EFORWOOD
Sustainability Impact Assessment
of the Forestry - Wood Chain

Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

Instrument: IP

Thematic Priority: 6.3 Global Change and Ecosystems

Deliverable PD2.2.5
Report on time and scale integration of environmental impacts of forest management alternatives by use of generic modelling approach

Due date of deliverable: Month 44
Actual submission date: Month 55

Start date of project: 011105
Duration: 4 years

Organisation name of lead contractor for this deliverable: University of Copenhagen (KU), Denmark

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	x
RE	Restricted to a group specified by the consortium (including the Commission	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Deliverable PD 2.2.5 - Report on time and scale integration of environmental impacts of forest management alternatives by use of generic modelling approaches: a case study of synergies and trade-offs between production and ecological services.

Philipp Duncker[1], Karsten Raulund-Rasmussen[2], Per Gundersen[2], Johnny de Jong[3]
Klaus Katzensteiner[4], Hans Peter Ravn[2], Mike Smith[5], Otto Eckmüllner[4]

[1] Institute for Forest Growth, Albert-Ludwigs-University Freiburg, Germany
[2] Forest & Landscape Denmark, University of Copenhagen, Denmark
3 Swedish University of Agricultural Sciences, Uppsala, Sweden
4 Department of Forest and Soil Sciences, University of Natural Resources and Applied Life Sciences (BOKU) Vienna, Austria

ABSTRACT

Forests provide multiple functions and services among which society traditionally tends to have a high interest in wood production. In consequence, forest management aims at increasing the timber volume produced and the economic return through intervening with natural processes. However, forests serve further aims and functions like carbon sequestration, protection of biodiversity and water quantity and quality. In order to develop and implement sustainable forest management strategies, it is of importance to anticipate the long term effects of alternative forest management operations on the status and dynamics of processes in forest ecosystems. Thus, the management objective might emphasize the economic interest possibly at the expense of an impact on the environmental services. However, this is to be ascertained for the multiple services addressed. By use of virtual but realistic data-sets, effects of alternative forest management strategies forming an intensity gradient are quantified for multiple services. For the environmental services the untouched natural forest reserve serves as a reference. Wherever possible, response functions are deduced to couple the various services via stand level data to demonstrate trade-off and harmonic relationships between the services. The virtual forest management units are representing Central European forest ecosystems in the sub-mountain vegetation zone under a humid-temperate climate with acidic soils. Norway spruce and European beech are the dominating tree species. Management units comprise all development phases in the sense of a Normal Forest Model. Today, only few attempts have been made to illustrate and evaluate quantitatively synergies and trade-offs between the goods and services. It is clearly illustrated that maximizing biomass production and carbon sequestration rates may be in contrast to maintaining protection of authentic biodiversity. Several operations may, however, have positive effects on biodiversity and water protection without high costs. We also illustrate that water quality and quantity, and maintenance of future soil fertility may be affected either positively or negatively by several forest management operations. Water quantity can be influenced by forest management only within a narrow range. For the virtual forest in a humid climate differences of 100 mm per year in runoff are negligible. Under dry continental conditions, however, such differences may have important implications for groundwater formation.

CONTENT

I. Introduction

Wood production and economic yield are important objectives of forestry which are achieved through intervening into natural processes. However, forest ecosystems provide a multiple of viable functions which are increasingly valued by society (ref to the Helsinki process. Fx http://www.mcpfe.org/filestore/mcpfe/publications/pdf/FE_EN.pdf). Over time, various models of forest management ranging from "exploitive" to "back-to-nature" systems have evolved, all intended to fulfil requested goods and services (Hunter, 2001; Seymour et. al. 2001; Gamborg & Larsen, 2003). Contemporary sustainable forest management aims to ensure that goods and services derived from forest meet present-day needs while at the same time securing their continued availability and contribution to long-term development. As such, forest management requires prudent management in order to conserve essential ecosystem services as soil and water quality. Further, additional forest values, such as carbon sequestration, maintenance of biodiversity or recreational value, are to be considered as well. One of the most important questions for the future is how to manage the forest for timber production while conserving at the same time important environmental services.

In order to develop and implement such strategies, it is of importance to anticipate the long term effect of alternative forest management approaches on the status and dynamics of forest ecosystems. In order to achieve specific objectives, forest management acts through coherent sets of silvicultural operations at the stand level. This implies purposeful manipulation of one or more key parameters, i.e. tree species composition, stand density and age structure, stand edges, or site resulting in a changed ecosystem (Duncker et al 2010).

The quantification to which extent forest management affects different forest functions has been subject to countless studies. Although empirical studies often face a large number of factors difficult to control, they provide solid knowledge for model formulation. Accordingly, scenario modelling aims to describe stand evolution under complex alternative silvicultural regimes. It allows predicting physical and financial productivity measures (Hasenauer, 2006). In a recent comprehensive review the impacts of silvicultural operations on environmental services are evaluated and responses described (reference WP2.2 D2.2.2). The environmental services observed include biodiversity, soil quality, carbon stock and sequestration, water quality and water quantity. The corresponding impact of silvicultural operations is evaluated by use of an indicator concept (more references from WP2.2 work). Since the responses are related to key stand parameters, altered by silvicultural operations, they can be integrated into scenario modelling. Thus, model evaluation is applicable for comparative impact analysis of management alternatives on forest functions.

In case of conflicting objectives segregation by forest function on landscape level might seem appropriate. Concerning the maintenance of biodiversity one possibility might be to set aside ecological reserves with strict protection. Without reducing timber harvest this requires a compensatory increase in production elsewhere. Where such increase in timber yields are possible, timber lost from setting aside landscape in ecological reserves could be replaced by timber from a small area of land dedicated to intensive production silviculture. Embedded in a predominant matrix of ecological forestry this forms the vision of a landscape triad as for example formulated for Maine (Seymour and Hunter, 1992; Seymour et. al. 2001). This vision intrinsically implies that there is no best single solution combining all functions. However, one problem with this strategy is that large areas are required to conserve viable populations, and that nature reserves eventually become isolated islands in the landscape (references). Further, identified responses of environmental services to silvicultural operations enable to integrate appropriate conservation measures in forest management approaches. In case of preserving biodiversity this might include the retention of habitat elements such as coarse woody debris (CWD) or veteran trees (Lindenmayer et al. 2006) and emulation of natural disturbances (Bengtsson et al. 2000). Further, maintaining soil and water quality requests reduction of nutrient losses, e.g. through harvesting of stem wood only instead of whole tree harvesting (Raulund-Rasmussen et al., 2007). In case of nitrogen saturation, surplus nitrogen may however be removed with biomass to decrease nitrate pollution of seepage water.

Much in contrast to carbon sequestration rates being a harmonic objective to high amounts of merchantable timber production, measures of maintaining soil quality and biodiversity may reduce timber production. However, opportunity costs might actually be modest. Reversely, a management objective might emphasize the economic interest possibly at the expense of an accordingly higher impact on the environmental services. However, this is to be ascertained through quantifying the impact on the multiple forest functions addressed.

Only few studies have tried to quantify the impact of different forest management decisions on several forest functions. In a recent study Weslien et al. (2009) did set up a system of coupled models to analyse the effects of shorter rotation lengths in boreal forests on C-sequestration, water quality and CWD. The concluded …..Further investigations must be cited.

The objective of this study is to reveal synergies and trade-offs by quantifying the impact of five different forest management alternatives (FMA) on selected production as well as environmental services, i.e. merchantable timber production, land expectation value, biodiversity, water quality, water quantity, soil fertility, carbon sequestration and carbon stock. The impact analysis is based on simulation of a virtual reference normal forest located in a central European beech forest vegetation zone. The forest management alternatives are forming a gradient from non intervention to intensive silvicultural systems which includes a change from European beech to Norway spruce management. The quantification of impacts further allows a balancing of the supply of forest functions through selecting appropriate management intensity being subject to multi-objective forest planning (Pukkala, 2002).

II. Materials and methods

A. Site and stands

The virtual forest management units are representing Central European forest ecosystems in a humid-temperate climate with acidic soils, and Norway spruce and European beech as dominating tree species. The management unites are thought be located in the South-western part of Germany, in the sub-mountain vegetation zone around 500 meter above sea level. The soil is a Dystric Cambisol developed on granite/gneiss material. Slight podzolisation takes place, particular under conifers. The sandy loam soil is well drained. Soil physical properties and species specific rooting patterns, both important parameters for hydrological modelling, have been estimated based upon results for similar site conditions (Table x). pH is low and the nutrient contents are modest (Table). In contrast, nitrogen availability is relatively high mainly due to nitrogen deposition (Table) having its origin in cattle farming and industrial emissions. In consequence, soil C/N ratios are moderate to low (<25) indicating that soil N retention will be low or negligible. The sub-oceanic climate provides for a yearly sum of precipitation of 1050 mm and an average air temperature of 8 ºC with modest summers and rather mild winters.

It is assumed that the site has been forested for a long time since last glaciations with European beech (Fagus sylvatica L.) being the dominating tree species. The forest community (flora type) and the potential natural vegetation is Luzulo-Fagetum (Ellenberg, 1996). The site quality provides favourable growing conditions for European beech close to its potential optimum. Regional yield classifications result in a site index (H_{100}) of 32 m (top height at age 100) for European beech and 35 m for Norway spruce (Picea abies [L.] Karst.), respectively. Accordingly, yield is assumed to be 8 $m^3 ha^{-1} y^{-1}$ for beech and 13 $m^3 ha^{-1} y^{-1}$ for spruce (Landesforstverwaltung Baden-Württemberg, 1993).

B. Forest Management Alternatives

Forest management alternatives are characterised by their approach and objectives from which essentially coherent sets of forest operational processes at the stand level emerge (Duncker et al 2010). The implementation of a forest management approach includes a range of options in silvicultural operations along the management cycle throughout the stand development phases. The purposive implementation of forest operations requires coming to basic decisions. These decisions relate to manipulation of stand key parameters, i.e., tree species composition, stand density and age structure, stand edges, and site conditions, as well as entry and discharge (import/export) of energy and matters. Alternative forest management strategies are differentiated by limitations in acceptable intervention and controlling of natural processes and conditions. These limitations which are to be considered in the decision making are set as so-called “basic principles”. In order to analyse the effect of different management strategies on goods and services provided by the virtual forests five alternative forest management approaches (FMA) are defined by the general management objective and the corresponding principles. The FMAs form a gradient from passive to high forest management intensity. The following descriptions of FMAs allow for an increasing degree of freedom in possibly applied silvicultural operations. They provide the general guidelines for simulating corresponding stand developments.

1. “Unmanaged forest nature reserve” in passive intervention forest management (FMA1)

The main objective of an unmanaged forest nature reserve is to allow natural processes and natural cycles to develop without management intervention to create natural ecological valuable habitats and biodiversity. The forest is set aside for this sole purpose, as well as a study object in basic research, and may be protected by an ordinance or forest act. No operations are allowed in a forest reserve that might change the nature of the area and it has a history of development without direct management or exploitation resulting in various qualities of naturalness (Peterken, 1996; Sprugel, 1991). The no intervention philosophy is applied in a strict sense. Thus, even treatments are excluded that are occasionally undertaken elsewhere if natural disturbances such as fire, pest, invasive species, etc were affecting the area.

2. “Close-to-nature forestry” in low intervention European beech management (FMA2)

The objective is to produce valuable timber with the emulation of natural processes as a guiding principle. Economic interests are valid within the framework of close-to-nature forestry but must occur within this principle. Biological legacies and natural biotopes as well as habitat trees are promoted inside the stand and have to remain on the site. European beech is chosen for timber production as being the dominating tree species in the potential natural vegetation. The preferred method of regeneration is natural regeneration. Planting is only done to complete natural regeneration, and genetic engineered planting material can not be used. Site cultivation, fertilization or liming is not applied. The final harvesting system is target diameter harvest of individual trees over a period of 40 years in order to initiate natural regeneration of beech. The target diameter is chosen to be 65 cm at breast height which shall be reached with 60 future crop trees per hectare.

Due to the risk of red heartwood formation target diameter is to be reached within 120 years. The crop trees are released in thinnings from above. Only trunks are allowed to be extracted from the stands while branches and leaves are left on site to stay within in the nutrient cycle. Habitat and biodiversity protection is incorporated by selection of single trees to be left in the stand. In practical forestry, those are often of low quality, damaged, non productive or rare species, of special habitat, or veteran trees. This was implemented in the model as leaving 20 % of the area unmanaged.

3. "Combined-objective forestry" in medium intervention European beech and Norway spruce management (FMA3)

The objectives are combined emphasizing economic return while respecting ecological and social services. Contrary to low intervention (close-to-nature) forestry, Norway spruce can be chosen for economic purposes on sites where it does not occur originally. European beech and Norway spruce are only managed on adequate sites. The preferred method of regeneration is natural regeneration. If planting is necessary to introduce European beech or Norway spruce into a devastated forest or to change the managed species, planting is done, but no genetic engineered planting material is used. In this study it is assumed that beech regeneration needs to be fostered by planting of 2000 trees per hectare. Mixture type is group wise to promote self pruning processes in beech. There is no site cultivation or fertilization. Pest control is usually not performed. The final harvesting system is a target diameter harvest as group harvest over a period of 20 years. Target diameter for beech is 55 cm to be reached with 100 future crop trees per hectare and 50 cm diameter with 150 crop trees in spruce respectively. The future crop trees are released in thinnings from above starting at top height of 12 m. Due to the risk of red heartwood formation target diameter is to be reached in beech within 120 years. Only pole sized solid wood is utilized while branches, twigs and leaves stay in the stand within the nutrient cycle. Habitat and biodiversity protection is incorporated by leaving 5 % of the area unmanaged mainly as leaving all dead wood, big trees (beech > 100 cm dbh), old trees (> 150 years), trees with holes and unusual tree species in the final cutting.

4. "Even-aged forestry" in high intervention Norway spruce management (FMA4)

The main objective with even-aged forestry is to produce timber and profit in monocultures. Ecological objectives are pursued within the legal framework and if they are not cost intensive (mixed-in species, deadwood). Still, sustainability and environmental protection are important in this management objective. National "Best Management Practices" limit the possible operations, allowing for a sustainable and not environment damaging management. Norway spruce is planted in a density of 3000 trees per hectare. The planting material can be genetically selected, but is not genetically modified. A low percentage of mixed-in species (less than 20 %) is tolerated, preferably in groups over the stand. Successional elements are only used if some parts of the stand did fail, and no economic loss is associated with it, otherwise they are replanted. There is no site preparation or fertilization, and liming is only applied to compensate for intensive use of biomass. Chemical agents are used to a minimum necessary to treat pest. The final harvesting systems are stripe wise clearings once the economic objective is maximized, i.e. land expectation value at 3 % interest rate. Around 250 trees are released in strong thinning grade from below. Only pole sized solid wood is utilized while branches, twigs and leaves stay in the stand within the nutrient cycle.

5. "Wood biomass production" in intensive intervention Norway spruce management (FMA5)

The main aim of management is to maximize the woody biomass production of both, saw logs for the construction market using even-aged management regimes and the removals from small dimension thinnings and woody residues as biomass for the woodfuel market.

Site preparation and planting will be the normal methods of regeneration, with chemical weed control being used as required. Planting density and thinning regime are thought to be identical to FMA4 in order to ease cross comparison. However, in addition to solid wood harvesting practised in FMA4, about 80 % of the branches, needles and woody tops (slash) are chipped and recovered as woodfuel. Patch clear felling is the normal silvicultural practice.

C. Growth, production and its economic value

The actual growth of beech and 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 thinning intensity. 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 1963). The tree-level diameter growth rate is modelled in the initial step as a function of the relative cumulative diameter distribution. The growth rate is mediated by stand age, basal area and intra-stand competition. The stand level basal area increment model predicts growth as a function of site index, stand age, quadratic mean diameter and basal area. The two models are combined through the variance- and covariance-based combination approach of Bates and Granger (1969). Growth and mortality are calculated in annual steps or a multiple of it. (Yue et al., 2008) are describing the concept in much detail and provide a comprehensive model evaluation. Input data for the model are, besides site index and stand age, a list of sample trees with their breast height diameter (dbh) and height. Where empirical data on sample trees are missing Johnson curves (Elderton and Johnson 1969) are used to generate diameter distribution based on stem number, basal area, age and mean height. This was applied to initiate stands for simulating the forest development under the treatment regimes representing the considered forest management alternatives. Stand development was modelled for a whole rotation period which is further assumed to represent a virtual normal forest of size 100 hectare. Some management alternatives imply a prolonged period of regeneration cuttings intended to stimulate natural regeneration. In this case, regeneration was assumed to establish and to develop under the canopy of the former stand. It was assumed that the phase of overlapping generations accounted for half of the prolonged period of regeneration cuttings which shortens the rotation length to repeating phases of individual management classes. This time needs to be considered in allocating the reference normal area to the age classes (Assmann, 1961).

The productive function of the forest was assessed in merchantable wood volume production which refers to solid stemwood, and in case of beech to branch wood above a minimum diameter of 7 cm at the smaller end over bark. The different FMAs were compared in mean annual increment (MAI_u [$m^3\,ha^{-1}\,y^{-1}$]) being gross yield of merchantable wood per hectare at end of rotation divided by rotation length. In addition, land expectation value (LEV) sensu (Faustmann, 1849) was calculated to assess the economic yield from wood production in the management alternatives. LEV is a common discounted cash flow method applied to value timberland (Straka and Bullard, 1996) and was calculated for interest rates from 1 to 5 %. The cash flows integrated in LEV resulted from forest operations, e.g. planting, tending, thinning or harvesting. Applied planting costs in spruce FMA5 and 4 were 2,300, as well as 2,100 € ha^{-1} in beech FMA3. Tending costs were 500 € ha^{-1} at ages 5 and 15. The cash flows for thinning or harvesting operations were estimated by sum-of-products of volume and net return per cubic metre of cut trees. The net revenue per m^3 at roadside for medium quality round wood according to the mean prize level of period 1995 – 2005 was described as a function of dbh and is provided in Fig. 1 (Duncker & Zell, 2009). Chipped residues incurred in FMA5 are assumed to provide for a net revenue roadside of 5 € per loose cubic metre. Fix costs have not been considered in LEV calculation, accordingly the LEV for FMA1 and set aside areas are zero. The later is proportionally accounted for in FMA2.

D. Carbon

Carbon stock and sequestration are obtained by converting the volume growth referring to solid wood as estimated with W+ to ecological productivity measures with generic biomass functions for spruce (Wirth et al., 2004, Eckmüllner, 2006) and beech (Wutzler et al., 2008). These functions are applied to estimate dry mass in different tree compartments, i.e. foliage, branch, stem and root biomass respectively, based on individual tree and stand variables.

While the annual amount of harvested carbon within the FMAs is the sum of carbon in all extracted biomass over a stand generation divided by mean production time, mean carbon stock per hectare is estimated as the total sum of carbon in dry masses for the different above ground tree compartments divided by mean production time. It is generally assumed that carbon accounts for 50 % of biomass (Knigge & Schulz, 1966). Mean carbon stock in dead biomass is estimated by multiplying mean amount of deadwood with a mean carbon density of 122 kg m-3 in deadwood (Vesterdal and Christensen, 2007). The accrue amount of deadwood itself was simulated with the mortality model implemented in W+ (Yue et al., 2008). Further, harvest residues left on site consisting of stumps, branches and tree tops are added in case of stem wood harvesting only. The coarse woody debris was split in two dimensions, i.e. basically solid stem wood with diameter > 10 cm and remaining above ground biomass usually smaller than 10 cm. Mean amount of coarse woody debris in two fractions is calculated as dynamic equilibrium of mean annual accrue amount of deadwood and constant decay rates (Zell et al., 2009). These decay rates for the two fractions of spruce and beech are estimated with a mixed model including July temperature and annual sum of precipitation (Zell et al., 2009). Annual ephemeral losses of twigs and branches are not considered.

Mean annual carbon sequestration rates are calculated according to a proxy of net primary production (NPP) within the FMAs. This proxy of NPP is defined here as net growth and turnover of individual trees without ephemeral losses of foliage, branch or root biomass as trees grow. This measure is an intermediate of NPP, where only respiration is subtracted from grossproduction, and net growth (NG_{total}) as defined by Pretzsch, 2009. NPP is expressed as mean annual carbon sequestration in dendro biomass per hectare.

E. Water

To visualize the effect of tree species, rotation length and thinning regime, the hydrological model BROOK90 (Federer, 1995) was used to calculate water balances for the generic forest systems. Parametrization was based upon experience from experiments where the model was thoroughly tested (e.g. Katzensteiner, 2000, Schume et al. 2005). Leaf areas (single sided, projected) have been calculated for the different development stages for beech according to (Hietz et al., 2009). For spruce, leaf area was estimated from needle mass using a variation of specific leaf area depending on social position of trees (Eckmüllner and Sterba 2001). Maximum canopy conductance per unit leaf area was set to 0.25 for spruce and 0.45 for beech. Albedo was set to 0.14 for spruce and 0.20 for beech. For snow cover albedo was set to 0.23 (spruce) and 0.3 (beech). To simulate the effect of clear cut and herbaceous vegetation in the clear cut phase of spruce for even aged forestry, a decreasing conductance from 0.4 to 0.25 in the first 10 years and an increasing albedo from 0.15 to 0.23 in the first four years, decreasing then to 0.14 over the next six years were assumed according

to Katzensteiner (2000). For the clear cut stage in FMA 5, assuming bare soil in year 1 and 2, LAI was set to 0.1, albedo was allowed to increase from 0.05 in year 1 to 0.15 in year 10.
For the unmanaged forest nature reserve a lignomor of 70 mm thickness and a high proportion of intercepting dead wood (high ratio of stem area index to height) was simulated. Soil physical properties and rooting patterns are described in table 4.

A 10 years generic time series of weather records on a daily basis has been developed, using data from Deutscher Wetterdienst - Station Beerfelden (http://www.dwd.de) and Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg -Station Heidelberg (http://www.fva-bw.de/monitoring/index9.html) for the years 1997 to 2006. This way a realistic dataset including information on precipitation, radiation, temperature, vapour pressure and wind speed, including both dry and wet years could be used for further modelling. The 10 years time series was repeated over the rotation length and thus applied for every stand development stage (year) for every forest management alternative. Average output over the rotation length of water consumed (evapotranspiration) and seepage below the root zone (Q) is given in table 5. The reaction of mixed stands has been calculated as a weighted average of the output for respective development stages of pure stands.

We use NO_3 concentration in the water leaving the root zone as an indicator for impact on water quality (Gundersen et al. 2010) since high NO_3 concentrations are not desired in surface and ground water. Furthermore, NO3 leaching contributes to soil acidification and in acid soils are NO_3 concentrations correlating with concentrations of plant toxic aluminium (Al3+) and some heavy metals (Gundersen et al. 2010). The NO_3-N concentration is calculated based on a rotation scale N mass balance i.e. as the cumulative input of N over the rotation minus the cumulative removal of N in harvested products divided by the volume of water draining the stand as estimated above (N-dep – N-removal)/run-off. This implies that the incorporation of N in soil organic matter over the rotation is negligible, which is expected with the mineral soil C/N ratio below 20 at the site (Gundersen et al. 1998). The calculated NO_3-N concentration will likely approximate the concentration observed in mature stands (age c. 20 to harvest) and will also be a reasonable estimate for the average NO_3 concentration over the whole rotation (Gundersen et al. 2010).

F. Nutrients and acidity

Removed amount of nutrient through harvesting was approximated by multiplying the average nutrient concentrations within different tree compartments and their corresponding dry masses (Jacobsen et al., 2002). The later were estimated with generic biomass functions for spruce (Wirth et al., 2004, Eckmüllner, 2006) and beech (Wutzler et al., 2008). Average annual nutrient export is calculated for the harvested stem wood including bark. In addition, for spruce FMA5 the nutrient content within exported harvest residues assumed to be 80 % of foliage and branches is added. For beech in FMA2 the export is proportionally reduced by the set asides area for conservation (20 %).

Input to the systems originating from deposition is defined based on typical amount in the region (www.fva-bw.de). It assumed that input to spruce is 1.5 times input to beech (Table x). To illustrate the effect of harvesting and of beech versus spruce in the various FMA’s deposition minus export is calculated. The acidifying effect of biomass harvesting is estimated as the sum of calcium, magnesium and potassium on equivalence basis (Hansen et al., 2010).

G. **Biodiversity**

The amount of deadwood was simulated with the mortality model implemented in W+ (see above). In addition, harvest residues consisting of stumps, branches and tree tops are added in case of stem wood harvesting only. The coarse woody debris was split in two dimensions, i.e. basically solid stem wood with diameter > 10 cm and remaining above ground biomass usually smaller than 10 cm. Mean amount of coarse woody debris in two fractions is calculated dynamic equilibrium of mean annual accrue amount of deadwood and constant decay rates (Zell et al., 2009). Decay rates for spruce and beech for the two fractions are estimated with a mixed model including July temperature and annual sum of precipitation. Annual ephemeral losses of twigs and branches are not considered.

The biodiversity values of different FMA were measured by using biodiversity scores. There have been many different attempts finding methods for biodiversity evaluation of different forests (Drakenberg & Linde 1999, Gustafsson et al. 1999). All attempts to use biodiversity scores in practical conservation work are based on the idea that structures in the forests which are important for rare or read-listed species (old trees, big trees, dead wood etc.) are given scores. The assumption behind is that if the forest contains habitats for rare or red-listed species all natural occurring species will survive, and the forest should have high conservation values. In our study we have based our biodiversity scores on Möller (20xx), which is developed for measuring biodiversity values in nemoral forests. However, because this study is based on simulations instead of real inventories we had to adapt the biodiversity scores for our purposes (table x). The most important variables selected in our study were abundance of dead wood, number of big trees, number of tree species, area of woodland key habitats (which in our case is the same as area of set aside).

III. Results

The results are summarised in Table 5 illustrating the effects of the FMAs for all indicators.

A. Merchantable wood volume production and land expectation value

The merchantable wood production as expressed in MAI_u on a stand level is highest in spruce FMA4 and 5 and lowest in beech FMA2 (see **Error! Reference source not found.**). MAI_u in beech FMA2 accounts for about 54 %, or 68 % if the managed part is considered only, compared to spruce FMA4 and 5. Due to different wood density of beech and spruce mean annual net primary production (NPP) differs to a smaller extend between the FMAs. Here, the productivity in beech FMA2 accounts for 92 % of the highest NPP achieved in spruce FMA4 and 5 (see **Error! Reference source not found.**). The ranking of FMAs in land expectation value (LEV) is strongly sensitive to assumed interest rate. The ranking does only coincidence with corresponding volume productivity at low interest rates (see **Error! Reference source not found.**). In spite of providing for highest merchantable wood production, LEV is lowest in spruce FMA4 as soon as interest rate is higher than 2 %. As demonstrated in FMA5, additional extraction of harvest residues for woodfuel production can only compensated for this effect until an interest rate of 3 %. As soon as interest rate is higher than 3 % beech FMA2 is favourable in resulting at the lowest negative LEV compared to the other alternatives.

B. Carbon storage and export

The carbon stock in living biomass is clearly largest in the untouched forest reserve (FMA1) due to the no harvesting regime whereas the other FMAs only show minor differences (Table). The carbon in dead stocks is of similar magnitude in FMA2, 3 and 4, but significantly higher in the reserve due to no harvesting and clearly less in FMA5 due to removal of residues as well. The assimilated carbon (NPP-proxy) is of same magnitude for all the 5 FMAs whereas carbon removal significantly increases from 0 in the reserve to an amount almost corresponding to the assimilation in FMA5. The difference between assimilated and harvested carbon is left in the ecosystem for decomposition and for a minor part giving origin to the dead stock.

C. Water

Due to the cool humid climate with high precipitation rates and low evaporative demand there is a water surplus around 600 mm and only minor relative differences between the FMA's (Table x). The lowest run-off is seen in FMA4 and 5 due to higher evapotranspiration loss of spruce compared to beech. The nature reserve FMA1 has a lower run-off than the two other beech alternatives (FMA2 and 3) due to absence of clear cut regeneration characterised by high run-off. At the scale of single forest stands there is a clear relation of water consumption with stand age, stand structure and leaf area (Figure x).

Water quality indicated by nitrate concentrations in seepage below the root zone is not affected much by the FMAs. Estimated concentrations (1.2-3.3 mgN l^{-1}, Table X) are well below the drinking water standard at 11 mgN/l (50 mg NO_3 l^{-1}) because of the relative high seepage amount in the region studied. Since the seepage amounts only vary c. 10 % among the FMAs the differences in nitrate concentrations mainly reflect the differences in N surplus among the FMAs (6-18 kgN ha^{-1} yr^{-1}, Table X).

D. Nutrients and acidity

For all FMA's more nitrogen is deposited than exported in harvested products. The surplus is related to tree species where spruce has a higher surplus than beech due higher deposition rates, and to the degree of harvesting where especially high surplus in the reserve and low surplus in the very intensive FMA5 should be noticed. The other elements all show higher export due to harvesting than deposition except for the reserve where a small positive balance is seen for all elements. Especially the very intensive FMA5 shows much higher export than deposition. The acidification due to harvesting is of equal size in FMA2, 3 and 4 whereas the intensive FMA5 shows almost the double acidification rate. No acidification due to harvesting takes place in the unmanaged reserve.

E. Biodiversity

There is a steep decrease in conservation qualities from FMA1 to FMA4/5 (Table 5, Fig 1), and there is a negative correlation between conservation qualities and Land expectation value (Fig. 2). The abundance of fine woody debris is not decreasing with management intensity, because thinning with extraction of solid wood only creates large amount of fine dead wood in the managed forest. However, the highest conservation values are in general connected with coarse woody debris. While the amount of CWD in FMA2 still comprises about 1/5 compared to the estimated amount in FMA1, no CWD is maintained in FMA4 and 5. Also the mean number of trees with dbh > 60 cm shows the same trend. In contrast, the stands in FMA4 and 5 consist of slightly more midsize trees with dbh > 40 cm compared to the other management alternatives, while the number of big trees, which are more important for biodiversity, is more abundant in FMA1 and FMA2.

IV. DISCUSSION

A. Production and its economic value

The resulting merchantable wood volume productivity of the FMAs differs from the yield quality assumed for simulation. The yield quality, which was 8 and 13 $m^3 ha^{-1} a^{-1}$ for beech and spruce, is estimated for a 100 year rotation. The actual production times within the FMAs are about 15 to 20 years shorter in spruce and respectively longer in beech. In addition to this production time related effect, the stand density regime within the FMAs influences volume productivity of spruce and beech (Pretzsch, 2004; Skovsgaard and Vanclay, 2008). The reduced volume productivity of spruce within FMA3 compared to FMA4 (MAI_u 11 vs. 14 $m^3 ha^{-1} a^{-1}$) likely has its origin in the strong crop tree oriented thinnings, as demonstrated with empirical data (Herbstritt et al 2006). These productivity figures are related to one stand generation only and thus are a conservative estimated for the estate level. The prolonged regeneration cuttings in FMA3 and 2 with natural regeneration under canopy lead to overlapping stand generations. This effect increases mean annual volume production on forest estate level to 11.3 $m^3 ha^{-1} a^{-1}$ within the managed part of beech FMA2, as well as to 10.8 and 12.6 $m^3 ha^{-1} a^{-1}$ for beech and spruce in FMA3 (Assmann, 1965).

Beside the discussed effect on volume productivity the production time strongly influences LEV through consideration of interest rates. Ideal wise, mean production time is coincident to point of LEV culmination. The simulated mean production times of the FMAs are close to the point in time of LEV culmination at interest rate 3 %. However, they are about 15 to 20 years past the LEV culmination point at interest rate 5 %. Though, this effect had not changed the ranking of the FMAs.

For calculating LEV net timber revenues had to be assumed. The assumed revenues are estimated on basis of observed prices in period 1995-2005 for medium wood quality road side. As such, they are a pessimistic estimate concerning the value of the crop tree assortment structure in FMA3 and 2. Especially for beech, crop tree oriented thinning approaches result in increased amounts of high quality timber (Hein et al., 2006). For spruce the same effect has to be assumed but to a minor extend. Although, net revenues are stagnating with dbh > 50 cm, it is noteworthy that the management approach for spruce within FMA3 considered for itself is resulting in highest LEV of 7.100 down to 298 € ha^{-1} for interest rates from 2 up to 5 %. This finding is well in agreement to economic comparisons of alternative approaches for spruce revealing the advantage of crop tree oriented approaches (Kohnle and von Teuffel, 2004). For the same range of interest rate, beech management according to FMA2 is favourable against beech under FMA3, even including the 20 % set aside areas. However, beech management never reaches the possible LEV from spruce management at any given interest rates.

Beside cash flows from thinning and harvesting operations, costs for stand establishment influence LEV. In case of beech, LEV had levelled out between FMA3 and the managed part of FMA2 when plantation costs were avoided in FMA3. The differences in LEV are higher between the spruce alternatives. They had allowed to hypothetically spent 1160 € ha^{-1} for regeneration in FMA3 at interest rate 1 %, and even 2440 € ha^{-1} at 5 % respectively, until the LEVs of FMA4 were achieved.

B. Carbon

The carbon stock in living and dead biomass found in the reserve in this study is of same magnitude as found in an assessment of a Danish seminatural beech forest (Vesterdal and Christensen, 2007). Likewise, the carbon stocks of living and dead biomass are also of the same magnitude as found in conventional nemoral forests. Opposite to storage, highest amount of carbon is extracted from the intensive FMAs illustrating a clear trade-off between storage of carbon in the system and export from the system. Whether storage in the system or export of carbon, serve global carbon balances and impact on climate best, depends on the fate of exported carbon. Exported carbon substituting fossil fuel in energy production will definitely have the best climate change impact. In its essence, oxidation of woody material can take place in the forest for the benefit of biodiversity, or in the power plant for the benefit of humans and climate.

Carbon stock in the soil is not considered in this study because we have no reliable models available and because the effects of FMA's may be of minor importance (Johnson and Curtis, 2001; Pistorius et. al., 2006). Model results indicate, however, that soil organic carbon will decrease as a result of intensive harvesting (Reference). Recent investigations in the field seem to support the modelling results (reference).

C. Water

At the scale of a 'normal forest' the FMA effects are levelled out to a great extent. So the differences in runoff for the different FMA's are quite unspectacular. There is a clear difference between the coniferous forest FMA's with higher water consumption and the broadleaf-dominated FMA's with higher run off (run off stands for total water surplus, independent of water pathways). When comparing the results with other comparisons of beech and spruce e.g. from Solling (Benecke, 1984) under similar climatic conditions, one has to be aware, that in case of our study the higher consumption of pole stage and mature spruce stands is partly compensated by higher runoff in the clear cut stage. The nature reserve has an intermediate position. Continuous cover and high interception rates of coarse woody debris are most likely responsible for this response.

The fact, that the generic model approach shows low differences for our virtual forest must not be generalized. In case of dry continental climate even 70 mm difference in seepage per year will have a pronounced impact on groundwater formation. Under such conditions transpiration rates may even be higher.

Despite the relative high N deposition in the region our estimated nitrate concentrations (1.2-3.3 mgN/l, Table X) were relative low across FMAs. Concentrations observed at monitoring plots in the region that we exemplify are in the same range (ref. to FBW data). With a precipitation at >1000 mm high nitrate concentration over longer periods are unlikely. However had the precipitation been 650 mm the FMAs 1 and 4 would have nitrate concentration above the drinking water standard. Although the nitrate concentration per se is low, the estimated N leaching (i.e. the N surplus of 6-18 kgN/ha/yr, Table X) is high for managed forests in Europe (Dise et al. 2009) and implies a soil acidification by 0.4 to 1.3 keqv/ha/yr similar to that caused by biomass removal (Table X). The marked reduction in N surplus estimated going from FMA 4 to FMA5 illustrate the possibility to counteract effects of N saturation by increasing the biomass removal. This may be an option on fertile sites where base cations are in ample supply or at sites where nutrients are recycled by wood ash fertilisation.

D. Nutrients and acidification

Input of elements due to deposition exceeding export in harvested biomass may either cause accumulation in the soil or leaching to the water system. Oppositely, export in biomass exceeding deposition has to be compensated by release from the soil taking place either as weathering or as a decrease in pools available for plant uptake (Raulund-Rasmsusen et al. 2007). In our virtual study we are facing excess of nitrogen together with shortage of the other elements.

Acidification processes have been studied intensively for decades (Raulund-Rasmussen et al., 2008; Hansen et al., 2010). In this study we estimate the contribution coming from biomass harvesting and the acidification resulting from nitrate leaching.

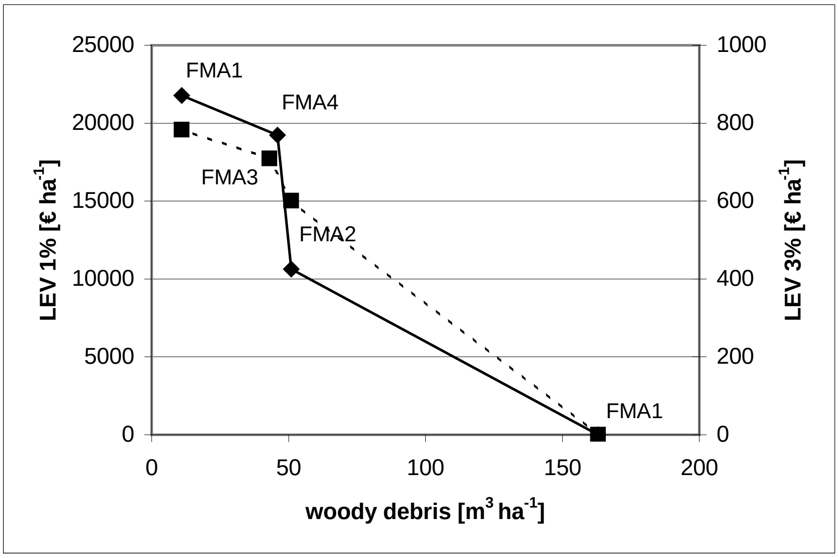
E. Biodiversity

The decrease in conservation value with increasing management intensity, as well as the negative relation between conservation and Land Expectation value, is very obvious. Two conclusions could be drawn from this. First, if the goal is to create opportunities for all species to survive in the landscape it is necessary to set aside some areas for conservation purposes. There are qualities in FMA1 which are lacking in FMA2, and in order to facilitate dispersal and long term survival larger and coherent areas are in general better than small, isolated set asides However, the importance of these factors vary depending on the type of organism you consider (Cabeza 2003). Second, even if some qualities are lost the FMA2-scenario shows that it is possible to combine conservation of important factors for biodiversity with positive economic output. In this scenario important biodiversity qualities remain at the same time as the land expectation value is high.

F. Synergism and trade-offs

The results demonstrate that FMAs effect the considered forest functions and services in different ways. Under the assumed framework conditions, the selection of a FMA maximizing the economic value is dominated by interest rate. Under this single service considered for itself FMA5 were best selection at 1 % rate (LEV_{low}), FMA3 at 3 % and FMA2 at higher rates (LEV_{high}). These approaches intervene into natural processes at decreasing intensity from FMA5 to FMA2. Consequently, all other forest functions and services are responding as well, since they are influenced by tree species composition, stand density and age structure, or import and export of matter too.

The increasing management intensity of FMA4 and 5 clearly minimizes all biodiversity attributes revealing the well known trade-off between maximum volume production and maintaining biodiversity at stand level (Seymour and Hunter, 1992; Hunter, 2001; Seymour et. al. 2001; Gamborg & Larsen, 2003). However, it is shown that maximum volume production does not necessarily coincide with highest LEV. Depending on interest rate, low intervention forestry targeted to produce less volume but of high quality wood turns out better. In FMA2 biodiversity attributes are still negatively affected when compared to FMA1 but they are considerably higher compared to more intense approaches. Accordingly, it is possible to maintain biodiversity in an integrative approach while selecting for best economic result. It becomes rather more the question which attribute level is to be maintained.



solid line = LEV 1% dotted line = LEV 3%

With this graph I want to state that depending on interest rate the same amount of woody debris can be maintained on estate level with different combinations of FMAs. The points always locate 100% area advocated for one FMA… The space in between are linear interpolations. This is intended to be an example how LEV is best fulfilled at constraint level of one biodiversity attribute. Possibly this example could substituted Johnnys consideration.

It is not possible to optimize biodiversity and economic output at the stand level. Both FMA4 and 5 contain almost no biodiversity values. However, at the landscape level it is possible. If the goal is a Land Expectation Value of around 10 000 €/ha (1 % level in Table 5) in combination with biodiversity conservation there are a number of alternatives (Fig. 3). Which one to select depends mainly on what kind of qualities the landowners want to conserve, or which species that are considered, the distribution of the species in the landscape, dispersal abilities etc (reference). This means that not only the proportion of the FMA, but also the spatial distribution is important.

Based on our result, one might argue that the worst alternative is FMA3 (in which 5 % of the area is used for conservation), which seem to be a bad compromise. There are almost no biodiversity values left, but still the economic output is negatively affected.

At first glance it seems easier to recognize that FMA2 leads less to acidification than FMA5. This corresponds to a harmonic relationship toLEV_{high} and a corresponding trade-off to LEV_{low}, respectively. However, this needs to be seen in a wider scope….. Karsten please explain.

Similarly, the effect on the carbon budget is difficult at least to be seen twofold. Reducing carbon stock in dead wood is disadvantageous from a biodiversity point of view. However, high carbon sequestration rates as achieved though selecting FMA5 and possible substitution of fossil fuel is to be seen beneficial when considering CO_2 emissions to the atmosphere

V. Cited references

Assmann, E., 1961. Waldertragskunde: Organische Produktion, Struktur, Zuwachs und Ertrag von Waldbeständen. Bayerischer Landwirtschaftsverlag, München, 490 pp.

Assmann, E., 1963. Vorläufige Fichten-Ertragstafel für Bayern. Institut für Ertragskunde der Forstlichen Forschungsanstalt München, München, 102 pp.

Assmann, E., 1965. der Zuwachs im Verjüngungsstadium. Waldbauliche Probleme in ertragskundlicher Sicht. Cntralblatt für das gesammte Forstwesen, 82 (4), 193-217.

Bates, J.M., Granger, C.W.J., 1969. The combination of forecasts. Oper. Res. Q. 20: 451-468.

Duncker, P., Zell, J., 2009. Die Auswirkung der Berücksichtigung von Nebenzielen auf den Kapitalwert der Baden-Württembergischen Fichtenwälder. Nagel, J. 191-199. 2009. Göttingen, Deutscher Verband Forstlicher Forschungsanstalten. Sektion Ertragskunde: Beiträge zur Jahrestagung 2009.

Duncker, P., Barreiro, S., Hengeveld, G.M., Lind, T., Spiecker, H., Mason, W.L., Ambrozy, S., 2010. A Classification of Forest Management Approaches in European Forestry: A Conceptual Introduction. In preparation.

Eckmüllner, O., 2006. Allometric relations to estimate needle and branch mass of Norway spruce and Scots pine in Austria. Austrian Journal of Forest Science 123, 7-16.

Elderton, W. P. und Johnson, N. L., 1969. Systems of frequency curves. Bd. Cambridge University Press, Cambridge, 216 pp.

Ellenberg,H., 1996. Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht. Ulmer, Stuttgart, 1095 pp.

Faustmann,M., 1849. Berechnung des Werthes, welchen Waldboden, sowie noch nicht haubare Holzbestände für die Waldwirthschaft besitzen. Allgemeine Forst- und Jagdzeitung 1949, 441-455.

Faustmann, M., 1849. [Linnard (tr.) and Gane (ed.) 1968]. On the Determination of the Value Which Forest Land and Immature Stands Possess for Forestry. English Translation in: Martin Faustmann and the Evolution of Discounted Cash Flow (Translated by W. Linnard; with editing and introduction by M. Gane). 1968. Commonwealth Forestry Institute Paper No. 42. University of Oxford: Oxford, England. [Translation republished with permission from Commonwealth Forestry Association in Journal of Forest Economics 1: 1 (1995).]

Federer, C.A., 1995. BROOK90: a simulation model for evaporation, soil water, and streamflow. Version 3.1 Computer Freeware and documentation. USDA Forest Servics, PO Box 640, Durham NH, 03824.

Gamborg, Ch., Larsen, J.B., 2003. 'Back to nature'-a sustainable future for forestry? Forest Ecology and Management 179, 559-571.

Hein, S., Lenk, E. Klädtke, J., Kohnle,U. 2007. Z-Baum orientierte Auslesedurchforstung in Buche [*Fagus sylvatica* L.]: Auswirkung auf Qualität, Sortenstruktur und Wertleistung. Allgemeine Forst- und Jagdzeitung, 178 (1), 8-20.

Herbstritt,S., Kohnle,U., Abetz,P., Kenk,G. 2010. The European Stem Number Experiment in Norway Spruce (*Picea abies* (L.) Karst.). 3. Report. IUFRO Working Party 1.05.05 "Thinning Experiments". Berichte Freiburger Forstliche Forschung, Heft 66. Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg, Freiburg, 132pp.

Hietz, P., Eckmüllner, O., Sterba, H., 2010. Leaf area of beech (*Fagus sylvatica* L.) from different stands in eastern Austria studied by randomized branch sampling. European Journal of Forest Research. In press.

Hunter, M.L., 2001. Maintaining biodiversity in forest ecosystems. Cambridge Univ. Press, Cambridge, 698pp.

Jacobsen, C., Rademacher, P., Meesenburg, H., Meiwes, K.J., 2002. Gehalte chemischer Elemente in Baumkompartimenten. Literaturstudie und Datensammlung. Göttingen, 80 pp.

Katzensteiner, K., 2000. Wasser- und Stoffhaushalt von Waldökosystemen in den nördlichen Kalkalpen. Forstliche Schriftenreihe der Universität für Bodenkultur, Wien 15.

Kimmins, H., 1992. Balancing Act: Environmental Issues in Forestry. University of British Columbia Press, Vancouver. 244 pp.

Knigge, W., Schulz, H., 1966. Grundriß der Forstbenutzung. Paul Parey Verlag, Hamburg und Berlin, 584 pp.

Kohnle, U., von Teuffel, K. 2004. Ist die Produktion von Fichten-Starkholz noch zeitgemäß in Baden-Württemberg? Ertragsvergleich von vier Modellen zur Produktion von starkem und mittelstarkem Holz. Allgemeine Forst- und Jagdzeitung, 175 (9), 171-182.

Landesforstverwaltung Baden-Württemberg, 1993. Hilfstabellen für die Forsteinrichtung. Zusammengestellt für den Gebrauch in der Landesforstverwaltung. Ministerium für Ländlichen Raum, Ernährung Landwirtschaft und Forsten Baden-Württemberg. Stuttgart, 188 pp.

Peterken,G.F., 1996. Natural woodland. Ecology and conservation in northern temperate regions. Cambridge University Press, Cambridge, 552p.

Pretzsch, H., 2004. Gesetzmäßigkeit zwischen Bestandesdichte und Zuwachs. Lösungsansatz am Beispiel von Reinbeständen aus Fichte (*Picea abies* [L.] Karst.) und Buche (*Fagus sylvatica* L.). Allgemeine Forst- und Jadgzeitung. 175 (12), 225-234.

Pretzsch, H., 2009. Forest dynamics, growth and yield: From Measurement to model, DOI: 10.1007/978-3-540-88307-4 2, Springer -Verlag, Berling, Heidelberg.

Pistorius, T.; Zell, J.; Hartebrodt, C., 2006: Untersuchungen zur Rolle des Waldes und der Forstwirtschaft im Kohlenstoffhaushalt des Landes Baden-Württemberg. FZKA-BWPLUS, Forschungszentrum Karlsruhe, Institut für Meteorologie und Klimaforschung Karlsruhe, 211 pp.. http://bwplus.fzk.de/berichte/SBer/ZO3K23004SBer.pdf.

Pukkala, T., 2002. Multi-objective forest planning. Kluwer, Dordrecht. 207pp.

Seymour, R. S. and Hunter, M.L., 1992. New Forestry in eastern spruce-fir forests: principles and applications to Maine. Maine Agricultural and Forestry Experiment Station Miscellaneous Publication 716. 36pp.

Seymour, R. S., 1993. Plantations or natural stands? Options and tradeoffs for high-yield silviculture. Pp. 16-32 in R.D. Briggs, and W.B. Krohn (eds.) Nurturing the North-eastern forest. Proceedings New England Society American Foresters, March 3-5, 1993. Portland, ME. Maine Agricultural and Forestry Experiment Station Miscellaneous Report 382.

Seymour, R.S., and M.L. Hunter, Jr., 1999. Principles of ecological forestry. pp. 22-61. In: Maintaining Biodiversity in Forested Ecosystems. Edited by M. Hunter. Cambridge University Press, Cambridge, UK.

Skovsgaard, J.P. and Vanclay, J.K., 2008. Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. Forestry, 81 (1), 13-31.

Sprugel, D.G., 1991. Disturbance, Equilibrium, and Environmental Variability: What is 'Natural' Vegetation in a Changing Environment? Biological Conservation 58, 1-18.

Weise, U., Kublin, E., 1997. Distanzunabhängiges Wachstumsmodell zur Optimierung der Behandlung von Fichtenbeständen. Sektion Ertragskunde: Beiträge zur Jahrestagung 1997 , 259-278. Deutscher Verband Forstlicher Forschungsanstalten. Sektion Ertragskunde: Beiträge zur Jahrestagung 1997 in Grünberg.

Weise, U., Kublin, E., 1998. Modellierung langfristiger Wachstumsabläufe von Fichtenbeständen. Allgemeine Forst Zeitschrift - Der Wald 53, 422-423.

Weslien, J., Finér, L., Jónsson, J.A., Koivusalo, H., Laurén, A., Ranius, T. & Sigurdsson, B.D., 2009. Effects of increased forest productivity and warmer climates on carbon sequestration, runoff water quality and accumulation of dead wood in a Boreal landscape: a modelling study. Scand. J. For. Res. 24:333-347.

Wirth, Ch., Schumacher, J., Schulze, E.-D., 2004. Generic biomass functions for Norway spruce in Central Europe - a meta-analysis approach toward prediction and uncertainty estimation. Tree Physiology 24, 121-139.

Wutzler, Th., Wirth, Ch., Schumacher, J., 2008. Generic biomass functions for Common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty. Can. J. For. Res. 38, 1661-1675.

Yue, Ch., Kohnle, U., Hein, S., 2008. Combining Tree- and Stand-Level Models: A New Approach to Growth Prediction. Forest Science 54, 553-566.

Zell, J., Kändler, G., Hanewinkel, M., 2009. Predicting constant decay rates of coarse woody debris—A meta-analysis approach with a mixed model. Ecological Modelling 220, 904-912.

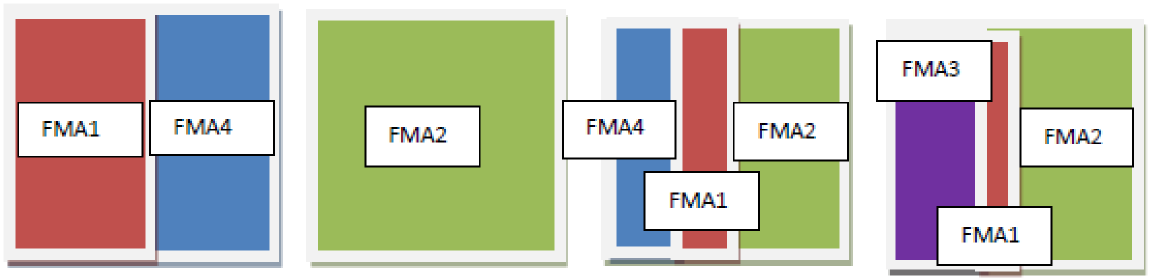


Fig. 3. Different alternatives, with the same economic output, of combining management alternatives in the landscape (see Table 5 for more details). Biodiversity is not only affected by the proportion of each management alternative, but also by the distribution of management alternatives in the landscape.

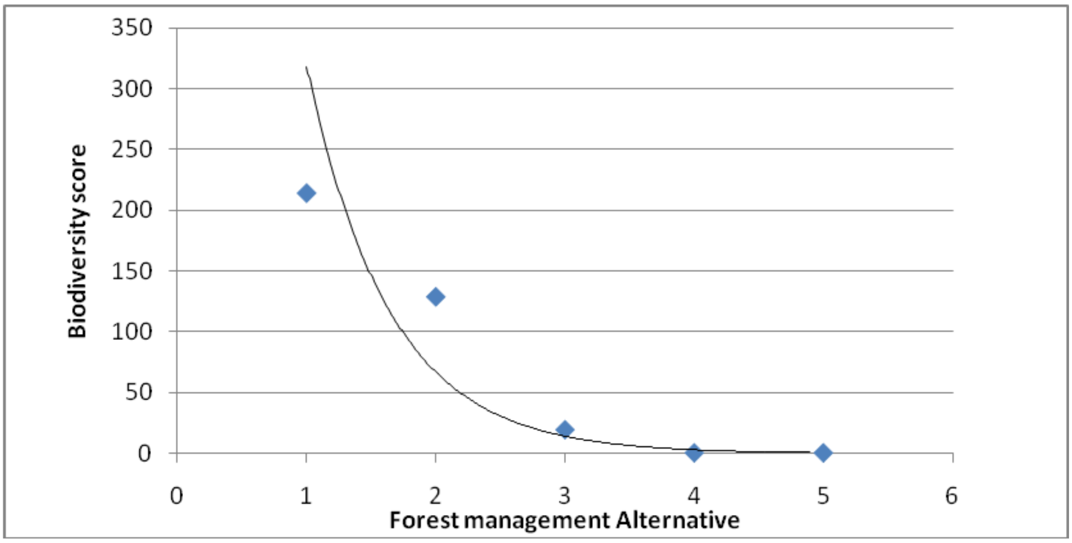


Fig. 1. Relation between Biodiversity score and Forest Management Alternative

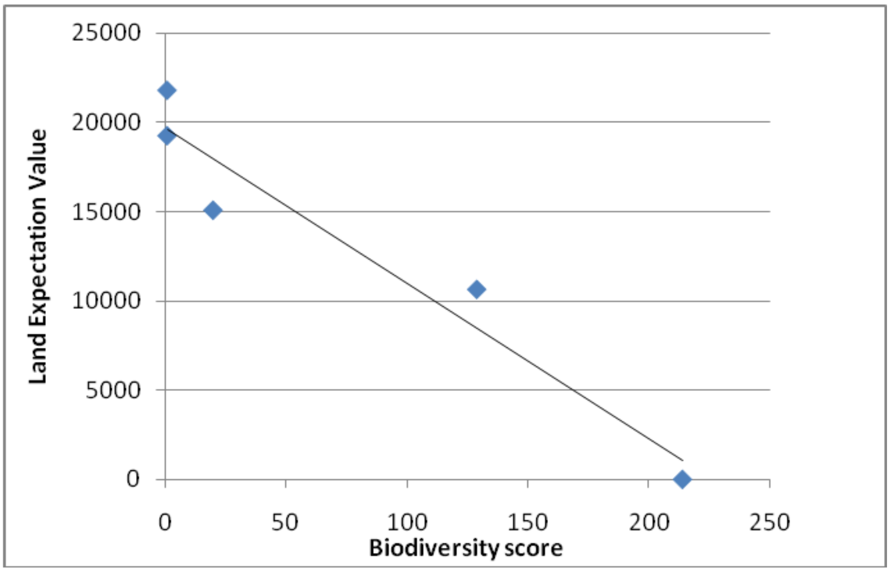
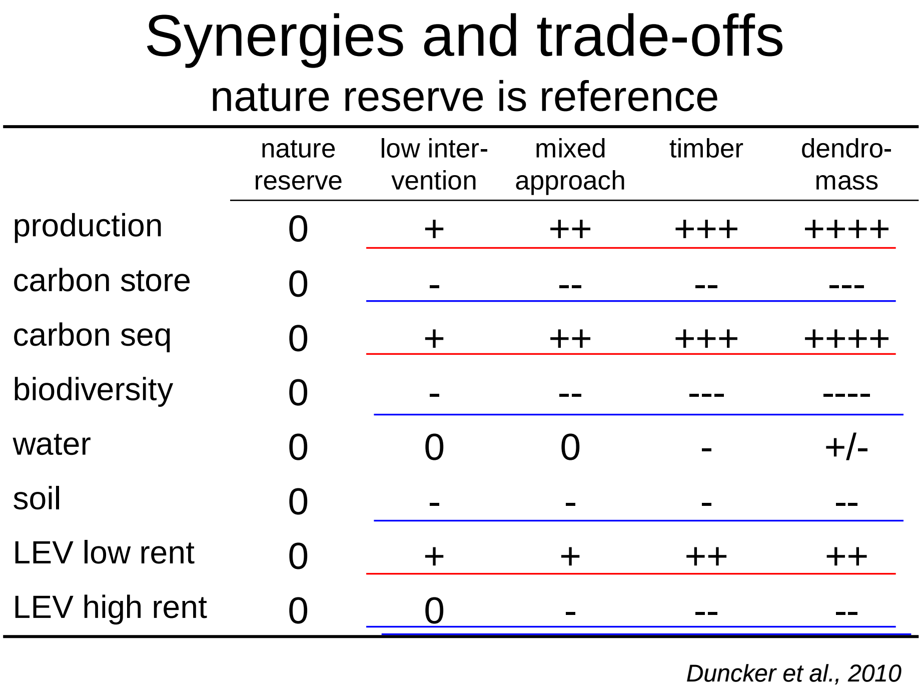


Fig. 2. Relation between Biodiversity score and Land Expectation value

Table/ Figure for inspiration to the Synergy and trade-off discussion



Synergies and trade-offs

nature reserve is reference

	nature reserve	low inter-vention	mixed approach	timber	dendro-mass
production	0	+	++	+++	++++
carbon store	0	-	--	--	---
carbon seq	0	+	++	+++	++++
biodiversity	0	-	--	---	----
water	0	0	0	-	+/-
soil	0	-	-	-	--
LEV low rent	0	+	+	++	++
LEV high rent	0	0	-	--	--

Duncker et al., 2010

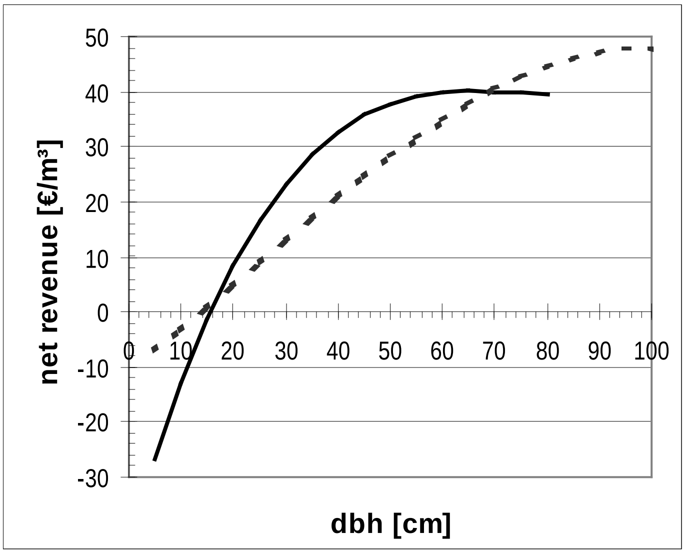


Fig. 1: Net revenue for solid wood [€ m^{-3}] as a function of diameter at breast height (dbh) for Norway spruce (black) and European beech (dottted), medium quality roadside with average prize level for period 1995 – 2005.

Tab. 1: Deposition (open air [kg ha^{-1} y^{-1}]) and storage of nutrients in the top 100 cm of the soil profile [kg ha^{-1}]

	N	P	K	Ca	Mg
Deposition, beech, kg ha^{-1y-1}	20 (17)	0.5 (0.2)	5 (2)	8 (2.7)	1.0 (0.7)
Deposition, spruce, kg ha^{-1y-1}	30 (25)	0.7 (0.3)	7 (3)	10 (4)	1.2 (1.0)
Soil Storage to 1 meter depth, kg ha^{-1}	6000	300	250	400	150

Tab. 2: Productivity measures for the different forest management alternatives at stand level.

Species	**Management**	**Prod. time** [a]	**NPP*** [tC ha^{-1} a^{-1}]	**MAI$_u$**** [m^3 ha^{-1} a^{-1}]	**Land Expectation Value [€ ha^{-1} a^{-1}]**				
					i = 0.01	i = 0.02	i = 0.03	i = 0.04	i = 0.05
Spruce	**FMA5**	81	3,6	13,9	21.771	5.427	783	-1.050	-1.856
Spruce	**FMA4**	81	3,6	13,9	19.232	4.237	64	-1.523	-2.180
Spruce	**FMA3**	84	3,0	11,1	21.273	7.107	2.874	1.113	298
Beech	**FMA3**	120	3,4	9,9	10.441	1.010	-1.381	-2.151	-2.396
Beech	FMA2 (mgd)	118	3,2	9,4	13.288	3.301	751	-92	-379
Beech	**FMA2**	N.N.	3,3	7,5	10.630	2.641	601	-73	-303

* Net primary production (NPP) is defined here as net growth [tC ha^{-1} a^{-1}] and turnover of individual trees without continuous losses of foliage, branch or root biomass as tree grows.

** Mean annual increment of commercial timber with diameter > 7 cm at smaller end. Increment in set aside areas is not considered.

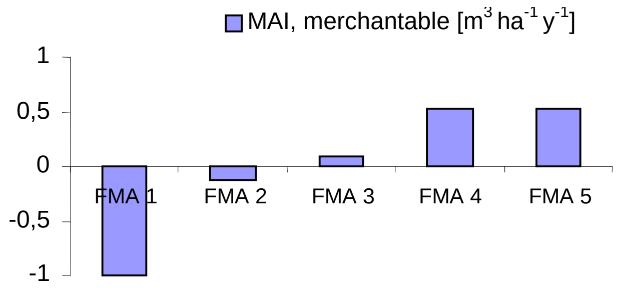
Tab. 3: Soil properties

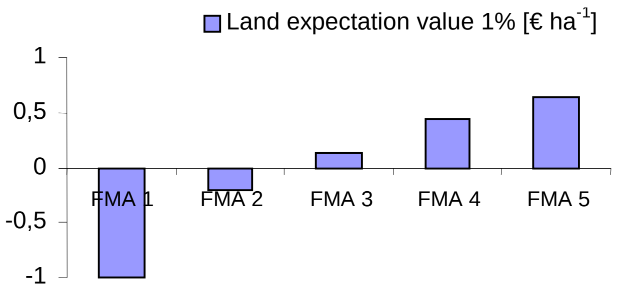
	Depth	pH (CaCl2)	C	N	C/N	clay	CEC	BS
Olfh	-8-0	3.5	45		25			12
Ae	0-5	3.8	3		24	5		9
Bw1	5-12	4.2	1		23	5		10
Bw2	12-65	4.5	1.5		17	7		15
C	65-	4.8	0.7		16	6		18

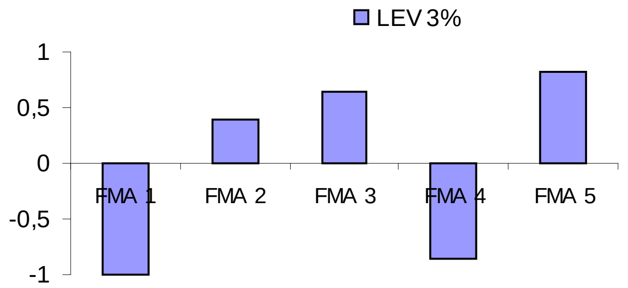
Tab. 4: Site data - Topography: slope 10 %, aspect W

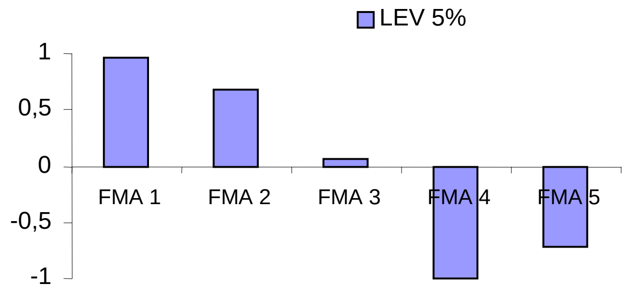
Horizon		Depth [mm]		Stone fraction [%]		Texture		
Spruce	Beech	Spruce	Beech	Spruce	Beech	Spruce	Beech	
O	O	80	30	0	0	-	-	
Ae	Ah	50	120	10	10	Sandy loam	Sandy loam	
Bs	Bw	70	530	10	25	Loamy sand	Sandy loam	
Bw	Cw	530	350	25	50	Sandy loam	Loamy sand	
Cw		350		50		Loamy sand		
Horizon		Porosity (volume fraction)		Water content at field capacity (volume fraction)		Negative slope of the log (matrix potential) – log (water content) relationship		
Spruce	Beech	Spruce	Beech	Spruce	Beech	Spruce	Beech	
O	O	0.9	0.9	0.3	0.3	6	6	
Ae	Ah	0.55	0.6	0.25	0.25	4	5.5	
Bs	Bw	0.6	0.55	0.25	0.25	5.2	4.8	
Bw	Cw	0.5	0.4	0.20	0.2	4.8	4.5	
Cw		0.4		0.2		4.5		

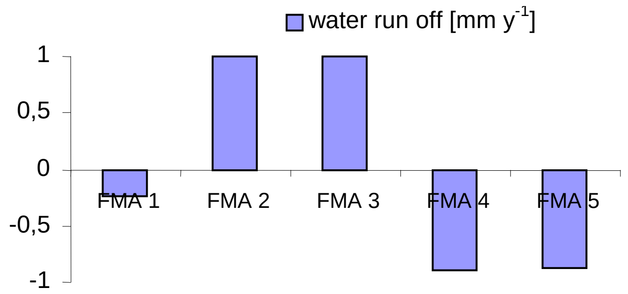
Fig 4. Freely draining soil

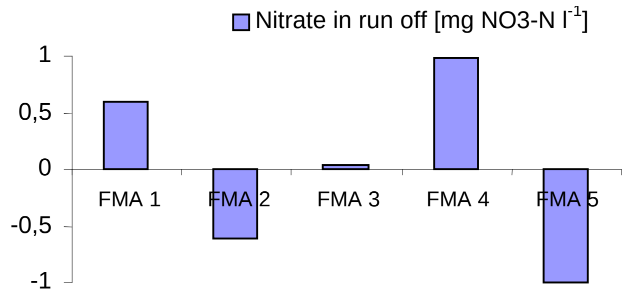

■ MAI, merchantable [m^3 ha^{-1} y^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5

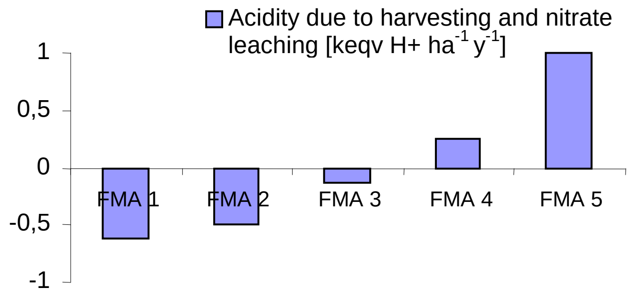

■ Land expectation value 1% [€ ha^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5

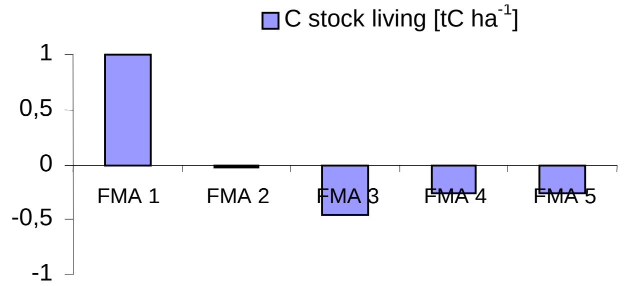

■ LEV 3%
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5

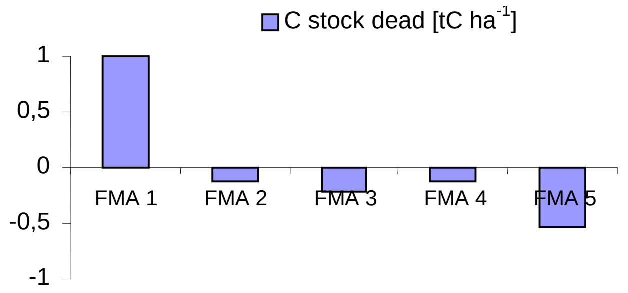

■ LEV 5%
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5

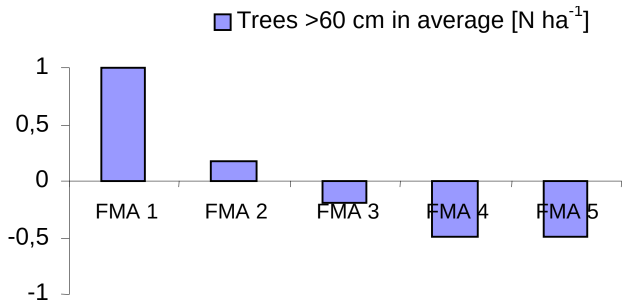

■ water run off [mm y^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5


■ Nitrate in run off [mg NO3-N l^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5


■ Acidity due to harvesting and nitrate leaching [keqv H+ ha^{-1} y^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5


■ C stock living [tC ha^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5


■ C stock dead [tC ha^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5


■ Trees >60 cm in average [N ha^{-1}]
1
0,5
0
-0,5
-1
FMA 1
FMA 2
FMA 3
FMA 4
FMA 5

Tab. 5: Impact assessment of FMA on environmental service

	FMA 1 Nature reserve	FMA 2 low intervention	FMA 3 mixed approach	FMA 4 timber	FMA 5 biomass
Productive functions					
Mean annual increment, merchantable m^3 ha^{-1} y^{-1}	0	8	10	14	14
Land expectation value 1 %, € ha^{-1}	0	10630	15064	19232	21771
LEV 2 %	0	2641	3856	4237	5427
LEV 3 %	0	601	709	64	783
LEV 4 %	0	-73	-493	-1523	-1050
LEV 5 %	0	-303	-996	-2180	-1856
Carbon					
C stock living, ton C ha^{-1}	177	112	85	97	97
C stock dead, ton C ha^{-1}	20	6	5	6	1
C harvested, tons C ha^{-1} y^{-1}	0	2,1	2,3	2,7	3.5
C assimilated, tons C ha^{-1} y^{-1} (NNP-proxy)	3.9	3.3	3.2	3.6	3.6
Nutrients / Acidity					
N deposition–harvesting, kg ha^{-1} y^{-1}	17	10	14	18	6
P - do -	0.2	-0.4	-0.4	-0.5	-1.8
K - do -	2.0	-2.4	-1.8	-1.1	-6.4
Ca - do -	2.7	-5.0	-4.3	-3.6	-10
Mg - do -	0.7	-0.4	0.2	0	-0.9
Acidification due to harvesting*, keqv H$^+$ ha^{-1} y^{-1}	0	0.6	0.6	0.6	1.1
Potential acidification due to nitrate leaching, -- do --	1.2	0.7	1.0	1.3	1.4
Water					
water run off, mm y^{-1}	579	622	622	556	557
Nitrate in run off, mg NO_3-N l^{-1}	2.9	1.6	2.3	3.3	1.2
Biodiversity					
Fine woody debris, m^3 ha^{-1}	34	25	36	46	11
Coarse woody debris, m^3 ha^{-1}	129	26	7	0	0
Trees >40 cm in average, number ha^{-1}	44	36	41	51	51
Trees >60 cm in average, number ha^{-1}	21	10	5	1	1
Trees >70 cm in average, number ha^{-1}	15	4	1	0	0
Trees >80 cm in average, number ha^{-1}	11	2	0	0	0
Trees >100 cm in average, number ha^{-1}	6	1	0	0	0
number of tree species, number ha^{-1}	7	7	2	1	1
Score	214	129	20	1	1