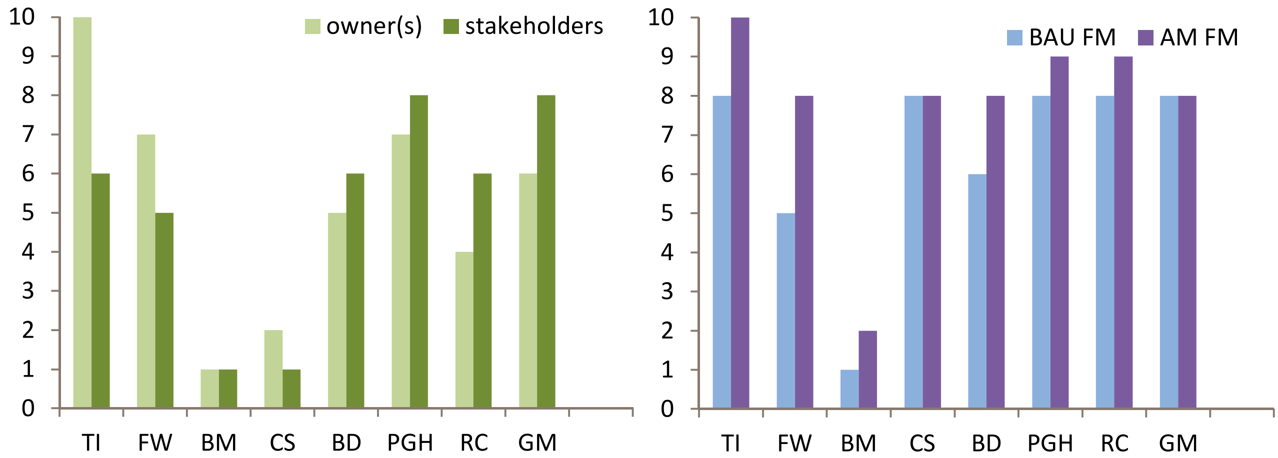

Figure 5.3.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RC – recreation, GM – game management and hunting)

In this CSA, the BAU FM (i.e. group selection system) is effective in provisioning the demanded ES, but not as much as in some other CSAs. The support of BAU FM for provisioning the most demanded TI was assessed to be only 80 % effective (rank 8/10).The same rank was given for provisioning of CS (although practically not demanded!), PGH, RC, and GM, which were all highly demanded by the owner(s) or stakeholders. Relatively the least supported ES by BAU FM was FW.

BAU FM is attempting to integrate ES on a stand spatial level. Although BD, GM and RC are attempting to be integrated on a stand spatial scale, they are mainly provided on larger allocated areas (landscape scale). The integrational approach is especially exposed for simultaneous provisioning of 1) TI, FW, BD, PGH, RC, and GM, and 2) TI, FW, and PGH.

Simultaneous provisioning of TI and GM is imposing a conflict when integrated on a small spatial scale. The forestry experts estimated that non-conflict provisioning would be possible on a spatial scale of 100-1000 ha.

5.3.2 BAU FM and harvesting technologies

The harvesting technology used in the CSA is partly mechanized and consists of chain saw for felling and processing and sledge winch for timber extraction. The cut-to-length harvesting method is applied. Such a technology does not imply any constraints to BAU FM implementation; moreover it efficiently implements BAU FM (rank 8/10). The road density is 19.2 m/ha and the mean extraction distance is 495 m.

The high average extraction distance of 495 m hinders the utilization of appropriate mix of HS, especially for moderate slope classes (e.g. forwarders), due to lack of access to those areas. With current road density and HS available, the expected extraction distance would be 250 – 300 m. Thus, the productivity of forest operations is low (18 % below the average across CSAs), thus the harvesting costs (44.9 €/m^3) are the highest across CSAs, with about 70% above the average costs. The productivity of the BAU HS is 17% lower than the optimum productivity for cable yarders, which means that the layout of the road network should be improved with new roads for increasing the efficiency of cable yarders' utilization.

Based on the analysis, it was recommended to shift from partly mechanized systems (chain saw and cable yarder) to highly mechanized systems (harvester and forwarder) wherever the terrain and stand conditions allow. By applying the appropriate harvesting systems (e.g. chain saw and cable yarder in steep terrain and harvester and forwarder in moderate slopes), productivity of forest operations would increase, while harvesting costs and fuel consumption would lower and the number of accidents, the level of $CO2_{eq}$ emissions and the residual stand damage would decrease as well. In order to make accessible the harvesting sites where harvester + forwarder HS is the most suitable option, and to decrease the average skyline length at sites where MTY are the appropriate means, it is necessary to extend the road network. The utilization of mobile tower yarders with processor heads could have been another improvement of HS and apart from the cut-to-length method, tree-length and whole-tree methods should also be considered, in order to increase the efficiency of the extraction process and to provide biomass for bioenergy.

5.3.3 BAU FM and climate change

Climate change will have some impact on the effectiveness of BAU FM in provisioning ES in the CSA (Table 5.3.1). The effectiveness of BAU FM in TI, FW, BM, and BD provisioning will be moderately positively affected, while moderately negative effect is anticipated in provisioning CS, PGH, and RC. No impact of climate change is expected on provisioning GM.

Table 5.3.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change

ES	Sensitivity of BAU FM in providing ES under climate change conditions				
	strongly negative	moderately negative	neutral	moderately positive	strongly positive
Timber				×	
Fuel wood				×	
Biomass for energy				×	
Carbon sequestration		×			
Biodiversity conservation				×	
Protection against gr. hazards		×			
Recreation		×			
Game management and hunting			×		

A sufficient adaptation to possible climate change is anticipated to be feasible within the BAU FM; therefore no urgent need for AM was identified by the CRS. According to expert knowledge a promotion of mixed stands will provide sufficient adaptation to climate change effects. Admixed tree species, such as *Abies alba*, *Fagus sylvatica*, *Acer pseudoplatanus*, etc., should improve the resistance and resilience of currently *Picea abies* dominated forests against an intensifying disturbance regime.

5.3.4 Alternative FM

Although no urgent need to change BAU FM into AM, the simulated AM could result in some improvement in the provisioning of certain ES in the CSA both under current climate (Figure 4.3.1; TI, FW, BD, PGH, RC) and conditions of possible climate change (TI, FW, CS, PGH, RC).

The recommended AM promotes mixed tree species composition which would be assured by an additional artificial planting of *Abies alba*, *Fagus sylvatica*, *Acer pseudoplatanus,* and *Larix decidua* and promotion of these species in tending operations and reduction of browsing pressure. In addition, shorter (virtual) rotations would improve the effectiveness of FM in provisioning some ES. In parts of the forest with focus on nature conservation the area turnover should be maintained at current levels.

5.4 Sneznik, Dinaric Mountains, Slovenia

5.4.1 Effectiveness of BAU FM in providing ES

In the Slovenian CSA Sneznik, there is high demand for wood supply (TI, FW), but also for biodiversity conservation (BD) and somewhat less for game (GM). Stakeholders' demands are similar to those of the forest owner (the state), with the exception of PGH (Figure 5.4.1).

The BAU FM (i.e. small-scale irregular shelterwood system) supports provisioning of the almost entire portfolio of ES close to perfectly (rank 7-9/10). It is most effective in providing TI, FW, CS, PGH, and GM, little less BD and WT, and the least effectively BM since harvesting residues (branches, twigs, leaves, etc.) remain in forest stands.

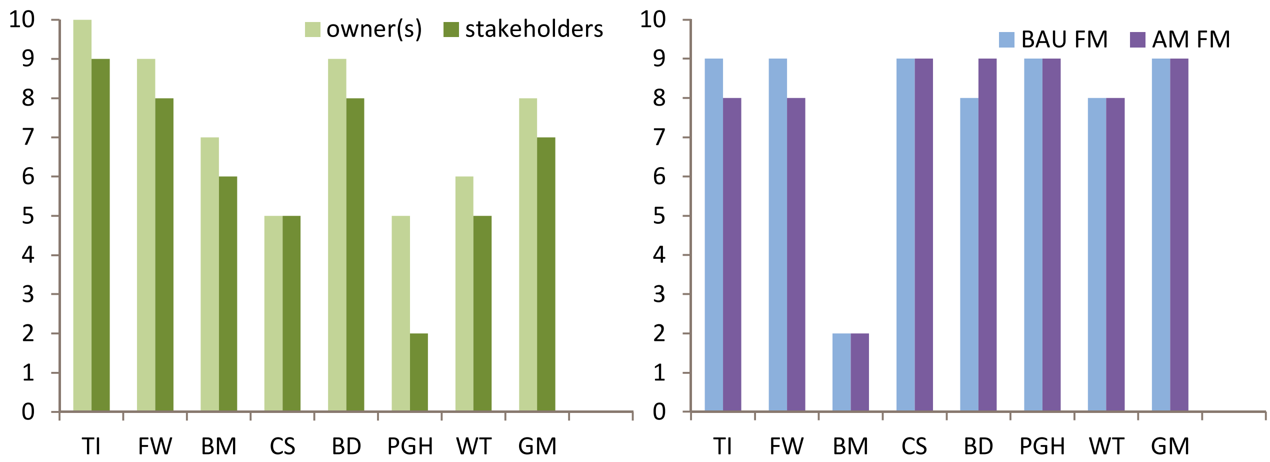

Figure 5.4.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) in CSA4 (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, WT – regulation water balance, GM – game management and hunting)

Provisioning of all ES is integrated on a stand level with a matrix approach to forest management, an exception being BD which is sometimes provided in allocated stand and/or landscape sized areas (i.e. forest reserves).

Some ES may impose conflicts when managing forests: 1) TI and BD, and 2) TI and GM. The first conflict can be efficiently solved on a 5-20 ha spatial scale, while the conflict between TI and GM is not a spatial scale related problem, but more a conceptual one.

5.4.2 BAU FM and harvesting technologies

Forest operations are in 94% performed with partly mechanized systems (chain saw for timber harvesting, tractor and skidder for timber extraction) and 6% with fully mechanized systems (harvester and forwarder), using cut-to-length harvesting method in 68% of the cases and tree-length method in 32% of the harvesting sites. The data about the forest road network was not available and the reported mean extraction distance is 446 m. Such a harvesting technology does not impose constraints for BAU FM to be implemented. In contrary, the harvesting systems are perceived as well suitable: technology combinations chain saw-tractor and chain saw-skidder were ranked 9/10, while combination harvester-forwarder 8/10.

Currently, the harvesting productivity in the CSA is 8% below the average value across CSAs, but similar to those CSAs which use partly mechanized systems. The harvesting costs are about 13% higher than the mean value across CSAs. The obtained results suggest that the quality and density of the road network is suitable for the HS used in the BAU FM. In only about 6% of the CSA fully mechanized HS (harvester and forwarder) are used, although the potential is much higher (i.e. about 53% of the area), but some other constraints (i.e. legislation, ecological constraints) need to be taken under consideration.

By further extending and improving the layout of the road network there are opportunities for i) utilization of more efficient and better adapted fully mechanized HS to moderate slope conditions (22 % of the CSA) and ii) reducing the extraction distance towards the optimal one (from 446 m towards 366 m). This would increase the productivity of forest operations, reduce the costs and numbers of accidents, increase the CO_{2eq} emissions and decrease the mean residual stand damage. By increasing the utilization rate of the cut-to-length harvesting method over the tree-length method, especially when using skidders, the fully suspended transport of logs would cause less soil disturbance and thus foster provisioning of (soil) protective ES.

5.4.3 BAU FM and climate change

Climate change will have some impact on the effectiveness of BAU FM in provisioning ES in the CSA (Table 5.4.1), but for the majority of ES this influence will be neutral. Climate change is expected to have positive effect only on BD and negative influence on TI and CS.

A sufficient adaptation with BAU FM to possible climate change is possible. A promotion of resilient tree species and mixed stands should provide sufficient adaptation and increase resistance and resilience of the studied forests. Some artificial regeneration of certain tree species should additionally enhance the resistance of forests, preserve vulnerable tree species and thus promote biodiversity. As described, no urgent need for AM was identified.

Table 5.4.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change

ES	Sensitivity of BAU FM in providing ES under climate change conditions				
	strongly negative	moderately negative	neutral	moderately positive	strongly positive
Timber		×			
Fuel wood			×		
Biomass for energy			×		
Carbon sequestration		×			
Biodiversity conservation				×	
Protection against gr. hazards			×		
Regulating water balance			×		
Game management and hunting			×		

5.4.4 Alternative FM

A model simulation of stand development under different AM revealed that AM may improve provisioning of some ES under current climate (Figure 5.4.1) and climate change conditions. The main such ES was BD.

No AM can be explicitly recommended, however some features from some of the simulated AMs could represent possible adaptation measures to climate change. According to the stand development simulation results under different forest management strategies and different climate scenarios, different silvicultural systems in different representative stand types should be used in order to sufficiently provide the demanded portfolio of ES. The artificial regeneration (i.e. extensive planting of *Picea abies*) might be a possible solution to preserve a sufficient and desired proportion of conifers in these forests in order to fulfill the owner's demands towards productive ES (i.e. timber supply). However, such an adaptation measure must be implemented cautiously since the expected climate change impact on conifers in the area is supposed to be substantial in some sites, especially at low elevations and flat and south exposed sites.

5.5 Vilhelmina, Scandinavian Mountains, Sweden

5.5.1 Effectiveness of BAU FM in providing ES

In the CSA 5 Vilhelmina, Sweden, the main owners' demand is timber supply (TI), while biodiversity conservation (BD) is ranked second (Figure 5.5.1). The provisioning of all other ES is estimated as less relevant. From the stakeholders perspective there are higher demands for provision of reindeer fodder (RF) and aesthetics (AS), but somewhat lower for TI.

The BAU FM (i.e. clear cutting system) seems effective in provisioning all productive ES related to wood supply (TI, FW, BM), as well as carbon sequestration (CS), but less so for BD and PGH, and much less for RF and AS.

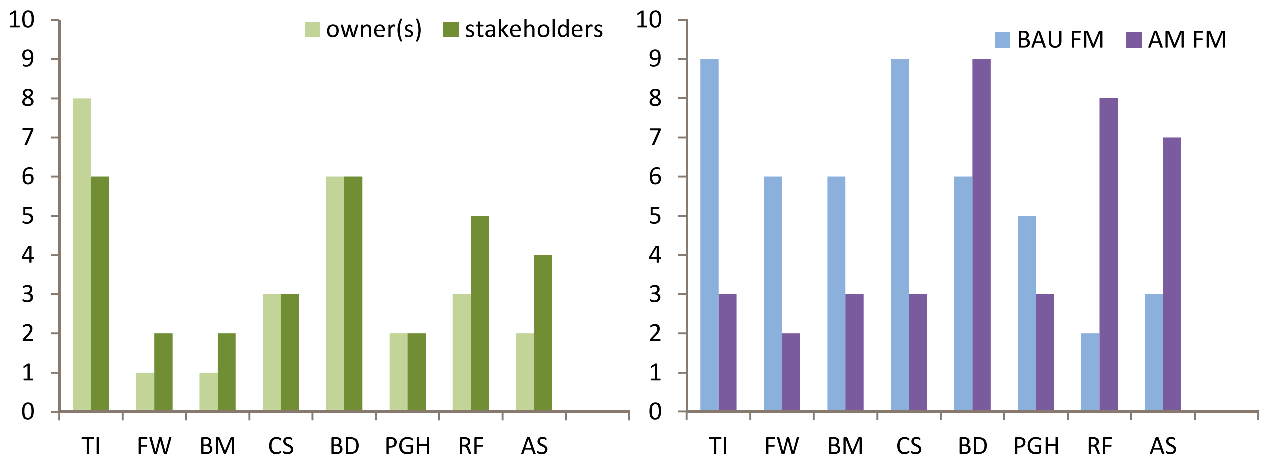

Figure 5.5.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) in CSA5 (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RF – reindeer fodder, AS – aesthetics)

The BAU FM is generally attempting to integrate most of ES on a stand spatial scale, only FW is provided in small (stand) scale allocations. The integrational approach is especially seen as suitable for simultaneous provisioning of 1) TI, BD, RF, and AS, and 2) TI, FW, BM, and CS. BD, PGH, and AS are mainly integrated on a stand scale, but provided also on large (landscape) and small (stand) scale allocated areas.

Both exposed combinations of ES also impose conflicts. The forestry experts estimated that non-conflict provisioning of the first combination of ES would be possible on a spatial scale of 20-100 ha, while ES listed in the second combination could be simultaneously provided on 1-5 ha spatial scale.

5.5.2 BAU FM and harvesting technologies

All forest operations in the CSA are performed with fully mechanized systems (harvester and forwarder) using cut-to-length harvesting method. The road network density is 7.0 m/ha and the mean extraction distance is 400 m. Such a technology is perfectly suitable to implement BAU FM in the CSA (rank 10/10), therefore no constraints were recognized by the CSR.

Although the road density is very low (48% below the average value across CSAs), the CSA has the highest productivity and one of the lowest harvesting costs across CSAs. The CSA has the lowest incidence of accidents among CSAs (about 38% below the average), proving that fully mechanized HS provide safer working conditions. The only gap that currently affects the performance of HS is the low road network density.

Some minor improvements in efficiency are possible by reducing the extraction distance from 400 m to about 300 m, and the use of high(er) efficiency machines. Thus, the productivity could increase and costs, fuel consumption and CO_{2eq} emissions could sink. In addition, the harvesting residues could be used for bioenergy production, extending the list of ES provision. Furthermore, the adjustments and improvements in planning and scheduling of the (harvesting) activities (i.e. forest management planning) would lead to additional efficiency improvements.

5.5.3 BAU FM and climate change

Climate change will have positive impacts on the effectiveness of BAU FM in provisioning ES in the CSA (Table 5.5.1).

Table 5.5.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change

ES	Sensitivity of BAU FM in providing ES under climate change conditions				
	strongly negative	moderately negative	neutral	moderately positive	strongly positive
Timber				×	
Fuel wood				×	
Biomass for energy				×	
Carbon sequestration				×	
Biodiversity conservation				×	
Protection against gr. hazards				×	
Reindeer fodder				×	
Aesthetics			×		

There is no need to adapt BAU FM to possible climate change effects since the BAU FM seems to be sufficiently adapted and also has sufficient flexibility for additional adaptation if needed.

5.5.4 Alternative FM

Although there is no need for AM due to climate change in the CSA, a simulated development of forest stands managed according to AM showed that there is potential for improvements in provisioning certain ES (Figure 5.5.1). A single tree selection system with mean dbh of harvested trees 25 cm would provide BD, RF, and AS on a reasonably higher level, while it would perform less efficiently in provisioning the ES related to wood supply (TI, FW).

5.6 Kozie chrbty, Carpathians, Slovakia

5.6.1 Effectiveness of BAU FM in providing ES

In the Slovakian CSA Kozie Chrbty, a large divergence between demands of the owner(s) and stakeholders could be observed (Figure 5.6.1). By the owner timber production (TI) is highly demanded, game management (GM) is also in his interest, while other ES are considered as less important. On the other hand, stakeholders' demands are oriented toward biodiversity conservation (BD), recreation (RC) and less to TI and carbon sequestration (CS).

BAU FM, being uniform shelterwood system, is not as effective in provisioning the required ES as desired. It is most effective in provisioning TI, but much less in provisioning other ES.

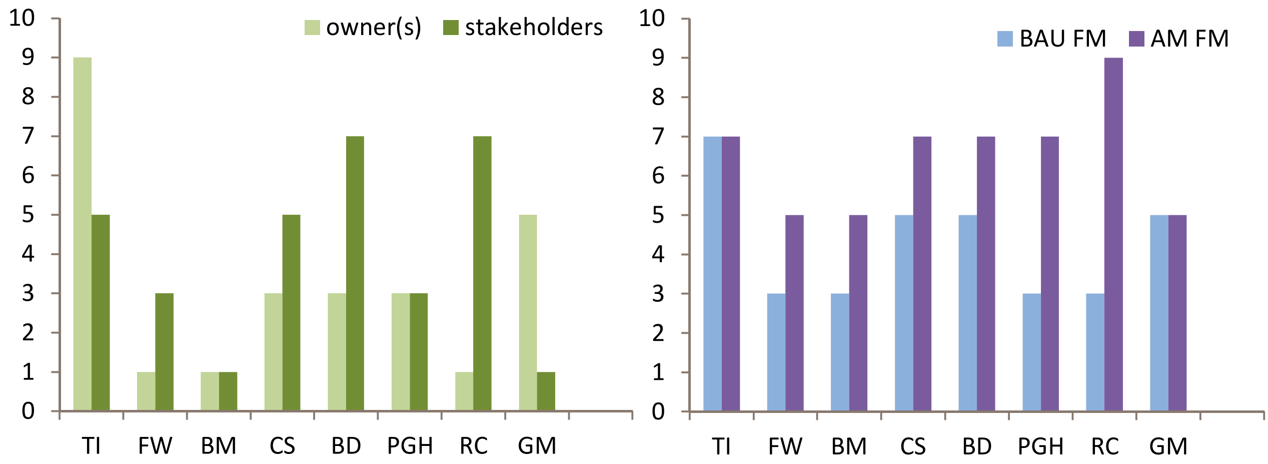

Figure 5.6.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU FM under current climate (right) in CSA6 (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RC – recreation, GM – game management and hunting)

In general, BAU FM is attempting to integrate ES at stand level, although some ES are mainly provided in allocated areas, either on a stand (BM, PGH) or landscape scale (BD, RC). Two main combinations of ES are integrated on a stand scale: 1) TI, FW, CS, BD, RC, and GM, and 2) CS, BD, PGH, RC, and GM.

Provisioning of certain ES also impose conflicts, such conflicting ES being 1) TI and RC, and 2) BD and GM. The forestry experts estimated that non-conflict provisioning of TI and RC would be possible on a spatial scale of 100-1000 ha, while for the second no estimation was provided.

5.6.2 BAU FM and harvesting technologies

Forest operations are in 95% performed with partly mechanized systems (chain saw for timber harvesting, animals and skidder for timber extraction) and 5% with fully mechanized systems (harvester and forwarder), using cut-to-length harvesting method in 95% of the cases and tree-length method in 5%. The road network density is 9.5 m/ha and the mean extraction distance is 570 m. Harvesting technology using skidder as a means of extraction was less suitable to implement BAU FM (rank 5/10), while the additional usage of animals for timber extraction seems more suitable (rank 7/10).

The road density in the CSA is below the average across CSAs with about 29% and hence, the mean extraction distance is the highest among the CSAs. Despite the long extraction distance and extraction methods used (skidder on 84% of the area, forwarder on 13%), the productivity of BAU HS is very high (i.e. 11% above the average value among CSAs, respectively 23% above the mean value of the CSAs with similar BAU HS), which is a rather surprising fact. There was no objective evidence explaining such high productivity values in the CSA, and therefore the reported productivity was considered as an outlier. As so, it was most likely that there were some data inconsistencies regarding the reported productivity of BAU HS in the CSA.

An important step towards more efficient forest operations would be to reduce the utilization of tractors and skidders by 50% and to promote instead the utilization of harvesters and forwarders and cable yarders according to their technical feasibility. This would increase the productivity, and reduce costs, incidence of accidents and slightly the residual stand damage. On the other hand, fuel consumption and CO_{2eq} emissions would increase. The road network should be extended to decrease the extraction distances and thus lowering the costs. For a more efficient utilization of harvesting and extraction machines, there is a need of know-how transfer and training of forest workers for operating them.

5.6.3 BAU FM and climate change

According to forestry experts climate change will impose mainly moderately negative impacts on the effectiveness of BAU FM in provisioning ES (Table 5.6.1). Note that disturbances such as storms and bark beetles seemed to be not explicitly taken into account. Climate change is expected to have positive effect only on GM and neutral influence on PGH and RC.

Despite negative influences of climate change on the effectiveness of BAU FM in providing ES, a sufficient adaptation to climate change with BAU FM is considered feasible. Promoting mixed tree species composition of forest stands through supporting species other than *Picea abies* in pre-commercial operations and thinning and reducing the length of *Picea abies* rotation period should be sufficient to tackle climate change impacts.

Table 5.6.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change.

ES	Sensitivity of BAU FM in providing ES under climate change conditions				
	strongly negative	moderately negative	neutral	moderately positive	strongly positive
Timber		×			
Fuel wood		×			
Biomass for energy		×			
Carbon sequestration		×			
Biodiversity conservation		×			
Protection against gr. hazards			×		
Recreation			×		
Game management and hunting				×	

5.6.4 Alternative FM

Although there was no urgent need perceived to apply AM in the CSA, a simulated development of forest stands managed according to prescribed AM showed that there is potential for improvements in provisioning several ES (Figure 5.5.1). Excluding TI and GM the provisioning of all ES would have been on a higher level if AM would have been applied under current climate conditions; especially provisioning PGH and RC would improve significantly.

In climate change conditions AM would perform better compared to BAU FM in providing TI, CS, BD, PGH, and RC.

As the most suitable AM forestry experts recommended uneven-aged FM with combined natural and artificial regeneration of *Fagus sylvatica*, *Abies alba*, *Picea abies*, *Acer pseudoplatanus*, *Pinus sylvestris* and *Quercus* sp. Four tending operations for mixture regulations and density reduction of 10 %, five thinning operations and patch cut/group selection regeneration fellings were recommended. Compared to BAU FM, such an AM would increase management flexibility, improve ES provisioning, and increase forest resistance.

5.7 Shiroka laka, Rhodope Mountains, Bulgaria

5.7.1 Effectiveness of BAU FM in providing ES

In the CSA Shiroka laka, Bulgaria, the demands of the owner and the stakeholders are mainly for wood supply, being timber, fuel wood or biomass for energy (Figure 5.7.1), demands for other ES are much less exposed. However, the effectiveness of BAU FM (i.e. large-scale irregular shelterwood system) in provisioning these ES is not on a high level, especially for woody biomass supply, which is currently also not aimed for in the management plan.

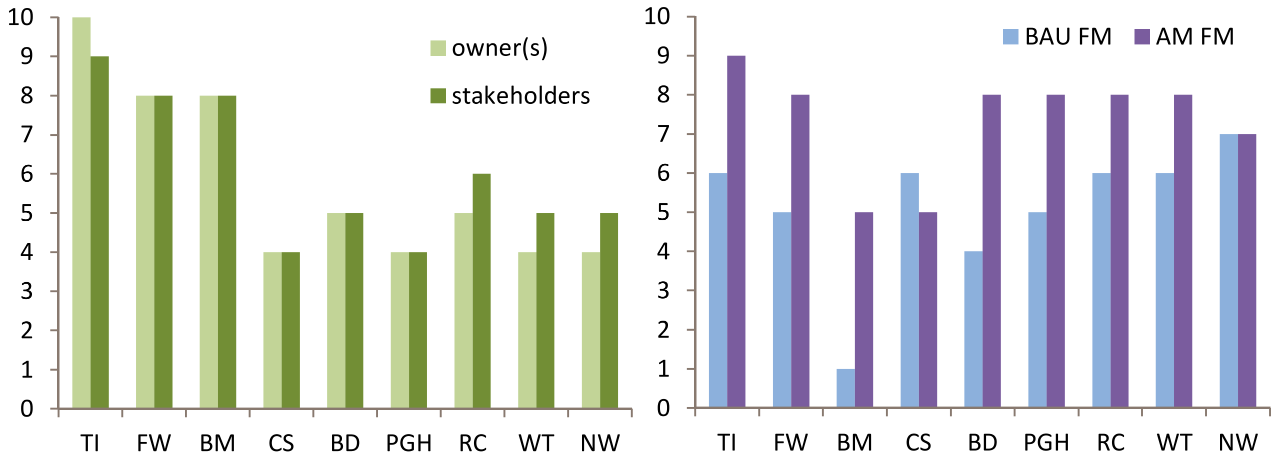

Figure 5.7.1: Currently demanded ES by the forest owner(s) and stakeholders (left) and the rate on how well supported are ES by BAU and AM under current climate (right) in the CSA 7 Shiroka laka, Bulgaria (TI - timber production, FW – fuel wood production, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards, RC – recreation, WT – regulation water balance, NW – non-wood forest products)

BAU FM is generally aiming to integrate ES at stand level; this is especially exposed for combinations of 1) TI, FW, PGH, and NW, and 2) CS, BD, PGH, RC, WT, and NW (for abbreviations see capture in Figure 4.7.1). However, some ES are provided in allocated areas of larger size, i.e. BD, PGH, RC, and WT.

In the CSA some ES impose conflicts if integrated at stand level: 1) TI, CS, BD, RC and WT could be hypothetically simultaneously provided on a scale of 100-1000 ha, while 2) BD and RC and 3) BD and NW could be simultaneously provided on a scale of 20-100 ha.

5.7.2 BAU FM and harvesting technologies

All forest operations are performed with partly mechanized systems; tree harvesting is done by chain saw, while 60% of timber extraction is done manually and with horses, 35% with skidders and 5% with cable yarders. The harvesting methods applied are cut-to-length in 67% of the cases and tree-length method in 33%. The density of the forest road network is 26.3 m/ha and the mean extraction distance is 196 m. There are no constraints in application of BAU FM with current harvesting technologies, since it was evaluated as almost perfectly suited (rate 9/10).

The road density in the CSA is about two times higher than the average across CSAs (13.4 m/ha) and the mean extraction distance is the lowest across CSAs, with 61% below the average value. Although these indicator values suggest that the layout of the roads is optimal for the currently used HS, one has to consider that the 30% ratio of the not managed forest stands might be due to the lack of access to those stands and hence, the road density and extraction distance reported might be only for the accessible forest area (70% of the entire area). On the other hand, the low extraction distance can also be explained by the high proportion of non-mechanized logging (60% manually and with animals) and by the obsolete harvesting systems available. Extraction of timber is a very hard work and therefore animals and especially humans are not able to transport the timber over a longer distance (i.e. maximum 200 m), while old machinery cannot be efficient on distances higher than 300 m. Indeed, the CSA has the lowest productivity in timber harvesting, which is about 3.5 times below the average value across CSAs. However, the harvesting costs are also the lowest, with about 42% below the average harvesting costs across CSAs. Because of the low mechanization degree, it is not a surprise that the CSA has the highest accident incidence in forest operations, which is 47% above the mean value across CSAs and 5.7 fold higher than in case of fully mechanized systems (CSA5).

The main directions of intervention recommended for increasing the efficiency and effectiveness of the forest operations are the following: i) increasing the mechanization degree by changing the outdated harvesting machinery fleet with new machines and by introducing new harvesting and extraction technologies (i.e. cable yarder); ii) capacity building and implementation of programmes of know-how transfer about timber harvesting in mountain areas (twinning projects with CSAs that have similar terrain characteristics, but a higher level of expertise; e.g. CSA2, CSA3); and iii) training forest workers for felling and processing trees and for operating harvesting machinery in mountain forests. These measures require good legal framework and forest governance with performant policy instruments and available financial support schemes.

5.7.3 BAU FM and climate change

In general, climate change will decrease the effectiveness of BAU FM in provision of practically all ES in the CSA (Table 5.7.1). There is also no possibility to make adaptation to climate change with the BAU FM, therefore alternative FM should be applied in the CSA. Some major changes are needed in the CSA, such as 1) the abandonment of even-aged silvicultural systems and application of uneven-aged systems, and 2) the retention of patches of old-growth stands within a matrix of managed stands.

Table 5.7.1: Sensitivity/Effectiveness of BAU FM in providing ES under conditions of climate change

ES	Sensitivity of BAU FM in providing ES under climate change conditions				
	strongly negative	moderately negative	neutral	moderately positive	strongly positive
Timber		×			
Fuel wood		×			
Biomass for energy		×			
Carbon sequestration		×			
Biodiversity conservation		×			
Protection against gr. hazards		×			
Recreation			×		
Regulating water balance	×				
Non-wood forest products		×			

5.7.4 Alternative FM

The introduction of AM practices might mitigate the combined unfavorable effects of climate change and current age structure of stands on the provisioning of ES. The AM was characterized as an uneven-aged silvicultural system practicing patch or group selection cuts. Small patches of old-growth stands should be retained and regularly distributed across the area. Mainly natural regeneration would be used, where applicable seeding or planting of native site adapted species with currently absent mother trees (e.g., *Quercus petraea*) could be practiced. In tending and thinning operations native tree species would be promoted.

Under climate change conditions such an alternative FM would enhance a support of provisioning of several ES (TI, FW, BD, PGH, RC, and WT), but would also improve the provision of ES under current climate (Figure 5.7.1).

6. Synthesis

6.1 Suitability of silvicultural systems for provisioning ES

Demands for ES from forests are crucial for defining forest management objectives, which are implemented by a suitable set of forest management measures, in turn promoting the demanded ES. According to our results (Table 6.1) timber production is the most demanded ES in European mountain forests. The relatively low coefficient of variation (CV) indicates rather uniform demands towards timber production across European mountain ranges. Demands toward fuelwood and biomass for energy are relatively less expressed; the higher CV values indicate larger differences among mountain regions.

Table 6.1: Averaged current demands for ES in European mountain forests (across all CSAs) (max value=10)

Ecosystem service	No. of CSAs with ES demands	Demand (mean value)	CV* (%)
Timber	7	7,9	32
Fuelwood	7	5,2	62
Biomass for energy	7	3,9	87
Carbon sequestration	7	4,4	46
Biodiversity conservation	7	5,9	31
Protection against gravitational hazards	7	4,3	42
Recreation	5	4,5	60
Game management (reindeer fodder)	6	4,9	61
Water balance	3	2,1	121
Aesthetics	1	0,4	270
Non-wood products	1	0,6	256

* CV – coefficient of variation

Among non-timber ES biodiversity scored the highest value and was ranked second most demanded ES in European mountain forests. Demands were very uniform across the analyzed mountain regions (i.e. the lowest CV among all ES). Other non-timber ES were much less demanded.

Noticeable differences were registered in demands for ES between forest owners and stakeholders. This indicates difference between private and public interests to mountain forests. The forest owners expressed higher demands for timber production (i.e. owners' vs. stakeholders' demands ranked 9.0 vs. 6.7, respectively), while stakeholders had much higher demands for recreation, and only slightly higher for biodiversity conservation, biomass production, and carbon sequestration.

Mountain forests in the analyzed CSAs are mainly managed by the principles of one silvicultural system, while in two CSAs (Montes Valsain, Spain, and Dinaric Mountains, Slovenia) more than one system is practiced (Table 6.2).

Table 6.2: Silvicultural systems practiced in the CSAs

Silvicultural system	General FM type*	CSA 1 Iberian Mts.	CSA 2 Eastern Alps	CSA 3 Western Alps	CSA 4 Dinaric Mts.	CSA 5 Scand. Mts.	CSA 6 Carpa-thians	CSA 7 Rhodope Mts.
Single tree selection	UA		×		×			
Group selection	UA/EA	×		×	×			
Irregular shelterwood	UA/EA				×			×
Uniform shelterwood.	EA						×	
Clear cutting	EA					×		
Simple coppice	EA	×						

* general FM type: UA – uneven-aged; EA – even-aged

During the past decades changes in forest management strategy (i.e. silvicultural system) were reported from three CSAs (Table 6.3); in the CSA1 and CSA4 stand dynamics was the main driver provoking the change, while in the CSA5 changes in legislation were the main cause. The analysis of ES indicators based on historical records showed that changes in the provisioning of ES cannot be solely attributed to changes in forest management strategies. This could be a paradox conclusion because the importance of and demands for ES have changed during the same period. However, management regime may change considerably by modifications within the same silvicultural system.

The analyzed ES indicators showed that the importance of timber production has increased during the analyzed period of several decades in all analyzed CSAs in terms of both timber stocking and productivity. Similarly, following the trend in stand stocking, the provisioning of carbon storage has also increased in all CSAs. However, indicators of biodiversity conservation differed significantly between the CSAs. Management systems that are creating even-aged stands (i.e., clear-cutting system, uniform shelterwood system) caused the decrease of the biodiversity indicators, whereas techniques that are promoting uneven-aged stand structures led to an increase of biodiversity indicators.

It seems that differences in silvicultural systems applied in the CSAs are greater than differences in demands for ES in the CSAs or even differences in natural conditions in the CSAs. Even when the same silvicultural system is used in different CSAs, noticeable differences in the implemented management regime was perceived (e.g. weeding and tending operations, thinning intensity, regeneration procedures etc). Such obvious differences among CSAs in the silvicultural system used are probably the result of many factors: i) natural conditions (site, stand, tree species), ii) portfolio of demanded ecosystem services/management objectives, iii) available harvest technologies, iv) forestry tradition and v) legislation and social acceptance.

Table 6.3: Summary of the historical changes in silvicultural systems and ES provisioning in the CSAs (↑- an increasing importance; ↓ - a decreasing importance; ↑↓ - an increasing importance in a certain period, but a decreasing one in the last period; ↓↑- a decreasing importance in a certain period, but an increasing one in the last period; ↔ - a stagnating importance of ES) (modified after Pardos et al., 2014 and Pasalodos et al., unpublished)

CSA	Spain	France	Slovenia	Sweden	Slovakia
Stand type	pure stands even-aged	mixed stands uneven-aged	mixed stands uneven-aged	mixed stands even-aged	mixed stands even-aged
FM	uniform shelterwood system ↓ group system	single tree selection system	single tree selection ↓ irregular shelterwood & group selection systems	selection cutting ↓ clear cutting system	uniform shelterwood system
ES / indicators					
Timber production	↑	↑	↑	↑	↑
TVH	↑	↔	↔	not available	↑
Productivity	↑↓	↑	↑	↑	↑
Stocking	↑	↑	↑	↑	↑
Carbon storage	↑	↑	↑	↑	↑
Biodiversity conservation	↑	↑	↔	↓	↓
Species diversity	not available	↑	↔	↓	↓
Tree size diversity	↔	↑	↑↓	↓	not available
Abundance of large living trees	↑	↑	↑↓	not available	not available

The results of our and other analyses in the frame of ARANGE project showed that the performance and efficiency of currently used silvicultural and harvesting systems related to BAU forest management in regard to provisioning the demanded portfolio of ES were satisfactory in most CSAs. However, surprising was that no obvious relationship was detected between the demanded ES (i.e. management objectives) and the BAU forest management approaches, meaning also silvicultural systems. Two main reasons might be decisive for this: i) silvicultural systems categorized in our analysis were probably too general to reflect (sometimes only detailed) differences in actual silvicultural activities carried out to reach management objectives, and ii) tradition and experiences seem to play an important role in determining the management regime.

Nevertheless, the efficiency of the BAU forest management and thus silvicultural systems applied within the BAU management seems to differentiate between uneven-aged and even-aged forest management approaches. The results obtained in the trade-off analysis between demands for ES and efficiency of BAU FM to provide demanded ES indicated generally higher efficiency of uneven-aged FM approaches in providing the demanded portfolio of ES if compared to even-aged approaches (Figure 6.1, Table 6.4). However, among the even-aged approaches clear cutting system seems to be the most efficient, being mainly the result of its efficient provisioning of timber production and carbon sequestration in the analyzed CSA. According to Figure 6.2 and based on the simulation results, it seems that the clear-cutting system is the favored silvicultural system when timber production is the dominant ES demand. On the other hand, uneven-aged forest management approaches and silvicultural systems were well efficient in timber production, biodiversity conservation and protection against gravitational hazards.

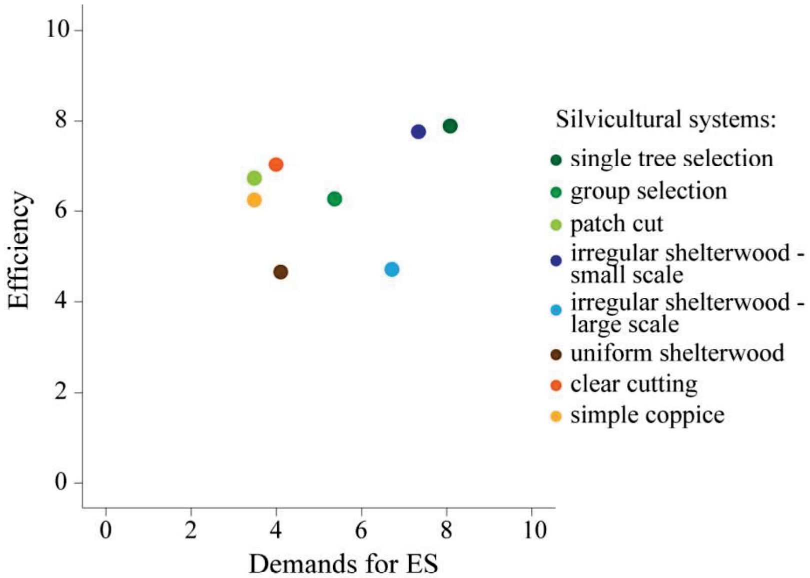

Figure 6.1: Trade-off analysis between demands for ES and efficiency of the BAU FM strategies (i.e. silvicultural systems) in providing the entire portfolio of ES

Table 6.4: Supporting information for trade-off analysis – some characteristics of silvicultural system applied in the ARANGE CSAs

Silvicultural system	General FM type*	Species mixture in CSA
Single tree selection	uneven-aged	Mixed
Group selection	uneven-aged	Mixed (*Picea* dominated)
Group selection (patch cut)	uneven-aged/ even-aged	Pure/mixed (*Pinus* dominated)
Irregular shelterwood – small scale	uneven-aged	Mixed
Irregular shelterwood – large scale	even-aged	Mixed
Uniform shelterwood.	even-aged	Mixed (*Picea* dominated)
Clear cutting	even-aged	Pure (*Picea* dominated)
Simple coppice	even-aged	Pure (Quercus pyrenaica)

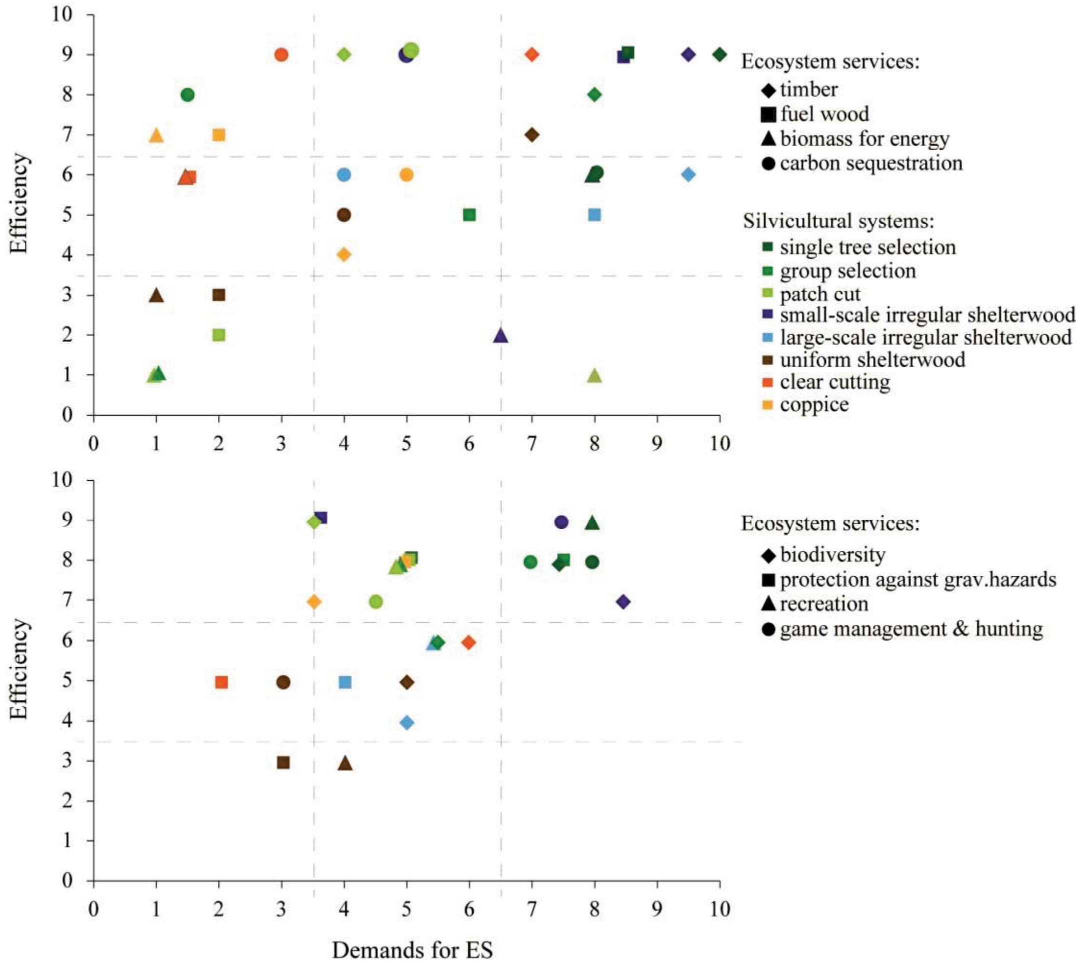

Figure 6.2: Trade-off analysis between demands for an individual ES and efficiency of the BAU FM strategies (i.e. silvicultural systems) to provide ES; only ES demanded in more than three CSAs are shown

When considering tree species composition the results implied that in mixed stands (uneven-aged) group selection and irregular shelterwood approaches seem to provide demanded ES more efficiently than even-aged approaches, while for pure stands no firm conclusion can be drawn. However, some important factors need to be considered when drawing the conclusions.

i) Past forest management may have changed stands significantly, which may have resulted in less effective current forest management as it would be if any or just smaller changes were present.

ii) Only one CSA within the same forest type was observed and analyzed in the project, therefore no comparison which would give detailed insights into differences in efficiency of provisioning ES was possible.

iii) Some other external factors may influence the efficiency of provisioning certain ES; for example the influence of large ungulates on tree species composition and consequently on (indicators of) biodiversity conservation.

Although the trade-off analysis results may have implied some general insights into the efficiency of silvicultural systems applied in European mountain forests, a possible bias might be included in the analysis. The demands for provisioning ES in each CSA were evaluated by several stakeholders, engaged in the Regional Stakeholder Panels established in each CSA, as well as the (representatives of) owners, thus their evaluation can be treated as objective and unbiased. In contrary, the effectiveness of BAU forest management and thus also the silvicultural system in provisioning ES in the CSA was evaluated by the Case Study Representative person (CSR); his/her evaluation was based on the results obtained in different tasks within the ARANGE project, but partly also on his/her subjective opinion if firm results were not available or unclear. Consequently, the obtained scores may be biased, but some general conclusions on suitability and effectiveness of silvicultural systems for provisioning ES in European mountain forests can be drawn.

Forest management approaches (silvicultural systems) distributed in the lower part of Figure 6.1 (i.e. large scale irregular shelterwood system, uniform shelterwood system, simple coppice system) were all recognized by CSRs as systems which efficiency in provisioning demanded portfolios of ES was not on an expected level. Despite possible biased scoring results, we can conclude that these systems need some modifications/adaptations or a transformation of silvicultural system to another one in order to be more efficient in providing demanded ES which was nevertheless in accordance to the experts' opinion and the model simulation results.

The analysis of the BAU harvesting systems (Appendix 2) and the analysis of the forestry expert opinion indicated some efficiency gaps. Among the most common efficiency gaps identified across CSAs are the insufficient forest road infrastructure, the lack of training of forest workers and the improper utilization of the harvesting systems according to their technical feasibility and the local terrain conditions. The most efficient harvesting systems were reported to be fully mechanized systems (harvester and forwarder), while the least performant HS were combined partly mechanized system chain saw & animal-skidder extraction. The latter was recognized as least effective due to the outdated harvesting machinery fleet and high percentage (60%) of non-mechanized harvesting operations. In all CSA the efficiency of harvesting systems could be improved, which would improve also the effectiveness of BAU forest management in provisioning demanded portfolio of ES; possible and recommended improvements are given in section 6.3.

6.2 Capacity of silvicultural systems to adapt to climate change

When BAU management was simulated under a set of climate change scenarios, a substantial variation regarding ES provisioning was observed among climate (change) scenarios. The simulated impacts of climate change varied in relation to climate change scenarios, elevation, tree species composition, state and flow variables, and ES service (or its indicator). The typical altitudinal gradient in mountain regions was detected with mainly negative impacts on forest growth at low elevations due to increasing summer drought, while at higher elevations growth is supposed to benefit from longer vegetation periods and more favorable thermal regimes. The latter was the case also in the most northerly located CSA5 Vilhelmina in Sweden, but the cause was the high latitude of this CSA and not a high elevation as in other CSAs. Another typical observation was a tree species shift from conifers to broadleaved species or to more mixed stands. Both were relatively consistent findings across all CSAs. Surprisingly, in the CSA5 mainly positive effects of climate change were reported, but there are many effects and drivers which were not studied in the analysis, e.g. fungi and insects, risk for windthrows which might be indirectly related to climate change.

In relation to the latter, it is important to note that stand growth model simulations that do not consider disturbance regimes are very likely too optimistic and such models were prevailingly applied in the ARANGE project, the model PICUS employed in the CSA3 Eastern Alps (Montafon) being an exception. Due to climate change intensifying disturbance regimes bear the potential to severely impact ES provisioning such as timber production, carbon storage and protection against gravitational hazards in the future. In the CSA3 it was exposed that increased bark beetle damages would pose a serious threat to landslide and rockfall protection ES of the analysed forests.

According to the expert knowledge of CSRs and the model simulation results, sufficient adaptation and modifications within the BAU forest management are feasible to adapt stands to possible climate change. In general, some modifications within the BAU forest management strategy would enhance the ability of forest stands to cope climate change. The most exposed adaptation measure was the enhancement of mixed stands through a promotion of native broadleaved and coniferous tree species. In the CSA3 Eastern Alps and CSA6 in the Carpathians, the admixture of *Abies alba*, *Fagus sylvatica*, *Acer pseudoplatanus* and other native tree species was revealed as the potential to improve the resistance and resilience of currently *Picea abies* dominated stands.

Another adaptation measures suggested were the reductions of harvesting diameter and the length of rotation period. Both would result in the avoidance of unstable highly stocked stands, which were often recognized as prone to natural disturbances, mainly windthrows, but also bark beetle attacks (e.g. Klopcic et al. 2009; Thom et al. 2013), and thus limit the duration of risk exposure. On the other hand, the reduction of harvesting diameter could result in a negative impact on biodiversity and carbon sequestration ES.

Within the single tree selection system (CSA2, France), a suggested adaptation measure was creating larger canopy gaps (according to group selection system) to enable regeneration of less-shade tolerant tree species and promote the additional admixture of tree species, and thus improve resistance and resilience of forest stands. Beside natural regeneration some artificial regeneration of certain tree species should enhance the resistance of forests, preserve vulnerable tree species and thus promote biodiversity.

In only two CSAs the experts recommended a change in forest management/silvicultural system and an application of an alternative silvicultural system. In the CSA1 in the Iberian Mountains, Spain, the currently used coppice system in pure and mixed *Quercus pyrenaica* stands was not providing ES on a desired level. The provisioning was simulated to be even lower in the future under the current climate scenario, while with climate change scenarios the decrease would strongly intensify. In order to increase stocking of this stands and a canopy cover, which is extremely important in the analyzed area, an alternative forest management strategy was suggested (see the next chapter 6.3). In the CSA7 in the Rhodope Mountains, Bulgaria, the provisioning of ES under the BAU forest management strategy was not on a desired level. With climate change scenarios, especially more pessimistic ones, this ES provisioning is supposed to become even less efficient. Thus the forestry experts expressed the need for alternative forest management strategies (see the next chapter 6.3), since no modifications within the BAU forest management are feasible to adapt forest stands to climate change.

6.3 Adaptations and improvements

The BAU forest management in European mountain forests was generally recognized to satisfactory provide demanded ES portfolio, but was not identified as the optimal forest management practice. The provisioning of ES desired by forest owners and stakeholders could be improved; also climate change impacts should have several negative impacts on the effectiveness of BAU forest management in provisioning portfolios of ES in mountain forests across Europe. Therefore, some urgent needs for adaptation and improvement of current forest management practices in mountain forests are necessary. However, these changes should not alter the BAU forest management practices, but should only complement and upgrade them.

The simulated development of forest stands indicated that even under current climate scenario the provisioning of ES might change significantly in the future. In addition, climate change may induce changes in forest stands and climate conditions which might not be tackled efficiently by BAU forest management. Therefore, adaptation measures need to be applied into forest management in order to improve its efficiency of provisioning the demanded portfolio of ES in changed environmental conditions (Kolström et al. 2011). The adaptation measures could be made within the BAU forest management strategy or the strategy as a whole can be transformed into an alternative forest management strategy which would tackle possible changes in forest stands and/or climate conditions more effectively. As already said, the results of the ARANGE project indicated that the adaptation of forest management practices to future conditions is feasible with changes and upgrades of the BAU practices, only in some cases the BAU forest management strategy should be transformed into an alternative forest management strategy. Some of the main adaptation measures within the BAU forest management strategies were already listed in the previous chapter 6.2; in this chapter they are addressed in details.

Enhancing mixed stands were the most exposed adaptation measure, listed as a priority measure in five CSAs. Mixed stands were often recognized as being more resistant and resilient to natural disturbances (e.g. Knoke et al. 2008) which are supposed to increase in frequency and severity in the future due to anticipated climate change (Christensen et al. 2011). Promoted should be the admixture of site adapted tree species, with a special emphasis on their adaptation to future climate conditions. This adaptation measure is of pronounced importance in pure *Picea abies* dominated forests (i.e. CSA3, CSA6), since the proportion of *Picea abies* is one of the key predisposing drivers of natural disturbance occurrence (Hlásny and Turčáni 2012; Thom et al. 2013). Even a low admixture of native broadleaves or disturbance resistant conifers may increase the resistance of stands to natural disturbance substantially (Schütz et al. 2006; Griess et al. 2012). These species can be promoted in silvicultural measures such as tending and thinning operations, if they occur in natural regeneration, but can be also artificially planted and further promoted in silvicultural measures to enhance their existence and growth. Another silvicultural tool to regulate tree species composition of natural regeneration is the type of regeneration cuts. In general, small-scale cuts (mainly applied in uneven-aged silvicultural systems) promote shade-tolerant tree species, while larger-scale cuts provide opportunities to regenerate and promote tree species with medium and high demands for light. In accordance to this fact and to promote higher admixture of shade-less-tolerant tree species, the forestry experts in the CSA2, France, suggested a contemporary application of the group selection and the single-tree selection systems in their CSA. A similar contemporary application of the concepts and techniques of different silvicultural systems ("freestyle silviculture"; Bončina 2011) is already applied in the CSA4, Slovenia, where forest adaptation to future environmental conditions is partly conditioned by the negative impact of large ungulates (Klopčič et al. 2010; Klopčič and Bončina 2011). To promote a diverse species mixture in regeneration stages of stand development, it requires a provision of heterogeneous conditions regarding light and other ecological gradients. Large scale regeneration approaches such as clear cuts and uniform shelterwood approach create relatively homogenous ecological conditions which tend to favour one tree species only.

Shorter rotation periods were addressed as a possible adaptation measure to climate change and/or more efficient provisioning of ES in the CSA7 in the Carpathians and in the CSA4 Dinaric Mountains. Shorter rotations would lead lower stand stocking and thus avoiding unstable and low-resistant high stocking stands (Klopčič et al. 2009; Thom et al. 2013). Another adaptation measure, which would lead to such an effect, is the reduction of harvest diameter, expressed as possible adaptation measure in a single-tree selection system, but could be applied if necessary and applicable also in other silvicultural systems. This measure would affect both the adaptation of forest stands to changed natural disturbance regimes and adaptation to possible altered demands for production (economic) ES provisioning (i.e. timber production). However, also possible negative economic and ecological consequences of this adaptation measure need to be taken under consideration.

As mainly the adaptation to climate change and changed demands towards ES in the future was evaluated as sufficient and feasible within the BAU forest management, in two CSAs the BAU forest management was recognized as relatively ineffective in provisioning the demanded ES under current climate scenario, but the inefficiency got even more expressed under different climate change scenarios. Therefore, the transformation from the BAU forest management strategy to the alternative forest management strategy was suggested by the forestry experts CSRs.

In the CSA1, Iberian Mountains, Spain, some ES provisioning in coppice *Quercus pyrenaica* stands were found out to be defective even under the current climate scenario. To increase productivity (stocking volume) and canopy cover (i.e. lower tree density but larger trees) a need for transformation of the BAU forest management strategy to an alternative one was recognized. It was suggested coppice system to be transformed into a silvicultural system creating high forests.

In the CSA7, Rhodope Mountains, Bulgaria, even-aged large scale irregular shelterwood system was recognized as inefficient in providing most of demanded ES and as unfeasible to adapt to cope climate change; therefore an alternative forest management approach was suggested. It is anticipated that the introduction of alternative management practices might mitigate to some extent the unfavorable combined effect of climate change and current age structure on the provisioning of ES. Based on the simulation results and forestry expert opinion, a group selection or patch cut silvicultural system creating uneven-aged stands should be applied in these mixed mountain forests, combined with a retention of small patches of old-growth stands regularly distributed across the area to promote biodiversity conservation ES. Natural regeneration should be used, however where applicable seeding or planting of native site adapted tree species with currently absent mother trees (e.g. *Quercus petraea*) could be practiced as well. In tending and thinning operations native tree species should be promoted.

In the CSA5 in the Carpathians, Slovakia, the need for alternative forest management strategy was not explicitly expressed, but according to the key issue analysis (chapter 5.6) and the stand development simulation results under the BAU and alternative forest management strategies (Hlásny et al. under revision; unpublished results), there might be a need to thoroughly modify and adapt the BAU strategy or even transform it to an alternative one. Based on stand development simulations under the BAU forest management the projected rate of forest adaptation seems insufficient to secure the sustainable provisioning of desired portfolio of ES under climate change, and a broader range and greater intensity of adaptation actions is needed (Hlasny et al. under revision). As the most suitable AM option, the forestry experts and the analysis of stand development simulation results suggested an uneven-aged forest management (i.e. group selection silvicultural system) with combined natural and artificial regeneration of *Fagus sylvatica*, *Abies alba*, *Picea abies*, *Acer pseudoplatanus*, *Pinus sylvestris* and *Quercus* sp., and frequent intensive tending and thinning operations for mixture regulations. Compared to the BAU forest management strategy, such an AM strategy would increase management flexibility, improve ES provisioning, and increase forest resistance.

As suggested by the efficiency gap analysis (Appendix 2) the harvesting systems in European mountain forests can be improved as well, which would enhance provisioning of mainly productive ES, but might have an influence on other non-productive ES as well (e.g. soil protection, habitats). The most important measures for increasing the efficiency of forest management operations related to timber harvesting, extraction and transport are: i) improve the quality and density of the forest road networks (i.e. the layout and geometric characteristics of the existing roads and additionally to build new roads), ii) increase the degree of mechanization (i.e. from non- or partly-mechanized to highly- or fully-mechanized harvesting systems); iii) promote utilization of state-of-the-art harvesting systems (harvesters, forwarders and cable yarders) wherever appropriate considering terrain features and whenever appropriate in front of outdated machinery and ground-based timber skidding with tractors and skidders; and iv) capacity building and training of forest workers.

When considering adaptation and especially improvements of forest management approaches in mountain forests, three main aspects should be regarded: i) past and future trends in forest stand dynamics, ii) important drivers of stand dynamics and forestry in general, and iii) future demands to ES in mountain forests. In scenarios on future development of mountain regions in Europe (Aggestam and Wolfslehner 2013), a great emphasis was given to environmental factors. Thus, the question appeared how forests will provide desired ES in a changing environmental (climate) conditions. An increased pressure on forests can be expected in certain mountain areas in the near future. New settlements, other buildings, infrastructure and facilities for different purposes (e.g. tourism, sport, industry, (green) energy) will probably cause some rate of deforestation as well as additional ecological burden for mountain forests. In contrast, an intensive depopulation of European mountain areas was observed in the last decades (Nordregio… 2004) and the same trend can be expected also in the future, which may result in decreased demands of local people for timber and fuel wood production as well as for some other ES provided by mountain forests. Both, the decreased demands on one hand and intensified pressures on the other may have a serious impact on forest management of mountain forests at a landscape as well as stand spatial scale. The demand for and the importance of ES will change in the future, and conflicts in the land use between different interest groups are highly possible.

To tackle conflicting situations between provisioning ES in (mountain) forests, different approaches to forest management can be used. There are two main approaches to multifunctional forest management – the integrative and the segregative (zoning) approach; however, usually the elements of both are followed in forest management. In the analyzed European mountain forests, the BAU forest management is attempting to integrate ES on a stand spatial scale, indicating the integrative approach as the main one. However, in some cases the integrative approach at stand level is not efficient in providing the demanded portfolio of ES and thus imposes conflicts in forest use.

In some CSAs simultaneous provisioning of timber production and game management and hunting is imposing a conflict when integrated on a stand scale, similarly may impose conflicts simultaneous provisioning of timber production, biodiversity conservation and recreation or just biodiversity conservation and recreation. To avoid conflicts in provisioning ES, some minimum forest area is needed. It seems that this size depends on the number and combination of ES to be provided simultaneously. It was found that variability in provisioning ES may differ substantially, depending on the size of the observed forest area (Irauschek et al. under review). Depending on the number of ES to be provided, the proportion of landscape supporting multifunctional forest management may decrease from over 70% to less than 50% if two of four ES are simultaneously provided on a 1 ha (stand) scale and current climate scenario is regarded. If spatial scale is enlarged to a 10 ha grain, the decrease is only from approximately 85 % to more than 70 %, respectively (*ibid.)*. This implies that beside the prevailing integrative approach a segregative (zoning) approach should be considered as well in management of mountain forests. According to the expert knowledge of the CSRs, the area of non-conflict provisioning of ES ranged from the minimum size of 5-20 ha to 100-1000 and >1000 ha, dependent on the combination of ES being under conflict. Within this range of suggested area, we may recommend to mainly applying the integrative approach, but if necessary due to unsolvable conflicts in provisioning ES the segregation and zone or priority areas creation can be applied as well. However, advantages and disadvantages of both approaches (e.g. ownership, constraints for harvesting technologies) need to be thoroughly considered.

7. Conclusions and recommendations for future management

Mountain forests are spread in several mountain ranges across Europe and are thus characterized by various climate, site and stand conditions. The most significant similarity of mountain forests across Europe is the comparable importance of ES provided by forests for different (private and public) stakeholders. However, the approaches for provisioning portfolios of ES differ significantly, but all of them are relatively successful in provisioning ES, yet mainly not in an optimal way.

The frame conditions and problems related to and occurring in mountain forests differ significantly between mountain ranges across Europe. In some mountain areas there are intensified pressures like tourism and related building of additional facilities and new infrastructure, while in other areas an intensive depopulation may lead to afforestation of abandoned agricultural or other land, but also to a lower importance of mountain forests. Different problems reflect in different demands towards mountain forests. The same is evident with the demands towards mountain forests and mountain landscape in general.

Therefore, a generalization of multifunctional forest management approaches in mountain forest is not appropriate or reasonable. Forest management must be adapted to stand, site and climate conditions as well as to expressed demands of forest owners and stakeholders for provisioning ES (i.e. forest management objectives). Since frame conditions as well as the environment (e.g. climate) are subjected to constant changes, forest management strategies (i.e. silvicultural systems & harvesting systems) need to be flexible and adaptive to be able to cope with changes.

Forestry experts expressed a common opinion that forest management strategies, but especially silvicultural systems need to be upgraded with additional measures to adapt forest stands to climate change and to enable stands to provide ES as are supposed to be demanded in the future. Several adaptation and improvement measures were disclosed to be the main ones: i) the enhancement of mixed stands, ii) the reductions of harvesting diameter and the length of rotation period, iii) the combination of different silvicultural systems, iv) improvements of harvesting systems. Within the silvicultural systems the adaptation measures should improve the resistance and resilience of forest stands to expected climate change impacts (e.g. more frequent and intensive natural disturbances, possible dieback or reduced vitality of certain tree species), while within the harvesting systems improvements should reduce the efficiency gaps between the used and optimal (state-of-the-art) harvesting technologies.

The main approach to forest management in mountain forests is recommended to be the integrative approach. However, due to a decreased capability of forest management in mountain forest to simultaneously provide some combinations of ES, also some elements of the segregative approach to forest management could be applied. Some ES may be in a trade-off with other ES, therefore a zoning approach may be the most suitable to provide certain ES.

Forest management will cope with many uncertainties in the future. Climate change is very likely to happen, but its intensity and consequences are almost impossible to predict reliably. The frame conditions in forestry economics are also hard to predict; many variables (e.g. timber price, labor costs, fuel costs) are highly uncertain and thus less predictable. Changes in society are ongoing, but their direction and intensity may vary substantially. Due to constant changes in the environment and society, the demands towards mountain forests change through time as well. Time lags in decision making and in forest response to changes in management regimes limit the ability to follow such changes instantly.

This conclusion does not invalidate the principles of the adaptive forest management approach (Holling 1978; Walters 1986; Walter and Holling 1990). But it emphasizes the limitations of a command and control approach to forest management.

Literature

Aggestam, F., Wolfslehner, B., 2013. ARANGE Deliverable D3.2. Mountain Forests and Land-use Scenarios – a review and scenario development.

Bončina, A., 2011. History, current status and future prospects of uneven-aged forest management in the Dinaric region: an overview. Forestry 84: 467-478.

Christensen, O. B, Goodess, C. M. Harris, I, and Watkiss, P. (2011). European and Global Climate Change Projections: Discussion of Climate Change Model Outputs, Scenarios and Uncertainty in the EC RTD ClimateCost Project. In: Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

European Commission (2013) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A new EU Forest Strategy: for forests and the forest-based sector – COM (2013) 659 final {SWD(2013)342 final} {SWD(2013)343 final}

FOREST EUROPE, UNECE, FAO, 2011. State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe. Ministerial Conference on the Protection of Forests in Europe FOREST EUROPE, Liaison Unit Oslo, Norway, 342 p.

Griess, V.C., Acevedo, R., Härtl, F., Staupendahl, K., Knoke, T., 2012. Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce. Forest Ecology and Management 267: 284-296.

Hlásny, T., Turčáni, M., 2013. Persisting bark beetle outbreak indicates the unsustainability of secondary Norway spruce forests: case study from Central Europe. Annals of Forest Science 70: 481-491.

Holling, C.S. (ed.), 1978. Adaptive environmental assessment and management. John Wiley, New York, New York, USA.

Irauschek, F., Rammer, W., Lexer, M.J. Can the current management regime maintain multifunctionality in an Alpine forest landscape under conditions of climate change (under review)

Johann, E., 2007. Traditional forest management under the influence of science and industry: The story of the alpine cultural landscapes. Forest Ecology and Management 249: 54-62.

Klopčič, M., Poljanec, A., Gartner, A., Bončina, A., 2009. Factors related to natural disturbances in mountain Norway spruce (*Picea abies*) forests in the Julian Alps. Ecoscience 16 (1): 48-57.

Klopčič, M., Jerina, K., Bončina, A., 2010. Long-term changes of structure and tree species composition in Dinaric uneven-aged forests: are red deer an important factor? European Journal of Forest Research 129: 277-288.

Klopčič, M., Bončina, A., 2011. Stand dynamics of silver fi r (*Abies alba* Mill.)-European beech (*Fagus sylvatica* L.) forests during the past century: a decline of silver fir? Forestry 84 (3): 259-271.

Klopčič, M., Leitner, T., Pardos, M., Barka, I., Calama, R., Cordonnier, T., Maroschek, M., Wilhelmsson, E., Hlasny, T., Zlatanov, T., Lexer, M.J., 2013. ARANE Deliverable D1.3 Current and historical forest management in the case study areas.

Knoke, T., Ammer, C., Stimm, B., Mosandl, R., 2008. Admixing broadleaved to coniferous tree species: a review on yield, ecological stability and economics. European Journal of Forest Research 127: 89-101.

Kolström, M., Lindner, M., Vilen, T., Maroschek, M., Seidl, R., Lexer, M.J., Netherer, S., Kremer, A., Delzon, S., Barbati, A., Marchetti, M., Corona, P., 2011. Reviewing the Science and Implementation of Climate Change Adaptation Measures in European Forestry. Forests 2011, 2: 961-982.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J., Marchetti, M., 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management 259 (4): 698-709.

Nordregio – Nordic Centre for Spatial Development, 2004. Mountain Areas in Europe: Analysis of mountain areas in EU member states, acceding and other European countries. European Commission contract No 2002.CE.16.0.AT.136, Final report.

Pardos, M., Lexer, M.J., Bugmann, H. (eds), 2014. ARANGE Deliverable 2.3 Analysis of historic & current forest management practices, forest dynamics and related ecosystem services.

Pasalodos, M., Klopčič, M., Hlasny, T., Wilhelmsson, E., Cordonnier, T., Pardos, M. Historical trends in the provision of ecosystem services in European Mountain forests. MS in preparation.

Price, M.F, Gratzer, G., Duguma, L.A., Kohler, T., Maselli, D., Romeo, R. (eds), 2011. Mountain Forests in a Changing World - Realizing Values, addressing challenges. FAO/MPS and SDC, Rome, 86 p.

Schuler, A., 1992. Die Alpenwalder: Heilige Bannwiilder oder Land- und Holzreserve? In: La dccouverte des Alpes. Actes du colloque Latsis 1990, Zurich, l" - 2 novembre 1990. Itinera 12, s. 109-116.

Schütz, J.-P., Götz, M., Schmidt, W., Mandallaz, D., 2006. Vulnerability of spruce (*Picea abies*) and beech (*Fagus sylvatica*) forest stands to storms and consequences for silviculture. European Journal of Forest Research 125: 291-302.

Thom, D., Seidl, R., Steyrer, G., Krehan, H., Formayer, H., 2013. Slow and fast drivers of the natural disturbance regime in Central European forest ecosystems. Forest Ecology and Management 307: 293-302.

Walters, C. 1986. Adaptive management of renewable resources. MacMillan, New York, New York, USA.

Walters, C. J., Holling, C.S., 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.

Appendix 1

Recommendations for multifunctional forest management strategies – Questionnaire for CSRs

The recommendations for multifunctional forest management will, inter alia, be based on the feedback of CSRs to a set of targeted questions. The means of preparing this feedback by CSRs will be a questionnaire. This questionnaire follows below.

Please fill the questionnaire for each BAU FM present in your CSA! In case you have more than one BAU FM in your case study area, please use one questionnaire for each BAU FM!

Please, answer the listed questions. In addition to the formalized responses feel free to add free text to each question. This will allow us to better interpret your response. Thank you.

0 BAU FM category

We would like you to characterize the BAU FM in your CSA with a selection of predefined elements of silvicultural systems. Please check preselected elements of the BAU FM system in your CSA (derived from deliverable D1.3!) in the BAU column! If our preselection in the BAU column is wrong, make a tick (×) or write text in the "Changes of BAU" column!

General system		**BAU**	**Changes of BAU**
	even-aged	☐	☐
	uneven-aged	☐	☐
	coppice	☐	☐
Tree species managed with this system in BAU			
	Add tree species (mixtures) which are managed with the BAU FM!		
Terrain conditions of the RSTs managed with this system in BAU			
	soil wet/water logged	Yes ☐ No ☐	Yes ☐ No ☐
	Terrain roughness and rock outcrops; *tick "yes" if wheeled vehicles cannot pass the terrain!*	Yes ☐ No ☐	Yes ☐ No ☐
	Slope *(flat: 0-30%, moderate: 30-60%, steep:*	flat ☐ moderate ☐	flat ☐ moderate ☐

	>60%)	steep ☐	steep ☐
	Gullies (steep streams that run within steepsided and deep channels)	Yes ☐ No ☐	Yes ☐ No ☐
Regeneration			
	Natural *Add species, please!*	☐	☐
	Artificial *Add species, please!*	☐	☐
	natural + artificial *Add species, please!*	☐	☐
Tending			
	Number of operations	0 ☐ 1-2 ☐ >2 ☐	0 ☐ 1-2 ☐ >2 ☐
	Mixture regulation		
	Density reduction	Oper.1: % Oper.2: % Oper.3: % Oper.4: %	Oper.1: % Oper.2: % Oper.3: % Oper.4: %
Thinning			
	Type	from above	from above
	Number of operations per rotation	0 ☐ 1-2 ☐ 3-4 ☐ >4 ☐	0 ☐ 1-2 ☐ 3-4 ☐ >4 ☐
	Mean DBH of harvested trees per operation	Oper.1: cm Oper.2: cm Oper.3: cm Oper.4: cm Oper.5: cm	Oper.1: cm Oper.2: cm Oper.3: cm Oper.4: cm Oper.5: cm
Regeneration felling			
	system	clearcutting	clearcutting
	Number of operations per rotation	0 ☐ 1-2 ☐ 3-4 ☐ >4 ☐	0 ☐ 1-2 ☐ 3-4 ☐ >4 ☐
	Mean DBH of harvested trees per operation	Oper.1: cm Oper.2: cm Oper.3: cm Oper.4: cm Oper.5: cm	Oper.1: cm Oper.2: cm Oper.3: cm Oper.4: cm Oper.5: cm

1 BAU FM and provision of ES!

1.1 How effective is BAU in provisioning of ES?

Please, express your judgement on currently demanded ES (from the owner perspective (columns 2a) and other stakeholder perspective (column 2b)), ES that are aimed for in the management objectives/plan (column 3), the relevancy of ES in the future (column 4), and the support of ES provisioning by BAU (column 5).

Please rank/tick according to the situation in your CSA. Ranking should be made on a ranking scale 1-10 (1=not supported at all – 10=perfectly supported).

If additional ES are present in your CSA, please add them to the table!

Please note that you may have the following situations to cover: (1) ES that are relevant NOW and in the future, (2) ES that are relevant just NOW, (3) ES that will become relevant in the future.

Ecosystem services **(1)**	Currently demanded by owner/ stakeholder in your CSA **(2)**		Currently aimed for in the management plan in your CSA **(3)**	Relevant in the future (10-20 years from now) **(4)**	How well supported are ES by BAU under current climate in your CSA? **(5)**
	Owner (2a)	stakeh. (2b)			
Timber	1	1	Yes ☐ No ☐	1	1
Fuel wood	1	1	Yes ☐ No ☐	1	1
Biomass for energy	1	1	Yes ☐ No ☐	1	1
Carbon sequestration	1	1	Yes ☐ No ☐	1	1
Biodiversity conservation	1	1	Yes ☐ No ☐	1	1
Protection against natural hazards	1	1	Yes ☐ No ☐	1	1
	1	1	Yes ☐ No ☐	1	1
	1	1	Yes ☐ No ☐	1	1
	1	1	Yes ☐ No ☐	1	1

1.2 Which approach is used in BAU to provide ES?

Please, tick according to the situation in your CSA!

Definitions: Matrix approach = ES is provided on an entire forest area (i.e. landscape) (Figure 1a); landscape approach = ES is provided on allocated forest areas on a landscape level (allocated areas relatively large in size – zoning; Figure 1b); stand approach = ES is provided on allocated forest areas on a stand level (allocated areas relatively small in size; Figure 1c)

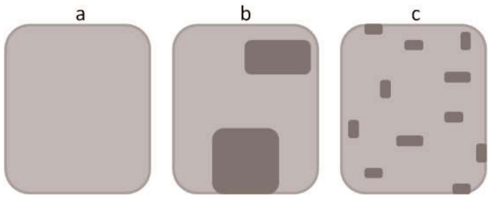

Figure 1: Sketches of approaches (light grey area represents CSA, dark grey areas represent allocated areas for provision of certain ES)

Ecosystem services **(1)**	Matrix approach **(2)**	Approach with allocations – landscape scale (i.e. zoning) **(3)**	Approach with allocations – stand scale **(4)**
Timber	☐	☐	☐
Fuel wood	☐	☐	☐
Biomass for energy	☐	☐	☐
Carbon sequestration	☐	☐	☐
Biodiversity conservation	☐	☐	☐
Protection against gravitational hazards	☐	☐	☐
	☐	☐	☐
	☐	☐	☐
	☐	☐	☐

1.3 Is BAU attempting to integrate ES (from columns 2 and 3 in the table at Q1.1 above) at stand level (typically 1-5(+) ha)? In other words: is BAU aiming at the provisioning of more than one ES at stand level?

If "YES", which combinations of ES? (TI – timber, FW – fuel wood, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards)

No ☐

Yes ☐

	TI	FW	BM	CS	BD	PGH			
Combination 1	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 2	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 3	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 4	☐	☐	☐	☐	☐	☐	☐	☐	☐

Combination 5	☐	☐	☐	☐	☐	☐	☐	☐	☐

1.4 Which ES combinations that are aimed at under BAU in your CSA (please see 1.1 above in columns 2 and 3!) impose conflicts when integrated at small scale (i.e. stand level, typically 1-5(+) hectares)?

Please check ES which impose conflicts! (TI – timber, FW – fuel wood, BM – biomass for energy, CS – carbon sequestration, BD – biodiversity conservation, PGH – protection against gravitational hazards)

	TI	FW	BM	CS	BD	PGH			
Combination 1	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 2	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 3	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 4	☐	☐	☐	☐	☐	☐	☐	☐	☐
Combination 5	☐	☐	☐	☐	☐	☐	☐	☐	☐

1.5 We ask for your judgment: What is the smallest scale at which BAU could hypothetically provide combinations of ES (from Q1.4 above) simultaneously?

	1-5 ha	5-20 ha	20-100 ha	100-1000 ha	>1000 ha
Combination 1	☐	☐	☐	☐	☐
Combination 2	☐	☐	☐	☐	☐
Combination 3	☐	☐	☐	☐	☐
Combination 4	☐	☐	☐	☐	☐
Combination 5	☐	☐	☐	☐	☐

2 BAU FM and harvesting technologies!

2.1 Which harvesting technology is used to implement BAU?

Please tick your choice! Multiple choices are possible!

Harvest technology	felling	processing
Chain saw	☐	☐
Harvester	☐	☐
Processor	☐	☐
	☐	☐
	☐	☐

Extraction technology	
Animals	☐
Tractor	☐
Skidder	☐
Forwarder	☐
Sledge winch	☐

Harvesting method	
Tree length	☐
Cut-to-length	☐
	☐
	☐
	☐

2.2 How suitable is the used harvesting technology (see 2.1) to implement BAU in your CSA?

Please express your opinion on a scale 1-10 (1=completely unsuitable - 10=perfectly suitable).

Technology combination	1	2	3	4	5	6	7	8	9	10
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

2.3 Could there be an improvement in:

- opening up the area (i.e. more roads, better road alignment, more skidding tracks, etc.):

  No ☐

  Yes ☐ *Which? (free text)!*

  Don't know ☐

- harvesting technology (type of machinery, etc.):

  No ☐

  Yes ☐ *Which? (free text)!*

  Don't know ☐

- harvesting methods (how the harvesting and logging is organized; e.g. whole tree length, cutting into assortments at roadside, ...):

  No ☐

  Yes ☐ *Which? (free text)!*

  Don't know ☐

3 BAU FM and climate change!

3.1 How sensitive is BAU in providing ES under conditions of climate change in your CSA?

Please provide your judgment on a provided scale (strongly negative – moderately negative – neutral – moderately positive – strongly positive)!

Ecosystem service	How sensitive is BAU in providing ES under climate change conditions?
Timber	strongly negative
Fuel wood	strongly negative
Biomass for energy	strongly negative
Carbon sequestration	strongly negative
Biodiversity conservation	strongly negative
Protection against gravitational hazards	strongly negative
	strongly negative
	strongly negative
	strongly negative

3.2 Is (sufficient) adaptation to climate change feasible with BAU (maintaining the same silvicultural system also in the future, but promoting species shifts, structural diversity, lower mean stocking levels, increased mechanical stability through better thinnings, …etc.) in your CSA?

No ☐

Yes ☐ *Which measures? (free text)*

3.3 In case in Q3.2 you have ticked NO: Does BAU need a major change of the silvicultural system to be useful for adaptation to climate change? Which major changes are needed?

Please add free text!

4 Alternative forest management (AM)!

4.1 Can the AM that you have analyzed in your CSA improve the provisioning of ES in the CSA under

- current climate:

No ☐

Yes ☐

- conditions of climate change:

No ☐

Yes ☐

If you answered "YES", please answer also questions 4.1.1-4.1.4:

4.1.1 Based on simulation results which AM would you recommend?

Please, select from the list of silvicultural system elements those that best characterize the recommended AM! For selected elements make a tick or write text in the AM column!

General system		**AM**
	even-aged	☐
	uneven-aged	☐
	coppice	☐
Regeneration		
	Natural *Add species, please!*	☐
	Artificial *Add species, please!*	☐
	natural + artificial *Add species, please!*	☐
Tending		
	Number of operations	0 ☐ 1-2 ☐ >2 ☐
	Mixture regulation	
	Density reduction	Oper.1: % Oper.2: % Oper.3: % Oper.4: %
Thinning		
	Type	from above
	Number of operations per rotation	0 ☐ 1-2 ☐

		3-4 >4	☐ ☐
	Mean DBH of harvested trees per operation	Oper.1: cm Oper.2: cm Oper.3: cm Oper.4: cm Oper.5: cm	
Regeneration felling			
	system	clearcutting	
	Number of operations per rotation	0 1-2 3-4 >4	☐ ☐ ☐ ☐
	Mean DBH of harvested trees per operation	Oper.1: cm Oper.2: cm Oper.3: cm Oper.4: cm Oper.5: cm	

4.1.2 What would be the improvements compared to BAU FM (e.g. flexibility, effectiveness in ES provisioning…)? *Please add text!*

4.1.3 Which ES are better supported by AM than by BAU under climate change conditions?

Please tick (×) (multiple answers possible)! Add additional ES if needed!

Ecosystem service	Which ES are better supported by AM than by BAU under climate change conditions?
Timber	☐
Fuel wood	☐
Biomass for energy	☐
Carbon sequestration	☐
Biodiversity conservation	☐
Protection against gravitational hazards	☐
	☐
	☐
	☐

4.1.4 How well would AM perform in provision of ES under current climate? (i.e. in case that AM will be implemented but there will be no climate change). *Please provide your judgement on a scale 1-10 (1=ES provision will be severely constrained; 10=ES provision will be strongly improved)! Add additional ES if needed!*

Ecosystem service	How well would AM perform in provision of ES under current climate?
Timber	1
Fuel wood	1
Biomass for energy	1
Carbon sequestration	1
Biodiversity conservation	1
Protection against gravitational hazards	1
	1
	1
	1

Appendix 2

Efficiency gap analysis of timber harvesting systems in European Mountain Forests

Adrian Enache, Martin Kühmaier, Karl Stampfer

Document Properties

Document number	…..
Document title	Efficiency gap analysis of timber harvesting systems in European Mountain Forests
Author(s)	Enache, A., Kühmaier, M., Stampfer, K..
Date of last revision	28.07.2015
Status	Final
Version	Version 1.6
Dissemination level	PU
Relation	WP 5, related to WP 1

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 289437.

Keywords:

Harvesting systems; business-as-usual management; efficiency gaps; recommendations

Abstract:

The purpose of this document is to present the business-as-usual (BAU) timber harvesting practices (technologies and systems), the identified efficiency gaps in the Case study areas (CSAs) and to formulate recommendations regarding utilization of the most suitable harvesting systems in CSAs. Among the most common efficiency gaps identified across CSAs are the insufficient forest road infrastructure, the lack of training of forest workers and the improper utilization of the harvesting systems (HS) according to their technical feasibility in the local terrain conditions. The most efficient HS were reported in CSA5 (Sweden), where only fully mechanized systems are used, while the least performant HS were in CSA7 (Bulgaria), where 60% of the operations are non-mechanized and the harvesting machinery fleet is outdated. The most important measures for increasing the efficiency of forest operations are: improve the quality of the forest road networks (the layout and geometric characteristics of the existing roads and additionally to build new roads); increase the degree of mechanization; promote utilization of state-of-the-art HS (harvesters, forwarders and cable yarders) whenever appropriate in front of outdated machinery and ground-based timber skidding with tractors and skidders; capacity building and training of forest workers.

TABLE OF CONTENTS

Abbreviations

AN – animal (timber extraction)
BAU – business as usual
BM – biomass for energy
CO – coppice (forest management)
CS – carbon sequestration
CSA – case study area
CSW – chainsaw (felling & processing)
CY – cable yarder (timber extraction)
EA – even aged (forest management)
ED – extraction distance
ES – ecosystem services
EU – European Union
FM – forest management (system)
FW – forwarder (timber extraction)
GM – game management
HS – harvesting system
HV – harvester (felling & processing)
NC – nature conservation
MA – manual (timber extraction)
NO – no forest management
PF – protective function
PSH_{15} – productive system hour including delays of 15 minutes
REC – recreation
SKD – skidder (timber extraction)
TP – timber production
TR – tractor (timber extraction)
UA – uneven aged (forest management)

1 Introduction

In the frame of *Task 5.2 Revised silvicultural systems for portfolios of ES* of the Work Package 5 and integrating the findings of the *Deliverable D1.3 Current and historical forest management practices* of Work Package 1 (D1.3 is described as an operational description of current and historical management practices and management plans at larger scales including employed harvesting technologies and approaches (DOW 2012: page 7), this report provides recommendations and best practice guidelines regarding utilization of timber harvesting systems in mountain forests, considering the interdependency of silvicultural systems and technically feasible harvesting systems.

European mountain regions are defined by altitude, slope, climate and topography; the minimum elevation varies by country between 250 and 1000 m and, usually, there is a decrease in the altitude threshold from southern to northern European countries (Nordregio… 2004). Forests cover about 42 % of the EU land area (Eurostat 2015) and about 41% of the total EU mountain areas (Price et al. 2011). Mountain forests provide goods and services essential to the livelihood of both highland and lowland communities, that is a wide variety of ecosystem services, from protection against rock fall, avalanches and torrential flows up to high quality drinking water, wildlife habitats, landscape scenic beauty, timber production and carbon sequestration (Forest Europe et al. 2011; Price et al. 2011). With an increasing demand for forest products and ecosystem services (European Commission 2013), selection of harvesting systems (HS) for timber production represents a complex decision problem due to its numerous constraints with direct influence on the entire wood supply chain, the environment and the local communities. There are a number of factors that influence the selection, the utilization rates and the efficiency of HS in mountain forests, but the most important are the technical limitations, the social and environmental compatibility, and the cost effectiveness of the systems (Holzleitner et al. 2011). Selection of HS is closely linked with the development of forest infrastructure and its maintenance priorities (i.e. planning, building and maintaining forest road networks), which are prerequisites for the sustainable forest management and wood mobilization (Enache et al. 2013). Productivity in timber harvesting and extraction varies considerably across European countries, depending on different factors like terrain topography, method of harvesting and degree of mechanization, type of machinery and extraction distance (Eriksson and Lindroos 2014; Ghaffariyan et al. 2007, 2008, 2009; Laitila et al. 2007; Nurminen et al. 2006; Sabo and Porsinsky 2005; Spinelli et al. 2012). Productivity has not only a direct economic impact, but also an environmental and social dimension, since it is linked with the energy requirements, the level of greenhouse gas emissions and the employment rate (Berg et al. 2012; Klvač et al. 2012; Vusić et al. 2013; Whittaker et al. 2011).
Therefore, the main goals of this report are:

a) to present the business-as-usual (BAU) timber harvesting practices (technologies and systems) and the identified efficiency gaps in the Case study areas (CSAs);
b) to formulate recommendations regarding utilization of most suitable harvesting systems in Case study areas in close correlation with provision of ecosystems services (ES).

2 General facts about HS utilization

From an environmental point of view, skidding operations should be generally avoided because of the greater potential damage to soil and residual stands compared to forwarding and cable yarding, especially in cases with long extraction distances and where tree-length (TL) method is applied (longer and heavier tree logs). Skidding should also be minimized because it is responsible for a higher incidence of accidents than other extraction methods (Potocnik et al. 2009; Tsioras et al. 2011). Forwarders, skidders and tractors are not recommended in steep terrain (Eriksson and Lindroos 2014; Borz et al. 2014; Marceta et al. 2014), neither in highly fragmented terrain (e.g. large areas covered by rock outcrops and mixed ground profiles; Sabo and Porsinsky 2005; Mihelič and Krč 2009). Cable yarders are the appropriate extraction means in such cases (e.g. CSA3; Ghaffariyan et al. 2009; Kanzian 2003). For terrain with moderate slopes, forwarders are recommended instead of skidders or tractors, due to their generally higher productivity and lower residual damage, and provision of safer working conditions.

Cable yarding systems – mobile tower yarders require a high road density of 25-30 m/ha, but the layout of the road network is also important. The maximum distance between the roads should be 400 m (optimum 300 m – Austrian case studies) and the average extraction distance (ED) should be 200 m (optimum 150 m – Austrian case studies). The harvesting team has 2-3 persons: 1 or 2 in the stand (felling, debranching and choking) and 1 operating the CY. This HS has a low impact on soil disturbance and residual trees and requires highly skilled workers (following strict work procedures) due to the steep terrain conditions. They are recommended both in even-aged (EA) and uneven-aged (UA) stands. All harvesting methods (WT- whole tree, TL – tree length, CTL – cut-to-length) may be used with this system. The average productivity is about 10 m^3/h.

Tractors and skidders – these HS are more versatile to the road network density. They are suitable both for lower road densities (10 m/ha) and for higher road densities (20-25 m/ha). The ED may vary between 250 m and over 1000 m. Tractors are recommended in thinnings (small size trees), skidders are recommended in final cuts (high size trees). The limitations of these HS are the high environmental footprint due to skidding logs on the ground (e.g. high soil disturbance, high rate of damaging residual trees) especially when the tree length (TL) harvesting method is used. Thus, they are recommended for EA stands, CTL method and EDs between 250 and 400 m. The risk and incidence rate of accidents is higher than in case of forwarders. The harvesting team has 3-4 persons: 1-2 persons in the forest stand (felling, debranching and choking), 1 machine operator and 1 person in the landing area for processing to assortments. The productivity is about 3-5 m^3/h for TR and 6-8 m^3/h for SKD.

Forwarders – this system requires a good road network density (15-20 m/ha), with a maxim road spacing of 600 m and an average extraction distance of 400 m (optimum 300 m – Austrian case studies). The residual stand damage and the risk of accidents are lower than in case of TR&SKD, because the logs are transported in full suspended mode (on the trailer). However the ground pressure of the loaded forwarder wheels is higher and hence it is recommended to use boogie belts over the wheels. This system can be used in EA and UA stands when CTL method is applied. In general, FWs are used in combination with harvesters. The harvesting team has 2 persons: 1 HV operator (felling, debranching, processing to assortments) and 1 FW operator (transport and piling of logs). In case of using chainsaw, the team requires 2 persons in the forest stand for felling and processing. The productivity of FW is about 12-15 m^3/h.

Animals and manual logging – this systems are usually used for pre-skidding the logs to the skid trails (i.e. case of underdeveloped road infrastructure) and for extracting small size timber (thinning, firewood). The CTL method has to be used. The recommended extraction distance is 200 m (maximum ED 300 m). The productivity of this system is extremely low (1-2 m^3/h).

3 Reports across case study areas

This section presents the BAU harvesting practices, the identified efficiency gaps and the recommendations to resource managers on how to improve efficiency in timber harvesting considering the multifunctional forest management perspective in each CSA. The general characteristics of the CSAs are presented in Table 1.

Table 1 CSAs characteristics

CSA	Country	Forest area (ha)	Altitude (m)	Slope (%)	Tree species	Ecosystem services	FM System
			mean±SD	mean±SD			
CSA 1	Spain	2654	1422±107	32±21	Scots pine, Pyrenean oak	TP, CS, NC, REC	59CO, 35EA, 6NO
CSA 2	France	5190	1310±189	36±25	Spruce, fir, beech	TP, BM, PF, NC	94UA, 6NO
CSA 3	Austria	579	1523±157	61±21	Spruce, beech, maple, fir	TP, PF, NC, GM	100UA
CSA 4	Slovenia	5016	973±201	22±14	Beech, fir, spruce	TP, GM, NC, PF	29EA, 65UA, 6NO
CSA 5	Sweden	10405	482±68	11±7	Scots pine, spruce, birch	TP, CS, NC	100EA
CSA 6	Slovakia	5130	1057±166	29±14	Spruce, fir, beech	TP, NC, REC, PF	100EA
CSA7	Bulgaria	1737	1580±176	56±52	Scots pine, black pine, fir, beech, spruce	TP, BM, CS, NC, PF	70EA, 30NO

LEGEND: Ecosystem services: TP – timber production; CS – carbon sequestration; NC – nature conservation; BM – biomass for energy; REC – recreation; PF – protective function; GM – game management; **FM systems:** EA – even-aged; UA – uneven-aged; CO – coppice; NO – no management.

3.1 Forest infrastructure

In order to benchmark the current forest infrastructure conditions with a desired state, the road densities reported in CSAs were compared with indicative optimum road density values determined for cable yarders, forwarders and skidders using road spacing optimization models based on the cost minimization approach. The indicative optimum road density values for each CSA were calculated for two assumptions (Figure 1): *a) optimum BAU HS* - considering the share of currently available HS in each CSA; and *b) optimum NEW HS* - considering the share of technically feasible state-of-the-art HS in each CSA.

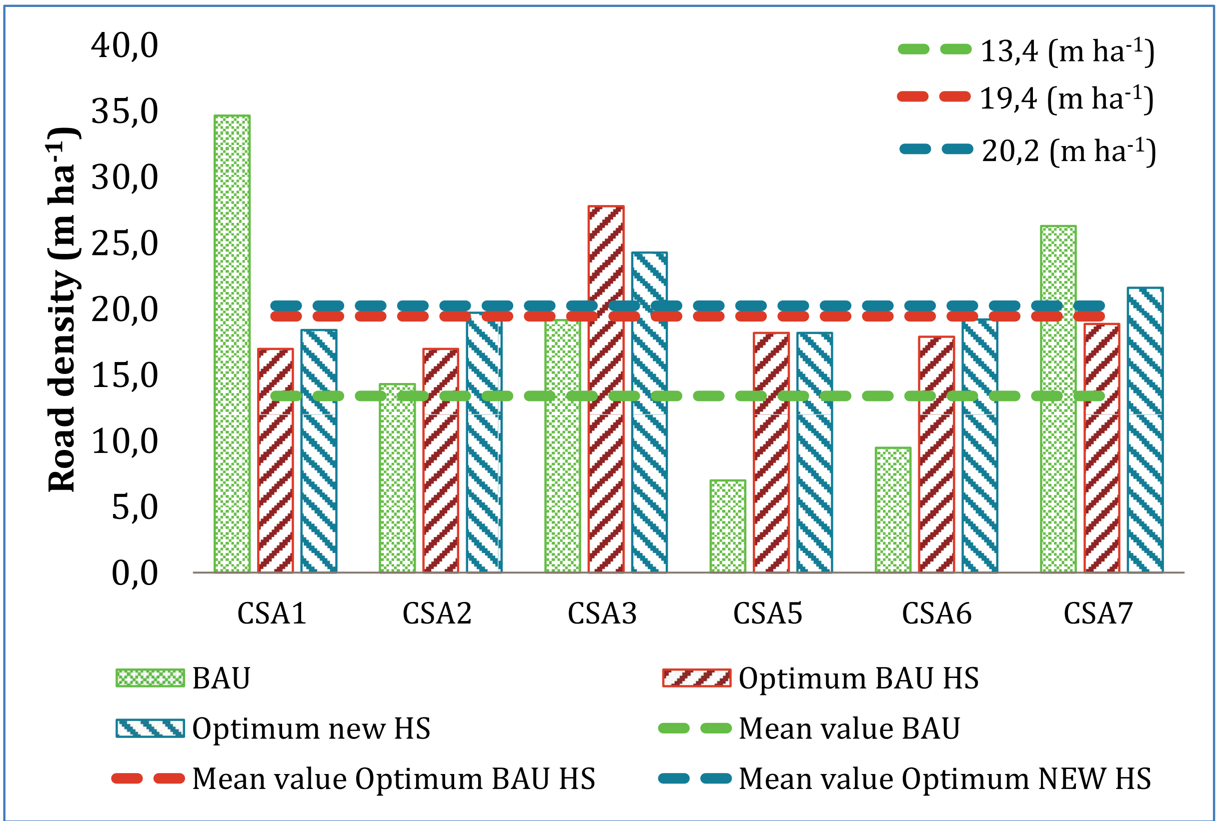

Figure 1 Road network densities across CSAs

Figure 1 shows that, in general, there is space for improving the forest road network in most of the CSAs. Referring to the mean values across CSAs, the road network density (13.4 m ha^{-1}) is about 45% below the required road density (19.4 m ha^{-1}) for the optimal use of BAU HS and about 51% below the required density (20.2 m ha^{-1}) for the optimal use of NEW HS. Though, the infrastructure situation is different from one CSA to another; for example, CSA1 (Spain) and CSA7 (Bulgaria) reported surplus of infrastructure, when comparing *BAU* with *optimum BAU HS* situation. That is, CSA1 and CSA7 seem to be well equipped with road infrastructure (i.e. the road networks exceed in length the requirements for both BAU and new HS) for providing high productivity in timber extraction. However, the productivity of forest operations in these CSAs is rather low (see Section 3) and it seems there are other factors (i.e. quality of the road network;

available harvesting technology) which influence the efficiency of forest operations in these two cases. On the other hand, CSA2 (France), CSA3 (Austria), CSA5 (Sweden) and CSA6 (Slovakia) revealed road infrastructure gaps. Filling these gaps would require extension of the road networks with 16% up to 160% depending on CSA and harvesting systems used. In CSA2 and CSA6 a higher road density is required for implementing NEW HS compared to BAU HS, while in CSA3 introducing NEW HS (i.e. forwarders) would require less road density than for extracting timber with BAU HS.

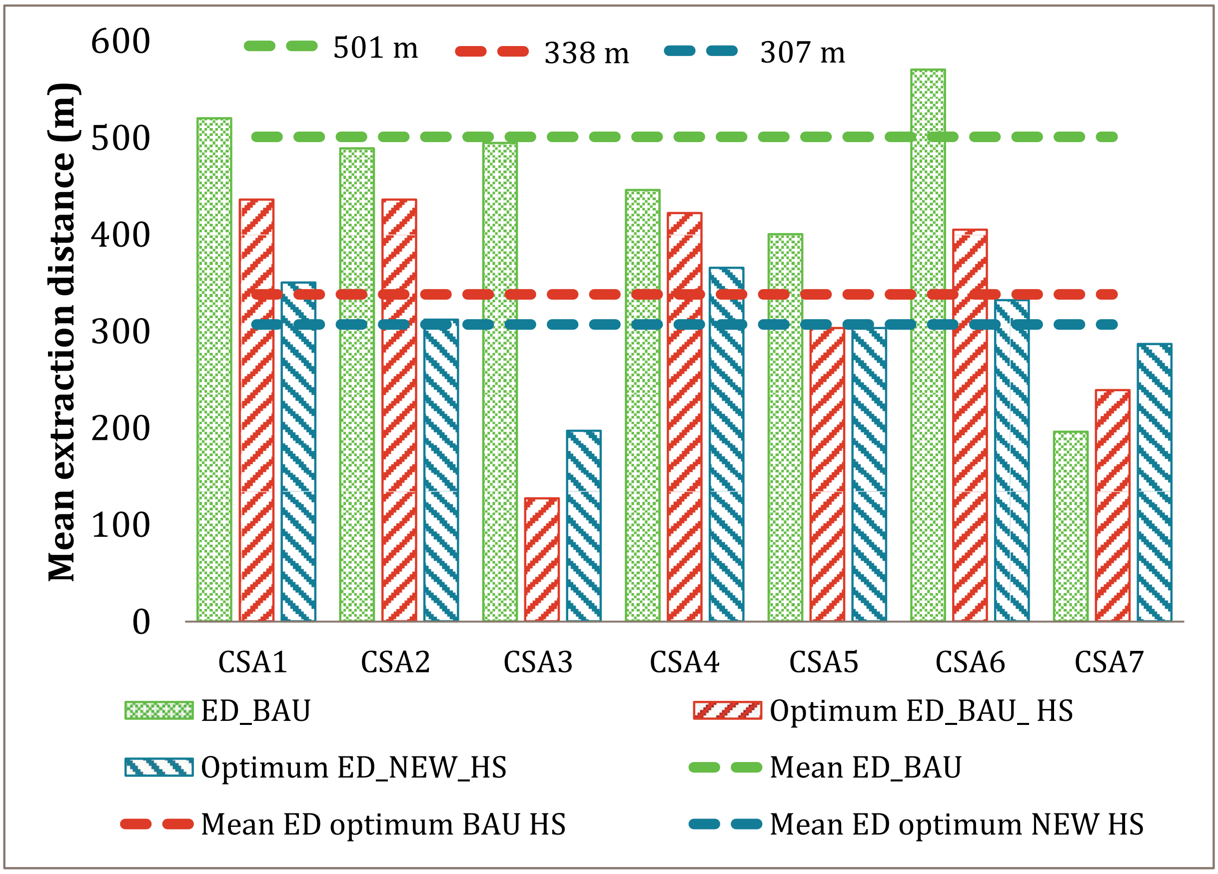

Figure 2 Mean extraction distance across CSAs

Referring to the mean extraction distance (ED), Figure 2 shows that the BAU ED (501 m) across CSAs is about 48% higher than in *optimum BAU HS* (338 m) and about 63% higher than in *optimum NEW HS* (307 m) scenarios, emphasizing once more the need for extending the forest road networks. Most of the CSAs require a reduction of the mean extraction distance in order to be more efficient from an economic (i.e. productivity and costs) and environmental point of view (i.e. lower emissions and lower energy requirements). From the social point of view, a lower extraction distance means higher productivity and therefore lower employment rate, but also an improved working safety.

3.2 Timber transport

The geometric characteristics and the trafficability of the road network are qualitative indicators which play an important role in timber transport efficiency. Depending on the minimum curve radius and the bearing capacity of the forest roads, there are two options for transporting timber: with trucks or with trucks equipped with trailers. The latter option is more efficient than the former in that higher payloads can be carried at lower fuel rates when measured per m^3. The transport efficiency was determined by dividing the loading capacity to the maximum allowable weight reported in each CSA (Figure 3). As depicted in Figure 3, efficiency gaps between 6% and 32% were reported in CSA1, CSA3 and CSA7, which also reported significant share of roads with trafficability only for trucks without trailer. That is the main reason of the identified gaps. Therefore, improving the quality of the existing road networks (e.g. geometric characteristics; pavement structure) in these CSAs is necessary. France (CSA2), Sweden (CSA5) and Slovakia (CSA6) reported surplus in transport efficiency. That is, the loading capacity exceeds the maximum allowable weight. If the higher surplus reported in Sweden may be caused by the higher maximum allowable weights on some public roads (up to 60 t) and by the necessity of reducing transport costs due to longer distances, there is no speculation about the reason of the slight overloading of the timber trucks in CSA2 and CSA6.

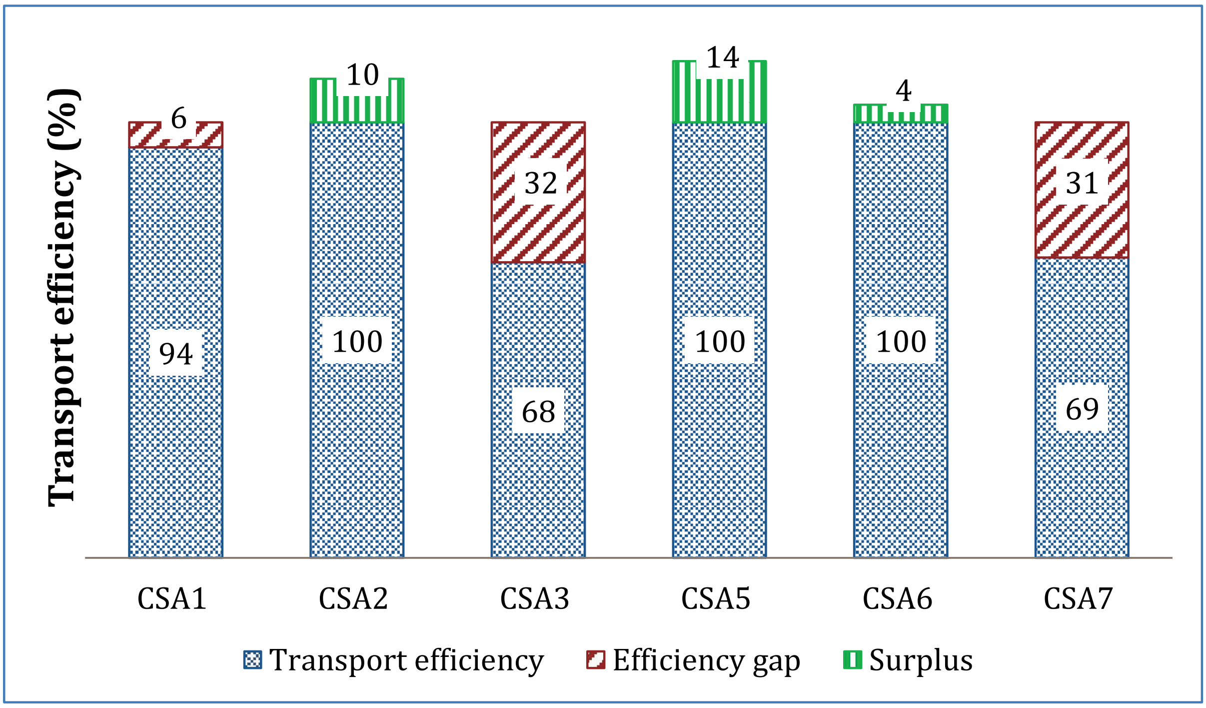

Figure 3 Timber transport efficiency across CSAs

3.3 Degree of mechanization and general facts of HS across CSAs

The degree of mechanization of the forest operations are presented in Table 2. The cross-case study analysis showed that CSA5 (Sweden) employs exclusively fully mechanized systems, CSA1 (Spain) only highly mechanized systems, while the other CSAs mainly use partly mechanized systems (Figure 4). Fully mechanized systems are more productive and more cost effective then partly mechanized ones. They may also produce more timber over a fixed period with positive effects in high value creation and in establishing additional jobs in the wood supply chain. Fully mechanized systems are also more ergonomic and safer than partly mechanized ones (Albizu-Urionabarrenetxea et al. 2013). In partly mechanized HS, the incidence of accidents is higher than in highly mechanized systems and the vast majority of accidents occur during felling trees with chainsaw, which is also the most frequent cause of fatal accidents in forestry. Some general facts about the performance of the currently used harvesting systems (BAU) across CSAs are depicted in Table 3.

Table 2 Degree of mechanization of the harvesting systems

Operation	Means of execution	Non-mechanized	Partly mechanized	Highly mechanized	Fully mechanized
Felling and processing	Saw/Axe	X	-	-	-
	Chainsaw	-	X	X	-
	Processor	-	-	X	-
	Harvester	-	-	-	X
Extracting	Manual	X	X	-	-
	Animal	X	X	-	-
	Tractor	-	X	X	-
	Skidder	-	X	X	-
	Forwarder	-	X	X	X
	Cable Yarder	-	X	X	-

Note: X = required; - = not required

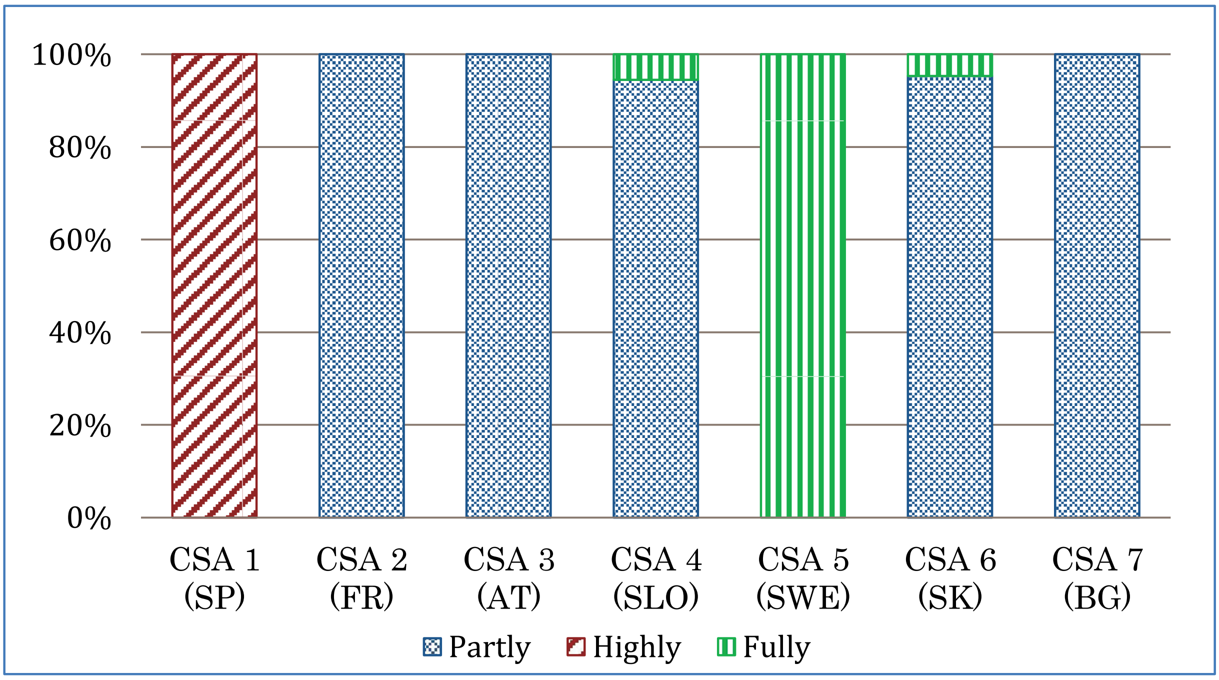

Figure 4 Degree of mechanization of harvesting systems across CSAs

Table 3 General performance indicators of BAU harvesting systems across CSAs

BAU CSA Performance	MEAN_BAU	Min_BAU		Max_BAU	
		Value	CSA	Value	CSA
Productivity (m^3/h)	**14,6**	4,0	CSA7	34,3	CSA5
Cost (€/m^3)	**26,4**	15,3	CSA7	44,9	CSA3
Consumption (l/m^3)	**2,1**	1,6	CSA6	3,1	CSA7
Accidents (n/mill. m^3)	**86,0**	22,0	CSA5	126,0	CSA7
CO_{2eq} emissions (kg/m^3)	**5,6**	4,2	CSA6	8,0	CSA7
Mean damage stand index (%)	**27,3**	17,0	CSA5	44,0	CSA3

3 Reports per case study areas

The efficiency gaps in timber harvesting were identified by comparing the performance of the harvesting systems in the following scenarios:

- *Scenario 1: Business-as-usual (BAU)* – considering current infrastructure conditions and currently used harvesting systems;
- *Scenario 2: Optimum ED_BAU_HS* – considering the indicative optimum extraction distance (ED) for the currently used harvesting systems (BAU HS) and optimum productivity in felling and processing of BAU HS. This hypothesis means the road network has to be extended for reaching the optimum ED of BAU HS.

- *Scenario 3: Optimum ED_NEW_HS* – considering the indicative optimum ED, optimum productivity in felling and processing and the share of technically feasible HS in each CSA. This hypothesis means the road network has to be extended for reaching the optimum ED of state-of-the-art HS.

The following performance indicators of the HS were analysed: *productivity* (m^3/PSH_{15}), *cost* (€/m^3), *fuel consumption* (l/m^3), *accidents rate* (n/million m^3), *CO_{2eq} emissions* (kg/m^3), *mean damage stand index* (%), *provision of ecosystem services* (ES).

3.1 CSA1 – Montes Valsain, Iberrian Mountains, Spain

BAU facts: About 60% of the stands are managed in coppice FM system, while 35% are even-aged stands and 5% of the stands are not managed (Table 1). The tree species composition is 49% Scots pine and 51% Mediterranean oaks. The harvesting operations are performed with highly mechanized systems (Figure 4) and the tree-length (TL) and cut-to-length (CTL) harvesting methods are used in almost equal shares, 49% and 51% respectively. The road density is 34.7 m/ha (Figure 1) and the mean extraction distance is 520 m (Figure 2).

Efficiency gaps: Although the road density in CSA1 is about two and a half times higher than the average across CSAs, the mean extraction distance is very high. With such high road network density, the expected mean extraction distance would be in the range of 150 – 200 m. Thus, it seems that either the layout of the roads is not optimal or not all roads of the road network are used for harvesting operations from various reasons (e.g. damaged roads, public roads). In BAU situation (Scenario 1), the timber felling and processing is performed entirely by chainsaw and the timber extraction is done 100% by skidders (Table 4). However, the terrain and stand conditions in CSA 1 allow utilization of more suitable and more efficient HS. The productivity of the overall BAU HS (felling, processing and extraction) is very low (50% below the average across CSAs), especially due to the low productivity of felling and processing operations with chainsaw. In this respect, the performance of CSA 1 is about 57% and 68% respectively lower than CSA 2 (France) and CSA 3 (Austria), which use the same HS for felling and processing. The productivity of BAU HS in CSA 1 can be improved with about 22% only by enhancing the road network infrastructure and still using the same HS (Scenario 2), but also with better trained forest workers. In addition, if state-of-the-art HS are used (Scenario 3) then the productivity would increase one and a half times. Consequently, the harvesting costs would sink with 42% in Scenario 2 and 47% in Scenario 3 respectively, compared to the BAU situation. Furthermore, the level of CO_{2eq} emissions can be diminished with 26% in Scenario 2 and 18% in Scenario 3. By introducing state of the art HS, Scenario 3 creates the premises not only for increased efficiency when compared to Scenarios 1 and 2, but also for safer working conditions (about 33% less expected accidents), less residual stand damage (with about 8%) and provision of additional ecosystem services.

Table 4 Efficiency gaps in timber harvesting (CSA1 Valsain, Spain)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	**Optimum ED_BAU_HS**	**Optimum ED_NEW_HS**
HS_Felling & processing (%)	100CSW	100CSW	50CSW 50HV
HS_Extraction (%)	100SKD	100SKD	35SKD 50FWD 15CY
Productivity (m^3/h)	9,5	11,6	23,1
Cost (€/m^3)	33,8	19,7	18,0
Consumption (l/m^3)	2,68	1,95	1,87
Accidents (n/mill. m^3)	87,0	87,0	58,1
CO_{2eq} emissions (kg/m^3)	6,72	5,00	5,54
Mean damage stand index (%)	26,5	26,5	24,4
Ecosystem services	TP, CS	TP, CS	Additional: BM, BD, GM, REC, PF

Causes of disparities: The possible reasons behind these efficiency gaps are: the layout (quality) of the forest road network; the small dimension trees in coppice FM; the level of know-how and the lack of training of forest workers in mountain forest operations; the availability and the affordability of state-of-the-art HS; and CSA's country specific characteristics (e.g. policies, socio-economic and cultural differences).

Recommendations: A logic step for achieving the desired state of efficiency of the forest operations (Scenario 3) is to change the BAU HS with state-of-the-art HS (Table 4), that is, to shift from the current 100% use of chainsaw (CS) and skidders (SKD) towards the following technically feasible HS and to use wherever possible highly mechanized systems: 50% CS and 50% harvesters (HV) for felling and processing, respectively 35% SKD, 50% forwarders (FW) and 15% cable yarders (CY) for timber extraction. This would require an improved layout of the road network in such a way that the access for HVs, CYs and FWs is guaranteed and the mean extraction distance would sink from 520 m to 350 m. That is, to extend the road network with about 9,3 km to 18,6 km of slope roads (i.e. new roads or upgrading existing skid trails), which means a financial effort between 185 000 € and 370 000 €. In addition, training forest workers is required both for improving their technique and efficiency in timber felling and processing, as well as for using the state-of-the-art HS (i.e. HV, FW and CY). Fostering the CTL harvesting method in combination with FW or CY instead of TL method in combination with SKD for timber extraction is also recommended, because it causes less residual stand and soil damage and provides safer working conditions for the forest workers.

3.2 CSA2 – Vercors, Western Alps, France

BAU facts: In CSA2, 94% of the stands are managed in uneven-aged FM system and 6% of the stands are not managed (Table 1). About 81% of the tree species are conifers (41% spruce, 38% fir and 2% dwarf pine) and 19% are broadleaves (8% beech and 11% other hardwoods). The harvesting operations are performed with partly mechanized systems (Figure 4) using 100% TL harvesting method. The road density is 14.7 m/ha (Figure 1) and the mean extraction distance is 490 m (Figure 2).

Table 5 Efficiency gaps in timber harvesting (CSA2 Vercor, France)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	Optimum ED_BAU_HS	Optimum ED_NEW_HS
HS_Felling & processing	100CSW	100CSW	53CSW 47HV
HS_Extraction	100SKD	100SKD	33SKD 47FWD 20CY
Productivity (m^3/h)	13,0	13,5	23,2
Cost (€/m^3)	23,0	22,5	19,9
Consumption (l/m^3)	1,75	1,69	1,83
Accidents (n/mill. m^3)	87,0	87,0	61,3
CO_{2eq} emissions (kg/m^3)	4,47	4,31	5,41
Mean damage stand index (%)	26,5	26,5	25,5
Ecosystem services	TP, CS	TP, CS	Additional: BM, BD, GM, REC, PF

Efficiency gaps: Currently, felling and processing are performed entirely by chainsaw and timber extraction is done 100% with skidders (Table 5). The BAU HS productivity is 11% below the average across CSAs (14,6 m^3/h), but it is as high as the average value across CSAs that use partly mechanized systems. The productivity of the BAU HS (Scenario 1) is only 4% lower than the optimum for this type of HS (Scenario 2), which means the road network is well developed in accordance with the skidding technology and forest workers are experienced using this technology. However, the terrain and stand conditions in CSA 1 allow utilization of more efficient HS. When implementing state-of-the-art HS (Scenario 3), the productivity can increase with about 78%, the harvesting costs can sink with 13%, the number of accidents would decrease by 30% and the residual stand damage by 4% compared to the BAU situation. Scenario 3 could also provide additional ecosystem services. Though, the fuel consumption would increase by 5% and the level of $CO2_{eq}$ emissions by 21% because of the utilization of highly mechanized systems.

Causes of disparities: The possible reasons behind these efficiency gaps are: the high dimension of trees in uneven-aged FM; the availability and the affordability of state-of-the-art HS; and CSA's country specific characteristics (e.g. policies, socio-economic and cultural differences).

Recommendations: Increasing the degree of mechanization (Scenario 3) and using new technically feasible HS makes sense from economic (increased productivity and lower costs), ecologic (less residual stand damage) and social point of view (safer working conditions). However, shifting from BAU HS to state-of-the-art HS in CSA2 is a matter of trade-off and sensitivity analysis, since selecting one option over another provides both gains and losses. From an environmental point of view, skidding operations have greater impact on soil and residual stands compared to forwarding and cable yarding, especially when the extraction distance is long and when TL method is applied (which is the case of CSA2). Therefore, the utilization of CTL harvesting method and a better fitting of HS utilization to their technical feasibility and to the terrain conditions should be fostered. Thus, CYs should be used in steep terrain (slope>60%) and FWs in moderate and flat terrain instead of the currently used SKDs. For that to happen, the forest road network needs to be improved in order to create access for HVs, CYs and FWs and to reduce the mean extraction distance from 490 m to 315 m. That is, to extend the road network with about 22,1 km to 44,2 km of slope roads (i.e. new roads or upgrading existing skid trails). The necessary investment effort would be between 775 000 € and 1 550 000 €.

3.3 CSA3 – Montafon, Eastern Alps, Austria

BAU facts: All stands are managed in uneven-aged FM system in CSA3 (Table 1). About 65% of the tree species are conifers (32% spruce, 7% fir and 26% other conifers) and 35% are broadleaves (beech and other hardwoods). The harvesting operations are performed with partly mechanized systems (Figure 4) using 100% the CTL harvesting method. The road density is 19.2 m/ha (Figure 1) and the mean extraction distance is 495 m (Figure 2).

Efficiency gaps: Currently, felling and processing are performed entirely by chainsaw and timber extraction is done 100% with cable yarders (Table 6). Although the road density in CSA3 is about 43% higher than the average across CSAs (13.4 m/ha), it is still 57% below the mean value in Austria (45 m/ha), which means the average extraction distance of 495 m in CSA3 is very high for Austrian conditions. This hinders the utilization of appropriate mix of HS, especially for moderate slope classes (e.g. forwarders), due to lack of access to those areas. With current road density and HS available, the expected extraction distance would be 250 – 300 m. Thus, the productivity of forest operations is low (18% below the average across CSAs) and the harvesting costs (44.9 €/m^3) are the highest across CSAs, with about 70% above the average costs. The productivity of the BAU HS (Scenario 1) is 17% lower than the optimum productivity for cable yarders (Scenario 2), which means that the layout of the road network should be improved with new roads for increasing the efficiency of cable yarders' utilization. It is also a sign that CYs are not the most efficient harvesting option in all stands and that there are better adapted HS to the local terrain and stand conditions that should be used. This is the case of FWs, which are a technically feasible option for about 36% of the area of CSA3. Thus, when FWs and CYs are used according to their technical feasibility (Scenario 3), the productivity of forest operations can increase with about 77%, the harvesting costs can sink with about 35% and the fuel consumption would be with 19% lower. In addition, the number of accidents would decrease by 22%, the level of $CO2_{eq}$ emissions would sink by 15% and the residual stand damage by 22% compared to the current situation.

Table 6 Efficiency gaps in timber harvesting (CSA3 Montafon, Austria)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	Optimum ED_BAU_HS	Optimum ED_NEW_HS
HS_Felling & processing	100CSW	100CSW	64CSW 36HV
HS_Extraction	100CY	100CY	64CY 36FW
Productivity (m^3/h)	12,0	14,5	21,2
Cost (€/m^3)	44,9	38,9	29,2
Consumption (l/m^3)	2,04	1,64	1,65
Accidents (n/mill. m^3)	111,0	111,0	79,0
CO_{2eq} emissions (kg/m^3)	5,34	4,27	4,55
Mean damage stand index (%)	44,0	44,0	34,3
Ecosystem services	TP, BD, REC, PF, CS	TP, BD, REC, PF, CS, GM	TP, REC, PF, CS, GM

Causes of disparities: The high harvesting costs in CSA3 are because of the high system costs of CYs (i.e. 200 €/h) and the high labour costs in Austria (i.e. 35 €/h). Some possible reasons for not utilizing FWs are the high investment costs (i.e. 95 €/m) in the additional road infrastructure necessary for accessing those sites where FWs are the feasible extraction technology and the difficulty of building roads in steep and rocky terrain.

Recommendations: In CSA3 it is recommended to use the appropriate harvesting systems for the local terrain conditions (e.g. CYs in steep terrain and HVs and FWs in moderate slopes) not only because of the economic benefits, but also due to the environmental and social gains, such as less GHG emissions and residual stand damage and lower risk of accidents, as shown in Table 6. Hence, it is recommended to shift from partly mechanized systems (CS+CY) to highly mechanized systems (HV+FW) wherever the terrain and stand conditions allow. In order to make accessible the harvesting sites where HV+FW is the most suitable option, it is necessary to extend the road network with about 6.6 km to 13.3 km, which means an approximate cost between 630 000 € and 1 260 000 €. The use of CTL method is appropriate in combination with harvesters and forwarders, but also when chainsaw and cable yarders are used. In this latter case, utilization of mobile tower yarders with processor heads is recommended and apart from

CTL method, TL and WT methods should also be applied, in order to increase the efficiency of the extraction process and to provide biomass for bioenergy (additional ES from processing the trees at the road side with the processor heads).

3.4 CSA4 – Sneznik, Dinaric Mountains, Slovenia

BAU facts: In CSA4, 29% of the stands are managed in even-aged FM system, 65% in uneven-aged FM system and 6% of the stands are not managed (Table 1). About 53% of the tree species are conifers (25% spruce, 23% fir and 5% other conifers) and 47% are broadleaves (25% beech, 10% maple and 12% other hardwoods). 94% of the forest operations are performed with partly mechanized systems and 6% with fully mechanized systems, using CTL harvesting method in 68% of the cases and TL method in 32% of the harvesting sites. The data about the forest road network was not available and the reported mean extraction distance is 446 m (Figure 2).

Table 7 Efficiency gaps in timber harvesting (CSA4 Sneznik, Slovenia)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	Optimum ED_BAU_HS	Optimum ED_NEW_HS
HS_Felling & processing	94CSW 6HV	94CSW 6HV	47CSW 53HV
HS_Extraction	94SKD 6FWD	94SKD 6FWD	47SKD 53FWD
Productivity (m^3/h)	13,5	13,7	23,4
Cost (€/m^3)	29,8	29,5	17,2
Consumption (l/m^3)	1,93	1,90	1,88
Accidents (n/mill. m^3)	83,1	83,1	52,6
CO_{2eq} emissions (kg/m^3)	5,15	5,08	5,54
Mean damage stand index (%)	25,9	25,9	21,5
Ecosystem services	TP, CS	TP, CS	TP, CS, PF

Efficiency gaps: In only about 6% of the CSA4 state-of-the-art HS are used (HVs and FWs), although the potential is much higher (i.e. in about 53% of the area; Table 7). Therefore, currently, the harvesting productivity is with 8% below the average value across CSAs, but similar to those CSAs which use partly mechanized systems. The harvesting costs are about 13% higher than the mean value across CSAs. The insignificant differences between Scenarios 1 and 2 suggest that the quality of the road network is suitable for the HS used in BAU situation. However, by further extending and improving the layout of the road network there are opportunities for utilization of more efficient and better adapted HS to moderate slope conditions (mean slope in CSA4 is 22%; see Table 1). Thus, the productivity of forest operations could increase by 73%, the costs would sink by 42% and the number of accidents would be about 37% lower (Scenario 3; Table 7). However, due to a higher degree of mechanization, the

CO_{2eq} emissions would increase by 8%, but in contrast, the mean residual stand damage would be lower with 17% compared to BAU. When using state-of-the-art HS (i.e. tracked FWs and HWs), because of the full suspended transport of logs and hence less soil disturbance compared with skidding logs on the bare ground, the provision of protective function ES is fostered.

Causes of disparities: The possible reasons behind these efficiency gaps may be the level of know-how and the lack of training of forest workers in mountain forest operations on one hand, and the availability and the affordability of state-of-the-art HS (harvesters and forwarders), including CSA's country specific characteristics, such as policies, subsidies and financial support schemes, on the other hand.

Recommendations: At first, it is recommended to increase the utilization rate of CTL over TL harvesting method, especially when using skidders, in order to reduce the stand damage potential. For reducing the extraction distance in CSA4 from 446 m (BAU) to 366 m (optimal theoretical case) and an increased efficiency of forest operations, the road network should be extended with about 9.2 km to 18.4 km, which would require investments between 325 000 € and 650 000 €. The investment effort is worthwhile when compared to the potential economic, environmental and social gains (Scenario 3; Table 7). Moreover, utilization of HVs and FWs (including tracked machinery) should be strongly fostered in front of felling with chainsaws and extracting with skidders, because the terrain and stand characteristics allow even a more intensive utilization of HVs and FWs, up to 100%, with even more benefits. However, introducing HVs and FWs technology requires a well-implemented training programme of the forest workers for operating these state-of-the-art HS, know-how transfer and available financial support schemes and a good planning and scheduling of the harvesting activities for the effective utilization of these very expensive machines.

3.5 CSA5 – Vilhelmina, Scandinavian Mountains, Sweden

BAU facts: In CSA5, all stands are managed in even-aged FM system (Table 1). About 69% of the forest stands are conifers (32% spruce, 30% scots pine and 7% lodge-pole pine) and 31% are birch stands. All forest operations are performed with fully mechanized systems using CTL harvesting method. The road network density is 7.0 m/ha (Figure 1) and the mean extraction distance is 400 m (Figure 2).

Efficiency gaps: Although the road density is very low (48% below the average value across CSAs), CSA5 has the highest productivity and one of the lowest harvesting costs across CSAs. CSA5 represents a benchmark for efficient timber harvesting in low and moderate slope conditions with highly mechanized systems. CSA5 has the lowest incidence of accidents among CSAs (about 38% below the average), proving that fully mechanized HS provide safer working conditions. Some minor improvements in efficiency are possible by reducing the extraction distance from 400 m to about 300 m. Thus, the productivity could increase by 5% and the costs could sink by 4%, while the fuel consumption could be 5% lower and the CO_{2eq} emissions 4%

lower (Table 8). In addition, the harvesting residues could be used for bioenergy production, extending the list of ES provision.

Table 8 Efficiency gaps in timber harvesting (CSA5 Vilhelmina, Sweden)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	Optimum ED_BAU_HS	Optimum ED_NEW_HS
HS_ Felling & processing	100HV	100HV	100HV
HS_ Extraction	100FW	100FW	100FW
Productivity (m^3/h)	34,3	36,2	36,2
Cost (€/m^3)	15,8	15,2	15,2
Consumption (l/m^3)	1,73	1,65	1,65
Accidents (n/mill. m^3)	22,0	22,0	22,0
CO_{2eq} emissions (kg/m^3)	5,27	5,07	5,07
Mean damage stand index (%)	17,0	17,0	17,0
Ecosystem services	TP, CS	TP, CS	TP, CS, BM

Causes of disparities: The only gap that currently affects the performance of HS, in an otherwise low proportion in CSA5, is the low road network density.

Recommendations: Being a benchmark for efficient timber harvesting, CSA5 requires only fine adjustments in planning and scheduling of the activities. For reducing the extraction distance in CSA4 from 400 m (BAU) to 303 m (optimal theoretical case), the road network should be extended with about 20.8 km to 41.6 km, which would require investments between 410 000 € and 830 000 €. The investment effort is subject to further cost-benefit and sensitivity analyses. They are necessary for helping decision makers to decide where to locate the new roads, provided the 4-5% increase in performance and the additional provision of ES. Better planning and scheduling of harvesting operations could also increase the efficiency.

3.6 CSA6 – Kozie Chrbty, Western Carpathians, Slovakia

BAU facts: In CSA6, all stands are managed in even-aged FM system (Table 1). About 92% of the stands are conifers (57% spruce, 24% larch, 6% scots pine and 5% fir) and 8% are beech forests. 95% of the forest operations are performed with partly mechanized systems and 5% with fully mechanized systems, using CTL harvesting method in 95% of the cases and TL method in 5%. The road network density is 9.5 m/ha (Figure 1) and the mean extraction distance is 570 m (Figure 2).

Table 9 Efficiency gaps in timber harvesting (CSA6 Kozie Chrbty, Slovakia)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	Optimum ED_BAU_HS	Optimum ED_NEW_HS
HS_ Felling & processing	95CSW 5HV	95CSW 5HV	59CSW 41HV
HS_ Extraction	87SKD 5FW 8CY	87SKD 5FW 8CY	43SKD 41FW 16CY
Productivity (m³/h)	16,2	14,1	21,6
Cost (€/m³)	21,9	24,3	15,9
Consumption (l/m³)	1,57	1,81	1,85
Accidents (n/mill. m³)	85,7	85,7	64,2
CO_{2eq} emissions (kg/m³)	4,25	4,89	5,40
Mean damage stand index (%)	27,4	27,4	25,4
Ecosystem services	TP, NC, REC, PF	TP, NC, REC, PF	

Efficiency gaps: The road density in CSA6 is below the average across CSAs with about 29% and hence, the mean extraction distance is the highest between CSAs, with about 14% above the average of the CSAs. Currently, tractors and skidders are the most commonly used timber extraction method (84% of the harvesting sites), while state-of-the-art HS are used only marginally in CSA6 (i.e. in about 13% of the area; Table 9). Despite the long extraction distance and extraction methods used, the productivity of BAU HS is very high (i.e. 11% above the average value among CSAs, respectively 23% above the mean value of the CSAs with similar BAU HS), which is a rather surprising fact. There was no objective evidence explaining such high productivity values in CSA6, and therefore the reported productivity was considered an outlier. This hypothesis is supported by the significant difference of the HS performance indicators (decreasing performance) between Scenario 1 (BAU HS) and Scenario 2 (optimal theoretical case for the BAU HS). CSA6 is the only case across CSAs where BAU HS perform better than the theoretical optimal case (Table 9), which cannot be supported by hard facts. Therefore, it is most likely there are some data inconsistencies regarding the reported productivity of BAU HS in Slovakia. Nonetheless, a comparison of the efficiency of Scenario 2 (optimum case for BAU HS) and Scenario 3 (optimum case for NEW HS) is possible, because they are not linked to the reported data in CSA1. Increasing the share of utilization of harvesters, forwarders and cable yarders in timber harvesting (Scenario 3) would mean a productivity increase of 53%, a cost reduction by 35%, an incidence of accidents with 25% lower and a slight decrease by 7% of the residual stand damage when compared to Scenario 2. The fuel consumption would increase by 2% and the CO_{2eq} emissions by 10% due to the increased level of mechanization and higher consumption rate of HVs, FWs and CYs compared to chainsaws, tractors and skidders.

Causes of disparities: The main reasons behind these efficiency gaps are the long extraction distance, the insufficient length and the poor quality of the forest road network, the lack of training of forest workers in mountain forest operations, the availability and the affordability of state-of-the-art HS (HVs, FWs and CYs), including CSA's country specific characteristics, such as financial support schemes for the forest sector.

Recommendations: One important step towards more efficient forest operations would be to balance the utilization of HS, which means to reduce the utilization of tractors and skidders by 50% and to promote instead the utilization of HVs, FWs and CYs according to their technical feasibility (Scenario 3; Table 9). Implementation of Scenario 3 requires the reduction of the mean extraction distance from 570 m to 332 m (see Figure 2). This means the road network should be extended with about 16.1 km to 32.2 km, which would mean an investment effort between 630 000 € and 1 260 000 €. The precise amount of investments and the layout of the new forest roads should be decided after cost-benefit analysis and sensitivity analysis of the potential economic, environmental and social gains (Scenario 3; Table 9). For a more efficient utilization of HVs, FWs and CYs, there is a need of know-how transfer and training of forest workers for operating these state-of-the-art HS.

3.7 CSA7 – Shiroka Laka, Rhodope Mountains, Bulgaria

BAU facts: In CSA7, 70% of the stands are managed in even-aged FM system and 30% of the stands are not managed at all (Table 1), which is the highest ratio across CSAs. About 70% of the forests are populated with conifers (39% spruce, 24% black and scots pines and 7% fir) and 30% are beech forests. All forest operations are performed with partly mechanized systems, 60% of the harvestings are done manually and with horses, 35% with skidders and 5% with cable yarders. The harvesting methods applied are CTL in 67% of the cases and TL method in 33%. The density of the forest road network is 26.3 m/ha (Figure 1) and the mean extraction distance is 196 m (Figure 2).

Table 10 Efficiency gaps in timber harvesting (CSA7 Shiroka Laka, Bulgaria)

Scenario	Scenario 1	Scenario 2	Scenario 3
	BAU	Optimum ED_BAU_HS	Optimum ED_NEW_HS
HS_Felling & processing	100CSW	100CSW	83CSW 17HV
HS_Extraction	40MA 20AN 35SKD 5CY	40MA 20AN 35SKD 5CY	42SKD 17FW 41CY
Productivity (m^3/h)	4,0	6,6	14,6
Cost (€/m^3)	15,3	10,4	20,3
Consumption (l/m^3)	3,10	1,89	2,17
Accidents (n/mill. m^3)	126,0	126,0	85,8
CO_{2eq} emissions (kg/m^3)	8,01	4,79	6,13
Mean damage stand index (%)	24,1	24,1	32,1
Ecosystem services	TP, CS, BD, GM, PF, REC	TP, CS, BD, GM, PF, REC	TP, CS, BM, PF, REC

Efficiency gaps: The road density in CSA2 is about two times higher than the average across CSAs (13.4 m/ha) and the mean extraction distance (ED) is the lowest across CSAs, with 61% below the mean ED. Although these indicator values suggest that the layout of the roads is optimal for the currently used HS, one has to consider that the 30% ratio of the not managed forest stands might be due to the lack of access to those stands and hence, the road density and ED reported might be only for the accessible forest area (70%). On the other hand, the low extraction distance can also be explained by the high proportion of non-mechanized logging (60% manually and with animals) and by the obsolete harvesting systems available in CSA7; extraction of timber is a very hard work and therefore animals and especially humans are not able to transport the timber over a longer distance (i.e. maximum 200 m), while old machinery cannot be efficient on distances higher than 300 m. Indeed, CSA7 has the lowest productivity in timber harvesting, which is about 3.5 times below the average value across CSAs. However, the harvesting costs are also the lowest, with about 42% below the average harvesting costs across CSAs. That is because of the low labour costs in Bulgaria, the non-mechanized harvesting systems and the low system costs of harvesting machinery. Due to the low productivity and the obsolete HS available in Bulgaria, CSA7 has the highest level of fuel consumption per cubic meter harvested, which is about 48% above the mean value across CSAs and about 98% above the lowest reported consumption rate (CSA6). Admittedly, the CO_{2eq} emissions are also the highest across CSAs, with about 43% above the mean value across CSAs and about 88% above the lowest CO_{2eq} emissions reported in fully mechanized systems (CSA5, Sweden). Because of the low mechanization degree, it is not a surprise that CSA7 has the highest accident incidence in forest operations, which is 47% above the mean value across CSAs and 5.7 fold higher than in case of fully mechanized systems (CSA5).

There is a big difference between the performance of BAU HS (Scenario 1) and the potential performance of the BAU HS (Scenario 2). The productivity is about 65% higher, while the costs, the fuel consumption and the CO_{2eq} emissions are with 32%, 39% and 40% respectively lower in Scenario 2 than in Scenario 1. The current road network density is about 39% higher than the optimum required by the BAU HS (Figure 1) and the optimum required ED in Scenario 2 is about 22% higher than in Scenario 1 (Figure 2), which means the road network is not the main cause of the differences in performance of HS. The most probable reasons are the lack of know-how and training of the forest workers and the outdated harvesting machinery. This can be also confirmed when comparing Scenario 3 (new HS) with Scenario 1 (BAU HS). The HS productivity in Scenario 3 is 3.7 fold higher than in BAU HS, while the fuel consumption, the accident rate and the CO_{2eq} emissions are with about 30%, 32% and 23% respectively lower. However, the costs would be higher in Scenario 3 than in BAU HS with about 33%, because of the higher system costs of the newly introduced harvesting machinery. The stand damage would be also 33% higher, because of the higher damage rate of mechanized systems compared to animal extraction. Again, the current road network density (Scenario 1) is higher than the optimum required for the new HS (Scenario 3) with about 23% and the mean ED is about 46% higher in Scenario 3 than in Scenario 1.

Causes of disparities: As previously mentioned the main reasons for the low efficiency of harvesting operations in CSA7 are the extremely low mechanization degree, the outdated harvesting machinery available and the lack of know-how and training of the forest workers for performing mechanized forest operations in mountain forests.

Recommendations: The main directions of intervention recommended for increasing the efficiency and effectiveness of the forest operations in CSA7 are the following: increasing the mechanization degree by changing the outdated harvesting machinery fleet with state-of-the-art harvesting systems; capacity building and implementation of programmes of know-how transfer about timber harvesting in mountain areas (twinning projects with CSAs that have similar terrain characteristics, but a higher level of expertise; e.g. CSA2, CSA3); training forest workers for felling and processing trees and for operating harvesting machinery in mountain forests. These measures require good legal framework and forest governance with performant policy instruments and available financial support schemes.

3 References

Albizu-Urionabarrenetxea P.M., Tolosana-Esteban E., Roman-Jordan E. (2013) Safety and health in forest harvesting operations. Diagnosis and preventive actions. A review. *Forest Systems* 22(3):392-400.

Berg S., Fischbach J., Brüchert F., Poissonnet M., Pizzirani S., Varet A., Sauter U.H. (2012) Towards assessing the sustainability of European logging operations. *European Journal of Forest Research* 131:81-94.

Borz S.A., Ignea G., Popa B. (2014) Assessing timber skidding efficiency in a group shelterwood system applied to a fir-beech stand. *African Journal of Agricultural Research* 9(1):160-167.

Enache A., Kühmaier M., Stampfer K., Ciobanu V.D. (2013) An integrative decision support tool for assessing forest road options in a mountainous region in Romania. Croat J For Eng 34(1):43-60.

Eriksson M., Lindroos O. (2014) Productivity of harvesters and forwarders in CTL operations in northern Sweden based on large follow-up datasets. *International Journal of Forest Engineering* 25(3):179-200.

European Commission (2013) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A new EU Forest Strategy: for forests and the forest-based sector – COM (2013) 659 final {SWD(2013)342 final} {SWD(2013)343 final}

Eurostat (2015): Statistics explained. Forestry statistics. Online at: <http://ec.europa.eu/eurostat/statistics-explained/index.php/Forestry_statistics>, accessed 23.03.2015

FOREST EUROPE Liaison Unit Oslo, UNECE - United Nations Economic Commission for Europe, FAO - Food and Agriculture Organization of the United Nations (2011) State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe, 342 p.

Ghaffariyan M.R., Stampfer K., Sessions J. (2007) Forwarding productivity in Southern Austria. *Croat J For Eng* 28(2):169-175.

Ghaffariyan M.R., Sobhani H. (2008) Optimum road spacing of ground based skidding operations in Nowshahr, Iran. *Caspian Journal of Environmental Sciences* 6(2):105-112.

Ghaffariyan M.R., Stampfer K., Sessions J. (2009) Production equations for tower yarders in Austria. *International Journal of Forest Engineering* 20(1):17-21.

Holzleitner F., Stampfer K., Visser R. (2011) Utilization rates and cost factors in timber harvesting based on long-term machine data. *Croat J of For Eng* 32(2):501-508.

Kanzian C. (2003): Modelle zur Abschätzung de Installationszeit von Seilgeräten. Dimploma Thesis, Institut für Alpine Naturgefahren und Forstliches Ingenieurwissen, Üniversität für Bodenkultur Wien, 64 p.

Klvač R., Fischer R., Skoupy A. (2012) Energy use of and emissions from the operation phase of a medium distance cableway system. *Croatian Journal of Forest Engineering* 33(1):79-88.

Laitila J., Asikainen A., Nuutinen Y. (2007) Forwarding of whole trees after manual and mechanized felling bunching in pre-commercial thinnings. *International Journal of Forest Engineering* 18(2):29-39.

Marceta D., Petkovic V., Kosir B. (2014) Comparison of two skidding methods in beech forests in mountainous conditions. *New Forestry Mechanization* 35(1):51-62.

Mihelič M., Krč J. (2009) Analysis of inclusion of wood forwarding into a skidding model. *Croatian Journal of Forest Engineering* 30(2):113-125.

Nordregio – Nordic Centre for Spatial Development (2004): Mountain Areas in Europe: Analysis of mountain areas in EU member states, acceding and other European countries. European Commission contract No 2002.CE.16.0.AT.136, Final report

Nurminen T., Korpunen H., Uusitalo J. (2006) Time consumption analysis of the mechanized cut-to-length harvesting system. *Silva Fennica* 40(2):335-363.

Potočnik I., Pentek T., Poje A. (2009) Severity analysis of accidents in forestry operations. *Cratian Journal of Forest Engineering* 30(2):171-184.

Price M. F, Gratzer G., Duguma L. A., Kohler T., Maselli D., Romeo R. (editors) (2011): Mountain Forests in a Changing World - Realizing Values, addressing challenges. Published by FAO/MPS and SDC, Rome, 86 p.

Sabo A., Porsinsky T. (2005) Skidding of fir roundwood by Timberjack 240C from selective forests of Gorski Kotar. *Cro J For Eng* 26(1):13-27.

Spinelli R., Magagnotti N., Relano R.L. (2012) An alternative skidding technology to the current use of crawler tractors in Alpine logging operations. *Journal of Cleaner Production* 31:73-79.

Tsioras A.P., Rottensteiner C., Stampfer K. (2011) Analysis of accidents during cable yarding operations in Austria 1998-2008. *Croatian Journal of Forest Engineering* 32(2):549-560

Vusić D., Susnjar M., Marchi E., Spina R., Zecic Z., Picchio R. (2013) Skidding operations in thinning and shelterwood cut of mixed stands – work productivity, energy inputs and emission. *Ecological Engineering* 61(A):216-223.

Whittaker C., Mortimer N., Murphy R., Matthews R. (2011) Energy and greenhouse gas balance of the use of forest residues for bioenergy production in the UK. *Biomass and bioenergy* 35(11):4581-4594, doi:10.1016/j.biombioe.2011.07.00