Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

Instrument: IP

Thematic Priority: 6.3 Global Change and Ecosystems

Deliverable PD2.1.5
Impact analysis on production of alternative forest management strategies based on simulations for European reference forest types

Due date of deliverable: Month 38
Actual submission date: Month 51

Start date of project: 011105
Duration: 4 years

Organisation name of lead contractor for this deliverable:
Albert-Ludwigs-Universität Freiburg, Institute for Forest Growth (Partner 5)

Final version

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

PD2.1.5: Impact analysis on production of alternative forest management strategies based on simulations for European reference forest types

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Abstract:

Forests provide many goods and services. Often, wood production is economically the most important societal request from forest ecosystems. Its quantity and corresponding economic returns can be increased by intervening with natural processes, i.e. by forest management. Standardized forest management approaches (FMAs) are selected along a gradient from low intervention in close-to-nature approaches to intensive management approaches and can be applied to various European spruce and pine reference forest types. FMAs consist of coherent sets of combined appropriate actions at the stand level. Thus, among other things, FMAs control the stand's density pattern and its species composition over time. Stand productivity in the different forest management approaches is assessed.

The different FMAs' implementation over time is achieved using stand level forest simulators which predict stands' development, its growth rates and volume production as well as cash flows. The effect of the FMAs' simulations is assessed focussing on merchantable wood volume produced and on land expectation value at perpetuity.

This standardized approach allows for cross-comparison of the natural and economical results within the considered reference forest types as well as between the European regions. Observed variations in the productivity ranking and in land expectation value of the various forest management alternatives are related to tree species growth dynamics, to preferences for specific assortments as expressed in stumpage prices, and to time as expressed through interest rate, respectively.

Key words: Volume production, land expectation value, Forest management alternative

Content

1 Introduction

The choice of a management strategy is made by the first link of the entire forest-wood chain, the foresters. This choice has a strong impact on the fulfilment of the different societal request from forest ecosystems for goods and services. Thus, selecting among alternative strategies is a crucial step in short- as well as long-term decision-making in forestry practice and reflects the frames set by a regional or national forest policy. The EFORWOOD project, funded under the EU "Global change and ecosystems research-activity" of the Sixth Framework Programme, aims at developing a decision support tool for Sustainability Impact Assessment (ToSIA) of the European forestry-wood chain. To assess the impact of different forest management strategies on production, the principles for five forest management alternatives have been defined for 9 Regional Cases in European countries (Duncker et al., 2007 (D 2.1.3)). These principles served to standardizedly describe forest management alternatives (FMAs) along a gradient of intensity of intervention into natural processes for regional reference forest types. FMAs consist of coherent sets of forest operational processes at the stand level. Thus, among other things, FMAs purposely control the stand's density pattern and its species composition over time.

Based on realistic but virtual data-sets this contribution shows the effect of different forest management alternatives forming an intensity gradient on the productive function of the forest. The impact on productivity which is described through volume of produced wood is simulated for reference forest types. However, since the management objective of the passive intervention alternative (FMA1) is to allow natural processes and natural disturbance regimes to develop without management intervention in order to create natural (or authentic) ecological valuable habitats and biodiversity this alternative is not further considered here.

The question of how to compare different management strategies is still unsolved (Hanewinkel et al., 2007), but the land expectation value sensu Faustmann (1849) is a common discounted cash flow method applied to value timberland (Straka and Bullard, 1996). Differences observed between management alternatives in their effect on production are related to volume flow, structure and stumpage value of cut volume, and cash flow against tree species growth dynamic.

2 Method and Material

Five forest management alternatives were defined in general form by Duncker et al. (2007) to cover an intensity gradient in forest management from non-intervention strategies to short rotation forestry. The intensity of a FMA results from the purposive alternation of stand key parameters through the utilization of production factors. Intensive forest management thus is characterized by increasing control and modification of natural conditions. So-called basic principles are set up to describe the options for applying forest operation processes, as well as for respecting limitations, along the management cycle through the stand developing phases. This provides for a standardisation in defining forest management alternatives for various tree species which are differentiated by acceptable limits in natural process intervention. A detailed operational description of the FMAs by the pursued management objective and a corresponding set of basic principles for various reference forest types is provided by Duncker et al. (2007). Although, the management alternatives are described for regional reference forest types the assessment of their impact on the productive function is based on abstract simulations at stand level. Since the differences between the alternatives are the objective assessed, rather than the development of a given resource towards the management alternatives, equilibrium state is assumed for the alternatives. Thus, transformation or conversion phases are excluded.

In order to enable cross comparison, the site index was standardized for all FMA simulations within one region and tree species. If not otherwise stated a region specific medium site class was assumed. The development of the virtual stands under the management alternatives was modelled with forest growth simulators. The simulations served to estimate both, changes in stand structure as well as wood volume flow over time for the total life span of the stands. Wood volume is one of the target variables to assess the productive function. It was measured in stem-wood volume or merchantable wood produced with a minimum diameter of 7 cm at the smaller end (if not otherwise stated) in unite of $m^3\,ha^{-1}$, which is referred to as yield, or in unite $m^3\,ha^{-1}\,yr^{-1}$ being stand growth. The later is commonly as well referred to as being the mean annual increment (MAI_V) and provides for a comparable mean long term average productivity measure.

In addition to the volume produced, the land expectation value was calculated according to (Faustmann, 1849) to assess the economic performance of the management regime. Although Faustmann dealt with even-aged stands, the principle remains valid for uneven-aged management (Buongiorno, 2001). However, it must be modified because, while even-aged management begins with bare land, uneven-aged management needs both land and some residual trees. The opportunity costs of those trees must be accounted for in calculating the land value (Buongiorno, 2001; Chang, 1981). The land expectation value was calculated for interest rates of 5 to 0%. When the interest rate equals zero, the forest value model becomes the forest rent model. The forest value model is the value of land and trees and thus nothing but the familiar Faustmann's formula once the opportunity costs of the optimal regrowing stock are denoted as "regeneration costs". If further the value of the growing stock is ignored, then the forest value model becomes the biological model of mean annual increment (Chang, 1981). It needs to be stated here that the models are not applied for maximization purpose but for economic comparison of the management alternatives only.

The cash flow at time t resulted from forest operation processes as for example planting, tending, fertilisation or harvesting. In case of a harvesting process the products of volume and net return per tree are summed. For this calculation models describing net value per m³ as a function of breast height diameter were applied. If not otherwise stated mean wood prizes at road side and mean costs for 2005 were used. In addition to these variable costs, fix costs related to a specific management alternative are provided where appropriate. However, fix costs were not considered in land expectation value calculation.

3 Results of regional productivity analyses

3.1 Simulation of two different forest management strategies with PROGNAUS in Austria, compared based on Faustmann's land expectation value

Markus Huber, Pascal Schedl and Hubert Sterba

3.1.1 Materials and Methods

The study area and the forest inventory data

The Austrian Regional Case for the EFORWOOD project is the alpine spring protection forest. The simulations are based on the data of the permanent forest inventory of a 15,300 ha forest management unit in the growth district "eastern part of the northern calcareous alps" (Forstliche Bundesversuchsanstalt, 1981). The mean monthly temperature at the nearest weather station is between -2.7 °C (January) and 16.1 °C (July) and the monthly precipitation is between 72 mm (October) and 145 mm (July) at 612 m a.s.l. For 1,274 plots located at the 200x200 m grid (only one third of the original 3,822 plots were used for permanent sampling) the site characteristics as described by Forstliche Bundesversuchsanstalt (1981, 1986, 1992) were determined and the sample trees were selected by angle count sampling according to Bitterlich (1984), using a basal area factor of 4. For every sample tree the diameter at 1.3 m above ground (diameter at breast height, dbh) was measured and the crown class according to Kraft (1884) was recorded. The quality of the lowermost log, its injuries and their possible causes were classified. The tree height of the median stem of the basal area distribution was measured for every species and the tree height of the remaining trees on the sample plot was then calculated using standard height curves (Knieling, 1994). An increment borer was used to determine the age at breast height of the median stem of the basal area distribution and the stand age at the sample plot was then estimated from the increment borings of the dominant trees. Furthermore a potential natural vegetation type for the sample plot was derived from the given site factors.

The individual-tree growth simulator PROGNAUS

PROGNAUS combines the basal area increment model according to Monserud and Sterba (1996) (for coefficients confer Hasenauer 2000), the crown ratio model according to Hasenauer and Monserud (1996), the height increment model according to Schieler (1997), the mortality model according to Monserud and Sterba (1999) (for coefficients confer Hasenauer 2000) and the ingrowth model according to Ledermann (2002). The parameterisation of all models is based on data of the Austrian National Forest Inventory (Forstliche Bundesversuchsanstalt 1981, 1986, 1992). PROGNAUS does not use stand age and site index as input variables, because the models allow direct predictions of the target variables by species specific functions of site factors, tree size factors and distance independent competition factors for a simulation interval of 5 years.

The mortality model (Monserud and Sterba 1999) is implausible for all species except Norway spruce (Picea abies L. Karst.) for large breast height diameters because it is missing the classic "U-shaped" probability for mortality over the dbh. For this study the probability for mortality was therefore estimated using the coefficients for Norway spruce also for the other species.

Management options have to be given as (i) pre-defined thinning actions (pre-commercial thinning, thinning from below and selective thinning) and (ii) pre-defined final harvesting actions (clearcut or target diameter harvest). The time of management interventions has to be defined by a certain variable, i.e. the stand's dominant height for thinning actions, the target dbh or a certain stand age for final harvesting actions. The variable for the intensity of the management intervention is the target stem number per hectare after the respective intervention (pre-commercial thinning), the percentage of the volume to be removed (commercial thinning) or the percentage of trees with a dbh greater or equal to the target diameter, which is to be removed from the stand.

For the present study all models were used deterministically. Tree volume was calculated according to Pollanschütz (1974) and Schieler (1988).
As a first step PROGNAUS was run with all 1,274 plots and the estimated increment data was compared with the increment data calculated from two subsequent measurements (permanent inventory). The growth models were then adjusted by species specific multipliers (data not shown), derived from this increment comparison.
Note, that climate change and its influences as well as changing site conditions as a consequence of a changing species composition are not considered in PROGNAUS.

The forest management strategies

Five forest management alternatives were defined in general form by Duncker et al. (2007) to cover the complete range of all forest management strategies over 11 European Countries. For the Austrian spring protection forests it was decided to focus on three of these strategies because the other 2 strategies were found either to be non applicable in the given forest management district (e.g. short rotation forestry) or to be redundant because the management interventions within one strategy would be the same as for another strategy.

Intensive even aged forestry

This strategy has the objective to obtain the highest possible profit from sustainable timber production. The management program, based on a clear cutting system with artificial regeneration, is described in Tab. 1.

Combined objective forestry

The main objective of this strategy is a combination of the protection of the alpine springs, which deliver the drinking water for adjacent large cities, and timber production. Therefore clearcuts are to be abandoned and the harvesting actions are to be carried out in a way that prevents soils from damage. The management program is based on natural regeneration and target diameter harvesting (Tab. 1).

The target tree species for both forest management strategies is Norway spruce, but other admixed tree species, e.g. common beech (Fagus sylvatica L.), Silver fir (Abies alba Mill.) or common ash (Fraxinus excelsior L.) are to be considered.
The third strategy (“unmanaged forest nature reserve”) was omitted for the presented study because it is incomparable to the others in terms of timber production.

Tab. 1: Description of the management program for the forest management strategies “intensive even aged forestry” and “combined objective forestry”.

Management intervention	Description “intensive even-aged forestry”	Description “combined objective forestry”
Site preparation	The forest soil is cleared from the remains of the previous rotation period. Afterwards the site is left untreated for three years.	
Planting	Prior to the tree planting the plant cover on the site is cut with a mechanical clearing saw. 2500 trees/ha with 2/3 seedlings of Norway spruce.	
Weed control	The weed around the seedlings is manually cut once a year during 3 years after the planting.	
Deer protection	A chemical repellent against browsing animals is applied manually once a year during 6 years after the planting.	
Pre-commercial thinning	At a top height of 5 m the stem number per hectare is reduced schematically to 1800.	If a reduction of the stem number is necessary, it is schematically reduced. This treatment is carried out immediately after the target diameter harvesting in the respective stand.
Commercial Thinning 1	At a top height of 15 m 25 % of the standing volume is cut by selective thinning.	
Commercial Thinning 2	At a top height of 20 m 20 % of the standing volume is cut by selective thinning.	
Final harvest	Clear cut at a certain stand age.	10 % of the trees with a dbh $\geq$ 45 cm are to be cut every 5 years (target diameter harvest).

The simulation runs

The dominant potential natural vegetation type for the given growth district is the spruce-fir-beech forest (Kilian et. al., 1993). Therefore it was decided to carry out the simulations only for forest inventory plots where this potential natural vegetation type was indicated. PROGNAUS was set up with the tree and site specific data of 7 plots for the forest management strategy “intensive even aged forestry” (Tab. 2) and with the data of 14 plots for the forest management strategy “combined objective forestry” (Tab. 3).

Management interventions as described in Tab. 1 were entered into the simulator and the simulation runs were carried out for 200 years, considering the increment multiplier mentioned above and setting the rotation length for the “intensive even aged” strategy to 200 years.

The simulator delivers the individual tree data for every simulation period, separately as a data file (i) “before management and mortality” (giving the representative stem number per hectare (nrep) for every tree at the beginning of the period), (ii) “mortality” (giving nrep for the mortality within the period), (iii) "harvest" (giving nrep for the harvested stems within the period) and (iv) "remaining" (giving nrep for every tree at the end of the period). Therefore it was possible to choose the time of the final cutting independently of the entered rotation length by using the "before management and mortality"-file as "harvest"-file for the grading of harvested stems.

Tab. 2: Characterisation of the forest inventory plots in 2005, used for the simulation of the forest management alternative "intensive even aged forestry".

ID	ELEV	SL	AZ	HF	HH	M	St	Vt	d_g	h_{dom}	N_{ha}	G_{ha}	V_{ha}	Pab	Fsy	Oth
1	854	42	359	0.6	0.3	3	18	2	21.2	17	1022	36	288	1	0	0
2	1287	45	29	0.6	0.3	4	21	1	14.2	19	2277	36	303	0.6	0	0.4
3	1177	36	92	1.4	1.5	3	18	4	15.6	14	2939	56	389	1	0	0
4	908	39	74	1.4	1.5	3	18	4	12.8	15	4667	60	438	1	0	0
5	835	28	322	1.4	1.5	3	18	12	23.9	15	712	31.9	204	0.9	0	0.1
6	755	51	52	0.6	0.3	3	21	1	17.4	19	1846	44.1	374	0.7	0.3	0
7	844	36	261	0.6	0.3	4	21	1	13.5	14	4773	68.1	453	1	0	0

Tab. 3: Characterisation of the forest inventory plots in 2005, used for the simulation of the forest management alternative "combined objective forestry".

ID	ELEV	SL	AZ	HF	HH	M	St	Vt	d_g	h_{dom}	N_{ha}	G_{ha}	V_{ha}	Pab	Fsy	Oth
8	807	56	53	1.4	1.5	4	19	4	33.2	21	462	40	365	1	0	0
9	729	46	336	1.4	1.5	4	19	4	53.6	37	123	27.7	425	0.7	0	0.3
10	961	67	198	0.6	0.3	2	19	19	30.9	24	694	52	577	0.5	0.2	0.3
11	1033	76	234	0.6	0.3	3	9	19	44.7	27	101	15.9	184	0.6	0.4	0
12	1264	57	196	1.4	1.5	3	18	13	45.8	27	291	47.9	569	0.8	0.1	0.1
13	1126	84	205	1.4	1.5	3	19	4	58.2	31	107	28.5	357	1	0	0
14	949	31	138	0.6	0.3	3	21	19	49.4	33	83	15.9	220	0.9	0.1	0
15	907	38	168	1.4	1.5	3	21	4	43.5	26	271	40.4	437	0.9	0	0.1
16	1007	24	84	0.6	0.3	2	9	1	47.8	24	111	20	190	0.2	0	0.8
17	1112	76	278	0.6	0.3	3	21	1	43.3	33	485	71.4	960	0.7	0.2	0.1
18	1215	49	45	1.4	1.5	4	19	4	42	33	433	59.9	791	0.8	0.1	0.1
19	1251	98	113	0.6	0.3	3	18	1	29.8	32	690	48.1	668	0.7	0.3	0
20	1163	44	125	0.6	0.3	3	9	2	36.8	32	451	47.9	617	0.7	0.2	0.1
21	887	71	348	1.4	1.5	3	18	4	25.2	24	797	39.8	389	0.8	0	0.2

Plot number (ID), elevation (ELEV, [m a.s.l.]), slope (SL, [%]), azimuth (AZ, [°]), depth of the F humus horizon (HF, [cm]), depth of the H humus horizon (HH, [cm]), soil moisture class (M, 2 = "moderately dry", 3 = "moist", 4 = "very moist"), soil type (St, 9 = "Heavy-textured Cambisols and Luvisols derived from moraine material, non-calcareous loess, or mudstone", 18 = "Colluvial soils showing properties of both Rendzic Leptosols and Chromic Cambisols (`Terra Fusca´)", 19 = "Chromic Cambisols on calcareous bedrock (`Terra Fusca´)", 21 = "Fluvisols along small rivers"; c.f. Monserud and Sterba, 1996), vegetation type (Vt, 1 = "Shade tolerant herb types", 2 = "Moderately moist herb types", 4 = "Oxalis acetosella types (Moderhumus in conifer stands)", 12 = "Competing grass cover", 13 = "Depletion or litter erosion sites", 19 = "Hydrophytic perennial shrub type"; c.f. Monserud and Sterba, 1996), diameter of the tree with the mean basal area (d_g, [cm]), dominant height (h_{dom}, [m]; c.f. Assmann, 1961), number of trees (N_{ha}, [ha-1]), basal area (G_{ha}, [m^2ha^{-1}]), volume (V_{ha}, [m^3ha^{-1}]) and the proportion of Picea abies (Pab), Fagus sylvatica (Fsy) and other tree species (Oth) by basal area [%].

The assortments of harvested trees

The grading was done according to Eckmüllner et al. (2007). The input-variables for the taper curves, which represent the base for grading procedures, are the dbh, tree height, height to the crown base, crown class and elevation.

Because in Austria timber logs are traded without bark, the bark thickness is calculated by functions using the same variables as for the taper curves. The so calculated middle diameter of each log is then rounded down to full centimetre as described in the Austrian timber trading usance (Kooperationsplattform Forst Holz Papier, 2006).

For the prediction of quality decreasing fungi, initialized by bark damages and their resulting fractions of soft and brown rot, the functions of Binder (1995) were implemented which assess the size of the rot along the stem by the size of the wound in cm² and its age. The forest inventory provided damages only as size ranges (size class of the damage). Thus the size of the wound was estimated using uniformly distributed random numbers in between each size range.
For coniferous species the model of Schmidt (2001), which predicts the maximum branch diameter, was implemented to get a realistic output for the log quality "Cx".
Thus it is possible to translate merchantable assortments into the log-qualities "A", "B", "C", "Cx", "Thin logs", "Brown rot" logs, or rather cheap quality soft rot logs which are usually used as biomass or left in the stand (for the quality characteristics c.f. Kooperationsplattform Forst Holz Papier, 2006). Additionally the biomass compartments needle and branch mass were calculated as dry branch or needle mass using functions of Eckmüllner (2006), Gschwantner and Schadauer (2006) and Rubatscher et al. (2006), respectively.

The calculation of the contribution margin 1 for the harvesting actions

Timber prices and earnings

The earnings for every harvested tree were calculated assuming the average timber price for the year 2005 (Tab. 4 and Tab. 5), whereas dry branch and needle mass and soft rot logs were not considered. Furthermore it was assumed, over all quality- and dimension classes, that the timber price of European larch (Larix decidua Mill.) is 15 EUR higher and the timber price of Scots pine (Pinus sylvestris L.) is 15 EUR lower than for Norway spruce, whereas prices for Norway spruce were applied for other coniferous tree species, and that the timber price for all other hardwood species than common beech is half of the price for common beech. The prices for spruce and beech were derived from monthly publications of the year 2005 (Anonymous, 2005, 2006) for Lower Austria and a price average for 2005 published by Statistics Austria (Statistik Austria, 2005).

Tab. 4: The average price 2005 [EUR m^{-3}] for Norway spruce timber by quality class and log dimension.

	Log diameter class								
Quality class	1a	1b	2a	2b	3a	3b	4	5	6+
A	--	57.5	63.4	69.4	70.6	71.8	73	74.2	75.4
B	--	57.5	63.4	69.4	70.6	71.8	73	74.2	75.4
C	--	47.5	53.4	59.4	60.6	61.8	63	64.2	65.4
Cx	--	42.5	48.4	54.4	55.6	56.8	58	59.2	60.4
Brown rot	--	43.0	44.0	45.0	46.0	47.0	47.0	47.0	47.0
Thin log	38.6	57.5	--	--	--	--	--	--	--
Pulpwood	27.6	--	--	--	--	--	--	--	--

Tab. 5: The average price 2005 [EUR m^{-3}] for common beach timber by quality class and log dimension.

	Log diameter class								
Quality class	1a	1b	2a	2b	3a	3b	4	5	6+
A	--	--	72.5	85.6	98.6	111.7	124.7	137.8	150.8
B	--	--	71.5	84.6	97.6	110.7	123.7	136.8	149.8
C	--	--	61.5	74.6	87.6	100.7	113.7	126.8	139.8
Cx	--	--	57.5	70.6	83.6	96.7	109.7	122.8	135.8
Brown rot	--	43	44	45	46	47	47	47	47
Thin log	58.9	58.9	--	--	--	--	--	--	--
Pulpwood	58.9	--	--	--	--	--	--	--	--

The quality class is depicted in descending order from "A" (best quality) to "Cx" (worst quality) for saw timber. "Brown rot" corresponds to logs showing early stages of brown rot and "Thin log" and "Pulpwood" correspond to logs normally disposed to pulp mills. The log dimension class is divided into subclasses for log diameters smaller than 40 cm (e.g. "2a" refers to a log diameter ≥ 20 cm and < 25 cm and "2b" refers to a log diameter ≥ 25 cm and < 30 cm, Kooperationsplattform Forst Holz Papier, 2006).

The earnings per hectare for the entire harvesting at the sample plot were calculated as follows:

$$E = \sum_{i=1}^{n} P_i \cdot v_i \cdot nrep_i \qquad (1)$$

E : Earnings per hectare at the sample plot [EUR ha^{-1}]
Pi : Price for log i according to its quality and dimension [EUR m^{-3}]
vi : Log volume [m^3]
nrepi : Representative stem number [ha^{-1}]
i : Index for the log at the sample plot
n : Number of logs at the sample plot

Harvesting costs

The harvesting methods used within the respective management strategy are indicated in Tab. 6. As a first step the time required for the harvesting actions “felling+processing” and skidding or hauling of the single tree per m^3 timber (PSH15 [min m^{-3}]) within the respective stand was calculated with the models indicated in Tab. 6 with tree factors (e.g. volume, dbh, crown length), site factors (Tab. 2 and Tab. 3) and different machine specific factors as input variables. The time required per hectare for the entire harvesting action at the sample plot was then derived as follows:

$$T = \sum_{i=1}^{n} PSH15_i \cdot nrep_i \cdot v_i \qquad (2)$$

T : Time required for the harvesting action at the sample plot [min ha^{-1}]
PSH15i: Productive system time [min m^{-3}]
nrepi : Representative stem number [ha^{-1}]
vi : Tree volume [m^3]
i : Index for the tree harvested at the sample plot
n : Number of trees harvested at the sample plot

And the costs for the harvesting action were valued with the respective wages and system-costs:

$$C = N \cdot \frac{T}{60} \cdot R \cdot W \cdot 2 + \frac{T}{60} \cdot Sc \qquad (3)$$

C : Costs for the harvesting action at the sample plot [EUR ha^{-1}]
N : Number of workers
T : Time required for the harvesting action at the sample plot [min ha^{-1}] after Equation (2)
R : Ratio between working hours and operating hours (R = 8/6)
W : Wage per hour [EUR h^{-1}] (W = 8.74 EUR h^{-1})
Sc : System costs [EUR h^{-1}]

The system costs for the respective machines (Tab. 6) and the wage per hour for the forest worker were found in Landwirtschaftskammer Niederösterreich (2007) or Arnold et al. (2004). Costs for the transfer and installation of the machine were not considered. Furthermore it was assumed that two workers are necessary for skidding and hauling.

Finally the contribution margin 1 for the harvesting action was calculated as the difference between the earnings per hectare (Equation 1) and the costs per hectare (Equation 3).

Tab. 6: The machines used for the harvesting under the respective forest management strategy and slope of the stand. The models used for the calculation of the required time per m3 timber are indicated by numbers in brackets: [1] WSL (2002a), [2] Stampfer and Steinmüller (2004), [3] Stampfer (2002), [4] Ghaffarian et al. (2007) and [5] WSL (2002b).

Management strategy	Slope [%]	Felling and processing	Skidding or hauling
Intensive even aged	< 40	John Deere 1470 [1]	Gremo 950 R [4]
Intensive even aged	≥ 40 and < 60	Valmet 911.1 [2]	Syncrofralke 3t [3]
Intensive even aged	≥ 60	STIHL 026 [3]	Syncrofralke 3t [3]
Combined objective	< 40	STIHL 026 [3]	Steyr M 9100 [5]
Combined objective	≥ 40 and < 60	STIHL 026 [3]	Syncrofralke 3t [3]
Combined objective	≥ 60	STIHL 026 [3]	Syncrofralke 3t [3]

The calculation of the land expectation value

The costs for the site preparation, planting, weed control, deer protection and pre commercial thinning were calculated similar to the harvesting costs. Time expenditure for these workings was found in Jirikowski (2005), whereas tree planting was carried out using the hoedad type "Rhoden" and weed cutting around the small trees was carried out using a sickle. Prices for plants and animal repellents were found in local forestry suppliers- and seedling nursery catalogues. For these calculations the slope at the respective sample plot was not considered.

The land expectation value (LEV) for every sample plot was calculated according to Straka and Bullard (1996):

$$LEV = \frac{\sum_{n=0}^{t} R_n \cdot (1+i)^{t-n} - \sum_{n=0}^{t} C_n \cdot (1+i)^{t-n} - M \cdot \frac{(1+i)^t - 1}{i}}{(1+i)^t - 1} \quad (4)$$

LEV : Land expectation value [EUR ha^{-1}]
Rn : Revenue received in year n [EUR ha^{-1}]
Cn : Cost incurred in year n [EUR ha^{-1}]
M : Annual management costs [EUR ha^{-1}]
t : Rotation length [years]
n : Year of particular revenue or cost
i : Discount rate, expressed as a decimal

The annual management costs of 84.89 EUR per hectare were derived from Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (2008) and were calculated as average over 98 Austrian forest companies with a size greater than 500 ha.

For the calculation of LEV for the combined objective strategy (i) the revenues were reduced by 10 % to account for pre commercial thinnings or other silvicultural treatments, carried out immediately after the target diameter harvesting at the respective stand, and (ii) the annual management costs were raised by 10 % to account for higher costs of road maintenance in this strategy because of a higher road density.

In order to derive an optimal rotation length for the intensive even aged strategy the LEV was calculated for different rotation lengths, using the "before management and mortality"-file of the respective year as "harvest"-file of a "hypothetical clear cut" for the assortment of harvested stems. Furthermore the LEV was calculated for discount rates of 1 to 5 %.

The calculation of the contribution margin 1 and the land expectation value was carried out using the language and environment R (R Development Core Team, 2008), whereas the additional package "lattice" (Sarkar, 2008) was used to produce the graphics.

3.1.2 Results

There is no rotation length for the combined objective strategy by definition. Therefore in the following the term “rotation length” in relation to the combined objective strategy is to be understood as the length of the considered period.

The land expectation value over the rotation length

The calculated land expectation value for different interest rates and rotation lengths is shown in Fig. 1. For all interest rates it is smaller for the intensive even aged strategy than for the combined objective strategy. The LEV for the intensive even aged strategy culminates with 14,103 ± 914 (standard error) EUR ha-1 at the rotation length of 90 years for an interest rate of 1 %. For this rotation length the LEV for the combined objective strategy is 30,400 ± 1,934 EUR ha^{-1}, but shows a slightly decreasing trend with increasing time. For an interest rate of 2 % the LEV for the intensive even aged strategy is just positive at the culmination point with 1,470 ± 345 EUR ha^{-1}, again for the rotation length of 90 years. With increasing interest rates the LEV for both forest management strategies is decreasing and independent of the rotation length, but it is at all times positive for the combined objective strategy and negative for the intensive even aged strategy, except for interest rates of 1 – 2 %.

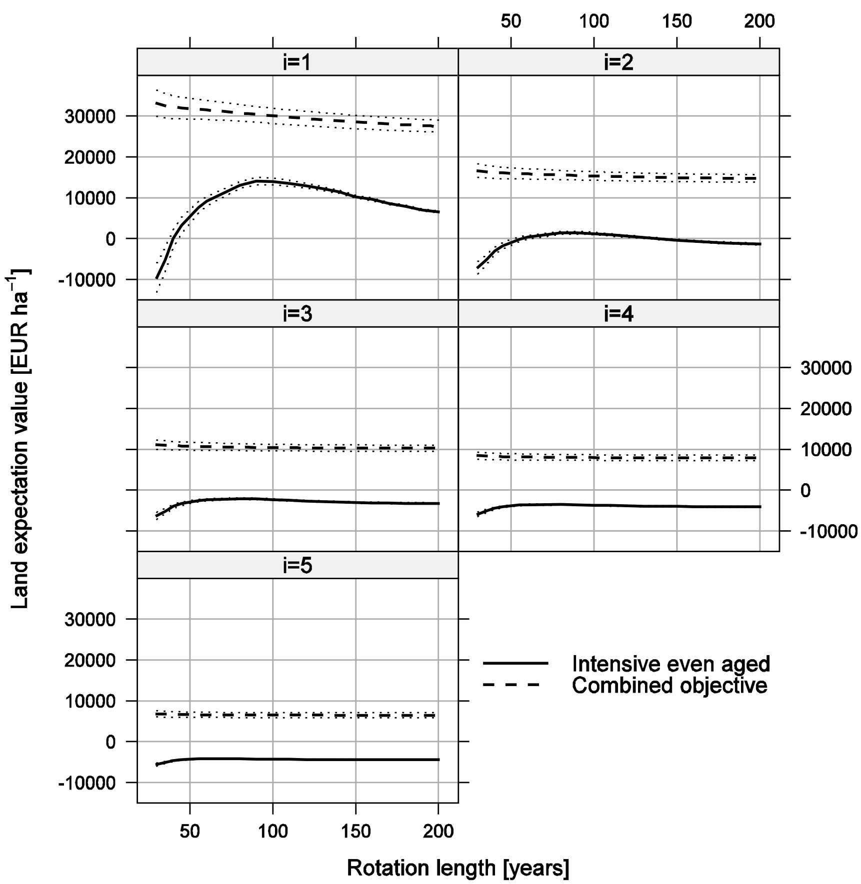

Fig. 1: The land expectation value ± standard error (marked as dotted line) by interest rate (i) and management strategy for rotation lengths between 30 and 200 years.

The dg and amount of hardwood in the annual harvest

The diameter of the tree with the mean annual harvested basal area per hectare (Fig. 2) is only slightly increasing with increasing time for the combined objective strategy (between 55 ± 13 cm and 59 ± 10 cm), but is clearly increasing with increasing rotation length until 160 years for the other strategy (from 15 ± 6 cm to 31 ± 7 cm), and slightly decreasing afterwards.

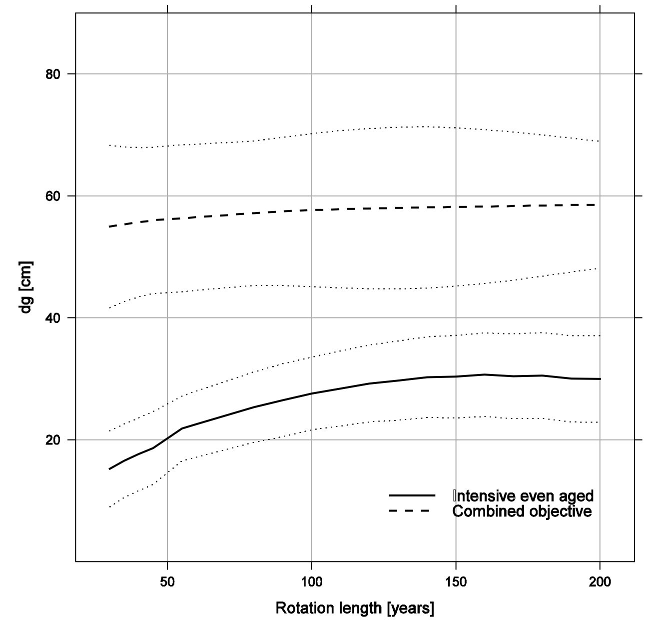

Fig. 2: The diameter ± standard error (marked as dotted line) of the tree with the mean annual harvested basal area (dg [cm]) for rotation lengths between 30 and 200 years. The standard error was calculated via the law of error propagation.

In contrary the amount of hardwood species in the annual harvested volume per hectare (Fig. 3) is clearly decreasing from 8.2 ± 2.8 % to 21.2 ± 5.3 % with increasing rotation length for the combined objective strategy, but is more or less constant between 1.4 ± 1.4 % and 1.9 ± 1.6 % for the intensive even aged strategy.

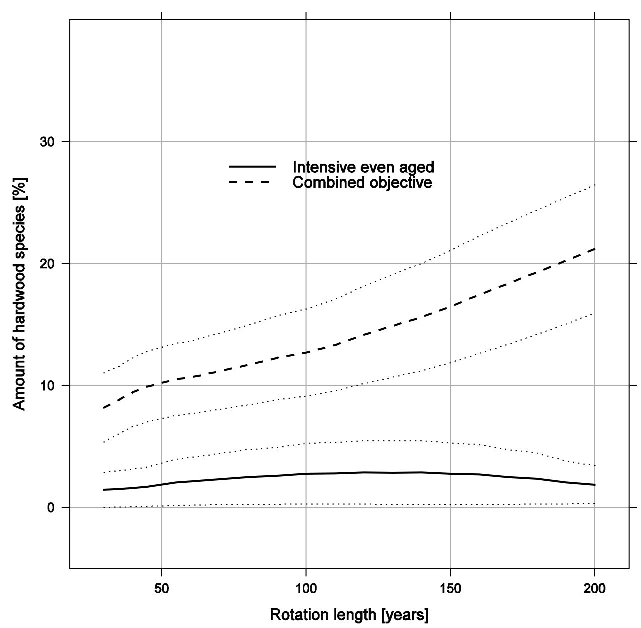

Fig. 3: The amount ± standard error (marked as dotted line) of hardwood species in the annual harvested volume for rotation lengths between 30 and 200 years.

The marketed assortments

The marketed timber volume by quality class, diameter class, tree species and management strategy for a rotation length of 90 years is shown in Fig. 4. The total amount of marketed volume is clearly higher for the intensive even aged strategy (632 ± 35.5 m^3 ha^{-1}) than for the combined objective strategy (393 ± 51.1 m^3 ha^{-1}). The proportion of the assortments “Thin log” and “Pulpwood” is also higher for the intensive even aged strategy and the main assortment for this strategy is saw timber (quality classes “B”, “C” and “Cx”) in the diameter classes 2 and 3. The target-diameter harvesting carried out in the combined objective strategy also results in the main assortment saw timber, but in the higher diameter classes. Note the presence of highest quality saw timber (“A”) and the higher proportion of timber from other species than Norway spruce in this strategy.

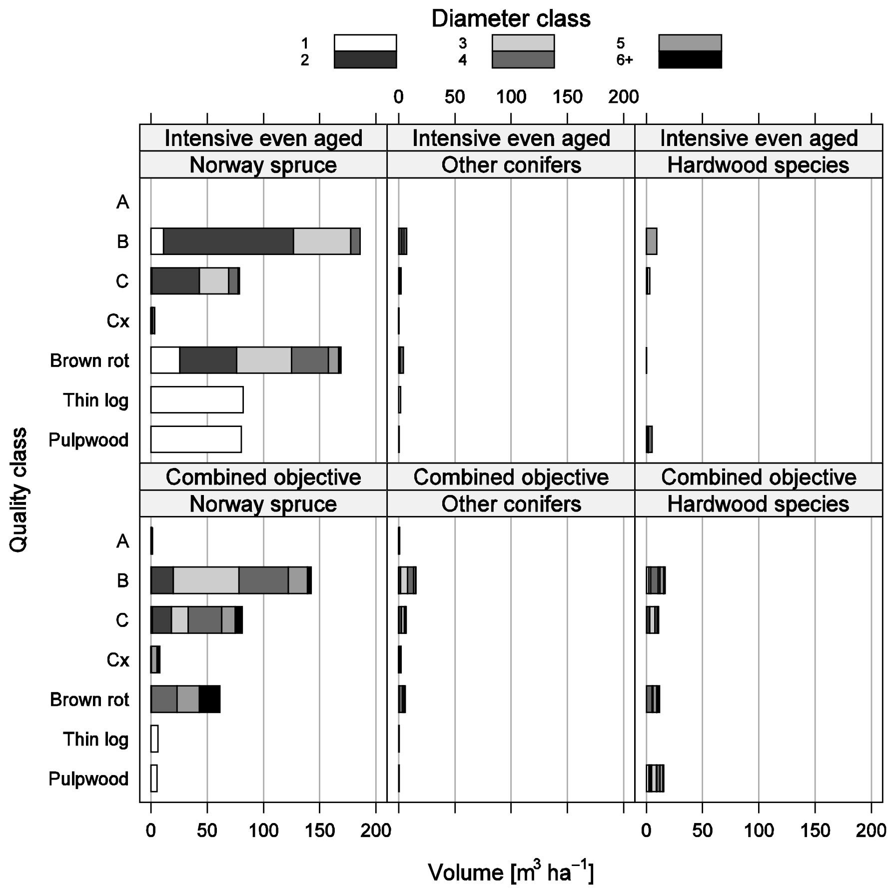

Fig. 4: Marketed volume per hectare by quality class, diameter class, tree species and forest management strategy for a rotation length of 90 years. The quality class is depicted in descending order from "A" (best quality) to "Cx" (worst quality) for saw timber. "Brown rot log" correspond to logs showing early stages of brown rot and "Thin log" and "Pulpwood" correspond to logs normally disposed to pulp mills. The log diameter class 1 refers to a log diameter < 20 cm, the classes 2 – 5 refer to 10 cm classes (e.g. the class 2 subsumes logs with a diameter ≥ 20 cm and < 30 cm) and the class 6+ refers to logs with a diameter ≥ 60 cm.

The mean annual harvested volume versus the mean annual increment

Fig. 5 shows, that for the intensive even aged strategy the mean annual harvested volume is clearly lower than the mean annual gross increment. For the rotation length with the highest LEV (90 years) the difference between annual harvest and increment amounts to 2.38 ± 0.83 m^3 ha^{-1} a^{-1} and reflects the annual losses due to natural mortality. These losses are increasing with increasing rotation length. The combined objective strategy, in contrary, shows no significant difference between annual harvest and increment (0.18 ± 0.49 m^3 ha^{-1} a^{-1}).

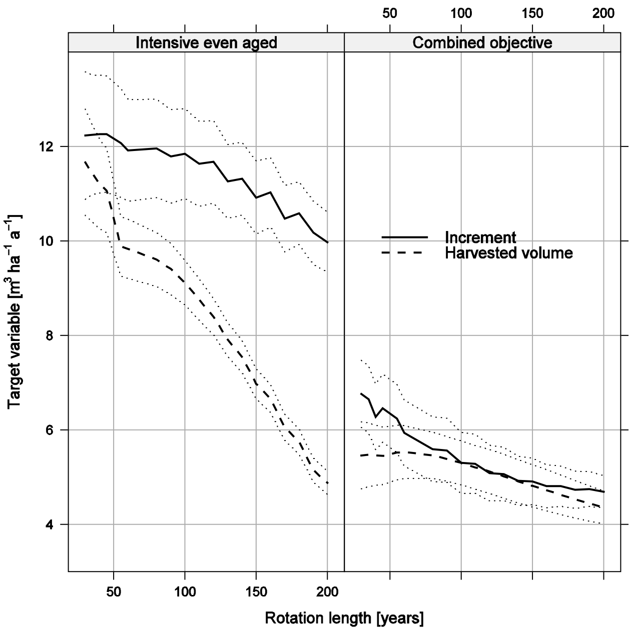

Fig. 5: The mean annual harvested volume and the mean annual increment ± standard error (marked as dotted line) by forest management strategy for rotation lengths between 30 and 200 years.

3.1.3 Discussion

Land expectation value is a discounted cash flow technique to value timberland and is applied since hundreds of years. It is directly proportional to the revenues and indirectly proportional to the costs and the discount rate (Speidel, 1967; cited in Sagl, 1995). Furthermore the date of incoming costs and revenues is essential. The land expectation value exhibits an optimum, whereas the higher the interest rate, the earlier and higher the revenues due to thinnings and the lower the costs for stand establishment, the shorter is the optimum rotation length (Riebel, 1905). The value can be interpreted as the minimum price for the land owner to earn by selling the forest soil without losses under the respective discount rate (Riebel, 1905; Straka and Bullard, 1996). Note, that land expectation value has to be interpreted as an economic value from a production forestry viewpoint (Barnes, 2002). This means, that the value is only dependent on productivity and costs and has nothing to do with a current market value or current market price, which is the value for a potential acquirer (Riebel, 1905). Land expectation value can be used as support tool when decisions between different investment alternatives have to be done. In this context our results indicate, that the investment in the intensive even aged strategy is unprofitable for interest rates higher than 2 %. With increasing interest rates it is impossible to compensate the costs for stand establishment, occurring early and being prolonged to the end of the rotation period, with the later occurring revenues due to thinnings or the final harvest.

Furthermore it can be seen in our results that the optimum time for the final harvest, at an interest rate of 1 %, is at the stand age of 90. Similar results were shown by Beinhofer (2008) with the individual tree growth simulator SILVA for Scots pine in eastern Bavaria, also under a clear cutting forest management strategy. In that study the optimum rotation length was between 50 and 120 years and the maximum LEV for a Scots pine stand thinned from above, at an interest rate of 1 %, was 12,035 ± 2,992 (standard deviation) EUR ha-1, which is comparable to our results (14,103 ± 914 (standard error) EUR ha^{-1}). However, one has to consider, that in Beinhofer (2008) the amount of the quality classes in the assortment was held constant over time and therefore the contribution margin 1 was only dependent on the diameter classes in the assortment of the respective harvest. Furthermore the calculation of the stand establishment costs was based only on the costs for the plants, and stumpage values per diameter classes were used for the calculation of the contribution margin 1.

The difference in the LEV for the two strategies may be the results of different causes. First of all the costs for the stand establishment, or at least some sort of conversion costs, were not considered for the calculation of the LEV for the combined objective strategy. This results in the LEV being never negative for this management strategy. The LEV, as a technique for valuing timber land, was invented at a time where even aged forestry was the only common management strategy and therefore the LEV should, by definition, be calculated “from bare land to bare land”. This results in our comparison of the two management strategies to be so unequal and benefiting for the combined objective variant. For the latter strategy the forest inventory data assigned to the age classes older than 80 years was used for the simulations with PROGNAUS and the costs for stand establishment as well as the stand treatment until the year 2005 are unknown. Therefore the LEV for the intensive even aged strategy was additionally calculated without consideration of the costs for the stand establishment in order to allow a more realistic comparison (Fig. 6).

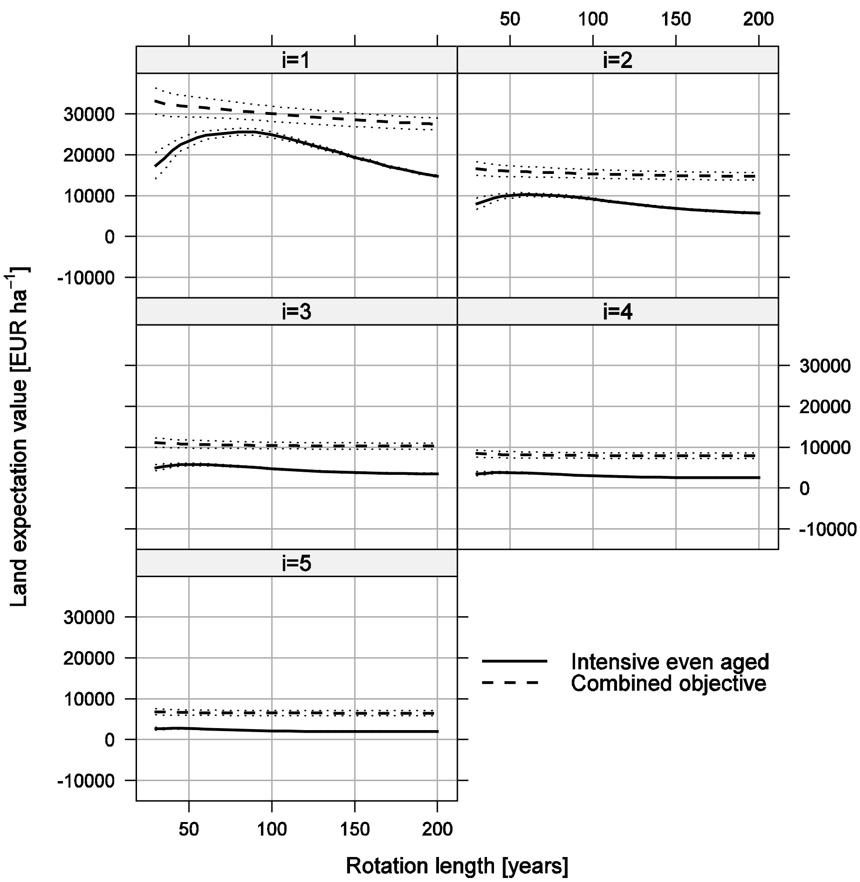

Fig. 6: The land expectation value ± standard error (marked as dotted line), calculated without consideration of stand establishment costs by interest rate (i) and management strategy for rotation lengths between 30 and 200 years.

This resulted in a maximum LEV for the intensive even aged strategy of 25,618 ± 834 EUR ha^{-1} at a rotation length of 80 years, being still lower than the LEV for the combined objective variant of 30,764 ± 2,035 EUR ha^{-1} for the period of 80 years. Note, that this LEV for the intensive even aged strategy is not the LEV by definition according to Faustmann (1849, cited in Sánchez Orois et al., 2004). But this comparison is surely more realistic. The reasons for differences between the two strategies may be: (i) clear differences in the assortment of the marketed logs (Fig. 4). In

the combined objective strategy diameter classes around the target diameter are dominating. Furthermore the percentage of "Pulpwood"
and "Thin logs" and the amount of logs showing early stages of brown rot is of lower and the percentage of hardwood species is essentially higher, whereof common beech has both the highest share and price per cubic meter. Furthermore the differences may be (ii) induced by the higher diameter of the tree with the mean annual harvested basal area per hectare (Fig. 2), resulting in lower harvesting costs per cubic meter and at the same time higher prices per cubic meter for the higher log diameter classes, (iii) the result of the higher percentage of better quality classes and (iv) the results of the higher percentage of common beech in the combined objective strategy.
A comparison of continuous cover forestry and rotation forest management was also carried out by Sánchez Orois et al. (2004) on the basis of simulations with a matrix model for Pinus pinaster in Spain. The authors found, that the LEV is higher for the continuous cover forestry at sites with a lower site index and higher for the rotation forest management at sites with a higher site index. In that study the LEV for the continuous cover strategy was between 2,000 and 5,000 EUR ha^{-1} at a discount rate of 4 %, depending on the intensity of the harvesting actions. For this strategy these results are comparable to ours with approximately 8,000 EUR ha^{-1} for the combined objective variant at a discount rate of 4 %. But the differences in the results are essential for the rotation forest management strategy: The LEV for P. pinaster in Sánchez Orois et al. (2004) at a discount rate of 4 % is between 5,650 and 9,050 EUR ha^{-1} for a rotation length of 35 years, depending on the harvesting type, the harvesting intensity and the site index, whereas our results never show a positive LEV for the intensive even aged strategy at this discount rate. However, the very low costs for the stand establishment as well as the fact, that the contribution margin 1 is generally higher, and surprisingly highest for the first thinnings in Sánchez Orois et al. (2004) make the comparison for this strategy rather doubtful. In our study the contribution margin 1 for the first thinning is negative or positive, depending on the site conditions and the harvested stems.
The difference between the mean annual harvested volume and the mean annual increment (Fig. 5) indicates that the intensive even aged strategy shows rather high losses in harvested volume due to natural mortality. In reality at least parts of this volume could be sold with the regular harvest and would therefore result in a slightly higher LEV for this strategy.

3.1.4 Conclusion

A comparison of the intensive even aged forest management strategy and the combined objective forest management strategy on the basis of the land expectation value, thus solely on the basis of the strategy's economic value in terms of timber production, showed, that the combined objective strategy is superior. This is the case even if the costs for the stand establishment of the intensive even aged strategy were not considered. The superiority of the combined objective variant is increasing if one considers that additionally the highly important protection of the alpine springs is ensured. With regard to the forest management interventions carried out along the management cycle further studies are needed in order to find an optimal intensity for these interventions.

Acknowledgements
The authors are grateful to the Forstamt und Landwirtschaftsbetrieb der Stadt Wien (MA 49), who provided the forest inventory data. Many thanks are due to Hubert Sterba for helpful suggestions and review comments.

3.2 Productivity of Norway spruce (*Picea abies (L.) Karst.*) under alternative forest management strategies in Baden-Württemberg

Philipp Duncker and Heinrich Spiecker

Four different forest management approaches were considered for Norway spruce which ranged from a low intervention (FMA2) to an intensive stand management approach (FMA5). For simulation of stand development under these treatment regimes site index 35 m at age 100 was chosen. Accordingly, the yield quality was estimated to be 13 $m^3\,ha^{-1}\,a^{-1}$ (Landesforstverwaltung Baden-Württemberg, 1993). The actual growth of spruce managed under the different treatment regimes was modelled with W+. It is a forest growth simulator based on a combined stand level and individual tree level growth model for even-aged forests. Its parameters are estimated from permanent thinning experimental plots situated in south western Germany. The plots cover a wide range of site types and growth conditions. Further, a wide range of different treatments is included with respect to initial spacing, type of thinning, and intensity of thinning. The simulator W+ is intended for use as silvicultural decision support system (Weise & Kublin, 1997). The growth potential and height growth dynamic is modelled according to a static site class determination (Assmann 1965). (Yue *et al.*, 2008) are describing the concept in much detail and provide a comprehensive model evaluation.

For simulation the following management operations were assumed to be pursued in the four FMAs, of which a summary is provided in Tab. 7. While the stands originate from natural regeneration in FMA2 and 3 they are planted in FMA4 and 5. In all approaches two tending operations were assumed except of FMA5 which is targeted on high volume production. The time of thinning operations followed the top height development in intervals of three meters staring at height 12 m and 15 m. In FMA2 a low number of 125 crop trees were released in strong crop tree oriented thinnings from above in ordered to promote the development of low h/d-ratios permitting a prolong period of regeneration cuttings once the target diameter of 60 cm is reached. In FMA3 the number of crop trees was slightly higher and thinning grade less strong. Still, a prolonged period of regeneration cuttings started once the crop trees reached a dbh of 50 cm. In FMA 4 strong thinnings from below released the dominant trees of the stand. The stand was regenerated in strip wise clearings at time the mean diameter reached 50 cm. In FMA5 only the smallest trees were thinned in moderate thinnings from below. The stand was cleared at culmination of land expectation value at interest rate 5%.

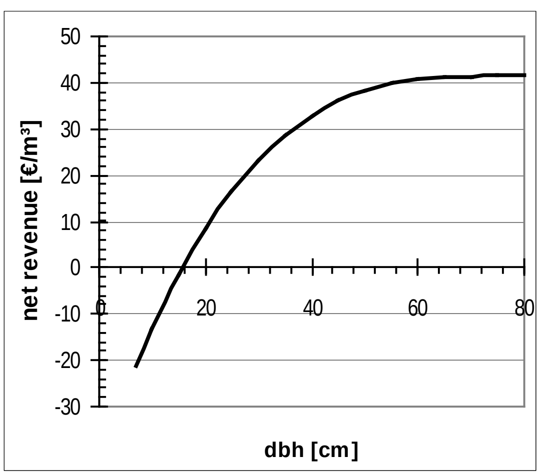

Fig 7: Net revenue [€ m^{-3}] as a function of diameter at breast height for Norway spruce, medium quality roadside with average prize level for period 1995 – 2005.

Tab. 7: Summary of operations in forest management alternatives for Norway spruce.

Operation	FMA2	FMA3	FMA4	FMA5
N/ha planted	-	-	3000	4500
tending (age)	5 15	5 15	5 15	-
Thinning regime				
begin (h_o [m])	12	12	12	15
interval (Δh [m])	3	3	3	3
type	above	above	below	below
N/ha crop trees	125	150	-	-
grade [% G rem.]	36-24	32-24	~20	~14
Final cutting regime				
target diameter [cm]	60	50	50	-
min. cut vol. [$m^3\,ha^{-1}$]	120	150	100	100
cut interv. [yr]	8	8	5	5
length harv. Period [yr]	30	20	10	10

The variable cost associated with the plantings were thought to be 2000 € ha^{-1} in FMA4 and 3000 € ha^{-1} in FMA5. Further, a tending operation was assumed to cost 500 € ha^{-1} independent of FMA. The cash flows resulting from thinning and harvesting operations were calculated based on the diameter distribution of the cut volume. The net revenue at roadside for medium quality round wood according to the mean prize level of period 1995 – 2005 was estimated with the function provided in Fig 7.

The different management alternatives resulted in production times of 96, 84, 81, and 72 years for FMA2 to FMA5. The effect of the different treatment regimes on the productive function through the intervention into natural stand development is first regarded in volume production. Fig. 8 shows distinct differences in total volume growth and standing volume at different ages between the alternatives. Both parameters are highest in FMA5 at a given age followed by the other alternatives in descending order. In consequence, mean annual increment being highest in FMA5 with 15.6 m^3 ha^{-1} yr^{-1} decreases down to 10.3 m^3 ha^{-1} yr^{-1} in FMA2, which is only 2/3 of the pervious value (see Tab. 8). However, the reduced stand density promotes diameter increment of the remaining trees. In combination with the different thinning regime this leads to higher positive cash flows during the thinning period in the opposite order of the FMAs (see Fig. 8). Further on, the multiple cash flows in the prolonged period of regeneration cuttings are between 4000 and 8000 € ha^{-1} in FMA2 and 3 compared to single cash flows in height of 26,000 and 16,000 € ha^{-1} from clearing stands in FMA4 and 5. In spite of the highest volume production, the land expectation value (LEV) is lowest in FMA5 (see Tab. 8). Only for interest rates lower than 3%

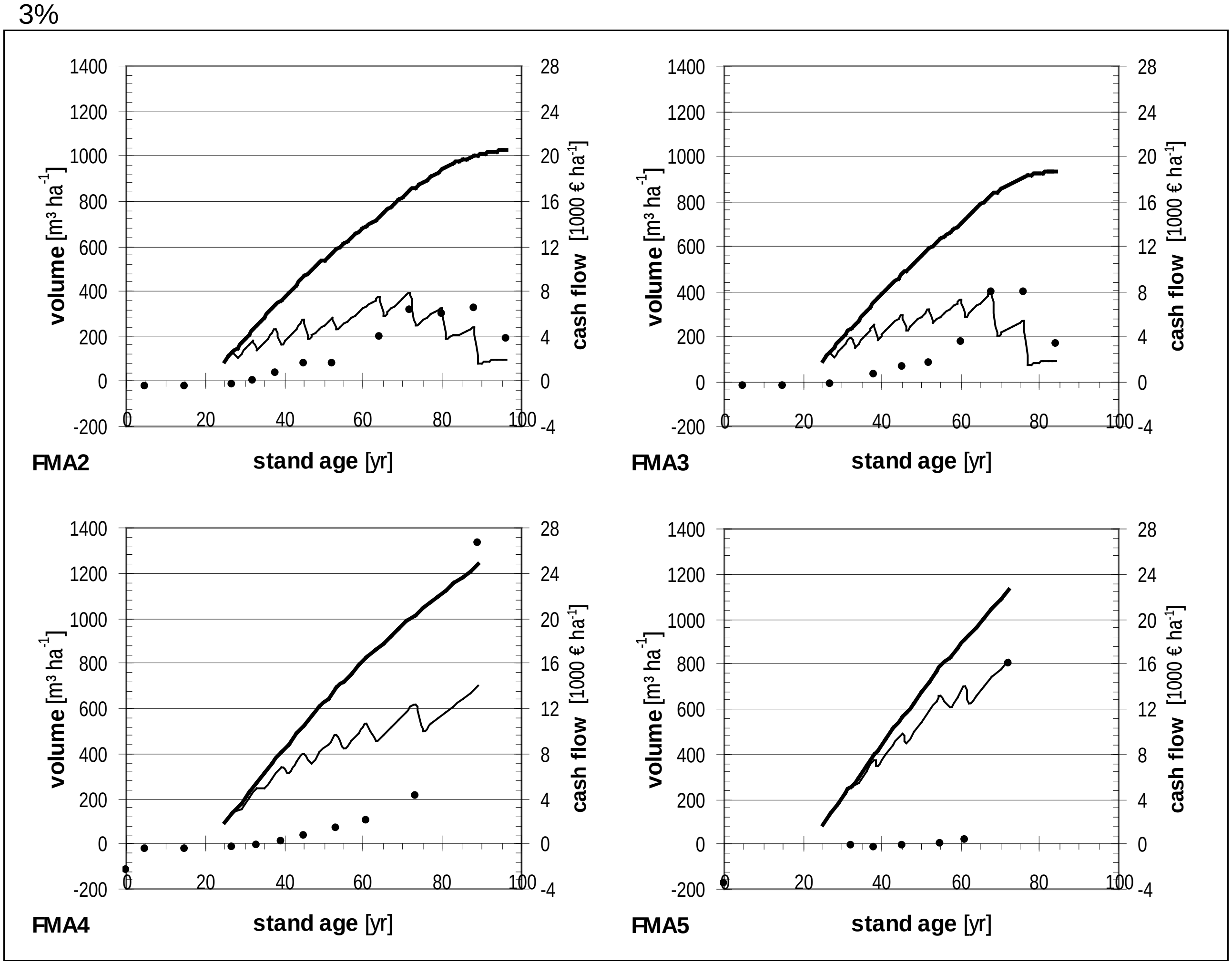

Fig. 8: Total volume growth (thick line), standing volume (thin line) and cash flow (points) within alternative forest management strategies for Norway spruce.

positive values are achieved at all. The resulting values for FMA4 are considerably higher than for FMA5 and are positive for interest rate smaller than 4%. All resulting values for FMA2 and 3 are positive with little differences between both alternatives compared to the other two.

Tab. 8: Mean annual increment and land expectation value achieved in alternative forest management strategies for Norway spruce.

Operation	FMA2	FMA3	FMA4	FMA5
MAI [m³ ha^{-1} yr^{-1}]	10,3	11,1	13,9	15,6
LEV $_{i = 0.01}$ [€ ha^{-1}]	21449	21288	19232	8089
LEV $_{i = 0.02}$ [€ ha^{-1}]	7007	7115	4237	295
LEV $_{i = 0.03}$ [€ ha^{-1}]	2747	2879	64	*-1864*
LEV $_{i = 0.04}$ [€ ha^{-1}]	1015	1117	*-1479*	*-2680*
LEV $_{i = 0.05}$ [€ ha^{-1}]	234	301	*-2114*	*-3014*

Beside the mentioned cash flows from thinning and harvesting operations, the reason for higher LEVs in FMA2 and 3 might be seen in avoided plantation costs for stand establishment. For comparison of uneven with even-aged management (Chang, 1981) are contrasting the LEV for both approaches. They suggest calculating the regeneration costs that might be spent in an uneven-aged management resulting in similar LEV as for even-aged management. When doing so with our FMA2 in comparison to FMA5 8327 € ha^{-1} might hypothetically additionally be spent for regeneration at interest rate 1% and still 3386 € ha^{-1} at 5%, respectively. For all considered interest rates with the exception of 5% these values exceed the assumed planting costs of 3462 € ha^{-1} in FMA5. The same finding holds true for the comparison of FMA3 to FMA5 as well. In consequence, the lower LEV values for FMA5 are not solely explained by regeneration costs but by revenues from thinning and harvesting operations along the management cycle within the alternative management strategies.

3.3 Productivity of European beech (*Fagus sylvatica L.*) under alternative forest management strategies in Baden-Württemberg

Philipp Duncker and Heinrich Spiecker

The Atlantic climate in south western Germany provides for favourable growing conditions for European beech close to its potential optimum. For many sites European beech is considered to be the dominating tree species in the potential natural vegetation with Fagetalia being the zonal forest climax community. For this study two different forest management approaches were considered for European beech, i.e. a low intervention (FMA2) and a medium intensive stand management approach (FMA3). For simulation of stand development under these treatment regimes site index 32 m at age 100 was chosen. Accordingly, the yield quality was estimated to be 8 m³ ha^{-1} a^{-1} (Landesforstverwaltung Baden-Württemberg, 1993). The actual growth of beech managed under the different treatment regimes was modelled with W+. As stated above for Norway spruce analysis the simulator is intended for use as silvicultural decision support system (Weise & Kublin, 1997). The growth potential and height growth dynamic is modelled according to a static site class determination (Assmann 1965), detailed description and comprehensive model evaluation are provided by (Yue *et al.*, 2008).

The stands for both FMAs were thought to originate from natural regeneration. However, in case of FMA3 it was assumed that natural regeneration needs to be enhanced by planting of 2000 trees per hectare to ensure satisfactory restocking. In both alternatives two tendings were applied during the young development phase. The thinnings started at a top height of 13 m and were targeted to reduce basal area to 20 and 26 m^2 ha^{-1} in FMA2 and FMA3, respectively. The thinnings released 60 and 100 future crop trees per hectare in future crop tree oriented thinnings from above. The final harvesting system in FMA2 was target diameter harvest of individual trees over a period of 30 years in order to initiate natural regeneration of beech. The target diameter was chosen to be 65 cm at breast height. In FMA3 the harvesting system was a target diameter oriented harvest as group harvest over a period of 20 years. Here target diameter was 55 cm. Due to the risk of red heartwood formation target diameter was to be reached latest within 120 years. The pursued forest management operations within the two alternatives for European beech are summarised in Tab. 9.

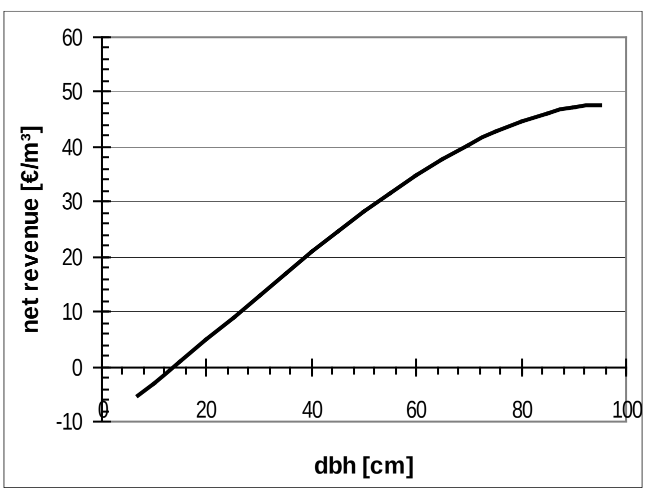

Fig. 9: Net revenue [€ m^{-3}] as a function of diameter at breast height for European beech, medium quality roadside with average prize level for period 1995 – 2005.

Tab. 9: Summary of operations in forest management alternatives for European beech.

Operation	FMA2	FMA3
N/ha planted	-	2000
tending (age)	5 15	5 15
Thinning regime		
begin (h_o [m])	13	13
interval (Δ age [yr])	~6	~6
type	above	above
N/ha crop trees	60	100
grade [target G]	20	26
Final cutting regime		
target diameter [cm]	65	55
min. cut vol. [m³ ha^{-1}]	100	120
cut interv. [yr]	8	8
length harv. Period [yr]	30	20

The variable costs associated with the plantings were thought to be 2100 € ha^{-1} in FMA3. Further, a tending operation in the young stands was assumed to cost 500 € ha^{-1}. The cash flows resulting from thinning and harvesting operations were calculated based on the diameter distribution of the cut volume. The net revenue at roadside for medium quality round wood according to the mean prize level of period 1995 – 2005 was estimated with the function provided in Fig. 9.

The total production length is rather similar between both alternatives with 118 years in FMA2 and 120 years in FMA3. Nonetheless, total volume growth in FMA2 is about 80 m³ ha^{-1} less than in FMA3 (see Fig. 10). This corresponds to almost a decadal volume increment when regarding the achieved MAIs of 9.4 vs. 9.9 $m^3\,ha^{-1}\,yr^{-1}$ (see Tab. 10). The reason might be seen in the higher thinning grades in FMA2 reducing stand density. The stronger thinnings in FMA2 result in cash flows of net timber revenue being in average about 50 € ha^{-1} and operation higher than those of FMA3. However, this is later (stand age >80 years) compensated during the final harvesting period where the sum over all cash flows in FMA3 exceeds the one in FMA2 by 1.338 € ha^{-1}.

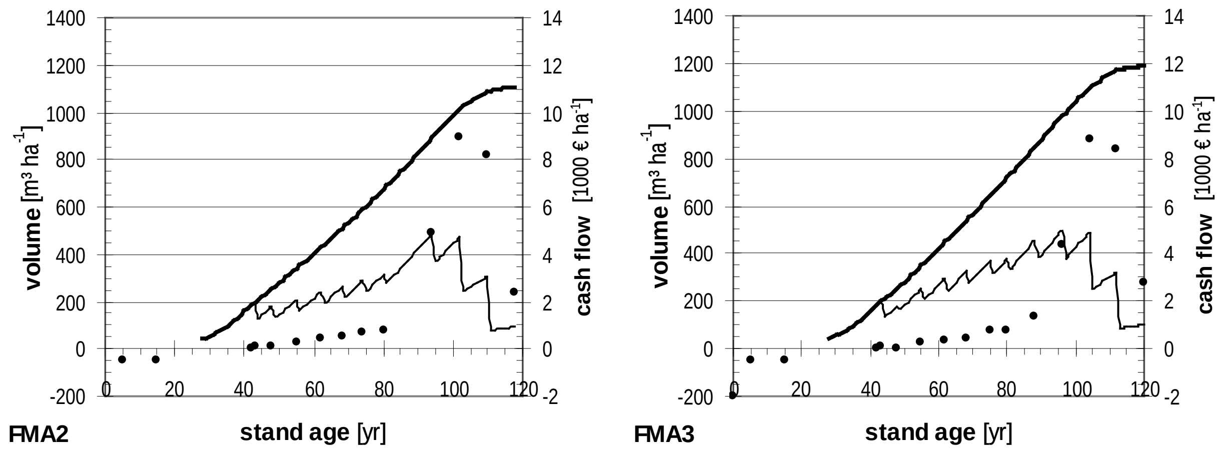

Fig. 10: Total volume growth (thick line), standing volume (thin line) and cash flow (points) within alternative forest management strategies for European beech.

Tab. 10: Mean annual increment and land expectation value achieved in alternative forest management strategies for European beech.

Operation	FMA2	FMA3
MAI [m³ ha^{-1} yr^{-1}]	9,4	9,9
LEV $_{i = 0.01}$ [€ ha^{-1}]	13288	10441
LEV $_{i = 0.02}$ [€ ha^{-1}]	3301	1010
LEV $_{i = 0.03}$ [€ ha^{-1}]	751	-1381
LEV $_{i = 0.04}$ [€ ha^{-1}]	-92	-2151
LEV $_{i = 0.05}$ [€ ha^{-1}]	-379	-2396

The land expectation values calculated with these cash flows for FMA2 outmatch those of FMA3 for all interest rates (see Tab. 10). While LEV for interest rate of 3% in FMA2 is still positive the corresponding value for FMA3 is already negative. The higher LEVs for FMA2 might be due to the discussed timing and amount of timber revenues over the management cycle. In addition, the planting costs for of 2100 € ha^{-1} in FMA3 could possibly explain the difference. And in fact, for a low interest rate of 1 % the observed difference would not allow to spend the same hypothetical costs for regeneration in FMA2. Already if costs of 1.990 € ha^{-1} were additionally assumed in FMA2 this had equalized both LEVs. For higher interest rates until 5% the difference would just allow to spent similar regeneration costs until the same LEV results.

3.4 Productivity of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) stands under alternative forest management strategies in Scotland in Great Britain

Bill Mason

In the Scottish reference case five forest management approaches in Sitka spruce dominated were considered. However, the passive intervention approach (FMA1) is only intended for region internal comparison against the actively managed FMAs 2-5. These forest management approaches are described in much detail in (Duncker et al., 2007 (D 2.1.3)). They were developed, where possible, from exemplars of Craik forest which is a 5,000 ha forest near Hawick in the Scottish Borders (NUTS region UKM 24). This is a forest where the main plantings took place on abandoned agricultural land between 1955 -1975 and which is now entering a period of intensive timber harvesting. The main management scenarios that can be discerned at Craik distinguish between the following categories:

a) Areas where timber production is a major objective, wind risk is sufficiently low for thinning to be feasible, and where genetically improved Sitka spruce will be planted that offer 20 % or more increase in volume over first rotation stands.
b) Areas where timber production is a major objective, but wind risk means that thinning throughout the rotation is unlikely. Such sites may be planted with genetically improved material of Sitka spruce, but can also be planted in a self-thinning mixture with Alaskan provenances of lodgepole pine. The latter are progressively eliminated during the stem exclusion phase because of competition-induced mortality, but their presence results in spruce of larger mean diameter at rotation and with fewer branches on the lower stem.
c) Sites where recreation or landscape pressures mean that clearfelling is difficult to practice without public concern and where good soils and low wind risk mean that thinning to implement continuous cover forestry (CCF) is feasible. These sites may also provide small amounts of large dimension and hopefully high quality timber.
d) Sites where timber production is not a priority and where landscape, biodiversity or other reasons indicate that conversion to native broadleaved woodland would be desirable.

For the simulations two classes of site index were considered. These are i) Yield Class 14 which is equivalent to an average site for Sitka spruce in Great Britain, and ii) Yield Class 20 which would be within the range of high productivity sites (the highest yield model we have access to is for a Yield Class 24 site). Yield Class is a means of classifying sites in terms of maximum mean annual volume increment per hectare [m^3 ha^{-1} a^{-1}]. The reason for not considering a low productivity site is that such sites would not be planted with Sitka spruce, but would carry Scots pine or lodgepole pine with a productivity of 6-8 m^3 ha^{-1} a^{-1}. This has been ignored in this analysis. Also in practice, one might expect a reduction in rotation length when moving from a medium to a high quality site, but in this case a constant rotation length for ease of yield calculations has been assumed.

The volume production was estimated with the standard British yield tables for even-aged pure stands (Edwards and Christie, 1981) assuming a 2 m spacing and an intermediate thinning (C/D grade). These can be assumed to be reasonably accurate for FMA 4 and 5 but an appreciable amount of extrapolation has been needed to apply these models to FMA 3 and 2. In essence, the assumptions amount to assuming that the volume obtained from thinnings is reduced compared to a pure stand because of the presence of other, lower yielding species in the stand – these are assumed to represent about 25 per cent of the stand and the volume. For FMA1 no volume production has been assumed and a rotation length was set to 200 years, which is appreciably less than the life span of Sitka spruce in its natural environment. However, experiences are limited to 150 years of Sitka spruce growth in British conditions.

The assumed timber prices are shown in Tab. 11 for 4 (5 for FMA 5) categories of product. The prices for the four main products are based on information held by Forest Research (Shaun Mochan, pers. comm.). Instead of price-size curves, the procedures outlined in Gardiner et al. (2005) and Macdonald et al. (2008) was used to link mean diameter to product break out. No allowance has been made for possible increases in volume or log quality as a result of using genetically improved Sitka spruce in FMA 4. The prices assumed for wood fuel products in 2005 in FMA 5 are indicative, since at that time there was no effective market for wood fuel products in the UK. All financial figures are provided in euros assuming a 2005 conversion rate of 1.45 € $£^{-1}$.

Tab. 11: Timber prices in 2005 for general Sitka spruce product types.

Type of general product	[€ m^{-3}]
1) Green logs (top quality sawlogs)	51
2) Red logs (second quality sawlogs).	36
3) Pallet logs (small logs)	29
4) Pulpwood	23
5) Fuelwood (FMA5 only)	19

Establishment and other management costs are based on figures given by Mason (2007) which are mainly relevant to FMA 4. Additional information was provided from Forest Research unpublished data (Ian Murgatroyd, pers. comm.). Despite of having little evidence to adjust costs between the FMAs, all fixed costs area were assumed to be much reduced in FMA1 compared to the other options. Tab. 12 provides a summary of variable and fixed costs applied in the economic analysis of the FMAs. Even so the operation in FMA4 and 5 are essentially the same the variable costs differ. FMA4 employs genetically improved Sitka spruce planting stock which costs about 1.5 times more per plant than the ordinary seedling plants used in FMA 5. In addition, less weeding is assumed in FMA 5. Further, FMA 3 also includes a percentage of other conifers (e.g. larch, Douglas fir) which cost less than improved Sitka spruce as well as it shows an increased percentage of broadleaves. For FMA 2 it was assumed that the bulk of the plants are derived from natural regeneration other than some enrichment planting of broadleaves. However, the resulting stand is respaced through a precommercial thinning at year 10 followed by cleaning at year 15. The intensity of deer control was assumed to be constant throughout FMA 2-5, but the duration is longer in FMA 2 because of the need to ensure a favourable regeneration environment.

Tab. 12: Summary of variable and fixed costs by FMA [€ ha^{-1}] at price level 2005.

			FMA				
Variable costs		**Operation(s)**	**1**	**2**	**3**	**4**	**5**
Year	0	Cultivation and planting	0	0	1728	1755	1526
	1	Replacing failures, weeding	0	0	418	479	246
	2	Weeding, hylobius protection	0	0	277	273	277
	3	Hylobius protection	0	0	178	174	178
	4	Maintaining drains	0	0	234	234	234
	5	Enrichment planting	0	145	0	0	0
	10	Respace regeneration	0	435	0	0	0
	15	Cleaning	0	163	136	136	136
Other variable costs							
Deer control			3	6	6	6	6
(Years)			0-200	0-100	0-30	0-30	0-30
Fixed costs							
Management			44	73	73	73	73
Insurance			15	44	44	44	44
Maintenance			15	29	29	29	29
Fire			7	22	22	22	22

The LEV calculations followed the procedures outlined by Straka and Bullard (1996). Calculations are provided for all FMAs but it is noteworthy that there are no data provided for the non-thinning option in FMA 4 which is a common feature of British plantation silviculture in zones of high wind risk. Net Present Value (NPV) for a single rotation was calculated in addition to LEV.

The volume production, rotation length, and financial outturn of the different FMAs at both yield classes are summarized in Tab. 13. Apart from FMA1, at both sites total volume production is highest in FMA2 followed by the other FMAs in ascending order. Since the same finding holds true for the rotation length the order changes for MAI_u. Here FMA4 provides for the highest annual volume increment, followed by FMA5, 3, and 2. When considering the economic target variables it becomes apparent that at the medium productivity site all options are negative at interest rates of 3 per cent or higher. FMA 4 is by far the most attractive option at rates below 3 per cent while FMA 2 is the least negative of the wood producing options at the higher rates, presumably because of the lower establishment costs involved. At the higher productivity site most options are still positive at the 3 per cent interest rate while FMA 5 is positive at 4 per cent most likely because of the combination of a shorter rotation and an early yield from a wood fuel thinning. In general, FMA 3 comes out relatively poorly compared to either FMA 2 or 4, presumably because there is slightly lower volume production compared to FMA 4 due to the mixed stands while establishment costs are higher than in FMA 2. This trend would be more apparent if a more dynamic silviculture enabled the effective rotation length in FMA 2 to be reduced to 80 years. The sensitivity of these results to different rotation lengths and/or timber price combinations remains to be explored.

Tab. 13: Summary of volume production, rotation length, and financial outturn for two different site qualities.

	Moderate site = YC 14 or 14 $m^3\ ha^{-1}\ yr^{-1}$					Fertile site = YC 20 or 20$m^3\ ha^{-1}\ yr^{-1}$				
target variable	**FMA**					**FMA**				
and interest rate	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Total volume production [$m^3\ ha^{-1}$]	0	880	653	600	475	0	1120	945	880	690
Rotation [a]	200	100	60	50	40	200	100	60	50	40
MAI_u [$m^3\ ha^{-1}\ a^{-1}$]	0	8,8	10,9	12,0	11,9	0	11,2	15,8	17,6	17,3
1%										
NPV [€ ha^{-1}]	-5292	4627	3262	4852	2376	-5292	9199	9546	11637	9302
LEV [€ ha^{-1}]	-838	2714	3994	7526	4860	-838	5396	11688	18053	19028
2%										
NPV [€ ha^{-1}]	-3645	782	-320	1093	123	-3645	3488	3515	6049	4884
LEV [€ ha^{-1}]	-71	125	-140	646	102	-71	559	1541	3576	4043
3%										
NPV [€ ha^{-1}]	-2694	-751	-2216	-1405	-1284	-2694	969	176	1820	2013
LEV [€ ha^{-1}]	-7	-41	-453	-415	-568	-7	53	36	538	890
4%										
NPV [€ ha^{-1}]	-2108	-1221	-3046	-2751	-2018	-2108	-69	-1525	-456	283
LEV [€ ha^{-1}]	-1	-25	-320	-450	-531	-1	-1	-160	-75	74
5%										
NPV [€ ha^{-1}]	-1723	-1538	-3605	-3513	-2621	-1723	-738	-2610	-1844	-1003
LEV [€ ha^{-1}]	0	-12	-204	-336	-434	0	-6	-148	-176	-166

3.5 Norway spruce stands under alternative forest management approaches in Västerbotten (Sweden)

Torgny Lind

The effect of FMAs was modelled for a Norway spruce (Picea abies (L.) Karst) stand in the Northern Sweden. Site index (SI100) was 22 m corresponding to a yield quality of 4.9 [m^3 ha^{-1} a^{-1}]. This is considered as a medium-high site quality in Västerbotten. Norway Spruce dominated forests, i.e. where more than 70% of growing stock constitutes of Norway spruce, are widely distributed in the county on about 22% of the total forest.

Three FMAs were considered ranging from low to high intervention, i.e. from close-to-nature forestry (FMA2) to intensive even-aged forestry management approach (FMA4). The three different FMAs were applied on the example stand starting with bare land giving different results on growth and LEVs. The stand development was simulated with the stand simulator StandWise (Wikström et al. 2008) developed within the Heureka research programme (Lämås & Eriksson, 2003). To simulate tree growth it uses a combination of plotwise and single tree level growth models. The growth models are developed by using NFI sample plot data (Ranneby et al. 1987).

In Tab. 14 the forest management operations made in the simulations are summarized. The simulations started with bare land regenerated with natural regeneration in FMA2 or planting as in FMA3 and 4. Soil scarification and cleaning were applied in FMA3 and 4 but not in FMA2. Two thinnings were applied at a basal area weighted height at about 14 and 19 m in all FMAs. The form of thinning was from below in FMA2, uniform in FMA3 and from above in FMA4. The thinning strength was between 35 – 36 %. The rotation lengths were 120, 90 and 75 years for FMA2, 3 and 4, respectively. The MAI culminates at the same ages as when final felling is made for FMA2 and for FMA3. For FMA4 the final felling is made before culmination at the lowest allowable age according to the Swedish Forestry Act. In final felling harvest residues were extracted giving an extra income of 800 € ha^{-1} based on a price of 41 € ton^{-1}.

The costs for planting was set to 0.27 € per plant and for soil scarification to 109 € ha^{-1}. Costs for cleaning was 272 € ha^{-1} and for fertilization 250 € ha^{-1}. Costs for cuttings and forwarding were calculated by time consumption functions for harvesting and forwarding based on studies made by Brunberg (1995, 1997 & 2004). Forwarding costs was based on a transport distance to road of 300 m. Costs for extracting harvest residues was set to 9.8 € ton^{-1}. The revenues for timber and pulp wood was based on a pricelist valid for the area in year 2005. The average price of spruce timber (see Fig. 11) varies from about 42 to 52 € per m^3 for diameter class 14 to 30. For pulpwood, the prices was set to 26 € per m^3 for Pine and Spruce and for birch 24 € per m^3. All birch was assumed to become pulpwood.

Conclusions & discussion

The productivity expressed as M.A.I. [m^3 ha^{-1} yr^{-1}] differs a lot between the FMAs. It ranges from 4.8 (FMA2), 6.8 (FMA3) to 8.2 (FMA4). The most important reason for the large differences in productivity is the intensity of the regeneration measures, see Tab. 15. Natural regeneration without cleaning gives a higher share of broad-leaved trees resulting in lower growth. At the time of final felling broad-leaved trees constitute of about 30 % of growing stock in FMA 2. This can be compared with about 15 and 1 % in FMA3 and FMA4, respectively. The difference between FMA3 and 4 is due to intensity differences in regeneration measures and the fertilization made simultaneous as the second thinning.

For interest rates between 1 – 3 % FMA4 gives the highest LEV and for rates 4 - 5 % FMA2 is the only FMA with positive LEV, see Tab. 1. This because high investment cost in regeneration measures doesn't pay off with higher demand of return on investment. Interestingly, FMA3 isn't the best option at any rate but LEV is still higher than FMA2 with low rates (1 and 2 %). Another reason of the lower LEV for FMA2 and 3 when interest rate was 1 – 3 % compared to FMA4 was that some volumes are not accessible in final felling because succession elements were created by leaving eternity trees for next generation for FMA2 10 trees, FMA3 5 trees and for FMA4 no trees per ha.

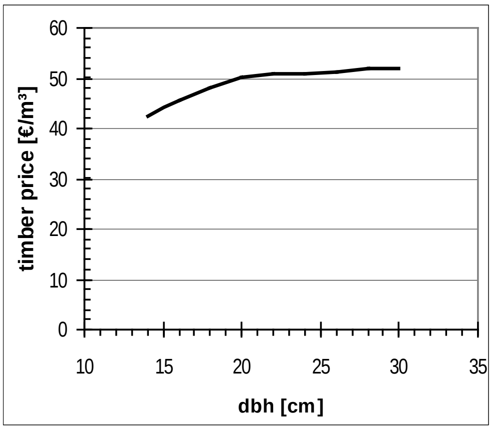

Fig. 11: Timber price for Norway spruce as a function of diameter with price level 2005.

Tab. 14: Summary of operations in forest management approaches for Norway spruce.

Operation	FMA2	FMA3	FMA4
Regeneration			
N·ha^{-1} planted	-	2200	2700
Soil scarification	-	yes	yes
Cleaning, no of stems removed	-	1500	2600
Thinning regime, first thinning			
Height, (h [m])	14	14	14
Form	0.89	1	1.05
Grade, %	35	0.35	0.36
Thinning regime, second thinning			
Height, (h [m])	20	19	19
Form	0.86	1	1.05
Grade %	35	0.35	0.35
Fertilization [kg ha^{-1}]	-	-	150
Final cutting			
Age	120	90	75
Diameter, [cm baw]	32	32.0	31.2
Volume [m³]	380	416	412
Extracted forest fuel [t·ha^{-1}]	-	-	50
Eternity trees [N·ha^{-1}]	10	5	0

3.6 Productivity of Maritime pine stands under alternative forest management approaches in Aquitaine (France)

Sebastien Cavaignac, Mohamed Najar and Guillaume Chantre

3.6.1 State of situation of maritime pine in Aquitaine in the scope of eforwood forest management approaches

Five forest management approaches (FMA) are described for the maritime pine in Aquitaine. The first step is to evaluate the present distribution of these approaches over the Aquitaine forest. From the characteristics of each approach defined by Duncker et al. (2007), it is possible to assign one FMA among the five to the different types of stands described by the National Forest Inventory. Using the representativity of each National Forest Inventory type of stand, we evaluate for each approach the current area, the volume and the production. Theses results are shown in Tab. 15.

Tab. 15: Main statistics on maritime pine FMA in Aquitaine (from the 1999 references)

FMA	Area (ha)	Volume (1 000 000 m3)	Mean production (maritime pine only) (m³/ha/year)	Mean production Maritime pine + other species (m³/ha/year)
1- Nature reserve				
2- Close to nature	28 382	3.3	5.9	6.2
3 – Combined objectives	222 432	28.2	6.9	8.5
4 – Intensive even-aged	739 322	124	10.4	10.5
5 – Wood biomass				
Temporarily deforested area	46 595			
Total	1 036 731	155.5 165.3		Maritime pine Maritime pine + other species

The analysis shows that three main approaches are used in practice for managing maritime pine stands; since maritime pine is mainly cultivated, the intensive even-aged alternative (FMA4) is dominating obviously the other ones. According to our criteria, 74% of maritime pine forest area is managed in that way in the South Western France, which corresponds to the standard cultivation technique practised over the last decades. The sites concerned with FMA 4 are mainly located in the central part of the Landes forest and spread from low fertility (site index lower than 6 meters at 11 year old) to very good fertility (site index upper than 10 meters at 11 year old).

The second approach is “combined objectives” (FMA3), which represents 23% of forest area. This forest management approach is mainly located in the periphery of the Landes of Gascony (sub-part of Aquitaine Region where maritime pine is located). Presently, different objectives are simultaneously considered:

- soil protection and sand dune stabilisation
- protection of human habitat against sand along the coast
- tourism and recreation activities along the coast, near the lakes and the towns
- hunting places mainly in the North

As the precedent one, different site index can be found for this approach. It should be mentioned that the relative weight of sand dunes, with bad fertility sites, may give an average site index lower than the previous one.

The other stands (around 3%) can be described as “close to nature” (FMA2). They are places where trees are growing with minimal human intervention. We can thus have stands with density either very important or very low, compared with the reference guidelines. These stands can be located everywhere in the Landes and thus present on a broad range of site index.

3.6.2 Simulation tools and hypotheses

In order to perform simulations, we use the maritime pine model developed in FCBA for the intensive maritime pine management (Najar, 1999). This model uses relationships between top height and age, top height and average height, a statistical prediction of the circumference growth based on the individual past growth and the basal area and a relation to estimate mortality.

This simulator was established with data covering various conditions of site, type of regeneration or density but all only under intensive even-aged forestry. Its validity domain is thus limited to forest management approach 4. It can be reasonably extrapolated to forest management approach 5 under the conditions pine should be cut after 20 years.

In order to calculate results for FMA2 and FMA3 we have to define a relation between the results of the model and the prediction for these approaches.

First of all, regarding the National Forest Inventory results (Tab. 15), we can see that mean forest productivity is varying according to the management approach. This difference is mainly due to the site where the approach can be applied (for example sand dune protection makes sense only along the coast) and to the way pines are managed: planting genetically improved material under mechanized and more intensive cultural techniques has a positive impact on production. Using the mean production evaluated for each forest management type it is possible to assess a scale ratio between the different FMAs

To investigate this question in detail we use experimental data. Two populations of maritime pine can be found in these stands. The first one corresponds to trees older than forty years, cultivated close to FMA3. The other one corresponds to pines generally younger than thirty years (new stands or re-afforestation). We first looked at the dendrometrics characteristics of the pines and particularly the height and the circumference (Fig. 12).

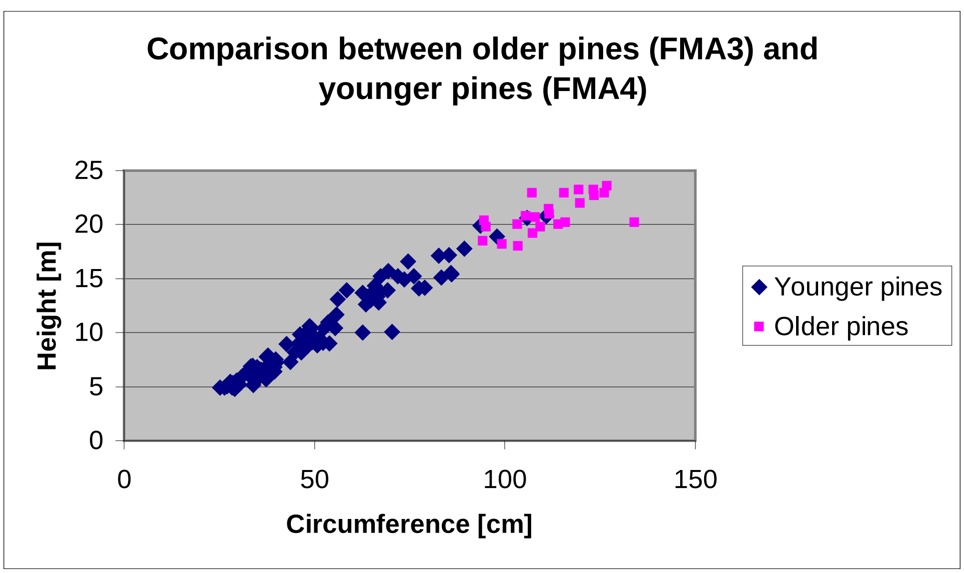

Fig. 12: Comparison between older and younger pines.

Fig. 15 shows that the two populations of pines are perfectly fitting a common curve. Young pines can reach the height of the old pines -more than 40 years old-. As the main difference between the populations of pine is the management approach, we can expect extensively managed pine stands (FM2 or 3) to lead to similar traits (diameter and height) with longer rotation time.

Regarding the circumference vs. the stand age (Fig. 13), we can observe that the “young” pines reach the level of the older ones with a ten year difference. It is then possible to define a transformation by considering that one year of a young pine correspond to 1.33 year of an older pine. The application of this homotethie is shown Fig. 14.

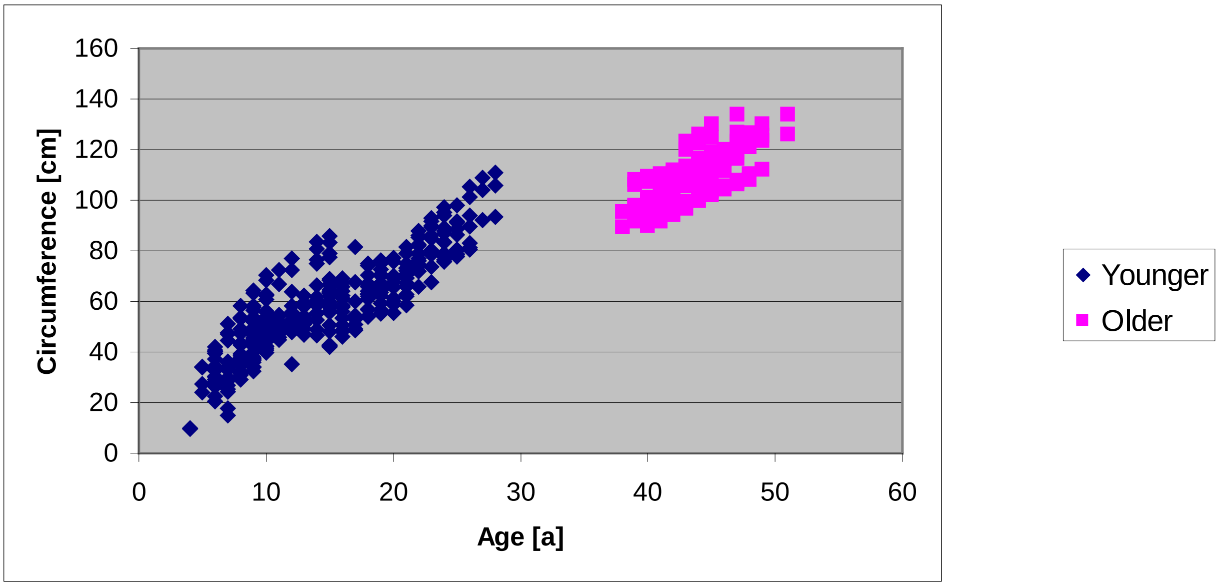

Fig. 13: Circumferences of “old” and “young” pines vs. age.

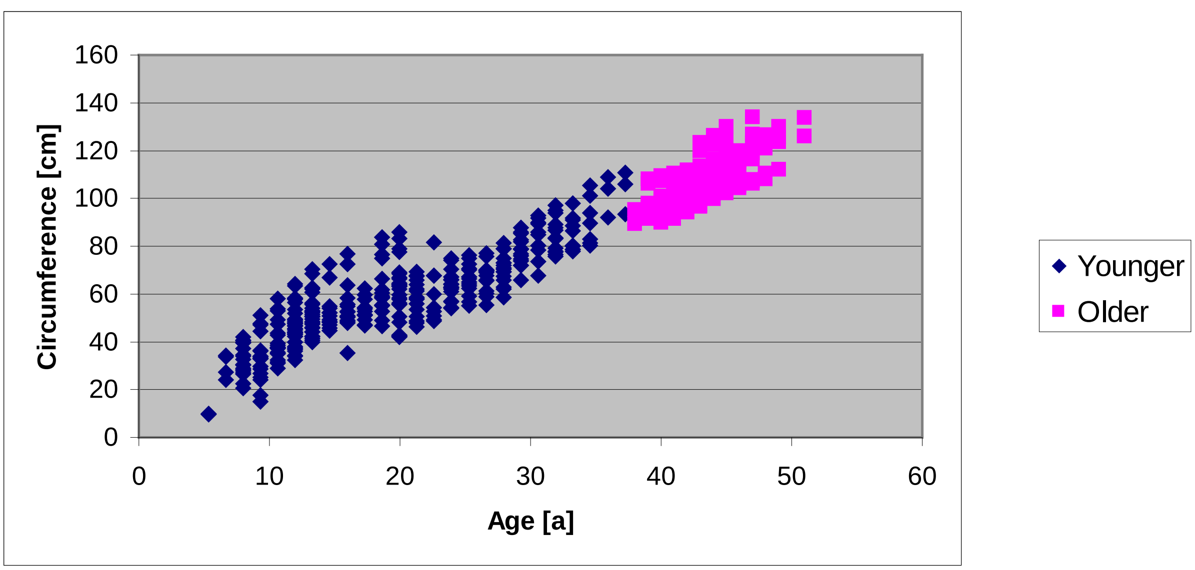

Fig. 14: Transformation of the age of younger pines

It seems feasible to estimate physical characteristics of older pines grown under approaches close to FMA3 by changing the scale of age of young pines raised under FMA4 approach. In order to define the scale factor between age of pines under FMA4 and pines under FMA3 or FMA2, we use the ratio between the mean productions as indicated earlier. For example, the ratio of mean production between FMA3 and FMA4 is 1.23. For instance, when the revolution under FMA4 takes 50 years, it would take 61 years under FM3 for the same products and objectives.

Other specificities:

FMA2 being "close to nature" we therefore consider that natural regeneration is preferred. In order to avoid clear cut and bare land, the regeneration is started 15 years before the end of the previous rotation. The fixed costs of 30€ ha^{-1} a^{-1} are not charged during the fifteenth first years of management.

For FMA5, we consider a revolution of 30 years with one thinning and a starting density of 2500 trees ha^{-1}. We use the same site index than FMA4.

Hypothesis for each FMA are presented Tab. 16.

Tab. 16: Process and cost for each FMA.

FMA	Process	Description	Cost (€ ha^{-1})
2	Installation	Regeneration	100
	Annual cost	Taxes, subscriptions,...	30 after 15 years
	Tending	2 times	2*200
	Thinning	4 times	4*100
	Final harvest	cut when circumference reaches 120, natural regeneration already present	285
3	Installation	Seeding	815
	Annual cost	Taxes, subscriptions,...	30
	Tending	1 time	200
	Thinning	4 times	4*100
	Final harvest	Clear cut when circumference reaches 120	285
4	Installation	Planting	1055
	Annual cost	Taxes, subscriptions,...	30
	Thinning	4 times	4*100
	Final harvest	Clear cut when circumference reaches 120	285
5	Installation	Seeding	815
	Annual cost	Taxes, subscriptions,...	30
	Tending	1 time	200
	Thinning	1 time	1*100
	Final harvest	Clear cut when age reaches 30 years	285

The prices curves are established on observed sales which took place before February 2009. They are represented in Fig. 15.

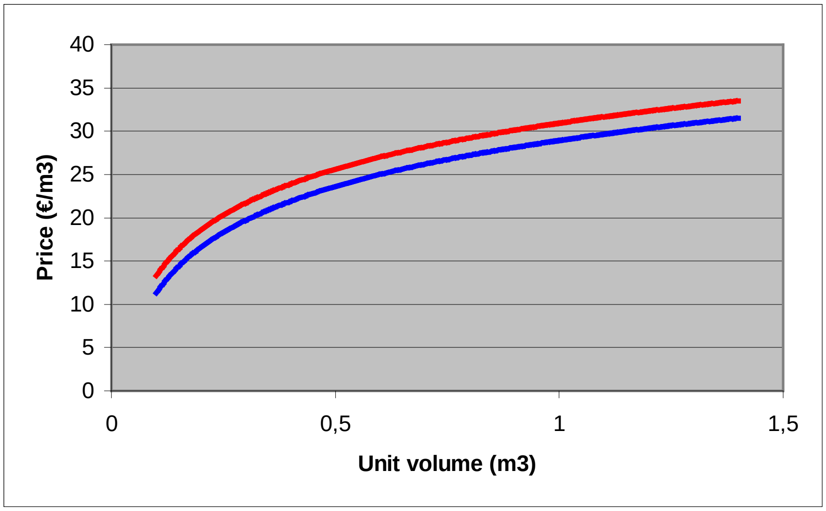

Fig. 15: Price curves in function of unit volume. The upper curb corresponds to clear cut prices and the lower one to thinning prices.

3.6.3 Simulation results

The results obtained for each FMA are summarized in Tab. 17. The Land Expected Value (LEV) is calculated for five interest rates. The different FMA resulted in production times of 83 years for FMA2, 61 years for FMA3, 50 years for FMA4 and 30 years for FMA5. Mean annual increment varies inversely with rotation length and ranges from 6.3 to 12.5 m^3 ha^{-1} a^{-1}. The MAI is an average value over different site quality: higher values can be observed on the best site index.

The best results for Land Expectation Value are achieved for FMA4 whatever the interest rate. For interest rates above 3%, FMA2 gives better results than FMA3 but values are however negative. In other cases FM3 is more interesting than FMA2.

FMA5 is the shortest approach. Considering LEV and compared with other approaches, FMA 5 is more attractive with high interest rates. For interests rates below 2% this approach is in fourth position just before FMA2. For interest rates above 2% it is the second approach, and with a 5% interest rate FMA2, FMA4 and FMA5 give similar economic results.

Tab. 17: Mean annual increment, Rotation time and land expectation value achieved in different FMA for maritime pine.

FMA	2	3	4	5
MAI	6.3	8.8	10.8	12.5
Rotation time	83	61	50	30
LEV i=0.01	6600	9500	13100	7400
LEV i=0.02	1700	2600	4400	2400
LEV i=0.03	400	600	1600	800
LEV i=0.04	-100	-300	400	100
LEV i=0.05	-300	-700	-300	-300

3.6.4 Comparison of the different approaches with FMA3

In order to compare the different FMA, we use the results obtain with FMA3 approach as a reference and we study the results of the other approaches according to this reference.

Considering the 61 year rotation time to achieve the FMA3 rotation, the duration is drastically shorter for FMA4 and FMA5 but longer for FMA2.

Regarding the mean annual increment (Fig. 16), FMA3 gives a better production than FMA2 but a lower production than FMA4 and FMA5.

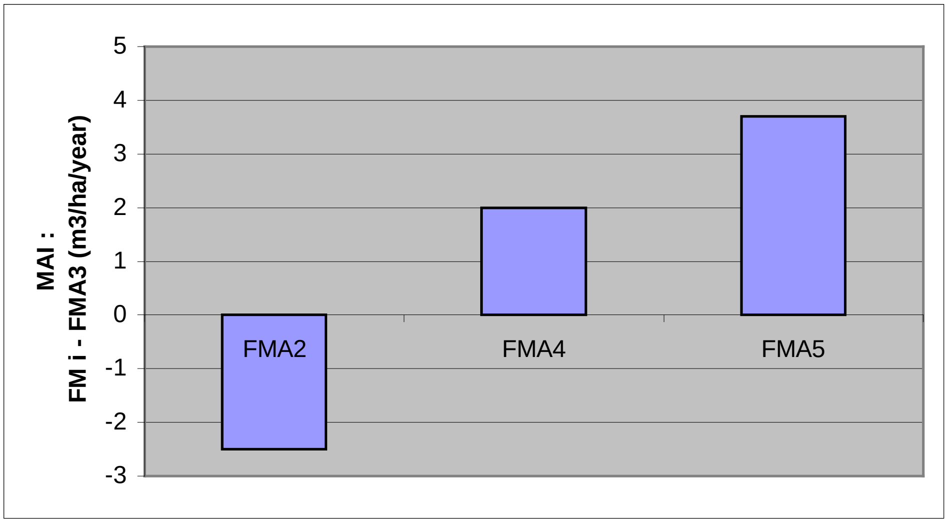

Fig. 16: Mean annual increment = comparison between FMA3 and other approaches.

Considering the LEV (Fig. 17), FMA4 always leads to better results than FMA3. For the two other approaches the ranking depends on the level of the interest rate. For lower interest rates FMA3 is more interesting than FMA2 and FMA5 but we observe the opposite ranking for upper rates.

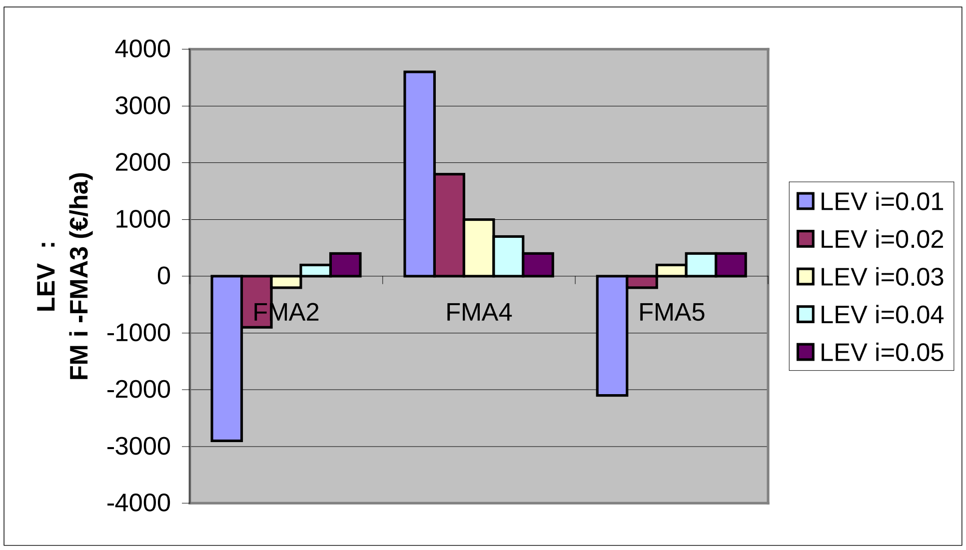

Fig. 17: LEV = comparison between FMA3 and other approaches.

3.6.5 Conclusion:

Considering four different forest management approaches from the less intensive (FMA2) to the more intensive (FMA5), based on a traditional price curve hypothesis in the Aquitaine region, we can conclude that the optimum, considering land expectation value, is the intensive even-age approach (FMA4). This approach is also the more representative (forest area) for maritime pine in Aquitaine, which remains the specificity of this cultivated forest in the South Western France.

The comparison of different approaches taking FMA3 as reference shows that the relative ranking mainly depends on the interest rate, except FMA4 which always gives the highest economic return. For interest below 3%, FMA3 is more valuable than FMA2 or FMA5 but FMA3 becomes the worse option if rates exceed 3%.

3.7 Productivity of Mediterranean pine stands (*Pinus sylvestris* L.) under alternative forest management approaches in Catalonia

José Ramon Gonzalez

Scots pine (*Pinus sylverstris* L.) forest is the second most common among the forest types in Catalonia, covering approximately 18,4% of its forested land, while being the forest where most of timber is extracted (Gracia et al., 2004). The effect of FMAs on the productive function for Scots pine stands in the Mediterranean region was modelled for SI100 of 16 m. This index is considered to be representative medium / medium-low site quality in Mediterranean regions within Catalonia. Additionally, average conditions of steepness and distance to roads for Scots pines stands in Catalonia, were assigned to our study stand as part of the information required to obtain harvesting costs. In this region, Scots pine usually grows in mountainous areas, being specially abundant in places located between 800 and 1600 meters above sea level. The mountainous nature of Scots pine in Catalonia encloses certain restrictions to its management, like the necessity of maintain a continuous forest cover (relaying mainly in natural regeneration attained through seltherwood cutting methods), and the influence that terrain roughness and accessibility represents to estimate managerial costs (Solano et al., 2007).

Three management approaches are assessed, ranging from low intervention (FMA2) to intense even-aged wood production (FMA4). Stand development under the three management approaches was simulated with the commercial stand level simulation-optimisation system RODAL (reg. T Pukkala, 2003). Individual tree level models were used to simulate the evolution of the stand (Palahí et. al. 2003, 2004, Palahí and Pukkala. 2003).

The development of an initial stand of age 30 years was modelled for three management approaches (see Fig. 18). In all three a tending operation was assumed at age 24 years. The approaches differ in the thinning regime and in rotation length. FMA2 actually intends to reduce the number of interventions in the stand. However, under current market conditions this approach proofs to maximize the economic revenue. In FMA3 the management objective is to combine the production of a considerable amount of timber and the economic revenue. Having no economic constraints the objective of FMA4 is wood production. In FMA3 an additional thinning was included to reduce the risk of fires (however the possible decrease in fire occurrence and damage is not reflected in the results of none of the approaches).

While FMA2 goes without any thinning at all, FMA3 was modelled with a one time thinning at age 70 years, and FMA4 with two thinning operations at ages 50 an 70 years. The rotation lengths are 140, 120 and 100 years for FMA2, 3 and 4, respectively. In all management approaches the last 20 years of the rotation period included two shelter wood and a final cutting to achieve a successful natural regeneration. Keeping a continuous cover is considered a restriction due to soil erosion in mountainous areas of Catalonia, therefore forest management normally relays in natural regeneration in *Pinus sylvestris* stands.

The first tending operation was assumed to cost 900 € ha^{-1}. In order to calculate the resulting cash flows from thinning and harvesting operations a function was fitted to estimate timber prices for different breast height diameters (see Fig. 19). Based on the corresponding costs and revenues along the management cycle within the three approaches land expectation values was calculated for interest rates of 1, 3, and 5 %.

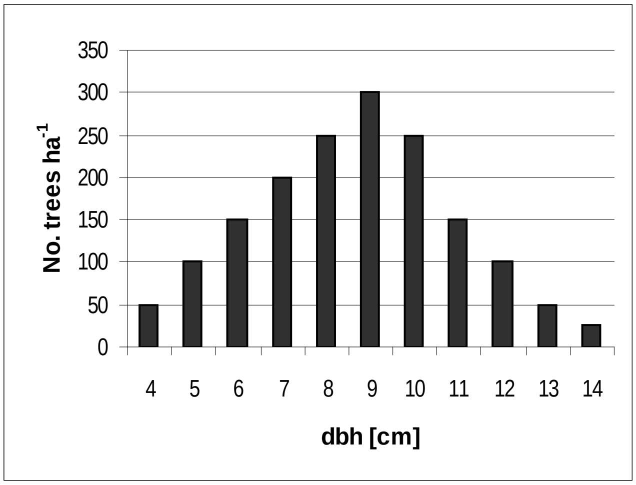

Fig. 18: Initial stand of 30 years

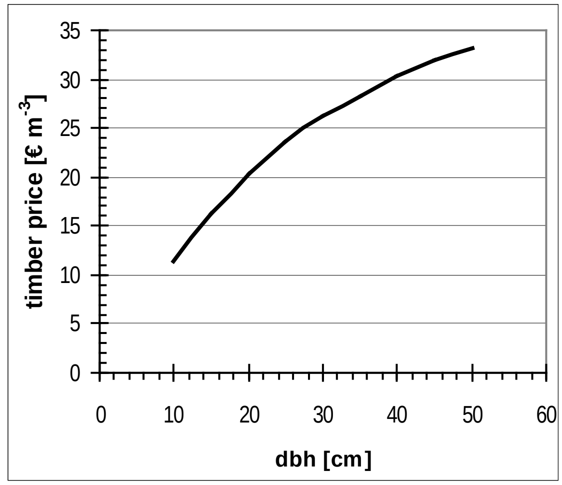

Fig. 19: Timber price as a function of diameter.

For describing the stand development over increasing stand age the basal area in the three approaches is provided (Fig. 20, Fig. 21, and Fig. 22). Further the removals and the MAIu are stated below. The 1st management results in a MAIu of 3.1 and thus is less productive than the other two management approaches both revealing 3.3 m^3 ha^{-1} a^{-1}. However, in economic turnout the 1st approach outmatches the other two at all considered interest rates. For interest rate 1 %the corresponding LEVs are 2375, 1731, and 1215 € ha^{-1} from the 1st to the 3rd approach. For higher interest rates the resulting LEVs are always negative.

3.7.1 1st management approach (FMA2)

This management approach tries to reduce the number of interventions in the stand. However, under current conditions this is the approach that maximizes the economic revenue.

Rotation of 140 years - Tending at 24 years - No thinning

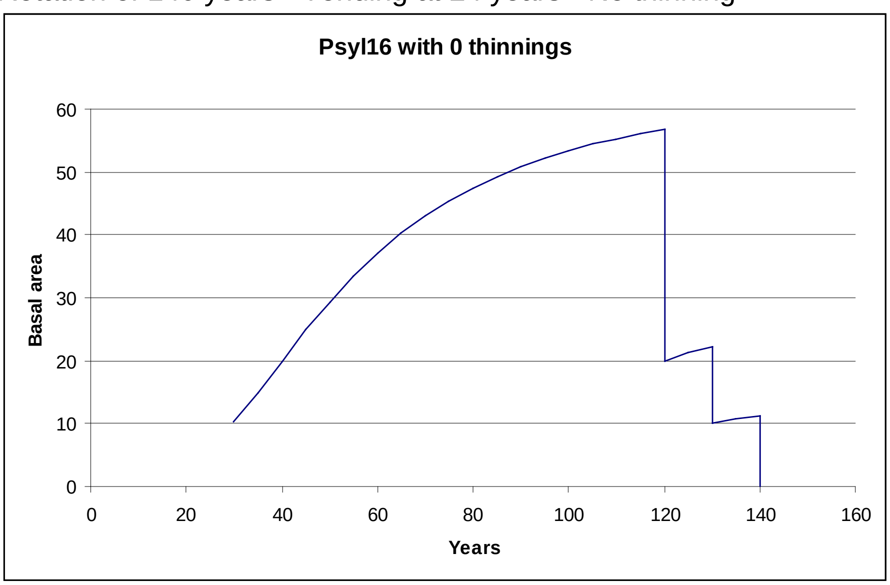

Fig. 20: Basal area development over stand age in 1st management approach.

Removals

Year	Treatment	Removal $[m^3 ha^{-1}]$	MeanVol $[m^3 tree^{-1}]$	Mean dbh [cm]
0	Establishment	0	0	0
24	Tending	0	0	0
120	Shelter tree cut	250.3	0.4	27
130	Thin shelter	91.5	1.1	42.6
140	Remove shelter	87.4	1.6	51.8

Total removals: 429.2 $m^3 ha^{-1}$

Mean annual increment: 3.1 $m^3 ha^{-1} a^{-1}$

3.7.2 2nd management approach (FMA3)

This management approach tries to combine the production of timber and the economic revenue.

Rotation of 120 years - Tending at 24 years - 1 thinning at 70 years

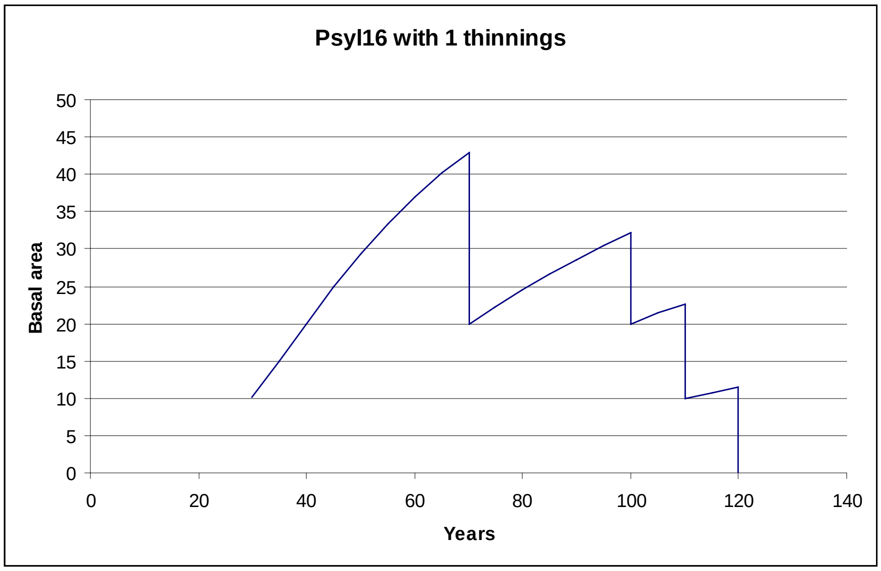

Fig. 21: Basal area development over stand age in 2nd management approach.

Removals

Year	Treatment	Removal $[m^3 ha^{-1}]$	MeanVol $[m^3 tree^{-1}]$	Mean dbh [cm]
0	Establishment	0	0	0
24	Tending	0	0	0
70	Thinning	133.6	0.1	17.1
100	Shelter tree cut	84.8	0.6	31.9
110	Thin shelter	92.6	0.9	38.9
120	Remove shelter	87.8	1.4	48.2

Total removals: 398.8 $m^3 ha^{-1}$

Mean annual increment: 3.3 $m^3 ha^{-1} a^{-1}$

3.7.3 3rd management approach (FMA4)

This management approach has not economic constraints and only the wood production was considered as lone objective. An additional thinning was included to reduce the risk of fires (however the possible decrease in fire occurrence and damage is not reflected in the results of none of the approaches)

Rotation of 110 years - Tending at 24 years - 2 thinnings at years 50 and 70

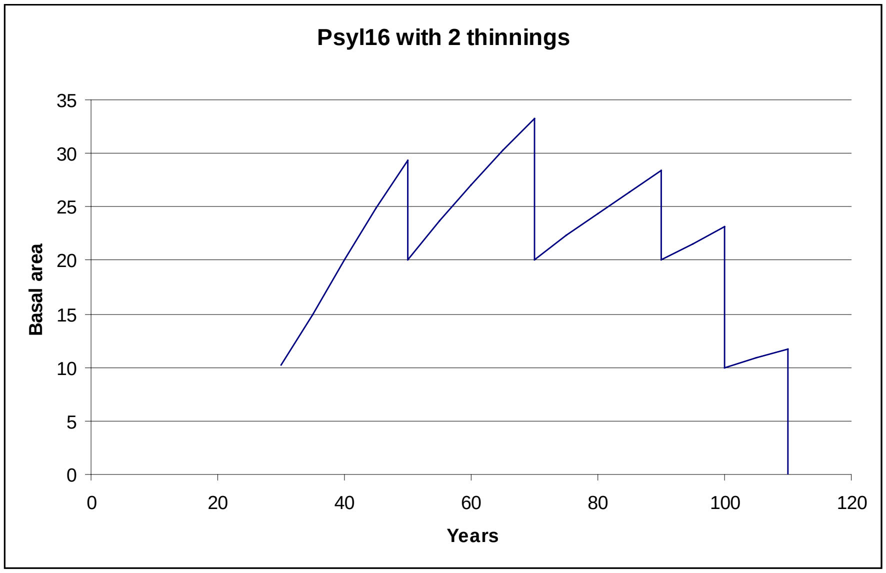

Fig. 22: Basal area development over stand age in 3rd management approach.

Removals

Year	Treatment	Removal [$m^3 ha^{-1}$]	MeanVol [$m^3 tree^{-1}$]	Mean dbh [cm]
0	Establishment	0	0	0
24	Tending	0	0	0
50	Thinning	44.4	0.1	11.9
70	Thinning	82	0.2	21.8
90	Shelter tree cut	57.5	0.5	30.7
100	Thin shelter	93.5	0.7	35.8
110	Remove shelter	88	1.2	45.2

Total removals: 365.4 $m^3 ha^{-1}$
Mean annual increment: 3.3 $m^3 ha^{-1} a^{-1}$

Comparison of management approaches

Absolute values

	FM1	FM3	FM4
Rotation (years)	140	120	110
Removals ($m^3 ha^{-1}$)	429.2	398.8	365.4
Mean annual increment ($m^3 ha^{-1} a^{-1}$)	3.1	3.3	3.3
LEV (€ ha^{-1})			
Discounting rate 1%	2374.8	1731.0	1215.0
Discounting rate 3%	-236.0	-243.5	-367.0
Discounting rate 5%	-257.0	-255.1	-311.5

Relative to FMA3

	FM1	FM3	FM4
Rotation	1.17	1.00	0.92
Removals	1.08	1.00	0.92
Mean annual increment	0.92	1.00	1.00
LEV			
Discounting rate 1%	1.37	1.00	0.70
Discounting rate 3%	-0.97	-1.00	-1.51
Discounting rate 5%	-1.01	-1.00	-1.22

3.8 Productivity of Scots pine (*Pinus sylvestris* L.) stands under alternative forest management approaches in Silesia (Poland)

Sławomir Ambroży

Among the actual Scots pine (*Pinus sylverstris* L.) stands in the Silesian region 61.6 % are managed under “intensive even-aged forestry” (FMA4) and represent the largest share. Second most common are stands managed under “combined objective forestry” (FMA3) with about 20.2 % while “unmanaged forest nature reserves” (FMA1) do only account for 0.2 %. Approximately 18% of Scots pine stands are under conversion to broadleaf stands, representing the conversion phase to “close-to-nature forestry” (FMA2). However, FMA2 is not in an equilibrium state at present. Although Scots pine might be intensively managed with short production times targeted towards dendro-biomass production (FMA5) this is not practised in the Silesian region at present. Since the two first mentioned FMAs are most relevant for wood production they were considered in this study. Stand development for FMA3 and 4 is estimated with dendromatic tables (Szymkiewicz, 2001) under SI100 22, 26 and 30 m.

For both FMAs it was assumed that the stands have been planted in a density of 9000 trees per hectare. The young stands were tended twice, at age 5 and 15. This includes measures of deer protection, weed control and beating up. The corresponding costs were assumed to be 1,833 for planting and 654 € ha^{-1} for tending operations, respectively. Thus, the variable costs in the period before the first thinning are relatively considerably high. The largest share, almost 60 %, results from the artificial regeneration.

The FMA3 and 4 were considered to differ especially in the cutting regime (Tab. 18). FMA4 is characterized by a shorter rotation length and lower number of thinnings during the rotation period compared to FMA3. However, the individual thinnings were more intense in FMA4 through removing a higher amount of wood volume. The final harvesting systems in both approaches were clearcuts.

Tab. 18: Cutting regime in different Forest Management Approaches for Scots pine.

Operation	FMA3 Combined objective	FMA4 Intensive even-aged
Age at first thinning [a]	30	30
Age at last thinning [a]	90	90
Length of rotation period [a]	105 (100-110)	95 (90-100)
Number of thinnings in rotation period	5	4
Average period between thinnings [a]	15	20
Thinning intensity [% of standing volume]	20	25

The cash flows resulting from thinning and harvesting operations were calculated based on the diameter distribution of the cut volume. The net revenue for Scots pine at roadside for medium quality round wood according to the prize level in 2005 was estimated with the function provided in Fig. 23. The stumpage value at a given diameter was lower for FMA3 compared to FMA4. This was due to higher cutting costs in stands managed by a “combined objective” management approach compared to even-aged forestry. In addition, the annual mean timber prices for reference year 2005 are approximately 5% higher than the mean timber price observed for the period 1995 – 2005.

Further to the mentioned variable costs additional fix costs were assumed. With approximately 50 € ha-1 a-1 they were quite small. They almost equally consist of salaries for management as well as other maintenance and insurance costs. In the lowland conditions the fix costs for Scots pine were not assumed to vary between the two FMAs.

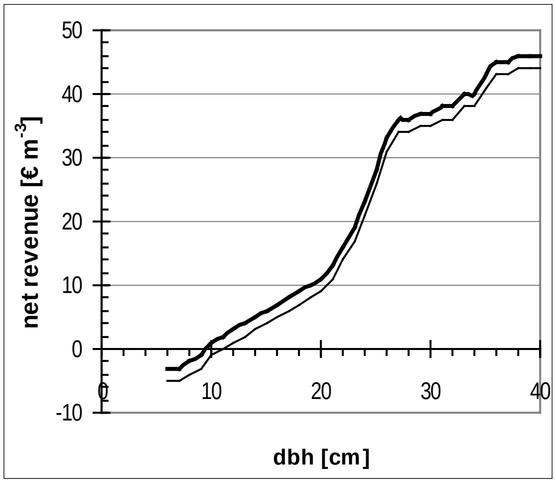

Fig. 23: Net revenue [€ ha^{-1}] as a function of breast height diameter for Scots pine with price level of 2005. Thin line represents FMA3, thick line FMA4.

Tab. 19: Productivity in different Forest Management Approaches for Scots pine.

Cut volume [m³ ha^{-1}]	FMA3	FMA4
1st thinning	22.2	28.0
2nd thinning	43.5	69.5
3rd thinning	69.0	108.2
4th thinning	94.2	122.9
5th thinning	103.5	-
Final cutting	539.6	400.0
Total productivity	**872.0**	**728.6**
MAI_u [m³ ha^{-1} a^{-1}]	**8.3**	**7.7**

The wood volume productivity of Scots pine at medium site index under FMA3 and 4 is provided in Tab. 19. The total productivity is about 20 % higher in FMA3, but this is achieved with a longer rotation period and higher cutting costs than in FMA4. Nonetheless, the average annual volume production (MAI) in FMA3 accounts for 8.3 m³ ha^{-1} a^{-1} and thus remains higher than the one achieved in FMA4 being 7.7 m³ ha^{-1} a^{-1}. Compared to the medium sites, the simulations for low and high site indices reveal total volume productivities being about 40% lower and respectively 60% higher than the indicated values of Tab. 19. The total volume growth, standing volume and cash flows at different stand ages in both management approaches is further provided in Fig. 24.

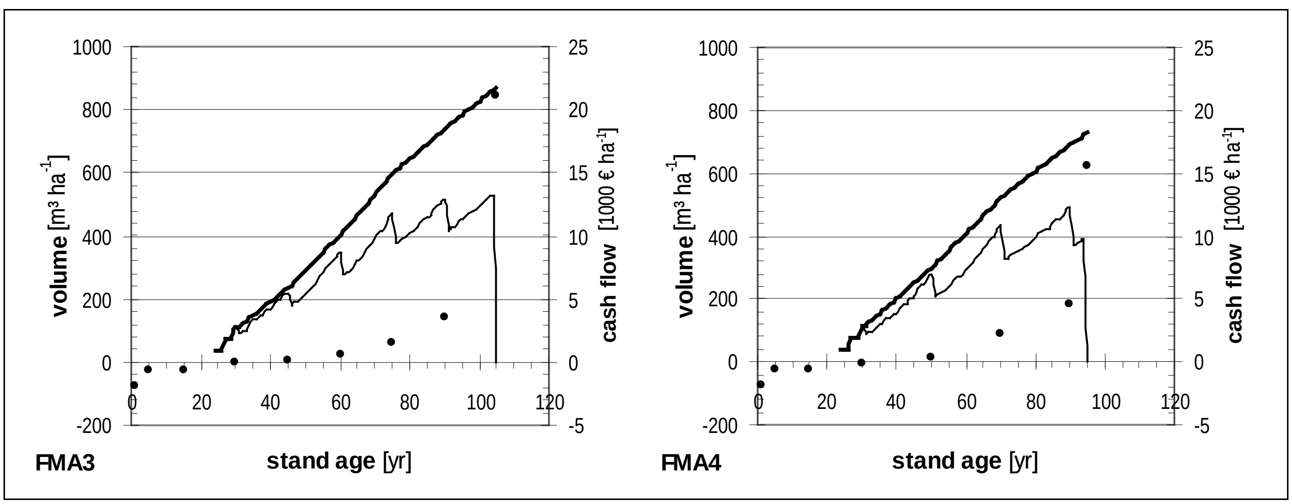

Fig. 24: Total volume growth (thick line), standing volume (thin line) and cash flow (points) within alternative forest management approaches for Scots pine.

The resulting land expectation value (LEV) for Scots pine stands with medium site index in Silesia Region are very similar for both described FMAs (Fig. 25). Thus it might be concluded that the fulfilment of multifunctional forestry objectives by longer rotation periods through “Combined objective forestry” (FMA3) does not cause relevant changes of profitability.

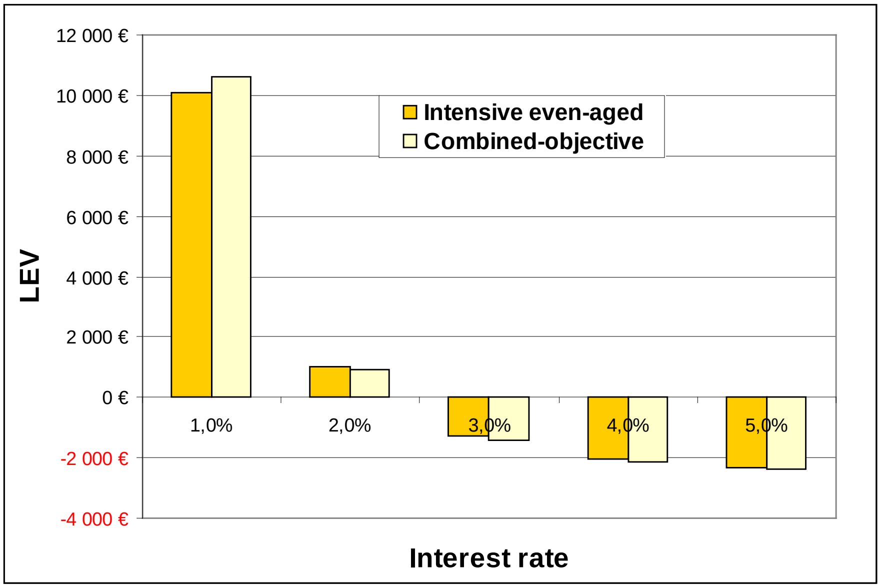

Fig. 25: Land expectation value at the end of rotation period for different Forest Management Approaches.

In comparison to the Forest Management Approaches mentioned above, LEV at 1% interest rate is on average 35 % lower for conversion phase of close-to-nature forestry. High additional variable costs during conversion phase are the main reason. It is to be expected that profits of conversion activities will only be visible in the future when an equilibrium state of close-to-nature forestry is achieved.

3.9 Productivity of *Eucalyptus globulus* under alternative forest management approaches in Portugal

Susana Barreiro and Margadida Tomé

Eucalyptus plantations are mainly used by the pulp and paper industries being managed as a short rotation coppice system, with a first cycle of planted seedlings followed by 2 or 3 coppiced stands. The average cutting cycle is 10 to 12 years. This species is usually planted with densities around the 1250 and 1111 trees per hectare (spacings of 4x2 m and 3x3m, respectively). At present, and most likely in the future, eucalyptus stands in Portugal are managed somewhere between FMAs 4 and 5: "Intensive Even-Aged Forestry" and "Dendro Biomass Production", despite this it will be considered that stands are currently being managed as "intensive even-aged forestry" (**FMA4**). Stand development was simulated with a stand level simulator that integrates Globulus 3.0 model. This model predicts growth and yield for pure even-aged stands taking into account the transition between rotations (Soares et al, 2006, Tomé et al, 2001). It includes two main modules (initialization and projection) which integrate two types of variables (state variables and external variables). This version of the model has some of the parameters expressed as a function of climatic and site variables such as the number of days with rain, the altitude, the total precipitation, the number of days with frost and the temperature.

In the Portuguese reference case four FMAs in Eucalyptus stands were considered: combined objective forestry (**FMA3**), intensive eve-aged forestry (**FMA4**) and dendro-biomass production (**FMA5**). Two options were simulated for **FMA4**, one for production/economic stands and another for poorly managed stands (Duncker et al, 2007 D 2.1.3).

Four virtual stands were simulated for the average site index SI (dominant height at the standard age of 10 = 19.5). The first **FMA4** stand is characterized by considerable investments in silvicultural operations with the aim of producing quality wood for pulp and paper industry throughout the rotation length of the stand. On the other hand, the second **FMA4** stand represents the stands managed by farmers who obtain from this species easier and faster revenue, when compared to their traditional crops, but who do not invest as much as the industry in silvicultural operations such as fertilization and weed control.

The other two types of stands are virtual stands and represent FMAs 3 and 5. The third type corresponds to the hypothetical use of *Eucalyptus globulus* in combined objective forestry (**FMA3**) focusing on the recreational use of the forest while the fourth one corresponds to the hypothetical use of *Eucalyptus globulus* for plantations specifically established for bio-energy production (**FMA5**). The assumptions made and/or the simulation parameters varied according to the FMA and the type of stand.

FMA3 stand is defined as a pure eucalyptus stand planted with 550 trees per hectare and managed as a 60 year rotation even-aged planted stand. With the aim to reduce stand density three thinning operations were done at the ages of 20, 30 and 40 each one of them removing 2/3 of the trees leaving some space for natural vegetation to progress. It was assumed that the thinning was followed by stump destruction in order to prevent having a coppice with standards stand. This FMA considers a reasonable investment in opening and maintaining walking tracks. Weed control operations, which are assumed to be done in the same years as road and track maintenance to reduce human intervention, were also considered. These operations intent to promote the use of forest for recreational purposes. Because the model used to obtain volume estimates does not reflect completion, a site index slightly above the average one was used. The wood resulting from thinnings and clear-cut is assumed to be used by saw-mills.

Both types of stands in **FMA4** are managed in three cycles of a planted stand followed by two coppice stands with duration of 12 years each resulting in a 36 years rotation period. The differences between silvicultural operations in each of these stand types are described in more detail in Duncker et al. (2007 D 2.1.3). The model used in the simulation runs is an empirical model, therefore to be able to reflect a fertility increase and a competition decrease resulting from fertilization and weed control operations a deviation from the average site index was used: **FMA4 - production/economics** was assumed to have a SI value of 20.5, while for **FMA4 – poorly managed** a 18.5 SI was considered. A starting density of 1250 trees per hectare was used in the two options of **FMA4**. The other simulation parameters considered were a top diameter of 6 cm, 20 percent of death occurring in the transition between rotations and an average number of shoots per stool of 1.6 resulting from the operation of selecting the shoots in coppice stands. For the production/economics option, apart from the revenue derived from the volume production for the pulp and paper industries additional revenue was obtained: 50% of the residues produced were considered to be used for bio-energy production.

The virtual **FMA5** stand is characterized by a 5 year planted stand followed by 4 coppice stands of the same duration (rotation length of 25 years). This forest management approach represents the most intensively managed one and despite considering that fertilizations are performed during 25 years, the average SI was maintained to compensate for the nutrient removal assumed to occur in this FMA. The model used to simulate this stand type was developed to simulate **FMA4**. In order to obtain more accurate simulation results the model was adapted for densities closer to the ones existing in plantations for bio-energy. In this case a stocking of 10000 trees per hectare was used. Given the fact that no studies have been made for managing this species with this purpose in Portugal, it was assumed that the percentage of death occurring between rotations is little higher than for **FMA4** (30%). It was also assumed that there is no selection of the shoots in coppice stands and the top diameter is irrelevant because the whole tree will be removed and used for bio-energy production.

Globulus 3.0 estimates can be assumed accurate for **FMA4** stands, although this model was also used to estimate stand variables for **FMA3** and **FMA5** stands, which required a considerable amount of extrapolation. The main assumption consists of assuming that stands with reduced density (**FMA3**) or extremely high densities (**FMA5**) present the same growth pattern found for stands with densities around the 1250 trees per hectare, not taking into account competition.

All costs of silvicultural operations were obtained from the Portuguese statistics produced every two years by the forest service (CAOF, 2008). On the other hand, timber prices published in the statistics are much lower than those practiced in the market. In order to avoid the error resulting from using public figures, the values used were obtained from unpublished data (Goes, pers. comm.). The price for standing volume (over bark) resulting from **FMA4** that is mainly used by the pulp industry is 45 € m^{-3}, while the price of biomass residues is 11 € Mg^{-1}. The latest price was used as an indicative price for **FMA5**. At present there is no market for timber resulting from **FMA3** so the price used is purely indicative and was considered to be a little higher than the one for pulp (50 € m^{-3}).

No information was found concerning fixed costs so, in order to make it simpler, fixed costs have not been accounted for. In terms of variable costs it was assumed that **FMA5** plants were genetically improved being therefore more expensive. This fact, together with the high density in this type of stand makes site establishment extremely expensive when compared with the other FMA/options, although it has about the same fertilization and weed control costs of as **FMA3**, which are below the same costs of **FMA4 – production economic**. It was assumed that in **FMA4 – poorly managed** stands no fertilizations or weeding operations were done. The corresponding treatment regimes and associated variable costs are summarised in Tab. 20.

Tab. 20: Characterisation of treatment regime and summary of variable costs [€ ha^{-1}] at price level 2005. 4a: FMA4 – poorly managed; 4b: FMA4 – production economic.

	FMA			
Characterisation of treatment regime	**3**	**4a**	**4b**	**5**
MAI $m^3 ha^{-1} year^{-1}$	10,1	6,77	9,65	31,64
rotation length	60	36	36	25
number of coppices following the planted stand	0	2	2	4
Starting density	550	1250	1250	10000
wood/biomass prices	50	45	5	11
wood/biomass prices	€ /m^3	€ /m^3	€/ m^3	€/ton
site quality	medium	medium	medium	medium
site quality	19,5	18,5	20,5	19,5
Variable costs				
site preparation	1113	1336	1453	6162
beating up	56	68	68	665
fertilization +weed control	1465	0	1838	1374
road opening /maintenance	0	0	0	0
variable costs -total of rotation length	**2633**	**1404**	**3360**	**8200**

The LEV calculations were done for each FMA/option based on the procedures described by (Faustmann, 1849 [Linnard (tr.) and Gane (ed.) 1968]). However it is important to call the attention for the fact that the same growth model was used to simulate all types of stands and that FMA3 and 5 have not been implemented in Portugal. As a consequence of these facts, results have to be carefully analysed when it comes to virtual stands simulation.

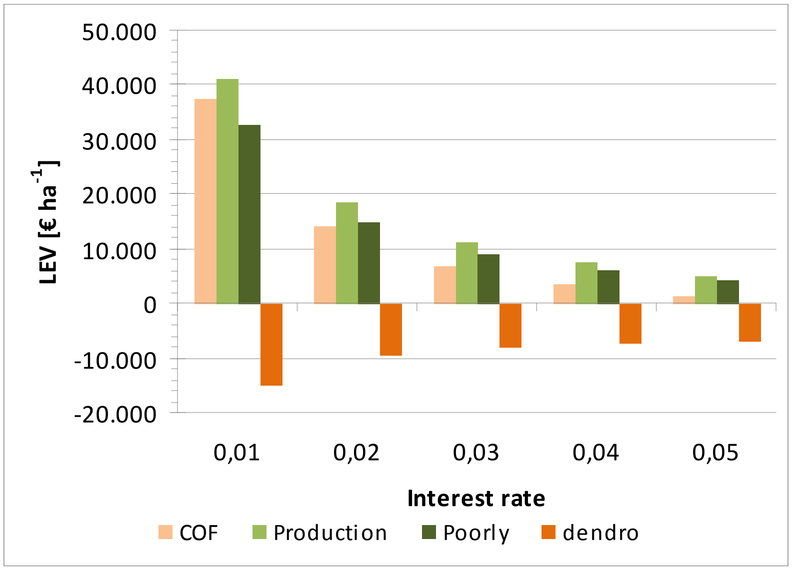

Fig. 26: Land expectation value for different Forest Management Approaches of Eucalyptus globulus. COF: FMA3; Production: FMA4b – production economic, Poorly: FMA4a – poorly managed; dendro: FMA5.

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