

Deliverable 1.1 – FMM descriptions (in report form)

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I. Forest Management Models (FMMs) description



2. Germany

2.1. Background and forest history

In historical time, German forests have undergone four waves of heavy devastation due to i) the invasion of the Romans (1st-3rd century), ii) rapid population growth in the middle ages (12th-13th century), iii) industrialization (18th-19th century), iv) war damages and reparation fellingings during and after World War I and II.

First approaches towards sustainable forest management were designed in the 18th-19th century; they mark the start of systematic forest science in our country. Since that time until a few decades ago, the mainstream FMMs were in favour of highly productive monospecific softwood plantations. These FMMs were implemented by state forest administrations, large private forest estates, and also farmers owning small forest areas. A common concept in this context was the so-called “wake theory”, expressing the view that all required ecosystem services would be produced as a side effect (in the wake) of sustainable wood production. However, in all categories of forest ownership, there have always been individualists maintaining mixed, partly uneven-aged forests, relying on natural regeneration. Most of them deemed such forest types economically superior to monocultures on the long run.

On the background of a widening ecological consciousness, and a focus on climate impact mitigation, within state forest (30% of Germany’s forest area) and corporate forest (20%) the last decades saw a silvicultural paradigm shift towards what had been a minority’s view before.

Therefore, management in public forest stands are often promoting forest conversion and a particular focus on natural regeneration in order to establish or maintain mixed forest stands. Multifunctionality is a very important concept, i.e. a broad range of ecosystem services is intended to be provided from the same forest area.

In the private owned forest land (50%), the picture is somewhat heterogeneous. Owners of large forest estates mostly adhere to the former mainstream concept in order to generate income as their primary goal. Small private forest owners who are organized in forest owner associations increasingly adopt the public forest concept. Considerable areas are also owned by non-organized forest owners, many of them not even being aware of owning forest (e.g. urban people who inherited land). Often, such forests are managed with low intensity or not at all.

The most relevant means of public control on private forest management are financial incentives for forest owners who obligate themselves to follow certain guidelines. In general, the diversity of FMMs in Germany is high.

In Germany approx. 50% of the forest land is owned by private, 30% of state and 20 % are corporate forest.

2.2. The case study areas

There are two case study areas in Germany. Augsburg Western Forest (AWF) in the federal state Bavaria, southern Germany and Lieberose-Schaubetal-Neuzelle (LFN), in the federal state Brandenburg in North-Eastern Germany. CSA AWF is more fertile and all land are classified as mesic, while CSA LFN have lower production and a large proportion of the land is classified as “dry” Table 4.

Table 4 A general description of forest land in the two case study areas in Germany, AWF in southern Germany and LFN in North-Eastern Germany.

Productivity/ moisture	Dry %	Mesic %	Moist %	Wet %
High		AWF 100%		
Medium		LFN 50%		
Low	LFN 50%			

2.2.1. Land area and forest cover

Table 5 Total land area, forest area, standing volumes, productivity and ownership in CSA.

	AWF	LFN	Germany
Total Area (ha)	120 000	60 000	35 737 600
Forest Area (ha) ¹	51 600	22 200	11 419 124
Forest cover (%) ¹	43 %	37 %	32 %
Average Volume (m ³ ha ⁻¹) ¹	396	288	336
Mean Yield Class (m ³ ha ⁻¹ yr ⁻¹) ¹	13.7	9.6	10.85
Forest Ownership (%) ¹			
Public / state and other	41 %	44 %	52 %
Private	59 %	56 %	48 %

2.2.2. Tree species

Tree species, proportion of total forest area in the two case study areas, in the two states and in Germany are shown in Table 6.

Table 6 Tree species, proportion of total forest area

Species (Latin name)	Case Study Area		Region		Germany
	Proportion (% total volume)		Proportion (% total volume)		Proportion (% total vol.)
	AWF	LSN	Bavaria1	Brand.2	
<i>Picea abies</i>	62.2%	2%	41.8%	≤ 5.2%	26%
<i>Pinus sylvestris</i>	3.4%	65%	17.1%	73.7%	22.9%
<i>Larix decidua</i>	2.0%	1%	2.1%	≤ 5.2%	2.9%
<i>Pseudotsuga menziesii</i>	0.6%	1%	0.8%	≤ 5.2%	2%
<i>Abies alba</i>	1.8%	≤ 6%	2.4%	≤ 5.2%	
<i>Quercus</i> sp.	3.5%	11%	6.8%	10%	
<i>Fagus sylvatica</i>	10.9%	4%	13.9%	3.2%	
other deciduous	15.6%	≤ 6%	15%	8%	

2.3. FMMs in Germany and in the two CSA

While the state forest concept strives to maintain or established mixed and to a certain degree uneven-aged forests, large private forest owners mostly do not intend to reduce the area of monospecific even aged softwood (Norway Spruce *Picea abies*) stands. Different thinning concepts (selective thinning, traditional thinning from below, future tree thinning) are applied in different strengths, seeking an optimum trade-off between increment and stability. The final cut and regeneration phase is kept comparably short, often increasing the share of Douglas fir (*Pseudotsuga menziesii*) is intended. However, this is just preliminary information, research about silviculture in the private forests is still going on.

However, about private forests, we will never be as precisely informed as about the state forest, as in private forests, silvicultural guidelines seldom are documented in such detail and as openly communicated as is the case for the state forest.

The concepts are highly differentiated as is the forest status in the case study region(s). Thus, below we can give only the general state forest concepts for the main species Norway spruce, European beech (*Fagus sylvatica*). And we give the general concept for Norway spruce in the large private forest estates. However in reality and in our model the differentiated concepts break down into a set of several hundred silvicultural rules.

We can so far give precise answers only for the state-owned forest in the AWF case study, which however can be extended to the municipal forest and – with lower intensity – to many of the small private forest owners who are organized in forest owner associations.

2.4. Alternative FMMs

There are no substantial differences between FMMs used in the two Case study areas and the region or country. The federal State forest services and other throughout the country have similar goals. We consider the CSA AWF quite representative for forest regions in dense populated areas close to cities and in an economically welldoing context. The LSN case study represents typical rural areas in economic weak settings.

In addition to the highly differentiated concepts mentioned above, a lot of different concepts exist in small private forests. Most important are no management at all and low intensity forestry without a real concept. However, many forms of more hobby gardening like management can be found, but not important in terms of covered area.

2.5. FMMs used in the two case study areas

Totally six Forest Management models are described, tree for each state, Table 7. Note the numbers of forest cover do not add up to 100%. However, the rest of the area is covered with a lot of different FMMs for different minor species and species mixtures. Small, unorganized private forest owners, often treat their forest with very low intensity and not with a real concept at all. Their share of the area might bring us near to 100%, together with the FMMs listed above.

Table 7 The six major forest management models (FMMs) used in the German CSA, Three in AWF/Bavaria and three in LSN/Brandenburg.

Tree-specie and forest owner	General characteristic of the FMM)	Coverage in the CSA (% forestland)	Coverage country (% forestland)
Case Study Area AWF Augsburg Western Forests, in Bavaria			
Norway spruce in large private	Shelterwood/Clear-cut/Non-uniform shelterwood	40	40
Norway spruce in state forest	selection	25	25
European beech in state forest	Selection/non-uniform shelterwood	10	10
Case study area LSN Lieberose-Schlaubetal-Neuzelle, in Brandenburg			
Scots pine state forest	Selection system / non-uniform shelterwood system without enlarging the gabs	30	30
Scots pine private	Clearcutting	25	25
Oak state forest	Selection system / Uniform / Non-uniform shelterwood system without enlarging the gabs	10	10

2.6. Ecosystem services

For private owners wood production is mentioned as the only ES but on state-land a number or services are listed. Wood production is listed first in all FMMs see Table 8.

Table 8. Ecosystem services connected to the four FMMs in the two CSA in Germany, CSA., AWF Augsburg Western Forests, in Bavaria and Case study area LSN Lieberose-Schlaubetal-Neuzelle, in Brandenbur. Ranking of important ES within each FMM. No ranking between FMM.

Forest manage model (FMM)	Ecosystem services, in order
Spruce large private forest owners (AWF Bavaria)	wood production
Spruce state forest (AWF Bavaria)	wood production, ecological stability

Forest manage model (FMM)	Ecosystem services, in order
	biodiversity, soil and water protection forest aesthetics
Beech, state forest (AWF Bavaria)	wood production, ecological stability biodiversity, soil and water protection forest aesthetics
Pine state forest (LSN Brandenburg)	wood production
Pine private (LSN Brandenburg)	wood production, ecological stability biodiversity, soil and water protection forest aesthetics
Oak State Forest (LSN Brandenburg)	wood production, ecological stability biodiversity, soil and water protection forest aesthetics

2.7. Common for the six FMMs

Many facts are true for all six FMMs in Germany. The use of introduced species, hybrids, genetic improvement, and use of chemicals and fertilizer.

Introduced species

All the six FMM described here focusses on native species. Norway spruce, the focus species of two FMM in Bavaria is native to the CS country but not native to the CS ecoregion. European larch (*Larix decidua*) which is sometimes mixed with European beech is native to the CS country (Bavaria/Germany), but not native to the CSA's ecoregion. The non-native Douglas fir will probably be-come more important as an admixture and as a stand-dominating species in the future, but its share of the CS forest area is still at about only 0.6 %.

Beech, oak (*Quercus petraea* and *Quercus robur*) and pine are all European species.

Local provenances are used. In most of the FMMs described the method for regeneration is natural regeneration which by natural reasons used very local seed sources. When underplanting is done local proveniences are used.

Genetically improved or modified seedlings

Genetically improved or modified seedlings are not used at all. The reasons are; 1) Legal restrictions, 2) Risk mitigation by maintaining genetic diversity, 3) genetically improved trees have no acceptance among most forest managers and the society.

Herbicides and

Hybrids are not used at all. The silvicultural potential of the used species is considered high enough.

Chemicals used

Applying herbicides/pesticides is not an element of any of the FMMs. Herbicides and chemicals are very rarely used. But there are some exceptions.

In case felled/fallen trees in private owned or state spruce forests the stand or timber stored for collection at the edge of the stand becomes infested by the spruce bark beetle *Ips typographus* and if timber can't be removed in time, an insecticide will be applied.

In state owned forests chemicals are avoided if ever possible. Bark beetle risk mitigation compared to classic monospecific even-aged Norway spruce stands is one of the goals of the FMM.

For pine the situation is the same, if timber stored for collection at the edge of the stand becomes infested by the beetle and if it can't be removed in time, an insecticide will be applied.

In beech dominated forests in the CSA, large-area insect defoliations (which would be the most probable reason for applying pesticides) are very rare. State forest managers would apply pesticides even in such a case only if the scenario would be really catastrophic. Usual defoliations are tolerated.

No chemicals are used in oak forests.

Fertilization

Fertilization is not done in any of the six FMMs described here.

Browsing and fencing

Browsing is a problem in parts of the areas. The (theoretical) goal is to have game densities so low that fences are not required. How much fences are used in practical forestry is not clear. Regulate game with hunting is an important task for forest management and state forest invest a lot in hunting to keep fencing on a low level.

Norway spruce monocultures tend to be quite robust against browsing, even with higher game densities. The highest risk connected with browsing in stands with Norway spruce is not the loss of spruce, but the loss of the other species in mixed stands.

Also for Beech the highest risk connected with browsing is not the loss of, but the loss of the other species in mixed stands.

The aim of the Brandenburg State Forest is to protect from browsing exclusively by shooting and without any fences in the two FMMs, for oak and pine. There is one exceptional case. If it is necessary seed the Oak the areas are fence because of the wild boars.

On the other hand, planted pine managed on small forest estates where clearcutting models are used, fences are used to 100%.

2.8. FMM Spruce in large private owned forest

The management of most Norway spruce (*Picea abies*) stands in the case study region AWF (Augsburg Western Forests) is not a single FMM, but a whole family of FMM's which have a few things in common: Even-aged, mostly monospecific forests, comparably short final harvesting phases, regeneration often from planting. Thinnings in spruce stands in the CSA have to establish a compromise between stability (keeping stands not too dense) and productivity (production losses if density is too low). The choice of the optimum compromise is owner-specific.

Commercial thinnings might follow very different concepts (depending on owners' preferences). Among the possibilities are classic thinning from below, selective thinning, future-tree selection.

We are investigating more details, but we will never be as precisely informed as about the state forest, as in private forests, silvicultural guidelines seldom are documented in such detail and openly communicated as is the case for the state forest.

In this example, almost all state forest managers would probably argue, that managing spruce in the way private owners do, should not be implemented at all, but that they can understand the reasons of forest owners who do so. Private forest owners would argue either that the state should adopt their silviculture (in order to make more money), or that it is ok that the state maintains multifunctional forests while private owners have to focus on generating income.

General characterization of the FMM

Private owners manage Norway spruce not in one way (one FMM) but in many ways including clear-cutting and shelterwood systems.

Tree species used and specie composition

The most important specie and totally domination is Norway spruce, sometimes with small shares of Scots Pine, European beech and Silver fir. Norway spruce is normally 80% or more at stand level.

Rotation periods

The decision of the rotation period is completely up to the owner. The optimum rotation age strongly depends on the goals of the owners (what kind of timber do they want to produce, do they like to take risks or not, culmination of mean annual increment financial performance, sometimes including interest rate and other investments.). Typically this result in rotation periods of 70-100 years, depending on about when the production performance desired by a forest owner.

Size of clearcuts

Size of clearcuts are not regulated, but clearcuts in forest that protect neighbouring forests from storm impact is forbidden. The size of clearcuts varies from 1 to 10 ha with an average of 5 ha. Large clearcuts are avoided.

Forest regeneration

Site preparation is not used and are not regarded as necessary.

About 40% of the seedlings are natural regenerated and 60% is planted.

Stand management

Pre-commercial thinning

If reducing over-densities (for stability reasons) is not necessary, pre-commercial thinnings are avoided. It's hard to estimate the area share requested. Assuming, 40 % of the FMM area are regenerated naturally, at least about that area would require a pre-commercial thinning.

Commercial thinning

About four to eight times. Rough estimate. Depends on a broad range of conditions.

Pruning

Cannot be answered yet, pruning is restricted to small areas, because the production goal usually is standard quality (not top quality) timber in high amounts. Pruning Norway spruce makes only sense, when the commercial thinnings imply a future tree concept.

Harvest and logging residues

A rough estimate is that harvesters and mechanized transport of logs, forwarder is used for 95%. For the logged volume.

Logging residues, e.g. branches are not used.

Nature protection

Nothing is normally done for nature values or nature protection as it is not among the owners' goal.

2.9. FMM for Spruce in the state forest

The FMM is the current binding concept of the Bavarian state forest for silviculture in mixed and pure stands with Norway spruce (*Picea abies*) as the main species. The silvicultural goal is to transform even-aged Norway spruce pre-dominated stands into Spruce-deciduous mixed stands. This concept covers a lot of variants of how to deal with very different initial stand and site conditions, so it is actually an overall FMM with a lot of sub-FMMs. In the standard case, the FMM includes pre-commercial thinnings, two phases of commercial thinnings which go over to a target diameter harvest combined with natural regeneration of all desired species.

General characterization of the FMM

State forest (Bavaria) manage spruce with Selection system (however with preceding pre-commercial thinning, goal-tree oriented thinning phase, and a differentiated goal tree and structure thinning). It is quite consequently executed, however this FMM comprises a lot of different variants depending on the initial stand's status (mixture, age, density) and site conditions. All of these variants are coded for our DSS.

Tree species used and specie composition

All monospecific and mixed stands with Norway spruce (*Picea abies*) being the most important species. The most important additional species in mixed stands with Norway spruce are European beech (*Fagus sylvatica*), Scots pine (*Pinus sylvestris*), and Silver fir (*Abies alba*). Proportions of

species in mixed stands depends on the goals of the managers. According to the guidelines (State forestry developed them in cooperation with the German partner in this project), the share of Norway spruce should not exceed 70%.

Rotation periods

Also for the state forest there are no regulations, but recommendations for when the thinning phase should be followed by the target diameter harvest phase. Individual trees are harvested at ages of 65 to 150 years depending on when the goal trees reach the desired stem diameters (in breast height) of (40) 45-50 cm.

Size of clearcuts

Size of clearcuts do not apply for a selection cutting system. Areas that are treated at one time, varies from 1 to 10 ha with an average of 5 ha.

Forest regeneration

Natural regeneration is totally dominating, 100%. Scarification are not necessary and are not performed at all.

Stand management

Pre-commercial thinning

The guidelines recommend 0-1 pre-commercial thinnings in ten years up to an age of 25. This is done in practice, thus approximately 100 % of the area this FMM applies is pre-commercially thinned at least once.

Commercial thinning

About eight times (four times in each of the two phases of commercial thinning). 100 % of the area is thinned several times. The two phases, lower H_{dom} than 25 m and higher than 25 m, differs in thinning strength.

Pruning

Cannot be answered yet, pruning is restricted to small areas, because the production goal usually is standard quality (not top quality) timber.

Harvest and logging residues

A rough estimate is that harvesters are used for 70% of the harvested volume and mechanized transport of logs, forwarder is used for 90% of the transport in the forest to the roadside.

Logging residues, e.g. branches are not extracted from the forest.

Nature protection

The goal to establish or maintain mixed and rich structured forests is seen as a nature protection feature by the managers.

2.10. FMM for beech in state forestry

The FMM is the current binding concept of the Bavarian state forest for silviculture in mixed and pure stands with European beech (*Fagus sylvatica*) as the main species.

The silvicultural goal is to establish and maintain nature-near uneven aged mixed beech forests which provide a multitude of ecosystem services at the same time.

This concept covers a lot of variants of how to deal with very different initial stand and site conditions, so it is actually an overall FMM with a lot of sub-FMMs. In the standard case, the FMM includes pre-commercial thinnings, three phases of commercial thinnings which go over to a target diameter harvest combined with a “femel gap” approach and mostly natural regeneration of all desired species. A “femel” is a small hole as a first operation in a stand with crop trees. The small gaps are distributed across the whole area of the stand. After a few years (when there is some regeneration) the holes are enlarged more and more. Thus there won't be a climate like on a clearcut area.

General characterization of the FMM

Selection system combined with non-uniform shelterwood system (however with preceding pre-commercial thinning, an elite-tree oriented selective thinning phase, a first elite tree promotion phase (100 elite trees/ha), and a second elite tree promotion phase (50 elite trees/ha)). It is quite consequently executed, however this FMM comprises a lot of different variants depending on the initial stand's status (mixture, age, density) and site conditions. All of these variants are coded for our DSS.

Tree species used and specie composition

All monospecific and mixed stands with European beech (*Fagus sylvatica*) being the most important species. The most important additional species in mixed stands with Norway spruce are Sessile oak (*Quercus robur*), sycamore maple (*Acer pseudoplatanus*), and common ash (*Fraxinus excelsior*). The guidelines do not give exact numbers about proportion, but the concept applies to stands with European beech shares of 50 % and more.

Rotation periods

Also for the state forest there are no regulations, but recommendations for when the thinning phase should be followed by the target diameter harvest phase. Individual trees are harvested at a tree ages of 80 to 200 years depending on when the goal trees reach the desired stem diameters (at breast height) of 65 cm. Given the management goals of the Bavarian State Forest – the guidelines mirror the actual optimum that is the best compromise between production and other ecosystem services the state forest has to provide.

Size of clearcuts

Size of clearcuts is regulated and do not apply for a selection cutting system. The whole area will never be totally harvested. Coherent areas that are treated at one time, varies from 1 to 10 ha with an average of 5 ha.

Forest regeneration



The guidelines recommend 100%, although there is an option to underplant desired additional species. In practice the amount of natural regeneration very roughly estimated is 90%, the rest would be under-planted additional species

Scarification are not necessary and are not performed at all.

Stand management

Pre-commercial thinning

The guidelines recommend 0-1 pre-commercial thinnings in ten years up to an age of 30. This is done in practice, thus approximately 100 % of the area the FMM applies is pre-commercially thinned at least once.

Commercial thinning

About seven times (distributed among the three phases of commercial thinning). 100 % of the area is thinned several times.

Pruning

Pruning is not a reasonable action for European beech and most other deciduous species in the CSA.

Harvest and logging residues

A rough estimate is that harvesters are used for 70% of the harvested volume and mechanized transport of logs, forwarder is used for 90% of the transport in the forest to the roadside.

Logging residues, e.g. branches are not extracted from the forest.

Nature protection

The goal to establish or maintain mixed and rich structured forests is seen as a nature protection feature by the managers. Deadwood accumulation is promoted, biotope trees (e.g. with hollows) are deliberately kept in beech stands. The state forest has given themselves a nature protection concept for beech (dominated) forests with certain goals of deadwood and biotope tree development depending on stand type and age.

2.11. FMM for Pine, private owner

The following description is about how most Scots pine (*Pinus sylvestris*) is managed in the small private forest estates in the case study region LSN (Lieberose Schlaubetal Neuzelle).

This, however, is not a single FMM, but a whole family of FMM's which have a few things in common: Even-aged, mostly monospecific forests, comparably short final harvesting phases, regeneration most of the time from planting. In most cases thinnings are done from below.

General characterization of the FMM

This FMM for pine is a clearcutting system.

Tree species used and specie composition



Typically, the share of Scots pine is 90% and more.

Rotation periods

The rotation period is a result of the FMM and the chronology of the silviculture interventions. The period ends with a target breast height diameter. Due to the marked spatial heterogeneity of forest structure, owner type and socioeconomic conditions in Germany, the optimal rotation period is subject to large variety on the spatial scale of the stand and also on the scale level of the forest enterprise. Thus, we are not able to define an optimal rotation period, moreover, as it will again depend on the scenario of wood demand and climate to be applied.

We have to assume that the actors know best what the optimal silviculture treatment is that leads to the wanted ESs. Tree ages of 150 years depending on when the goal trees reach the desired stem diameters (in breast height) of 45-50 cm.

Size of clearcuts

There is no regulation of size of clearcuts. The size depends on the owner and the area he focus on in each activity. In most cases the area of clearcut, or other operations as thinning is 0,4-2 ha.

Forest regeneration

Regeneration is done by planting only. Number of seedlings are 8000 per ha and size around 20 cm. Site preparation is not needed and is not done.

Stand management

Pre-commercial thinning

No pre-commercial thinning is done.

Commercial thinning

Thinning is done about 4 to 8 times. Depends on a wide range of conditions.

Pruning

Pruning is not done.

Harvest and logging residues

A rough estimate is that harvesters are used for 95% of the harvested volume and mechanized transport of logs, forwarder is used for 95% of the transport in the forest to the roadside.

Logging residues, e.g. branches are not extracted from the forest.

Nature protection

Typical not, because it is not among the forest owners' goals.

2.12. FMM for Pine, state forestry

The FMM is the current binding concept of the Brandenburg state forest for silviculture in mixed and pure stands with Scots pine (*Pinus sylvestris*) as the main species. The silvicultural goal is to

transform even-aged Scots pine pre-dominated stands into Pinus-deciduous mixed stands. This concept covers a lot of variants of how to deal with very different initial stand and site conditions, so it is actually an overall FMM with a lot of sub-FMMs. In the standard case, the FMM includes mix-ing regulation up to 7 m height of dominant trees. When height of dominant trees is higher than 7 m commercial thinnings are done to facilitate future trees. At the target breast height diameter groups of trees have to be cut to make gabs with natural regeneration.

General characterization of the FMM

This FMM for pine can be characterized as selection system combined with non-uniform shelter-wood system without enlarging the gaps. Different variants are used depending on initial stands status and site conditions.

Tree species used and specie composition

The FMM focusses on Scots pine. In general proportion of pine shall be higher than 50% and all mixing proportions together be lower than 50 % The most important additional species are beech and oak (*Quercus petrea*).

Rotation periods

The rotation period is a result of the FMM and the chronology of the silvicultural interventions. The period ends with a target breast height diameter. Due to the marked spatial heterogeneity of forest structure, owner type and socioeconomic conditions in Germany, the optimal rotation period is subject to large variety on the spatial scale of the stand and also on the scale level of the forest enterprise. Thus, we are not able to define an optimal rotation period, moreover, as it will again depend on the scenario of wood demand and climate to be applied.

We have to assume that the actors know best what the optimal silvicultural treatment is that leads to the wanted ESs. Tree ages of 150 years depending on when the goal trees reach the desired stem diameters (in breast height) of 45-50 cm.

Size of clearcuts

There is no regulation of size of clearcuts. Each size is possible, it depends on the spatial pattern of stratification. Gaps created is smaller than 0,3 ha and without further enlarging

Forest regeneration

As much as possible as natural regeneration. There is no information about the need for complementary planting. Failures depends on too much game and browsing.

Stand management

Pre-commercial thinning

Up to 7 m height of dominant trees there is just regulation of the species mixing, without harvest-ing, this is what normally is called pre-commercial thinning. From 7 m to 12 m there is the first harvesting intervention. If this intervention give a positive economic results is not clear.

Commercial thinning



All area is thinned several times

Pruning

Just single trees with an extremely high probability to become quality wood get pruned.

Harvest and logging residues

A rough estimate is that harvesters are used for 70% of the harvested volume and mechanized transport of logs, forwarder is used for 90% of the transport in the forest to the roadside.

Logging residues, e.g. branches are not extracted from the forest.

Nature protection

The goal to establish or maintain mixed and rich structured forests is seen as a nature protection feature by the managers. Deadwood accumulation is promoted, biotope trees (e.g. with hollows) are deliberately kept in beech stands.

The goal to establish or maintain mixed and rich structured forests is seen as a nature protection feature by the managers.

For reasons of biotope and species protection 5 oaks per ha must be selected in pine stands older than 80 years.

2.13. FMM for Oak, state forestry

The FMM is the current binding concept of the Brandenburg state forest for silviculture in stands with oak (*Quercus petraea* and *Quercus robur*) as the main species. The silvicultural goal is to establish oak stands with a high percentage (circa 35 %). This concept covers a lot of variants of how to deal with very different initial stand and site conditions, so it is actually an overall FMM with a lot of sub-s. In the standard case, the FMM includes closed canopy until a 7-10 m stem length with-out branches is reached. Then tending by single tree selection and facilitation until a target breast height diameter of 60 cm is reached. Meanwhile a layer of mixed species cares for shading the stems. In stands with shade tolerant species the regeneration is done with nature regeneration in 0,3 – 0,5 ha gabs. In stands without shade tolerant species areas with trees that are ready for harvesting will be thinned to become a shelter for the nature regeneration. If there are no seed trees, Oaks have to be seeded or planted.

General characterization of the FMM

This FMM for oak comprises a lot of different variants depending on the initial stand's status (mixture, age, density) and site conditions. The management combines uniform shelterwood system for parts with shade tolerant species with non-uniform shelterwood system for parts with light de-manding species. There is also elements that can be characterized as selective system. Regeneration only in groups (0,3-0,5 ha without trees) without further enlarging, and tending by future tree thinning

Tree species used and specie composition



The FMM focusses on oak, *Quercus petraea* and *Quercus robur*, accompanied by tree species *Pinus sylvestris*, *Fagus sylvatica*, *Carpinus betulus* and *Tilia cordata*.

Rotation periods

The rotation period is not regulated and is a result of the FMM and the chronology of the silvicultural interventions. The period ends with a target breast height diameter. Due to the marked spatial heterogeneity of forest structure, owner type and socioeconomic conditions in Germany, the optimal rotation period is subject to large variety on the spatial scale of the stand and also on the scale level of the forest enterprise. Thus, we are not able to define an optimal rotation period, moreover, as it will again depend on the scenario of wood demand and climate to be applied.

We have to assume that the actors know best what the optimal silvicultural treatment is that leads to the wanted ecosystem services. Rotation period is not determined as an interval of years or a target tree age. The time between regeneration up to the next regeneration of a group of trees depends on the time that a group of trees take to grow up to a desired breast height diameter of 60 cm. -> age is circa 200-240 years

Size of clearcuts

There is no regulation of size of clearcuts. Each size is possible. It depends on the spatial pattern of stratification. Gaps can have a typical size of 3000-5000 m².

Forest regeneration

More or less 100% of the seedlings are natural regenerated. Scarification are not necessary and are not performed at all.

Stand management

Pre-commercial thinning

Up to 7 m height of dominant trees there is just regulation of the species mixing, without harvesting, this is what normally is called pre-commercial thinning. From 7 m to 12 m there is the first harvesting intervention. It is not clear whether this intervention gives a positive economic result.

Commercial thinning

From 15 m height of dominant trees and higher every 5-8 years a commercial thinning has to be done. 100 % of the area is thinned several times.

Pruning

During the time up to a 12 m height of dominant trees the canopy should be kept closed. Then artificial pruning is not needed.

Harvest and logging residues

A rough estimate is that harvesters are used for 70% of the harvested volume and mechanized transport of logs, forwarder is used for 90% of the transport in the forest to the roadside.

Logging residues, e.g. branches are not extracted from the forest.

Nature protection

The goal to establish or maintain mixed and rich structured forests is seen as a nature protection feature by the managers. For reasons of biotope and species protection from an age of 100 years 5 oaks per ha or mixed tree species of low quality must be left in the natural decay phase and not used.

2.14. References

Sources

The silvicultural guidelines of the Brandenburg state forest contain the interests of the Brandenburg government and society and the validated scientific knowledge of the university in Eberswalde as a forestry competence centre. Further sources include silvicultural guidelines of the Bavarian state forest, knowledge and experience from long-term collaboration with experts from the Bavarian state forest, being involved in the recent forest planning process for the state forest in the CSA, over-regional and regional experts, preliminary results of the actor analysis, available CSA data.

Bayerische Forstverwaltung, Waldflächenbilanz 2015.

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II. Ranking of Ecosystem Services (ES)



2. Country reports

2.1. Germany

2.1.1. Biodiversity

For the FMMs in Germany the attainment of three key biodiversity characteristics were ranked on stand level with a 7-point scale (1 least, 7 maximum attainment). The ranking was done by forming a small expert team with silvicultural, forest dynamics, forest biology and ecosystem services background at the Chair for Forest Growth and Yield, Technische Universität München. The team assessed the FMMs based on the currently accepted knowledge among forest scientists and practitioners in Germany.

Table 2 Six German FMMs and associated subcategories ranked in terms of their relative capacity to close the gap between the habitat provided in production forests and the habitat requirements of forest dependent flora and fauna, 1 least, 7 maximum attainment.

FMM	FMM subcategory	Tree species composition (Native trees, broadleaf trees, tree species diversity)	Forest structures (older / larger trees coarse woody debris)	Disturbance regime (emulate natural disturbance regimes spatially and temporally)	Rank out of 7
Selection system combined with non-uniform shelterwood system	Scots pine state forest	5.5	6	4	5.2
	beech state forest	6	5	4.5	5.2
Clear cutting system	pine large private forest	1	1	3	1.7
Clear cutting system combined with uniform and non-uniform shelterwood system	spruce large private forest	1	2	3	2.0
	oak state forest	5	3.5	3.5	4.0
Selection system	spruce state forest	5	6	4	5.0

Selection system combined with non-uniform shelterwood system – Scots pine state forest

In terms of tree species composition, this concept was highly ranked, because the state forest actively promotes the establishment and preservation of native broadleaf species in conifer stands. Similarly, the concept earned a high rank for forest structures, larger trees and coarse woody debris, as the combination of a selection system with a non-uniform shelterwood system generates highly vertical and horizontal stand structures. A few large trees are preserved in such stands, when they die they are left in the stand. One of the intentions of this silvicultural systems is to partly emulate small scale disturbances like the death of large single trees, trying to keep the forest in a state which is also observed in unmanaged stands, but only transitional there.

Selection system combined with non-uniform shelterwood system – beech state forest

In principle, the same applies as for the Scots pine state forest FMMs. However, this FMM was slightly higher ranked than the one for Scots pine, as its tree species composition is in general nearer to the local natural tree species (Germany, without human intervention would be almost totally covered with beech-dominated forests). In terms of Forest structures we gave a slightly lower rank, as beech forests strongly tend to form close canopies with strong light interception. This can put trees below the dominant trees' crown layer at risk. The emulation of disturbance regimes was ranked slightly higher than for the pine state forest concept, as the death of large single-trees due to external influences was considered more typical for beech than for pine forests.

Selection system – spruce state forest

Again, the same general considerations apply as for the two state forest concepts mentioned above. However, among the state forest concepts, this one got the lowest rank, as the main tree species – Norway spruce – is not a native (dominating) tree species on the largest part of the areas where it is cultivated. As spruce, in mixture with other shade tolerant (beech, silver fir) or intermediately shade tolerant species (sycamore) can well be managed to form uneven-aged structured stands, this FMM got a higher ranking for forest structures than the beech state forest FMM. On the other hand, deliberately emulating natural disturbances in spruce forests (or – more general - conifer forests) could be riskier than for beech. Thus, this concept was given the same rank as the Scots pine state forest FMM.

Clear cutting system combined with uniform and non-uniform shelterwood system – oak state forest

While this concept was ranked quite highly for its tree species composition (oak together with other species like hornbeam, beech, sometimes rare Sorbus species), its ranking for forest structures is lower than for the previously mentioned state forest concepts. The reason being that uneven-aged forest management does not work well as with oak like it does for beech, spruce, and pine. Similarly, also the emulation of natural disturbance regimes is weaker there.

Clear cutting system – pine large private forest

Due to their main goal of obtaining income, large private forest owners are usually not interested in spending money for establishing or preserving additional tree species in monocultures of the locally most productive species. Thus this concept's ranking for tree species composition is very low. The same applies to forest structures and coarse woody debris, as this kind of management leads to homogeneous forest stands with only small amounts coarse deadwood. Disturbances are not

actively emulated, however, they regularly occur (frequently defoliations by insects) and foresters heavily counteract in order to prevent greater economic losses. Therefore, our ranking in this section is comparably low.

Clear cutting system combined with uniform and non-uniform shelterwood system – spruce large private forest

This FMM ranks between pine large private forest and oak state forest, being in all considered criteria nearer to the former than to the latter.

Summary

In terms of biodiversity, the three state forest FMMs for Scots pine, beech, and spruce obtain the highest ranks. The state forest concept for oak has an intermediate rank, while spruce and pine as managed mostly in large private forest are ranking lowest.

2.1.2. Cultural

The attainment of six key cultural service provision characteristics of the German stand level FMMs were ranked on a 7-point scale (1 least, 7 maximum attainment). The ranking was done by forming a small expert team with silvicultural, forest dynamics, forest biology and ecosystem services background at the Chair for Forest Growth and Yield, Technische Universität München. The team assessed the FMMs based on the currently accepted knowledge among forest scientists and practitioners in Germany.

Table 3 Six German stand level FMMs and associated subcategories ranked in terms of their contribution to the provision of cultural ecosystem services (1 min, 7 max).

FMM	FMM subcategory	stewardship	naturalness/disturbances	complexity	visual scale	historicity/image ability	ephemera	Rank out of 7
Selection system combined with non-uniform shelterwood system	scots pine state forest	5.5	6	6	5	5	5	5.5
	beech state forest	6	6	6	5	5	6	5.7
Clear cutting system	pine large private forest	3	3	2	3	2	2.5	2.9
Clear cutting system combined with uniform and non-uniform shelterwood system	spruce large private forest	3.5	3	2	3	2	2.5	2.9
	oak state forest	5	6	5	3	7	5.5	5.5
Selection system	spruce state forest	6	6	6	3	5	6	5.7

The considerations underlying the ranking of the single characteristics were as follows:

Stewardship

In general, the large private forests are used more intensive than the state forest resulting e.g. in lower amounts of residues from harvesting and thinning.

Naturalness

State forest aims for maintaining, introducing, and preserving more native tree species in mixture with the main species. More deadwood is allowed to accumulate, clearcuts are avoided.

Complexity

Close-to-nature uneven-aged structures are strived for in the state forest, leading to more complex, vertically and horizontally structured stands with higher tree size variation and higher species diversity than in the large private forests.

Visual scale

The FMMs in the large private forest and the state forest lead to visually different forest stands, even for the same (main) tree species. The private forest stands have a more plantation-like appearance (very similar tree sizes in the same stand, not much understory, if any) than state forest stands. Usually, recreationists prefer the esthetics of the latter ones.

Historicity

In average, trees in continuous cover forestry (as strived for in the state forest FMMs) get older than under even aged systems in Germany. The share of such stands is higher in the state forest.

Ephemera

In the state forest additional species are always promoted. Private owners prefer pure stands with the most productive species.

Ranking outcomes

The overall ranking results shows evidently higher ranks for the state forest FMMs, only with slight differentiation among the main tree species. The large private forest FMMs are on the other end of the scale. This, clearly does not come as a surprise, as the state forests are obliged to multiple-use forestry by law, while generation of income for the forest owners must be the dominant requirement in the large private forests.

2.1.3. Carbon

The attainment of three key C-Sequestration properties of the German stand level FMMs were ranked on a 7-point scale (1 least, 7 maximum attainment). The ranking was done by forming a small expert team with silvicultural, forest dynamics, forest biology and ecosystem services background at the Chair for Forest Growth and Yield, Technische Universität München. The team assessed the FMMs based on the currently accepted knowledge among forest scientists and practitioners in Germany. The result is presented in Table 4.

Table 4 Six German FMMs and associated subcategories ranked (min 1, max 7) in terms of their relative capacity for C-sequestration. We differentiated between C stored in a stand's living trees ("stand"), in deadwood, and in harvested wood products.

FMM	FMM subcategory	stand	deadwood	harvested products	Rank out of 7
Selection system combined with non-uniform shelterwood system	Scots pine state forest	4.5	3	4	3.8
	beech state forest	5.5	6	5	5.5
Clear cutting system	pine large private forest	5	2	3.5	3.5
Clear cutting system combined with uniform and non-uniform shelterwood system	spruce large private forest	7	2	4	4.3
	oak state forest	5	6	6	5.7
Selection system	spruce state forest	6	3	4	4.3

Selection system combined with non-uniform shelterwood system – Scots pine state forest

The amount of C stored in a stand's living trees results from the stand volume per unit area on the one hand, and the wood density on the other hand. This FMM got the lowest rank here, because compared with other species, both values are low for pine, and due to the goal of achieving uneven-aged forests, stand densities are lower in this FMM than they are with even-aged pine concepts (see pine large private forest below). As for deadwood, the state forest in general considers more ecological aspects than the private forests do, thus, there is more deadwood and consequently more C stored in that. For the harvested wood products a similar consideration applies as for the stand: The more is harvested and the denser the wood, the more C is stored in there. But in addition, the longevity of the wood products has to be taken into account as well. This ranking also considered, that the usage time of conifer wood products is in general shorter than for hardwoods, and that large private owners generally more strive for mass products, while the state forest strives for higher quality. For these reasons this FMM was ranked slightly higher for C-sequestration in harvested wood products than the Scots pine FMM for large private forests.

Selection system combined with non-uniform shelterwood system – beech state forest

Tendentially stand volumes are higher in beech forests than in pine forests together with a considerably higher wood density. This leads to a higher rank in terms of stand-level C-storage. Also the high ranking for C in deadwood results from the higher density and the by trend higher deadwood amounts in these beech forests. Ditto for the harvested wood products, higher ranking for beech than for pine because of higher wood density, but also higher usage time.

Selection system – spruce state forest

Wood density for spruce is somewhat lower than for pine, but the stand densities and therefore standing volumes are much higher, storing considerably more C. Deadwood and harvested wood products are ranked the same as for pine.

Clear cutting system combined with uniform and non-uniform shelterwood system – oak state forest

Despite the high density of oak wood, this FMM got a rank just slightly beyond pine state forest, as the low stand volumes outweigh the former. Vice versa, the deadwood of oak is very durable and thus accumulates to comparably high amounts. Wood products made from oak are in average the most durable ones compared to those provided by the other main species covered by the German stand level FMMs.

Clear cutting system – pine large private forest

As the private forest owners do not strive for vertically rich structured stands, they can keep higher levels of stand volumes and therefore more stored C. Under this kind of management, less deadwood accumulates compared to state forest, thus, the ranking of deadwood-stored C is lower. The higher share of shorter-living mass products from the private forests leads to a lower rank for C in harvested wood products compared to the state forest concept for the same species.

Clear cutting system combined with uniform and non-uniform shelterwood system – spruce large private forest

The even-aged, dense spruce stands as resulting from the large private forest FMM have very high stand densities and accordingly store large amounts of C, this results in the top rank in this category. For deadwood, we see no considerable difference with pine in the private forests, as production potential is higher for spruce, C stored in harvested wood products is ranked higher than for pine in the private forests. It is, due the products' shorter lifetime, however, lower ranked than beech and oak in the state forest.

Summary

Overall, the oak, and beech state forest FMMs rank highest in terms of C-sequestration, followed by both, the state and private spruce FMMs and the pine FMMs, whereby pine large private forest ranks lowest.

2.1.4. Regulatory

We ranked the attainment of four regulatory service characteristics of the German stand level FMMs on a 7-point scale (1 least, 7 maximum attainment). The ranking was done by forming a small expert team with silvicultural, forest dynamics, forest biology and ecosystem services background at the Chair for Forest Growth and Yield, Technische Universität München. The team assessed the FMMs based on the currently accepted knowledge among forest scientists and practitioners in Germany.

The considerations underlying the assessment were as follows:



Bark Beetle

Bark beetles (by far most important the spruce bark beetle *Ips typographus*) belong to the most dangerous harmful organisms affecting forest management in Germany. Mainly, they affect conifers (most important Norway spruce). In monospecific, even aged forests the risk of mass outbreaks is highest. Without countermeasures, large forest areas can be devitalized in short time. Thus the large private forest FMM for Norway spruce was given the highest rank in terms of bark beetle risk. Due to the less bark-beetle friendly stand structures created in the state forest spruce FMM, the latter concept is ranked slightly lower, however, still bearing a considerable risk of bark beetle infestations.

Wind

Wind breakage is a very common damage in German forests, conifers are more endangered than hardwoods, most affected is Norway spruce. Often wind breakage creates ample breeding material for bark beetles which may considerably increase the damage. Even-aged, monospecific stands usually are at higher risk than more complex structured stands due to a lack of individual tree stability and a higher tendency of air turbulence at steep stand edges. Thus the state forest FMMs for spruce and pine have lower ranks (lower risks) compared to the private forest FMMs.

Snow

The risk of snow breakage is very similarly distributed among the FMMs as is the wind breakage risk. Even-aged stands with a dense canopy can break down on larger areas while less homogeneous stands usually contain more individually stable trees which can bear higher snow loads. Breaks of whole areas are less frequent than in homogeneous stands. In both cases, snow and wind damages, the uneven-aged focused state forest FMMs result in more resilient stands. Usually dominant and co-dominant trees are broken in such events, and if there are waiting trees in the layers below, the losses can be more easily covered compared to the even-aged large private forest FMMs.

Fire

Fire damages are a prominent risk especially in the North-East German case study. Most exposed are pine stands which are often found on very dry, i.e. sites with a high wildfire risk. Young pine stands are at an especially high risk due to their dry dead branches covering almost the whole length of the stem below the living crown. Mixed stands are less vulnerable (hardwood admixtures reduce solar radiation reaching the ground, thus preventing the growth of grasses which, in dry summers, are highly flammable), which means a slight advantage for the pine state forest FMM compared to the large private forest pine FMM. Spruce is much less endangered by wildfires as its cultivation is not an option on such dry sites. Hardwoods in general contain more moisture than pine even in dry summers, making them considerably less inflammable.

Outcome of the ranking

The highest overall risk comes together with (the most productive) large private forest FMM for Norway spruce due to its susceptibility to the classic damaging agents bark beetle, wind, and snow. The second-highest overall risk is connected with the state forest pine FMM, here bark beetle risk is lower, but counterweighted by a high wildfire hazard. Due to the reasons given above, the state

forest conifer FMMs are considerably less risk-prone, actually, risk mitigation is an important motivation behind these FMMs. Hardwood stands in general are much less vulnerable, thus the beech and oak FMMs rank lowest.

Table 5 Six German FMMs and associated subcategories ranked in terms of their relative risk to be affected by damaging agents, (1 min risk "best" to 7 max, "high risk").

FMM	FMM subcategory	bark beetle	wind	snow	fire	Rank out of 7
Selection system combined with non-uniform shelterwood system	scots pine state forest	3.5	4	4	5	4.1
	beech state forest	2	3	3	2	2.5
Clear cutting system	pine large private forest	4	5	5	5.5	4.9
Clear cutting system combined with uniform and non-uniform shelterwood system	spruce large private forest	5	6	6	3	5
	oak state forest	2	2	2	2	2
Selection system	spruce state forest	4	3.5	3.5	3.5	3.6

2.1.5. Water

The attainment of five water-related characteristics of the German stand level FMMs were ranked on a 7-point scale (1 least, 7 maximum attainment). The ranking was done by forming a small expert team with silvicultural, forest dynamics, forest biology and ecosystem services background at the Chair for Forest Growth and Yield, Technische Universität München. The team assessed the FMMs based on the currently accepted knowledge among forest scientists and practitioners in Germany.

Compared to the other ES considered, less is known and information is more ambiguous about water related ES. Possibly more important for water related services than FMMs is the question whether an area is covered with forests or other vegetation.

Considerations behind the ranking:

Water yield, water flow maintenance

Groundwater recharge is considered higher in stands with oak or beech compared to pine and spruce dominated stands, but the difference that makes is under debate, see (<https://www.lwf.bayern.de/mam/cms04/boden-klima/dateien/a66-wasserverbrauch-von-waeldern.pdf>).

Flood protection

Scots pine is considered to have a lower rainfall interception than the other species, leading to a higher runoff. Thus, pine forests (both pine-based FMMs) rank lowest in terms of flood protection. In vertically structured stands interception is generally higher than in even aged ones. This is why the state forest spruce FMM ranks higher than the pine FMMs in general and the even-aged spruce in large private forests. For the same reason, the hardwood-focused FMMs rank higher than pine.

Erosion control

Here, our ranking covers the concept that mixtures of shallow rooters (spruce), deep rooters (pine, oak), and intermediate rooters (beech) have a stronger soil-stabilizing potential than monospecific stands which typically stabilize one soil layer only. The highest weights were therefore attributed to the (comparably rich in additional species) state forest FMMs for spruce and pine followed by beech. The even-aged large private forest spruce and both pine FMMs were given a similar comparably low rank.

Chemical conditions

Hardwood stands dominated by beech and oak are generally associated with a lower nitrate seepage than conifers due differences in key processes (interception, nitrate uptake).

Overall ranking outcome

Generally, due to often unclear information, we were cautious against introducing too high contrasts in the ranking of water related services. Currently we are performing orienting simulation studies with a process-based model whose results will allow us to be more precise when evaluating the ALTERFOR scenario runs.

However at the time being, our ranking is favors the state forest FMM for oak followed by the state forest concepts for spruce and beech. The lowest overall rank comes out for the even-aged spruce FMM of large private forests together with both pine FMMs.

Table 6 Six German FMMs and associated subcategories ranked in terms of their relative capacity to provide water-related ecosystem services (min 1, max 7).

FMM	FMM subcategory	water yield	flood protection	water flow maintenance	erosion control	chemical conditions	Rank out of 7
Selection system combined with non-uniform shelterwood system	scots pine state forest	4	3.5	4	3.5	3.5	3.7
	beech state forest	5	4	5	4	4	4.4
Clear cutting system	pine large private forest	4	3.5	4	3.5	3.5	3.7
Clear cutting system combined with uniform and non-uniform	spruce large private forest	4	3.5	4	3.5	3.5	3.7
	oak state forest	5	4.5	5	4.5	4	4.6

FMM	FMM subcategory	water yield	flood protection	water flow maintenance	erosion control	chemical conditions	Rank out of 7
Shelterwood system							
Selection system	spruce state forest	4	4.5	4	4.5	3.5	4.3