



Knowledge and Technologies for Effective Wood Procurement

Deliverable 2.3

REPORT ON ENSURING CONTINUED FOREST RESOURCE PRODUCTION IN THE LONG TERM

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1 Publishable summary

The need for the establishment of a bio-based economy to reduce emissions from the combustion of fossil fuels will increase the demand for wood. Thus, the European forestry sector is confronted with the challenge of increasing access to wood resources. Access to wood resources can be increased by making forest operations more efficient and increasing growth rates in forests through silvicultural practices. Mechanization is one way of increasing efficiency of forest operations, while also increasing safety at work and reducing the physical stress of forest workers. More efficient and safer forest operations in turn encourage the implementation of silvicultural practices such as thinning.

The potential area of application for different harvesting systems has been assessed in this work and is presented as a Harvesting Systems Map for Europe. Although this analysis includes data uncertainty, limitations and simplified assumption, it is evident that there is a huge, underutilized potential for the application of mechanized harvesting systems in Europe. Measurements for improving the efficiency of forest operations that include mechanized harvesting systems can thus potentially be applied for a great share of Europe's forest area. The impact of measurements suggested as results of case studies conducted in Task 2.2 of this Work package has been assessed by up-scaling the results to the country or ecoregional level using the Harvesting Systems Map for Europe. Although the up-scaling is a theoretical exercise and also includes limitations and simplifications, it is clear that there is a high potential for making forest operations more efficient and profitable by using mechanized systems and implementing appropriate silvicultural practices.

2 Introduction

2.1 The role of Task 2.3

The strategic objective of TECH4EFFECT project is to improve the efficiency of European forest management by enabling data-driven knowledge-based revolution of the European forest sector, while also providing key incremental improvements in technology. The overall aim of Work Package 2 is to increase the access to wood resources by promoting practices that increase growth rates in the forests and to achieve measurable improvements in the efficiency of forest operations. The aim of Task 2.3 within Work Package 2 is "Ensuring continued forest resource production in the long term". The need for the establishment of a bio-based economy to reduce emissions from the combustion of fossil fuels will increase the demand for wood. Thus, the European forestry sector is confronted with the challenge of increasing access to wood resources. For this purpose key silvicultural systems and increase potentials for silvicultural practices in Europe were identified in Task 2.1. Such increase potentials were evaluated in Task 2.2 by implementing case studies.

Ten case studies were implemented in seven countries. They analysed the potential of mechanizing silvicultural and forestry operations (tending, thinning), alternative silvicultural practices to the business as usual in the respective countries (corridor thinning, power cultures, no tree marking, more intensive thinning, stump removal), as well as tackling legal constraints for the use of mechanized harvesting systems (mechanized harvesting in coppice with standard).

Six of the ten case studies conducted in Task 2.2 used models to assess future developments. Models used include forest growth and yield simulation tools (MOTTI, MOSES, SIMA, PP3, yield tables) and a process based forest ecosystem model. These models allowed for the estimation of the potential increase in biomass and timber products, and in the case of the process based forest ecosystem the simulation of the effect of intensified silvicultural treatments under a climate change scenario.

Although models were extensively used the scale of the case studies still remained on the regional level. Thus, the aim of Task 2.3 was to expand the results of the case studies from their regional to the larger scale. This was done by first mapping the spatial distribution of forest resources in Europe based on harmonized National Forest Inventory data, large scale net primary production (NPP) model outputs and remotely sensed data. In a second step the accessibility of these forest resources by different harvesting systems was assessed. The outcome is a 'Harvesting Systems Map for Europe' showing the potential area of application for different harvesting systems in Europe and the wood resources that can be obtained by each system. In our aim to promote more mechanized timber harvesting operations the map prioritizes more mechanized harvesting systems, if more than one system is

applicable at a given site. This map was then used to assess the possible impact on wood resource accessibility by improving silvicultural practices and the harvesting systems involved. More specifically improvements suggested and evaluated in the case studies of Task 2.2 were up-scaled from their regional to the country or ecoregional scale.

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3 Results

3.1 Harvesting Systems Map for Europe

The decision which harvesting system is applied at a specific site depends on several factors. It may depend on the forest ownership structure, financial means, availability of trained forestry workers, legal constraints or simply personal preference. However, for most of these factors to come into consideration one has first to determine if a specific harvesting system can be applied at a given site. Technical limitations like slope or ruggedness of the terrain, tree species composition and tree dimensions, trafficability of the forest soil or accessibility of the forest site in general may prevent the application of a given harvesting system. Within this study we tried to assess these limiting factors at the European level. For this task pan-European datasets containing information about forest structure and tree species composition, land cover, conservation areas, topography, soil and road network were combined. We only considered technical and to some extent legal limitations, but did not take into account if it is economically viable. The outcome is a map that at 500 m resolution shows the highest mechanized harvesting system that can potentially be operated at any location in European forests.

Since Work Package 2 has a strong focus on promoting more mechanized harvesting systems, the map evaluates the highest possible mechanized system for any site. Higher mechanized harvesting systems improve the safety at work and reduce the physical stress of the workers. If operated correctly, cut-to-length harvesting, done by higher mechanized harvesting systems like harvester and forwarder, also lead to lower stand damage compared to motor-manual felling and forwarding in whole tree methods (Camp, 2002; Koşir, 2008; Kühmaier, 2011; Limbeck-Lilienau, 2003). The reason is that higher mechanized systems allow a more controlled tree handling, which is important for stand damage reduction (Magagnotti et al., 2012; Spinelli et al., 2014). However, soil compaction resulting from the ground load caused by the machines can have a long-term negative impact on the environment. The planning of forest operations including the most favourable season for harvesting operation is important in this context. Fuel consumption by heavier machines also needs to be considered. We do not explicitly address environmental factors in our analysis, but implicitly, by excluding some soil types as not being trafficable by heavier machines. Other soils may be trafficable only during favourable times as mentioned above. The map is not giving recommendations which harvesting system should be used at a given site, nor does it replace a field trip to a given forest site in order to determine if a specific machine can be used at that exact location at the given time. These decisions depend on factors either not at all or not adequately included in our analysis and have to be taken by the people leading and executing the forest operations. What our map shows is the share of possible areas of application for

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each harvesting systems at the large scale. It also shows that there is a huge, unutilized potential for the application of mechanized harvesting systems. This should emphasize the need for development and improvement of mechanized systems and methods for silvicultural work which meet the requirement of cost efficiency, environmentally friendliness and the adaptation of forest management measures. Some of the solutions proposed and analysed within the Tech4Effect project will be discussed and up-scaled in the second part of this document.

3.1.1 Data and data preparation

We utilize forest structure (forest type, tree species, diameter at breast height, standing volume), terrain (slope and soil), infrastructure (road network) and legal (conservation areas) information to create a pan-European map of harvesting systems at 500 m resolution. All datasets were either available or were projected to ETRS89-LAEA (European Terrestrial Reference System 89-Lambert Azimuthal Equal-Area) projection. Datasets that were not available at 500 m resolution were either aggregated or disaggregated to the required resolution. The forest structure gridded dataset limited the spatial extent of our calculations and was used as reference layer. All other data layers were aligned to this reference layer. Data preparation was done using the ArcGIS and R (R Core Team, 2018) statistical software and packages.

Forest Structure

Information about forest structure is extracted from a pan-European, gridded dataset (Moreno et al., 2017). The updated forest structure dataset used in this study contains harmonized national forest inventory (NFI) data from 14 European countries. This NFI plot level data was aggregated to 8 km grid-cell size using ETRS89-LAEA projection. A gap-filling algorithm was used to expand this aggregated NFI data to areas where no NFI data was available. Gap-filling was done by first grouping cells into clusters using biogeographical regions and land cover type information. In a second step for each cell without NFI data its nearest neighbour cell containing NFI data within the same cluster group was found using net primary production (NPP), NPP trend, canopy height and climate information as co-variates.

Tree Species

Information about tree species comes from a Tree Species Map for European forests based on NFI data and a multinomial logistic regression model fitted to ICP-level-I plots using various abiotic factors as predictors to fill areas without NFI data (Brus et al., 2012). Percentage share for 20 tree species and the dominant tree species per cell are provided. The data is available at 1 km resolution and ETRS89-LAEA projection.

Land cover

Land cover information is provided by the land cover product generated from reflectance data of the MODerate resolution Imaging Spectrometer (MODIS) on

board of the NASA operated Terra and Aqua satellites. The MODIS MCD12Q1 version 6 land cover data is available at 500 m resolution as a sinusoidal grid providing 5 different classification schemes (Friedl and Sulla-Menashe, 2015). We obtained the data for the year 2016 and used the University of Maryland (UMD) classification.

Conservation Areas

The Common Database on Designated Areas provided by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) in community with the European Environment Agency (EEA) gives information about officially designated protected areas such as national parks or nature reserves in Europe. The data is available as a shapefile and ETRS89-LAEA projection.

Digital Elevation Model (DEM)

The Copernicus Land Monitoring Service EU-DEM based on SRTM (Shuttle Radar Topography Mission) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data represents the first surface as illuminated by the sensors. The digital elevation model (DEM) is provided at 25 m resolution and ETRS89-LAEA projection. The overall vertical accuracy (RMSE) is 2.9 meters.

Soil data

Soil information comes from the European Soil Database (ESDB) of the European Soil Data Centre (ESDAC). They provide 'dominant value' raster data of 73 attributes grouped into 14 groups at 1 km resolution and ETRS89-LAEA projection. One has to note that considering the scale, the precision of the variables in the ESDB is weak (Panagos, 2006). Further the variables are often not measured on local soil samples but estimated over large areas by expert judgment resulting from synthesis and generalisation task of national or regional maps (Panagos, 2006). We decided to use this data as no other data source providing soil information at the needed spatial scale is available and our analysis still benefited from including the soil information despite its present limitations.

Road Network

Open Street Map (OSM) provides freely available geodata which can be used for the creation of maps. We were interested in the road network data provided by OSM. OSM is a community project and as such both the coverage as well as tagging accuracy of the OSM data varies from region to region as it ultimately depends on the activity of the respective voluntary OSM community. While this may limit the application of the data, OSM coverage or completeness of the road network for European countries in general seems to be high (Barrington-Leigh and Millard-Ball, 2017). This together with the lack of other consistent, European-wide and freely available road network datasets supported the use of OSM data for our purpose even with its possible limitations. OSM data as shapefiles for each country is provided by Geofabrik (www.geofabrik.de) and was obtained between January and

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April 2019. Roads are available as line shapefile features and key-value pairs can be used to extract certain road types.

3.1.2 Methods

In our study we focus on the technical applicability of different harvesting systems on a given site and look for the potentially most suitable harvesting system with respect to the chosen criteria. This potentially most suitable harvesting system might differ from the actually employed harvesting system at any given site due to reasons not considered in the analysis, like forest ownership structure, personal preference or financial means.

Definition of harvesting systems

We separated harvesting systems into means of felling, processing and extraction and defined nine harvesting systems and their technical limitations (Tab. 1). As technical limitations we considered extraction distance, slope of the terrain, trafficability of the soil, tree dimensions (diameter) and tree species composition. Tree dimension and tree species composition are the limiting factor for the operation of higher mechanized felling and processing systems. Extraction distance was only a limiting factor for harvesting systems where technical limitations (e.g. cable length) are present. For Skidder, Harvester and Forwarder on flat terrain we did not consider

Table 1: The nine harvesting systems and their technical limitations as used in the harvesting systems classification. Tree species specific diameter at breast height (DBH) limitations can be seen in Tab. 2

Harvesting System	Level of mechanization	Technical Limitations				
		Extraction Distance	Slope	DBH	Tree Species	Soil
Not Accessible or Helicopter	Partially	-	-	-	-	-
Chainsaw and Skidder	Partially		< 30 %	-	-	-
Chainsaw and Forwarder	Partially		< 30 %	-	-	limited
Harvester and Forwarder	Fully		< 30 %	tree spec. specific	limited	limited
Chainsaw and Cable Yarder	Highly	≤ 800 m	< 100 %	-	-	-
Chainsaw and Cable Yarder Processor	Highly	≤ 800 m	< 100 %	< 60 cm	-	-
Chainsaw and Winch-assisted Forwarder	Partially	≤ 400 m	< 60 %	-	-	limited
Steep Terrain Harvester and Cable Yarder	Fully	≤ 800 m	< 60 %	tree spec. specific	limited	limited
Steep Terrain Harvester and Winch-assisted Forwarder	Fully	≤ 400 m	< 60 %	tree spec. specific	limited	limited

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extraction distance to be limiting due to several reasons. First, harvester and forwarder may still be used despite the travelling and/or extraction distance being high. Second, the road network data although good is not complete and roads are missing. Further, temporary roads like winter roads may be established specifically for logging activities. Although ground-based heavy machines like harvesters and forwarder first need to be moved to the harvesting sites, we did not consider general accessibility of an area as a limiting factor. Slope and soil limit the general trafficability for higher mechanized, often heavier machinery at a given site. To assess these limiting criteria we use road network, elevation, soil, forest structure and land cover data available at the European scale (see Data section). Calculations were done at a 500 m resolution.

Data utilization

We calculated the road density within a certain radius as a proxy for extraction distance based on the OSM road network data. In our calculations the application of winch-assisted and cable-yarding systems can be limited by the extraction distance. To calculate road density we first used the highway key to extract road types, determined to be suited for forestry operations: secondary, tertiary, unclassified and track (description can be found at <https://wiki.openstreetmap.org/wiki/Key:highway>). Road density was then calculated using the line density tool in the ArcGIS toolbox. Line density was calculated for each 500 m cell using radii of 300 and 600 m. If at least a road density of 1 m/ha was calculated for a pixel, we assumed that the minimum extraction distance from the centre of the cell would be 300 or 600 m respectively. These correspond to the technical limitations of 400 and 800 m set for winch-assisted and cable-yarding systems (Tab. 1). We opted for lower values as the minimum extraction distance we calculated is the direct distance assuming a level surface. In reality the surface is sloped and obstacles may increase extraction distance or even prevent extraction to the considered road.

Ground-based harvesting systems are often limited by the terrain and a maximum slope until which they can be operated. Based on the digital elevation model we calculate the slope in percent for each cell based on its 8 neighbouring 25 m cells using the *raster* package (Hijmans, 2017) within the R software. Each 25 m cell was then classified into one of three slope classes used for the harvesting system classification: 1) slope up to 30 %, 2) slope between 30 and 60 %, 3) slope higher than 60 %. The information was then aggregated to 500 m resolution by finding the share of 25 m cells for each slope class. The dominant slope class for a 500 m grid cell was then calculated by combining information about the shares of each slope class within the cell and the cells mean slope. For instance for a 500 m grid cell to be classified as slope class 1 (slope up to 30 %), the majority of the 25 m cells within the 500 m cell had to fall into slope class one and the mean slope for the whole cell had to be lower than 22.5 %. For slope class 2 (slope between 30 and 60 %) the mean

slope for the whole cell had to be lower than 45 % additional than it being dominated by 25 m cells falling into slope class two.

Apart from slope and roughness of the terrain, trafficability is affected by the soil type and texture, as well as the soils condition as all influence the bearing capacity. On soils with low bearing capacity heavy machines are either unable to drive or would cause severe damage to the forest soil if they did. In general higher soil moisture leads to lower bearing capacity. Therefore the use of heavy machinery for forest operations on soils influenced by groundwater is either not possible or limited to specific times during the year when the soil is frozen or very dry. We used several of the attributes provided by the ESDB to define soil types affected by groundwater and used these soils as a limiting factor for the application of heavy machinery. This is a simplification as the soil moisture or water content is not only influenced by the soil type but also its texture as well as the prevailing weather conditions. Although we define these soils as a limiting factor there might still be times during the year where forest operations with heavy machines would be possible. However, compared to other soil types these favourable times may be very limited or do not occur at all.

Other than accessibility and trafficability the operation of harvester and processor systems for felling and/or processing is limited by a tree species specific maximum diameter at breast height (DBH) that can be handled (Tab. 2). We use tree species, land cover and forest structure (diameter at breast height) information to limit the use of these systems.

Table 2: Tree specific diameter at breast height (DBH) limits for felling and processing with harvester head. Tree species and ID as in the EU Tree Species Map (Brus et al., 2012).

ID	Tree Species	DBH limit (cm)
1	Abies spp	40
2	Alnus spp	40
3	Betula spp	40
4	Carpinus spp	25
5	Castanea spp	25
6	Eucalyptus spp	40
7	Fagus spp	25
8	Fraxinus spp	25
9	Larix spp	40
10	Broadleaved misc	25
11	Conifers misc	40
12	Pinus misc	40
13	Quercus misc	25
14	Picea spp	40
15	Pinus pinaster	40
16	Pinus sylvestris	40
17	Populus spp	unsuitable
18	Pseudotsuga menziesii	40
19	Quercus robur/petraea	25
20	Robinia spp	25

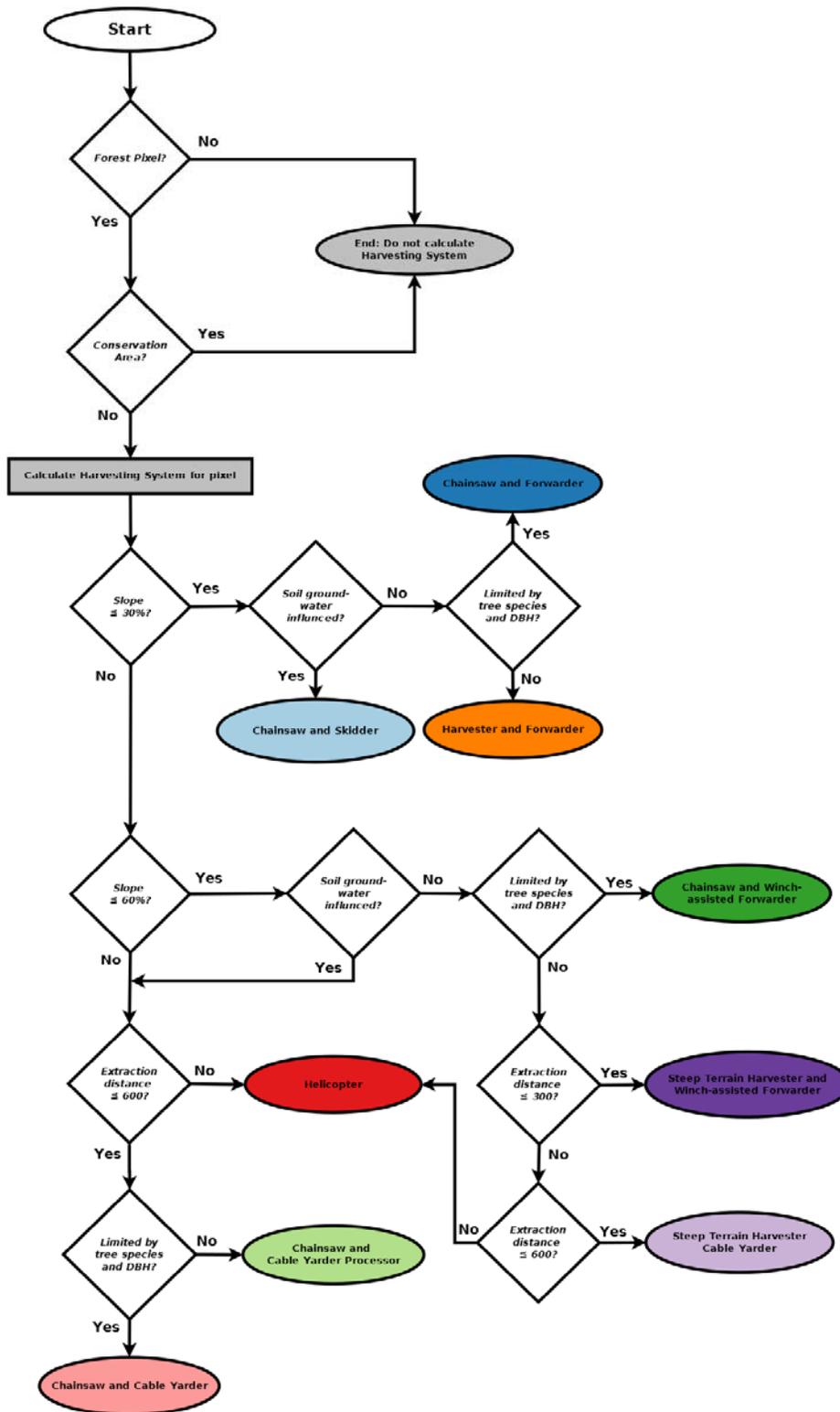


Figure 1: Decision tree showing how the potential most suitable harvesting system is found for each cell. The decision tree prefers more mechanized harvesting systems over lesser mechanized ones.

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Calculation of Harvesting Systems

The use of the before mentioned limitation criteria to determine the potential harvesting system for a forested cell can be illustrated by a decision tree (Fig. 1). The potential harvesting system was calculated for all forested grid cells except for conservation areas where timber harvesting is prohibited. A 500 m grid cell was determined to be forested if it had one of the following land cover types: evergreen needleleaf forests (ENF), evergreen broadleaf forests (EBF), deciduous needleleaf forests (DNF), deciduous broadleaf forests (DBF), mixed forests (MF) and woody savannas (WS). Using the conservation area data we determined grid cells falling into the IUCN categories Ia (Strict Nature Reserve), Ib (Wilderness Area) and II (National Park) as areas where harvesting activities are prohibited. If a forested grid cell did not fall into one of these IUCN categories the harvesting system was calculated. If more than one harvesting system would be applicable for a given grid cell the decision tree prefers more mechanized harvesting systems, e.g. preferring the 'Harvester and Forwarder' over the 'Chainsaw and Forwarder' system. Therefore exactly one harvesting system was assigned to each suitable grid cell. Calculations were done using the R software.

Calculating forest area and standing volume

To estimate the amount of wood resources which can be accessed by the different harvesting systems, we calculated standing volume for every forested grid cell. Within the UMD land cover classification forest land cover types (ENF, EBF, DNF, DBF and MF) by definition have tree cover over 60 %. In our calculations each forest type cell contributed 25 ha (500 m times 500 m) of forest area. Woody savannas (WS) are defined by tree cover between 30 and 60 % and canopy height greater than 2 m and we therefore defined a factor of 0.45 when calculating forested area for a WS cell so that each cell contributes 11.25 ha of forest area. This forest area is multiplied with the volume per hectare forest structure variable to obtain the standing volume for each 500 m grid cell.

3.1.3 Results and analysis

According to our analysis, around three percent of Europe's timber volume lies within IUCN categories Ia (Strict Nature Reserve), Ib (Wilderness Area) or II (National Park) protected areas and are not available for timber harvesting (Fig. 2). We consider the remaining volume of around 27 891 million m³ as available, although timber harvesting may also be limited in forests providing non-timber services like a protective or recreational function, factors not included in our analysis.

Predominant flat areas and a high share of needleleaf or mixed forests favour the use of mechanized harvesting systems with over half of European forests being suited for operating the 'Harvester and Forwarder' system (Fig. 2 and 3). It is the dominant harvesting system in the Scandinavian countries (Fig. 3), where in fact it is already the

predominantly system in use. As expected, it is also quite present in the flat areas of Central and Southern Europe. Although we did not consider general accessibility of a harvesting site as a limiting factor for ground-based heavy machines such as harvester and forwarder, their efficiency may be limited by a poor road network. Over 40 % of harvestable timber is located in areas where no road suitable for harvesting operations is present within a search radius of 282 m (representing an area of around 25 ha) in our data. However, this value is most likely exaggerated as roads are missing in the Open Street Map (OSM) data. In general mountainous (e.g. Carpathians, Dinarides, Alps, Pyrenees, Scandinavian Mountains) show a bad road network according to the OSM data (Fig. 4). This may reflect the actual situation in these regions as well as the factor that OSM data in these areas might be incomplete. As OSM depends on an active community it is likely that remote areas are not as well surveyed as populated areas. For the South-East European areas the poor road network may also reflect the general lack of an active OSM community. This effect is, however, hard to quantify. For Central Europe the road network situation in forested areas is good. Again this may reflect the actual situation as well as the completeness of the OSM data due to active communities. Only in steep terrain the extraction

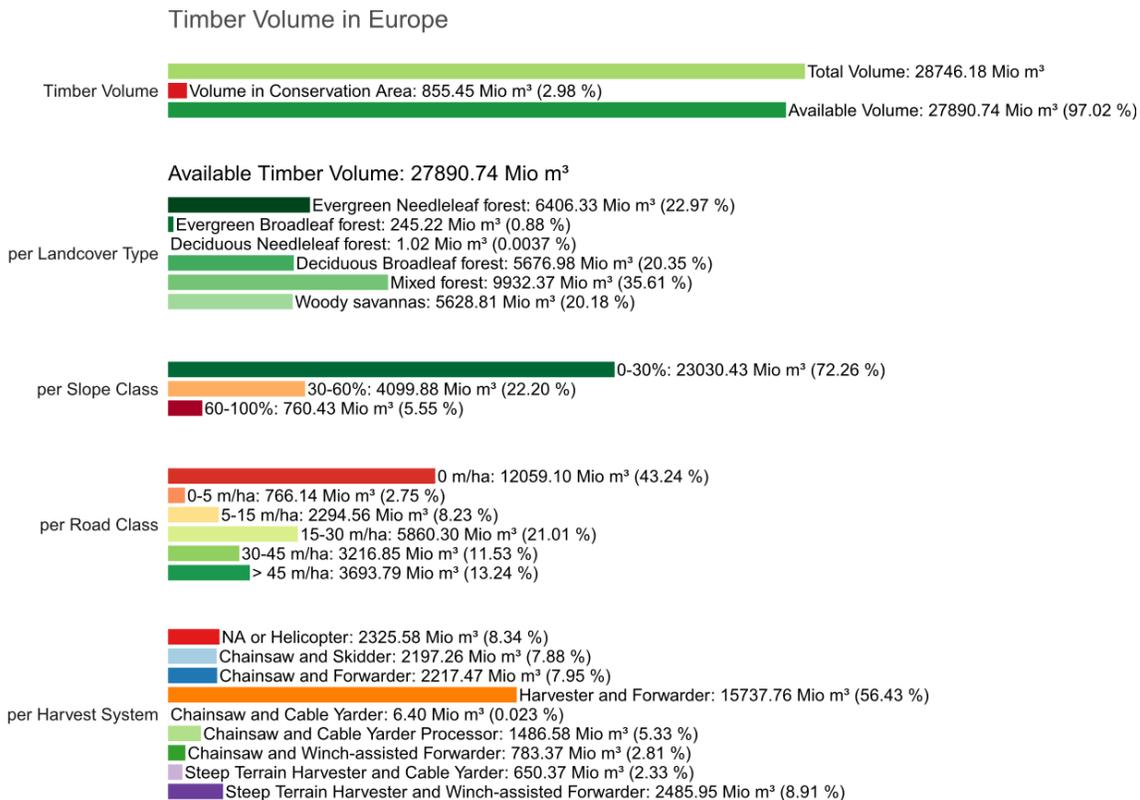


Figure 2: Distribution of European forest resources regarding landcover type, slope and road class and harvesting systems.

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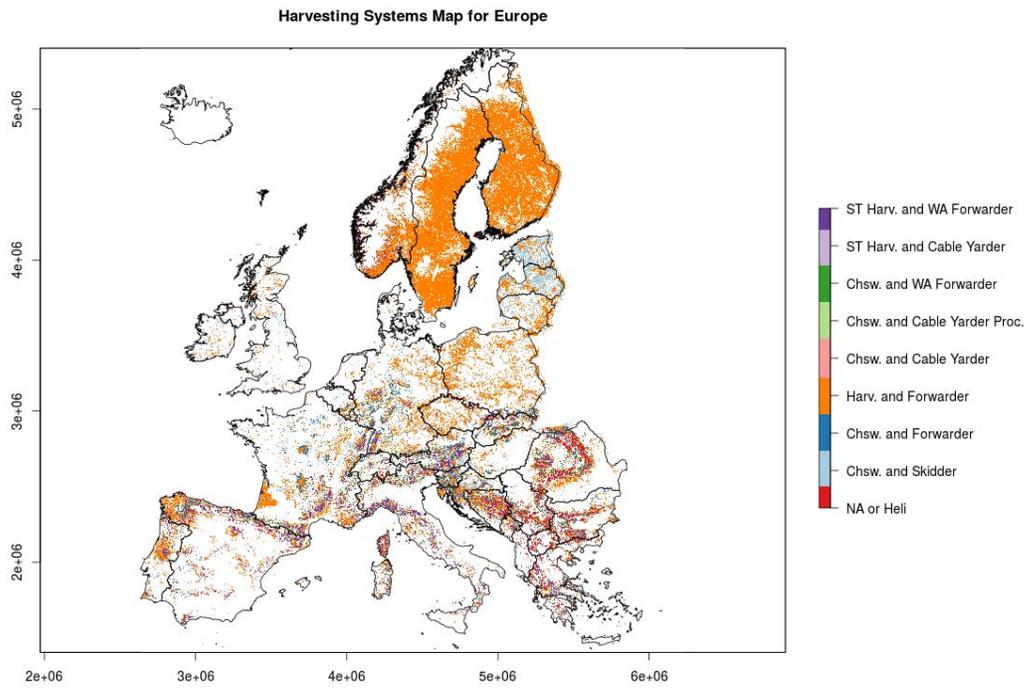


Figure 3: Harvesting Systems Map for Europe. The cell resolution is 500 m.

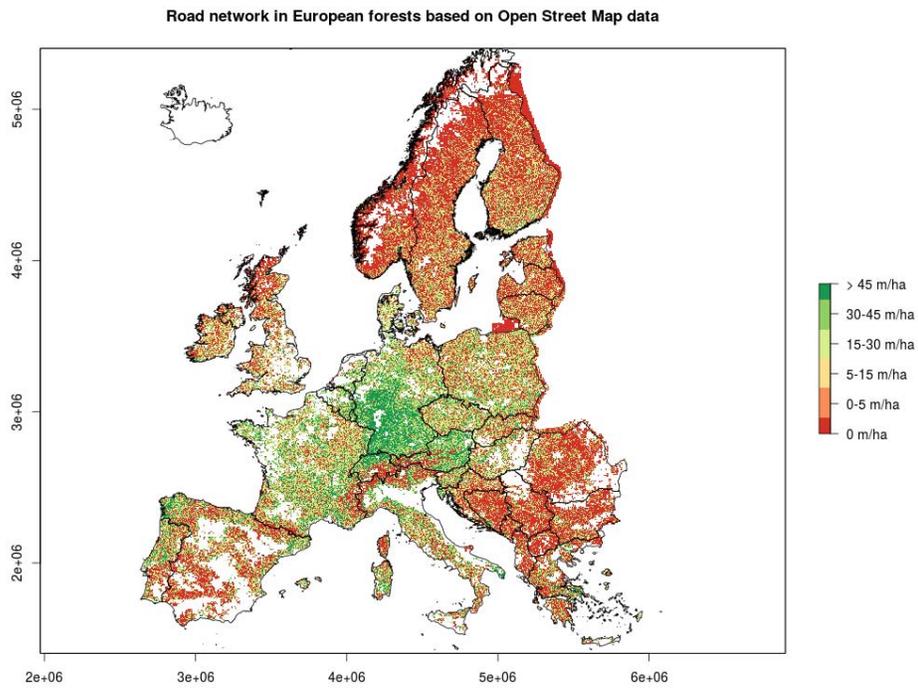


Figure 4: Road network in European based on Open Street Map data.

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distance was a limiting factor in our calculations. Based on these calculations around 8.3 % of timber is located in areas where no road is present at a distance suitable for operating winch-assisted or cable-yarding systems. These areas are classified as being not accessible or accessible only by helicopter. Great shares of these areas are located in the Carpathians and Dinarides (Fig. 3).

Where tree species composition and/or tree dimensions limit the use of a harvester, motor-manual felling can be operated. We choose low tree species specific diameter limits for the use of a harvester (Tab. 2) as we were not only concerned of the felling but also the subsequent processing of the tree by the harvester head. Around 8 % of Europe's timber in flat terrain cannot be harvested by a harvester due to diameter limitations. Most of these areas lie in Northern France, Germany and South- and Central-East Europe (Fig. 3). Only 0.02 % of timber cannot be processed by the cable-yarder processor due to diameter limitations.

Around 8 % of the timber volume is located at flat sites with a high potential of the soil limiting the use of heavy machines. Here the 'Chainsaw and Skidder' harvesting system can be operated. A great share of these areas can be found in the Baltic countries which are rich in wetlands. In Finland where wetlands can also be found these are extensively drained and in general do not limit the use of heavier machines. Other areas limiting the use of heavy machinery can be found on the British Isles, in Poland, Northern France, Croatia, southern Austria and the Benelux countries (Fig. 3). It has to be noted that during very favourable times when the soil is very dry or frozen, forest operations using heavy machines might still be possible in these areas. Likewise in areas where according to our calculations the use of heavy machinery is not limited in general, their use may also be limited to certain times during the year.

Validation

Validation was done at different scales. Six validation sites in four countries were used to compare the calculated results with the actual situation at these specific validation sites at the grid cell level. At coarser level (e.g. country-level) the results were validated by expert judgment on the plausibility of the results and by comparing it to the known general situation. First validation results showed that the share of winch-assisted or cable-yarding systems in steep terrain was underestimated. Based on these results the classification was updated to better reflect the actual situation. In general the validation results suggest that the calculations at the grid cell level show adequate agreement with the actual situation. There are, however, limitations, as had to be expected.

In general, these limitations can be attributed to two factors: The resolution of the input data being too coarse for depicting certain features or a lack of quality in the input data. For instance, the use of the 'Harvester and Forwarder' system is or may be limited by erosion channels, trenches, obstacles like boulders or the general slope and ruggedness of the terrain. These features are either not present in the original

digital elevation model, as their dimensions are below the 25 m resolution or information is lost by aggregating to the 500 m grid cell size. Regarding soil information the precision of the European Soil Database is weak in general. Further the classification of soils as not being suited for the operation of heavy machinery used in this study is based mainly on the soil type, while other factors like soil texture may be the deciding factor at a given site. Therefore it has to be expected, as was shown at one validation site, that this criterion is only weakly represented in our calculations. Some of the validation sites showed that our calculations prevents the use of a harvester due to tree species specific DBH limits at some sites although they actually use a harvester. This may be due to several reasons. We choose low tree specific DBH limits because we prefer to rather under- than overestimate the use of a harvester in this respect. Further, we choose the limits so that the tree can be felled as well as be processed by the harvester head. For some forest cells tree species information is lacking. If these cells are classified as a broadleaf forest landcover type we assume a tree species with low diameter limitations, although in reality it could be birch dominated forest for instance.

Table 3: Forest Area per harvesting system in 1000 ha and %; HS1 = NA or Helicopter, HS2 = Chainsaw and Skidder, HS3 = Chainsaw and Forwarder, HS4 = Harvester and Forwarder, HS5 = Chainsaw and Cable Yarder, HS6 = Chainsaw and Cable Yarder Processor, HS7 = Chainsaw and Winch-assisted Forwarder, HS8 = Steep Terrain Harvester and Cable Yarder, HS9 = Steep Terrain Harvester and Winch-assisted Forwarder

	Available	HS1	%	HS2	%	HS3	%	HS4	%	HS5	%	HS6	%	HS7	%	HS8	%	HS9	%
Austria	3732.5	132.0	3.54	252.3	6.76	104.6	2.80	731.3	19.59	5.9	0.16	999.0	26.76	125.3	3.36	67.3	1.80	1314.9	35.23
Belgium	531.4	0.3	0.05	50.8	9.56	152.3	28.67	304.6	57.32	0.0	0.00	1.1	0.20	8.5	1.60	0.4	0.07	13.5	2.53
Bulgaria	3079.4	829.3	26.93	149.1	4.84	357.2	11.60	898.1	29.16	0.0	0.00	199.8	6.49	138.2	4.49	199.3	6.47	308.4	10.01
Croatia	2022.6	107.7	5.33	361.4	17.87	366.4	18.11	822.9	40.69	0.0	0.00	66.7	3.30	83.4	4.13	66.5	3.29	147.6	7.30
Czech Rep.	2440.0	5.7	0.23	29.3	1.20	94.3	3.86	1955.2	80.13	0.0	0.00	10.8	0.44	19.7	0.81	32.1	1.31	292.9	12.00
Denmark	207.6	0.0	0.00	12.1	5.83	32.1	15.48	163.3	78.68	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Estonia	2182.8	0.0	0.00	1516.7	69.48	0.0	0.00	666.1	30.51	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Finland	16394.1	2.4	0.01	212.4	1.30	113.6	0.69	16063.9	97.99	0.0	0.00	0.0	0.00	0.0	0.00	0.9	0.01	1.0	0.01
France	10101.8	443.3	4.39	720.2	7.13	1325.2	13.12	4690.6	46.43	4.8	0.05	687.0	6.80	268.9	2.66	369.1	3.65	1592.7	15.77
Germany	9036.1	28.1	0.31	734.0	8.12	1470.1	16.27	5459.4	60.42	0.1	0.00	156.9	1.74	326.9	3.62	19.1	0.21	841.5	9.31
Greece	2323.8	503.2	21.65	2.3	0.10	70.3	3.02	562.9	24.22	0.5	0.02	227.2	9.78	63.2	2.72	258.9	11.14	635.4	27.34
Hungary	1120.6	2.5	0.23	190.3	16.98	110.9	9.89	717.1	64.00	0.0	0.00	11.5	1.03	16.3	1.45	9.6	0.85	62.4	5.57
Ireland	609.0	10.2	1.67	225.3	36.99	15.0	2.46	327.1	53.71	0.0	0.00	4.0	0.65	1.1	0.18	7.4	1.22	19.0	3.12
Italy	5953.4	729.5	12.25	39.1	0.66	128.7	2.16	1250.7	21.01	3.0	0.05	1302.4	21.88	151.3	2.54	476.8	8.01	1871.8	31.44
Latvia	2974.1	0.0	0.00	1730.5	58.19	0.9	0.03	1242.7	41.78	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Lithuania	1806.0	0.0	0.00	645.0	35.71	18.1	1.00	1142.9	63.28	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Luxembourg	53.3	0.0	0.05	2.1	3.89	10.6	19.79	33.2	62.34	0.0	0.02	0.2	0.34	3.3	6.27	0.0	0.09	3.8	7.21
Montenegro	376.8	116.7	30.99	5.4	1.44	11.9	3.15	85.4	22.68	0.3	0.09	42.0	11.15	20.5	5.43	36.5	9.68	58.0	15.40
Netherlands	171.6	0.0	0.00	90.2	52.58	0.1	0.06	81.3	47.35	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
N. Macedonia	570.9	332.1	58.18	0.1	0.02	48.0	8.41	61.9	10.84	0.0	0.00	37.9	6.64	24.1	4.21	30.0	5.26	36.7	6.43
Norway	6906.7	830.9	12.03	231.4	3.35	5.5	0.08	4894.8	70.87	0.0	0.00	179.3	2.60	0.7	0.01	316.3	4.58	447.9	6.48
Poland	8356.3	44.7	0.54	995.3	11.91	341.9	4.09	6661.6	79.72	0.0	0.00	34.4	0.41	72.0	0.86	45.0	0.54	161.4	1.93
Portugal	1367.2	40.3	2.95	17.2	1.26	55.0	4.02	865.0	63.27	0.4	0.03	15.1	1.10	11.5	0.84	66.4	4.86	296.3	21.68
Romania	6582.1	2039.1	30.98	203.5	3.09	620.5	9.43	2043.2	31.04	0.0	0.00	476.4	7.24	299.7	4.55	384.3	5.84	515.4	7.83
Serbia	2171.2	797.7	36.74	72.0	3.32	321.0	14.79	445.9	20.54	0.0	0.00	142.5	6.56	125.3	5.77	115.0	5.30	151.8	6.99
Slovakia	1949.2	101.7	5.22	66.1	3.39	281.1	14.42	583.2	29.92	0.0	0.00	98.5	5.05	202.3	10.38	127.5	6.54	488.7	25.07
Slovenia	1132.8	43.3	3.82	39.2	3.46	182.4	16.10	313.4	27.67	0.0	0.00	144.8	12.78	111.2	9.82	44.7	3.95	253.7	22.40
Spain	6030.0	720.9	11.96	14.4	0.24	268.8	4.46	2493.2	41.35	5.5	0.09	407.0	6.75	160.2	2.66	491.9	8.16	1468.2	24.35
Sweden	21581.6	67.3	0.31	58.3	0.27	61.3	0.28	21333.3	98.85	0.0	0.00	0.4	0.00	0.0	0.00	32.7	0.15	28.2	0.13
Switzerland	1010.3	112.0	11.08	28.8	2.85	40.1	3.97	159.9	15.83	2.0	0.19	359.1	35.55	65.9	6.53	17.3	1.71	225.2	22.29
UK	1565.4	54.6	3.49	354.9	22.67	99.1	6.33	873.0	55.77	0.2	0.01	32.1	2.05	9.2	0.59	39.4	2.52	102.9	6.57

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Table 4: Volume per Harvesting System in 10⁶ m³ and %; HS1 = NA or Helicopter, HS2 = Chainsaw and Skidder, HS3 = Chainsaw and Forwarder, HS4 = Harvester and Forwarder, HS5 = Chainsaw and Cable Yarder, HS6 = Chainsaw and Cable Yarder Processor, HS7 = Chainsaw and Winch-assisted Forwarder, HS8 = Steep Terrain Harvester and Cable Yarder, HS9 = Steep Terrain Harvester and Winch-assisted Forwarder

	Available	HS1	%	HS2	%	HS3	%	HS4	%	HS5	%	HS6	%	HS7	%	HS8	%	HS9	%
Austria	1187.9	40.6	3.42	83.6	7.04	33.6	2.83	229.9	19.35	2.9	0.24	321.6	27.07	41.3	3.47	20.9	1.76	413.6	34.82
Belgium	135.7	0.0	0.03	11.4	8.38	44.0	32.40	74.7	55.07	0.0	0.00	0.3	0.23	2.1	1.52	0.1	0.06	3.1	2.32
Bulgaria	970.1	271.7	28.00	42.1	4.34	143.5	14.80	237.7	24.50	0.0	0.00	72.6	7.48	59.0	6.08	56.3	5.81	87.2	8.98
Croatia	615.3	31.3	5.09	104.2	16.93	149.5	24.29	212.4	34.52	0.0	0.00	25.1	4.07	36.4	5.92	17.2	2.80	39.2	6.38
Czech Rep.	1230.3	3.1	0.26	13.4	1.09	50.2	4.08	981.7	79.80	0.0	0.00	5.1	0.42	10.3	0.84	16.9	1.38	149.4	12.14
Denmark	49.2	0.0	0.00	3.2	6.43	9.5	19.38	36.5	74.19	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Estonia	479.8	0.0	0.00	335.8	69.98	0.0	0.00	144.0	30.02	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Finland	2529.8	0.3	0.01	32.0	1.26	19.1	0.76	2478.2	97.96	0.0	0.00	0.0	0.00	0.0	0.00	0.1	0.00	0.1	0.01
France	1393.9	61.7	4.42	99.1	7.11	182.4	13.09	649.3	46.58	1.0	0.07	93.9	6.73	37.5	2.69	50.5	3.62	218.5	15.68
Germany	3079.8	10.0	0.33	220.8	7.17	516.1	16.76	1824.6	59.24	0.0	0.00	62.3	2.02	116.1	3.77	7.6	0.25	322.2	10.46
Greece	226.6	48.2	21.25	0.1	0.06	6.5	2.86	49.4	21.81	0.0	0.01	24.2	10.67	8.7	3.84	24.9	10.97	64.6	28.52
Hungary	354.7	0.8	0.23	57.7	16.28	40.5	11.41	221.8	62.53	0.0	0.00	3.9	1.11	6.0	1.69	3.1	0.87	20.9	5.88
Ireland	124.8	1.6	1.31	49.8	39.89	4.0	3.17	63.9	51.22	0.0	0.00	0.8	0.67	0.3	0.20	1.2	0.99	3.2	2.54
Italy	1015.8	135.1	13.30	6.5	0.64	28.1	2.77	152.1	14.97	1.0	0.10	285.5	28.11	37.5	3.69	68.8	6.78	301.2	29.65
Latvia	590.6	0.0	0.00	338.5	57.32	0.3	0.05	251.8	42.63	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Lithuania	378.6	0.0	0.00	138.6	36.61	3.6	0.94	236.5	62.46	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Luxembourg	18.0	0.0	0.05	0.5	2.58	4.3	23.97	10.4	57.54	0.0	0.03	0.1	0.50	1.5	8.44	0.0	0.12	1.2	6.76
Montenegro	95.0	31.7	33.33	0.3	0.34	3.5	3.72	18.1	19.04	0.1	0.12	12.2	12.82	7.5	7.87	8.3	8.71	13.3	14.05
Netherlands	34.9	0.0	0.00	17.9	51.39	0.0	0.09	16.9	48.53	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
N. Macedonia	164.0	96.6	58.93	0.0	0.02	18.4	11.24	12.8	7.83	0.0	0.00	11.9	7.27	9.1	5.58	6.8	4.14	8.2	5.00
Norway	800.3	79.9	9.99	28.8	3.60	1.4	0.17	585.8	73.19	0.0	0.00	19.4	2.42	0.2	0.02	34.0	4.25	50.9	6.35
Poland	2237.8	14.2	0.63	252.5	11.28	116.8	5.22	1752.3	78.30	0.0	0.00	11.6	0.52	24.6	1.10	13.8	0.62	52.0	2.32
Portugal	119.7	3.3	2.75	0.8	0.68	2.7	2.29	75.2	62.86	0.0	0.01	1.4	1.17	1.0	0.85	6.2	5.17	29.0	24.20
Romania	2261.3	778.9	34.44	57.2	2.53	260.7	11.53	560.3	24.78	0.0	0.00	193.3	8.55	130.4	5.77	120.5	5.33	160.0	7.08
Serbia	720.0	274.6	38.15	18.6	2.59	132.1	18.35	114.8	15.95	0.0	0.00	55.6	7.73	52.2	7.25	30.9	4.29	41.0	5.70
Slovakia	564.0	29.9	5.30	21.8	3.86	83.9	14.88	162.4	28.80	0.0	0.00	29.4	5.21	67.5	11.97	36.1	6.41	133.0	23.58
Slovenia	399.2	15.7	3.92	13.1	3.28	81.4	20.38	92.7	23.23	0.0	0.00	54.7	13.70	49.1	12.29	13.5	3.39	79.1	19.81
Spain	565.5	58.7	10.38	1.4	0.24	18.9	3.35	221.9	39.24	0.6	0.10	45.2	8.00	20.0	3.54	45.8	8.10	153.0	27.06
Sweden	3422.7	8.4	0.25	10.1	0.30	18.7	0.55	3376.7	98.66	0.0	0.00	0.1	0.00	0.0	0.00	4.6	0.14	4.1	0.12
Switzerland	240.3	28.8	12.00	6.3	2.61	10.6	4.42	35.4	14.71	0.8	0.34	86.0	35.80	18.6	7.72	4.0	1.67	49.8	20.71
UK	307.7	10.6	3.45	69.7	22.67	20.1	6.52	172.0	55.88	0.0	0.01	6.5	2.12	2.0	0.65	7.7	2.50	19.1	6.20

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3.2 Up-scaling of Case Studies

The case studies conducted as part of Task 2.2 were concerned with the improvement of silvicultural practices of early treatment and stand establishment as well as thinning. One focus was set on promoting and improving the mechanization of these silvicultural practices. The aim of Task 2.3 is the up-scaling of the local case studies findings to the country and bigger scales. By doing so, the potential area of application and the theoretical impact of the suggested measurements can be assessed. Eight out of ten case studies presented in Task 2.2 will be used in this task. We decided against up-scaling the “Mechanized harvesting in coppice with standard” and “Stump removal in maritime pine plantations” case studies conducted in Italy and France, respectively, as these are very specific cases which are difficult to up-scale to larger regions based on our data available.

For the remaining case studies, first a summary of the findings, grouped into thinning and early treatment/stand establishment will be provided. Then the up-scaling which will utilize the Harvesting Systems Map of Europe data (Fig. 2 and 3, Tab. 3 and 4) presented earlier within this deliverable will be presented. It should, however, be noted that the up-scaling is a theoretical exercise based on case studies, thus there are larger limitations and uncertainty on the presented up-scaling results.

3.2.1 Summary and description of the case studies

Mechanized thinning

Four case studies of Deliverable 2.2 conducted in Austria, Finland, Norway and Poland were concerned with the benefit and the improvement of mechanized thinning operations:

- Austria – Effects of thinning by tree marking vs harvester selection
- Finland – Corridor thinning
- Norway – Productivity of thinned and unthinned Norway spruce stands
- Poland – Mechanization of thinnings in conifer forests

Thinning is a well-recognized silvicultural treatment, which has significant influence on the future development of forest stands and the stand structure. Through thinning the resources available at a given site are shifted to the remaining trees. This favours the further development of the remaining trees, which in general leads to higher value trees and an increase in stand stability. However, thinning operations are time consuming and often uneconomical. Therefore many forest stands remain unthinned. Analysing the case studies, differences in thinning practice between North European and Central (Central-West and Central-East) European forest ecoregions emerge. Therefore these two regions and their respective countries (Fig. 5) will be treated separately.

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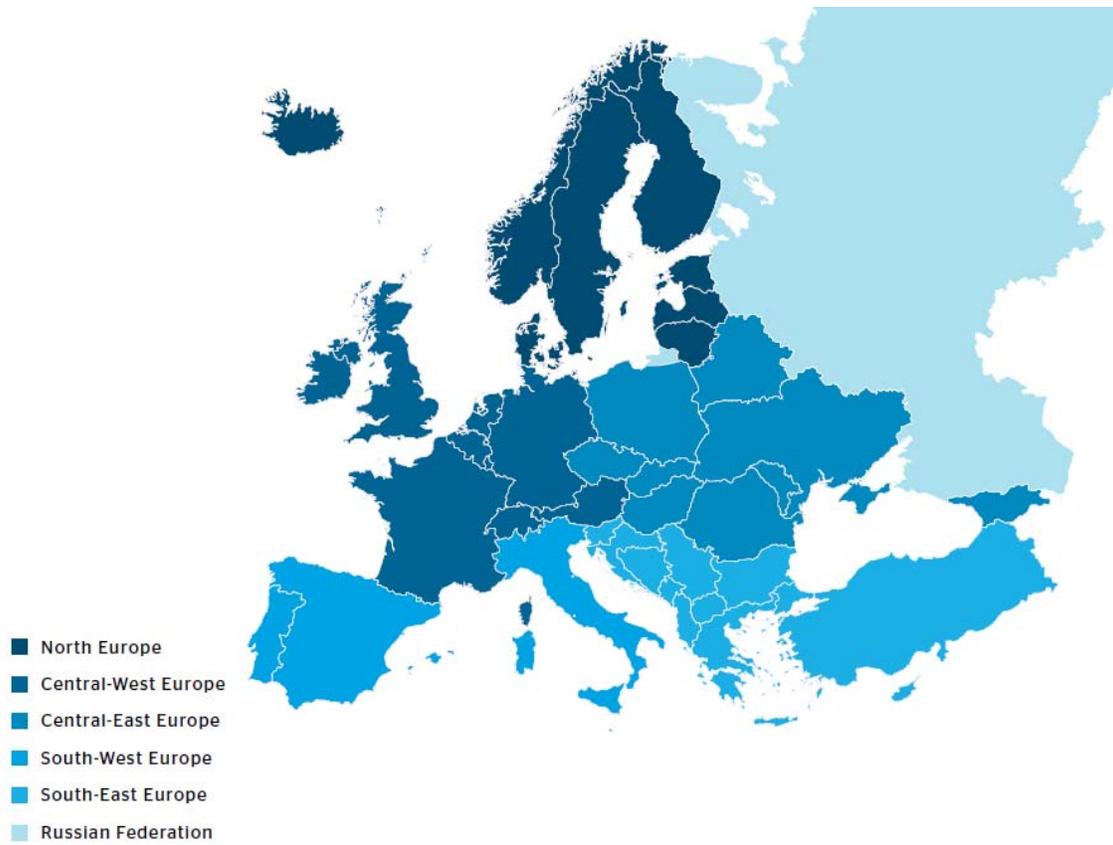


Figure 5: European forest ecoregions (source: <http://www.foresteurope.org/docs/fullsoef2015.pdf>).

Central Europe

In Austria thinning emphasizes on the further development of the remaining trees. Trees are not removed on basis of their current utility, but in favour of valuable future crop trees. In this procedure tree marking of the trees that are removed during the thinning plays a key role and is traditionally executed by a forester. Tree marking is time and money consuming which makes it unprofitable for young or poor sites. These sites therefore often remain unthinned.

The Austrian case study assessed the effect of thinning with tree marking in comparison with thinning without previous tree marking. In the second case the harvester driver is responsible for the tree selection directly during the thinning operation. The study showed that considering tree selection by forester or harvester driver there is not much difference in number of trees and volume removed, as well as in the resulting stand stability. Based on these results tree marking by a forester prior to the thinning operation is not needed and time and money could be saved if tree selection is left to the harvester driver. However, the study represents a special case: The harvester drivers involved in the study have been following tree marking instructions done by foresters for several years. By doing so they got trained in the silvicultural practice of the forester and internalised their principles. So when they

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selected trees on their own they were following this knowledge and imitated the forester.

The Polish case study assessed the general situation of mechanization of fellings including tending and final cuttings in Poland by comparing mechanized, motor-manual and mixed felling for the Polaów Forest District (North Poland). A questionnaire gathered as part of the case study showed that tree marking is well practiced in Poland. It further showed that more time is spend on tree marking for mechanised harvesting compared to mixed or motor-manual harvesting. However, this time could be reduced if tree selection was done by the harvester driver as proposed above. Keeping in mind the special case of the Austrian case study, based on their prior knowledge and experience this may involve a training period for the machine operators where they get familiar with silvicultural practices.

Finland may be seen as a role model in this context. Tree marking prior to the thinning operation was practiced in Finland until the 70s. Nowadays the education of harvester operators includes extensive lesson in silvicultural practices. This allows harvester operators to make informed decisions of which tree to cut during the thinning and harvesting operations and tree marking prior to the operation is omitted.

North Europe

In North European countries tree marking as a separate working phase prior to thinning nowadays plays a neglected role. Instead, the machine operators decide on the removal of trees and make the decision on which trees are left and which ones are removed. In Norway for instance thinning operations are currently more focused on the utility of the removed trees. The harvester driver removes the trees in order to make the thinning operation profitable. In Finland selective thinning from below/above is practiced. As mentioned above, machine operators in Finland, typically using CTL harvesters, are well educated through dedicated educational programmes. When removing trees the machine operator focus is on the improvement of the remaining stand by removing low quality trees and reducing the total number of stems.

In general thinning operations in forests characterized by small stem size, low removal per hectare and a high number of remaining trees as can often be found in North Europe (Fig. 6) are not viable as the low income from first thinnings are not able to compensate the high harvesting costs. As a consequence thinning wood is partly underutilized, although the situation has already improved to some extent due to an increased use of pulpwood after new investments in this field. Nevertheless, many young forests in North European countries are still thinned less than silvicultural practice would advise, especially in privately owned forests.

The case study conducted in Norway analysed the general benefit of thinning on wood production for Norway spruce stands. To make thinning operations profitable they are often applied late in the rotation. In Norway tree marking is neglected and the harvester operator decides which trees are removed. In contrast to the situation of the Austrian case study or Finish harvester drivers, Norwegian harvester drivers are not 'trained' in future crop tree marking as done by foresters. They heavily favour the selection of faster growing better quality trees for removal to maximize profitability. The late thinning in combination with removing better quality trees can reduce the stability, growth and quality of the residual stand. Thus, proper thinning may potentially increase total net production by reducing the losses due to mortality. Although this was not indicated by the management scenario examined, the study showed that no loss in total volume harvested is to be expected if thinning increases. Therefore more intensive and earlier thinning should be encouraged as there are no downsides in regard to volume harvested but advantages by increasing stand stability and possibly higher net production.

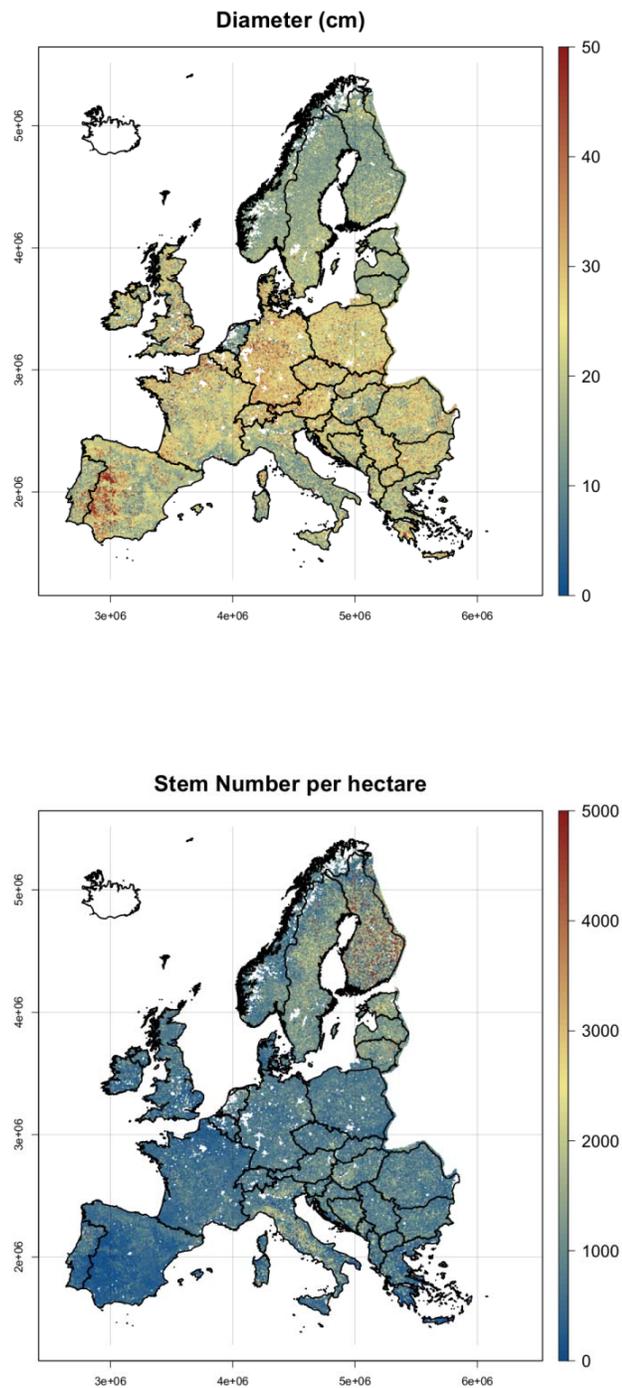


Figure 6: Diameter and stem number of European forests.

However, the challenge of profitability of the actual thinning operations remains. The Finish case study states that to promote thinning operations, an increased harvesting

productivity in young stands and a higher biomass yield per ha needs to be achieved. In Northern countries most harvesting and thinning operations are mechanized. For mechanized thinnings productivity can be increased by reducing the working time spent on boom movement. This is realised in the Corridor thinning technique, as described in Deliverable 2.2. Corridor thinning leads to higher productivity as well as higher volume of removal compared to selective thinnings and allows harvesting of stands with rich undergrowth without pre-clearing. By saving the undergrowth one also increases the option for future forest management by making transition to uneven and two-storied forests easier.

Early treatment and stand establishment

Four case studies of Deliverable 2.2 were concerned with improving and mechanizing early treatment and stand establishment silvicultural practices:

- Finland – Regional effects of timing of seedling stand tending
- Finland – Tending with Cutlink device
- Finland – Effects of improved regeneration material and fertilization on timber production
- Denmark – Power cultures; fast growing species on skid roads

Tending

Tending in young coniferous seedling stands is needed to control competition from fast growing hardwood and other competing vegetation. This increases the growth of the remaining trees and consequently enhances the yield of commercial wood. One case study in Finland analysed the effect of the timing of seedling stand tending on long term stand development and the associated profitability of forest management. The study indicates that right-time tending according to silvicultural guidelines results in more valuable and earlier harvesting removals when compared to other scenarios. Faster diameter development of the remaining trees further allows for earlier first commercial thinnings. For later pre-commercial thinnings a higher sawlog yield could be achieved when right-time tending was performed.

This emphasizes the need of right-time tending. However, as for thinning operations, tending is time consuming and unprofitable in the short term and solutions have to be found for increasing productivity of tending operations. Respecting the general need to mechanize silvicultural work, devices for mechanized tending need to be developed that are faster and cost effective compared to motor-manual work. The Cutlink device tries to meet this need and was analysed in a second case study conducted in Finland. The outcome of the case study was that motor-manual tending is noticeably faster while at the same time showing better quality compared to mechanized tending. While the Cutlink device thus could not meet the requirement of being faster and more cost effective, its reliability and technical availability was

promising regarding its current development stage. It has to be seen if the other needs can be met but the demand for mechanized tending solutions to emerge should encourage further development.

Stand establishment

Stand productivity can also be improved by using appropriate site-specific regeneration methods and materials. The effect of improved regeneration material as well as nitrogen (N) fertilization on sawlogs and pulpwood timber production in Norway spruce and Scots pine stands in medium-fertile upland forest sites was analysed in a case study conducted in Finland using process-based forest ecosystem model simulations. Using improved regeneration material lead to higher timber yield during first commercial thinning, as well as over the entire rotation length. Applying N fertilization once or twice during the rotation also improved timber yield. The highest increase in timber yield, which is accompanied by an increase of the amount and proportion of sawlogs from total timber production, was achieved when both silvicultural treatments were practiced. The study also showed that the investments made for better regeneration material, as well as N fertilization, are compensated by the higher yield and that for medium-fertile upland forest sites these are profitable investments under current conditions as well as under minor climate change.

The case study conducted in Denmark analysed the use of fast growing species on skid roads to increase biomass production early during the rotation period. They apply the concept of 'power cultures' regeneration systems which incorporate fast growing species into stands in order to support the main species as well as increase the profitable output after 10-25 years. In this study Norway spruce was used as main species for quality timber production and hybrid larch as supportive fast growing species planted on future skidding roads. An increase in biomass production could be shown, but the higher productivity was not able to compensate for the additional cost in most of the scenarios analysed. However, the profitability of the activity is highly dependent on the assumed discount rates, costs and prizes, which may change in the future. When also taking the effect on the quality of trees next to the skidding roads into account, this may be a promising measure which should also be transferable to other silvicultural contexts.

3.2.2 Up-scaling

Our approach for the up-scaling of the case studies builds upon the growing stocks and the share of these stocks that can theoretically be accessed by different harvesting systems as provided by our calculations. These calculations are based on simplifications and have limitations as demonstrated above. For the up-scaling additional simplifying assumptions are made and applied for all countries: Based on Eurostat for the 28 EU countries during the years 2000 to 2010 the net annual increment in forests available for wood supply made up around 3 percent of the total

growing stock available for wood supply. Therefore we assume that 3 % for the growing stock can be harvested annually while still being sustainable. For thinning operations and based on findings of Task 2.2 we assume that one third of total felling is done as part of thinning. We further assume that one third of the total thinning volume is done during the first thinning.

These simplifications, limitations and accompanied uncertainty thus have to be kept in mind when reading and interpreting the presented up-scaling results.

Case studies involving specific harvesting systems

Five of the eight case studies considered involve mechanised harvesting systems that either use a harvester or a forwarder. The possibility to take the methods suggested in the case studies into practice at a given forest area is thus above all limited by the technical applicability of these harvesting systems at that area.

For Finland, Corridor Thinning involves a harvester, while the mechanized tending with Cutlink device can be practised using a harvester or forwarder. Based on our map, almost all of Finland's forested area can be accessed by harvester and/or forwarder (Tab. 3). A mechanized tending device such as the Cutlink device could thus be potentially used all over Finland.

Tending is not limited to Finland but is practiced all over Europe as was identified in Task 2.1. The harvesting systems map shows, that the majority of the European forest area can be accessed by harvester and forwarder systems. Together with the expected increase in more mechanized harvesting systems in the future, this further emphasizes the need for sophisticated mechanized tending devices.

Corridor Thinning involves a harvester which again is applicable in the majority of European forests. In general Corridor Thinning could be practised all over Europe in areas accessible by a harvester. However, Corridor Thinning is a systematic thinning operation, which focusses on the effectiveness of the thinning operation and the utilization of the removed trees. Systematic thinning is more common in North compared to Central European countries. In Central Europe selective thinning with separate tree marking and a focus on the development of the remaining trees is often practiced.

As a result of this study, for Finland, around 16 million ha and 2 475 million m³ of timber can be accessed by a harvester (Tab. 3 and 4). This amounts to around 98 % of the forest area and volume in Finland in this up-scaling exercise. In practice, Finland already has a very high mechanization degree where nearly all operations are done by harvesters. The annual harvestable volume amounts to around is 74 million m³ for forest areas accessible by the 'Harvester and Forwarder' system and to 75.9 million m³ in total if all harvesting systems are considered. These numbers are in line with the fellings reported in the State of European Forests for the year 2010. Nevertheless, it should be noted that the Finnish National Forest Inventory (NFI 12

2014-2018, Forest resources statistics) estimated the maximum sustainable cutting possibilities (million m³/year) for the period 2015-2024 and across all species with a total of 84.28 million m³/year. Corridor Thinning is limited to first thinning. Following our assumptions regarding thinning the amount of volume felled as part of first thinning amounts to 8 million m³ per year. Depending on the undergrowth in a forest stand the higher productivity using Corridor Thinning leads to savings of 0.5 to 3 € per m³. As we have no information about the undergrowth we assume a mean saving of 1.5 €/m³. This leads to theoretical savings of around 12 million € per year based on our calculations. For harvest stands with rich undergrowth Corridor Thinning can be practiced without pre-clearing which leads to further savings of 300 to 400 € per hectare. If this analysis is extended to all North European countries and the same assumptions are applied, the annual harvestable volume amounts to around 75 million m³. Using a mean saving of 1 €/m³ would thus mean theoretical savings of 75 million € per year.

Systematic thinnings like Corridor Thinning often include the establishment of defined strip roads. The benefit of planting fast growing species on skid roads to increase the income of first thinnings was analysed by the Danish case study. In Denmark, around 163 thousand hectares and 36.5 million m³ of forest can be accessed by 'Harvester and Forwarder' (Tab. 3). Around 123 thousand hectares of this forest area is dominated by Norway spruce based on our calculations. The study showed that, depending on the planting distance, biomass production can be increased by around 60 tons per ha if hybrid larch is used for the skidding roads. This would mean a biomass increase of around 7.38 million tons for the Danish forests. For Northern countries the share of forest area dominated by Norway spruce that can be accessed by 'Harvester and Forwarder' is around 12 million hectares. Growing condition for great areas in Finland, Norway and Sweden are not suitable for using hybrid larch as the fast growing species. However, the case study also analysed that additional 18 tons per ha of biomass production can be achieved if Norway spruce is planted on skidding roads instead of leaving them empty. Using fast growing species suitable for the respective growing conditions the biomass increase would be even higher. However, it has to be noted that in the scenarios analysed as part of the case study, the higher productivity could not compensate for the additional cost.

Selective thinning focuses more on the future development of the remaining tress and less on the utilization of the removed trees. In Central European countries it often involves the precedent marking of the trees that are removed during the thinning. The Austrian case study showed that for the case where harvester drivers have previously been trained in silvicultural practice, either explicitly or by following foresters instructions for several years, the tree marking by a forester can be omitted. For Austria the National Forest Inventory recommends an annually 7.7 million m³ of stem volume to be thinned. This corresponds to 37 % of the total felling. Around one fifth of Austrians forest area in flat terrain can be accessed by a harvester. This means

that out of the 7.7 million m³ approximately 1.5 million m³ could be thinned by harvesters. For the case that all of the harvester drivers are as well trained as the ones in the case study, tree marking can be omitted for these areas. As an outcome of the Austrian case study conducted in Task 2.2, we can state that an experienced forester manages to tree mark about 150 m³ per day. This means that 10 000 workdays could be saved per year. With a salary of 136 € per day (17 €/hour) approximately 1.36 million € could be saved annually. Additional 40 % of forest area in steep terrain in Austria can be accessed by steep terrain harvester. In general tree selection in these areas can also be done by the harvester driver which leads to further potential savings. However one also has to keep in mind that a lot of forests in steep terrain serve as protection forest where commercial use is limited.

Tree marking is also practiced in Poland as was shown by the questionnaire gathered as part of Deliverable 2.2. Around 6.66 million ha of forest and around 1750 million m³ of timber in Poland can be accessed by harvester (Tab. 4). Again assuming that 3 % can be harvested sustainably, the annual total felling amounts to 52.5 million m³. Considering one third of total felling is to be done as part of thinning operations, 17.5 million m³ in forests accessible by harvester need to be thinned annually. Following the findings in the Austrian case study an experienced forest manager can mark around 150 m³ per day and would thus need around 116 000 days. With a salary of 64 € per day (8 €/hour or around 34 PLN/hour) approximately 7.4 million € could theoretically be saved if tree marking prior to the thinning operation is omitted. This, however, assumes already trained harvester drivers which may not be the case. Thus some of the savings may be invested in educational programs for machine operators as established in Finland.

The questionnaire also assessed factors limiting mechanized harvesting in Poland. The limiting factors indicated by the respondents were ranked from highest to lowest mentioned, which gives an idea of the relative importance of these factors. Topography, including slope and ravines, was the most frequently mentioned factor (over 40 % respondents). Poland is generally a lowland country, so at the large scale topography should not be a limiting factor for most areas (Fig. 7). However, small scale topographic features like trenches or roughness of the terrain, not recorded by our data, may limit the use of harvesters. The second most important limiting factor (mentioned by over 20% of respondents) was the species composition with dominating deciduous trees. Although most mechanized harvesting activities in the studied district were recorded for coniferous tree species and site types, a small share of deciduous tree species (birch, beech) were also felled with harvesters. According to our analysis, most of the forests in Poland are either needleleaf (conifer) dominated or mixed forests, with a high share of deciduous tree species that can be harvested using mechanized harvesting systems, if the respective diameter limit is not exceeded. Therefore, tree species is only a minor limiting factor for the use of harvesters in Poland. The wetness of the terrain was the third most frequently

Timber Volume in Poland

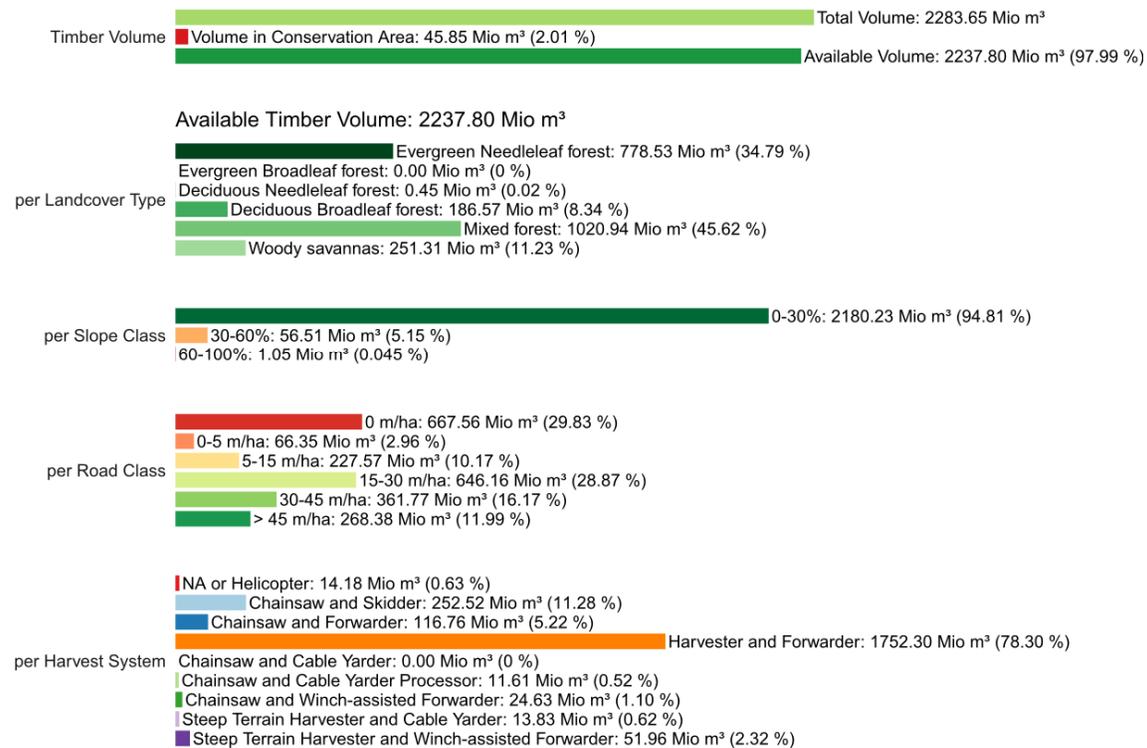


Figure 7: Distribution of forest resources in Poland

mentioned factor (around 18 %). According to our calculations around 0.9 million ha of the forested area in Poland (around 12 %) is located on soils which are influenced by groundwater. These areas are in general inaccessible for harvesters and motor-manual felling has to be performed instead. Taking all the limiting factors into account, our calculations result in the before mentioned 6.66 million ha of forest in Poland (around 80 %) as being accessible by harvester. Contracts between the Polish State Forests and private forest companies influence forest operations in Poland. Due to the way these contracts are concluded, the cost of harvesting did only slightly differ between motor-manual, mechanized and mixed harvesting methods in the case study. However, if certain conditions (e.g. stand size, tree dimensions, site conditions) are met, studies have shown that productivity is higher for mechanized felling by harvester as compared to motor-manual felling. This was also the outcome of Deliverable 3.5, where top level figures for main timber harvesting systems were gathered. For harvester and forwarder in the cut-to-length method, productivity depends on tree dimensions (average stem size and diameter at breast height), volume removed per hectare and the number of assortments. The highest productivity for thinning was 32.6 m³/PSH15 and 164.4 m³/PSH0 for clear cutting. In comparison the highest productivity for the chainsaw and skidder system was 89.0 m³/PSH. The higher productivity of the harvester and forwarder system should also lead to a decrease in harvesting costs, even though it was not present in this specific case study and forest district. In addition to the expected higher productivity, higher safety and lower physical stress of the forest worker favour the promotion of

mechanized harvesting systems.

Case studies focussing on silvicultural practices independent of harvesting system

Three case studies were not limited to a certain harvesting system but were concerned with improving timber yield by applying silvicultural practices. In Norway the difference in production of thinned and unthinned Norway spruce stands was examined. Around 2.5 million hectares of Norwegian forests are dominated by Norway spruce based on our calculations. Thinning in Norway spruce stands should be promoted as it does not reduce the total volume harvested but increases stand stability and potentially total net production.

In Finland the effect of right-time tending as well as the use of improved regeneration material and fertilization on timber production was analysed. Practicing right-time tending a higher sawlog-yield and, depending on the assumed interest rate, a higher net present value can be achieved. Based on our assumptions and calculations the harvestable volume in Finland amounts to around 75.9 million m³ per year. The share of sawlogs on the total harvesting removals is around 56 % for right-time tending and 46 % if no tending is practiced. This means each year theoretically additional 7.59 million m³ of sawlogs could be produced by practising right-time tending.

The effect of improved regeneration material and fertilization was analysed on medium-fertile upland forest sites for Norway spruce and Scots pine stands. According to NFI 12 around 13 million hectares of Finland's forests are dominated by Scots pine and around 5 million hectares by Norway spruce, the standing timber volumes are 1244 and 740 million m³ respectively. According to NFI 12 around 40 % of Finland's forest area lies on medium fertile soil. This leads to around 5.2 million hectares and 498 million m³ for Scots pine and around 2 million hectares and 296 million m³ for Scots pine stands. The case study showed an increase in timber yield of around 11.5 % for Scots pine and around 13 % for Norway spruces stands can be achieved if improved regeneration material is used. This means a theoretically increased annual timber yield of around 57 million m³ for Scots pine and 38 million m³ for Norway spruce. Using N fertilization the timber yield can be increased by up to 11 m³/ha for Scots pine and 25 m³/ha in Norway spruce stands. This would lead to a theoretically additional annual timber yield of 57.2 million m³ for Scots pine and around 50 million m³ for Norway spruce.

4 Conclusions

Mechanization of forest operations has been identified as one key measurement for achieving the goals set in Work Package 2: To increase the access to wood resources by promoting practices that increase growth rates in the forests and to achieve measurable improvements in the efficiency of forest operations. Often there is an interdependence between these two goals such that a higher efficiency of forest operations allows the practice of silvicultural treatments, which in turn increase the growth rates in forests. In other words, the inefficiency of forest operations often limits the practice of silvicultural treatments. This is quite evident in the case of thinning. The benefits of thinning are well known and were also shown in case studies conducted within this Work Package. Nevertheless, as thinning operations often are time and money consuming and therefore unprofitable, especially in the short term, many stands remain unthinned.

Mechanization is one way of making forest operations more efficient while also increasing the safety at work and lowering the physical stress of the forest workers. From the Harvesting Systems Map of Europe, although including uncertainty in the data as well as simplifications and limitations, it is evident that Europe has a high potential for the use of mechanized harvesting systems. Measurements for improving the efficiency of forest operations involving mechanized harvesting systems can thus potentially be applied for a great part of Europe's forest. This was shown by up-scaling the results of the case studies of Task 2.2 from their local to country or ecoregion scale. Other silvicultural treatments not limited to a certain harvesting system were also up-scaled where possible. The up-scaling is a theoretical exercise based on our data available and includes the uncertainty of the data, limitations and simplifications. The reported savings and earnings or areas of application have thus to be interpreted with care. Nevertheless, it is clear that by implementing the measurements suggested in the considered case studies there is high potential for making forest operations more efficient and profitable. For silvicultural treatments where appropriate mechanized tools are yet to evolve, as is the case for the mechanized tending device, the potential area of application should encourage further development.

The key finding of Task 2.3 is the high potential for the use of mechanized harvesting systems in Europe. This should encourage the development and improvement of

mechanized systems for silvicultural practices and harvesting. Silvicultural practices in turn should, where possible, consider the strength and weaknesses of the mechanized systems. By doing so the efficiency of forest operations can be increased as was shown in the Corridor Thinning case study. Making forest operations and silvicultural treatments efficient is the key for their actual implementation at forest sites. Minimizing negative environmental impacts like soil compaction accompanying forest operations and fuel consumption of supply chains should also be of high priority when developing and improving mechanized systems.

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