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**On economic consequences of transformation of a spruce (<u>Picea abies</u> (L.) KARST.) dominated stand from regular into irregular age structure**

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## Abstract

This paper compares a transformation strategy with an even-aged treatment (rotation period 98 years) that concludes in a clear-cut.

Transformation began at a stand age of 41 years after which both strategies were considered for 77 years. In order to describe the treatments, data from a thinning trial and measurements from a two-aged stand (spruce 58 years, fir 15 years) in Freising (Upper Bavaria, Germany) were used. To project the data up to a stand age of 118 years simulations using the single tree, distance dependent growth model SILVA were carried out.

The economic analysis showed a considerably lower amount on harvested timber and a considerably lower income earned for the transformation strategy. However, income from the transformation strategy occurred earlier and more uniformly distributed over time. Due to this fact, the net present value (NPV) of transformation exceeded that of even-aged management during a limited time period of 77 years given an interest rate of 2.6 % (break-even interest). Assuming an infinite time horizon, the break-even interest rate was 1.9 %. Changes in stumpage price or rotation length showed minor impact on the break-even interest of transformation.

**Keywords:** uneven-aged, economics, continuous cover, growth

## 1 Introduction

In Germany, federal forest administrations have integrated principles of continuous cover forestry in silviculture since storms in 1990 threw down more than 60 million $m^3$ of timber (König et al. 1995). Uneven-aged (u-a) silviculture has also become more popular in other countries, as the public increasingly responds negatively to clear felling (Stout 1998). In the future, management of u-a forests may probably be of increasing importance because scientists consider these forests more resistant towards natural hazards, and from the manager's point of view more flexible (Fabian and Menzel 1998, Lindner 1999).

Many researchers have carried out economic studies on optimisation of u-a silviculture. Static approaches (Duerr and Bond 1952, Adams 1976, Buongiorno and Michie 1980, Chang 1981, Hall 1983, Bare and Oppalach 1988, Buongiorno et al. 1994, Knoke 1998 a) are mainly aimed at analysing investment efficiency of steady states, ignoring the initial state of the stand. Dynamic economic models (Haight et al. 1985, Haight 1985, Haight and Getz 1987, Haight and Monserud 1990 a, b, Anderson and Bare 1994) start optimisation in u-e stands at the initial state of the stand, incorporating the transition phase. Although there have been numerous contributions to optimisation of u-a management, most of them apply to stands that are already of u-a structure. Little is known on economic consequences of a silvicultural treatment that transforms a stand from even-aged (e-a) into u-a stand structure.

Foresters managing e-a forests often do not expect economic improvement from application of u-a silviculture. However, several comparative studies mainly carried out in Central Europe showed a larger profitability for u-a silviculture under certain conditions (Ammon 1951, Mitscherlich 1952, 1961, 1963, Mayer 1968, Siegmund 1973, Leibundgut 1983, Schütz 1985, 1989, Schulz 1993, Hanewinkel 1998, Hanewinkel and Oesten 1998, Knoke 1999, Mohr and Schori 1999). U-a forests show a favourable relation between the value increment and the capital invested in the forest, as relatively low stocking density allows trees to develop long productive crowns (e.g., Knoke 1999). It is expected that stand stability, that is to say the resistance towards natural hazards like storm damage and insect attacks, of u-a forests will be higher than that of e-a forests (Kern 1966, Mayer 1992, Schütz 1989). Additionally, u-a stands provide a steady sequence of cash flows even at the stand level while e-a systems produce large income at the end of rotation, but not earlier. E-a silviculture can provide continuous income only when a regular distribution of e-a stands is given. For small-scale properties, which are common in Central Europe and where no regular distribution of age classes is present, the aspect of continuous income at the stand level is important. In

Germany 98 % of the forest enterprises manage on average only 4.2 hectares (AID 1995). Additionally, it has to be taken into consideration that enterprises, which show a regular distribution of age classes, will hardly be found at all, at least in Germany.

However, the above-mentioned advantages mainly derived from static comparative studies, might not compensate for potential losses during the transformation period (Moog 1997). Therefore, this paper investigates the following question:

What economic consequences do result from the transformation of an e-a stand into an u-a stand?

### 1.1 Basic research approach

An u-a stand can theoretically be seen as a mosaic of different age classes (fig. 1). The total number of stems of all diameter classes may form the classical reverse-J-shaped stem frequency distribution, as described by Meyer (1933).

To achieve an u-a stand structure, similar to that depicted in figure 1, early establishment of a new age class seems essential. After initial regeneration, periodic regeneration cuttings in combination with establishment of further age classes are necessary to support a steady regeneration process until an u-a stand structure is achieved. In contrast to this procedure, starting up late with old stands probably means that young age classes are not able to produce timber and income continuously. Their diameters will still be too small when main crops (oldest age class) achieve financial maturity.

The described transformation technique partly corresponds to that proposed by Schütz (1999), who emphasizes the importance of continuous recruitment to maintain an u-a stand structure. Experiences gained in Switzerland showed that a successful transformation requires a time period between 60 and 80 years.

Based on knowledge already available on transformation, this study analyses a transformation treatment starting with a 41-year-old spruce dominated stand. The stand structure aimed at is that of an u-a stand composed mainly of spruce and fir (Abies alba MILL.), consisting of four age classes. In order to evaluate the size structure of the stand at the end of transformation, a target stem frequency distribution served as a standard. The target stem frequency distribution resulted from static optimisation carried out earlier for u-a forests using an interest rate of 2.5 % (Knoke 1998 a). During the transformation period, the silvicultural objective of transformation was achieved, by establishing three age classes of fir saplings in small gaps (smaller than 500 $m^2$).

To analyse economic consequences, transformation for a period of 77 years was compared with an e-a treatment. To define rotation length, the same interest rate that was used in deriving target stem frequency distribution for transformation was applied. The current annual value growth percent of the e-a stand at age 88 is still higher than 2.5 %. At age 98 years the current annual value growth percent drops below 2.5 %. This indicates that, when an interest rate of 2.5 % is applied, the stand has achieved financial maturity approximately at an age of 98 years. Although this comparison is only an approximation, as it ignores the effect of subsequent rotations, a rotation of 98 years was applied to e-a silviculture because this rotation is often applied for spruce management in Germany. Stand regeneration by means of a clear-cut and planting of 3,000 spruces per ha were assumed. E-a silviculture basically corresponded to recommendations given by Abetz (1975), which were partly incorporated in the basic guidelines for the silvicultural treatment of spruce in the Bavarian State Forest (BMFAF 1993). E-a treatment is aimed at producing a stable stand of trees that forms a large standing volume and liquidation value at the end of rotation. This treatment meets the demands of wood production mainly by harvesting the final crop (Abetz 1975). The concept of Abetz is assumed to maximise the mean annual value increment within a certain rotation period. It is seen as the optimum treatment to produce valuable spruce timber (Strütt 1991).

### 1.2 Research hypotheses

The following specific research hypotheses were tested in this study:

> H1: A period of 77 years of transformation leads to an u-a stand structure that provides frequent and periodic income
>
> H2: During the transformation period, volume cut as well as income earned by transformation are significantly less compared with that of the e-a treatment
>
> H3: Given a certain interest rate, net present value (NPV) of transformation treatment exceeds that of e-a treatment, as transformation provides earlier income
>
> H4: The rate of interest that produces a larger NPV for the transformation depends on the level of the stumpage price and the rotation applied to e-a silviculture

## 2 Data employed

To describe transformation and e-a treatment, this investigation utilised data collected by Plusczyk (2000) during the survey of a 58-year-old stand, where transformation had already started 17 years ago. At a stand age of 41 years a snow breakage had formed small gaps in this stand. Six years later, the forest service planted four-year-old firs in the gaps that resulted from the snow breakage.

As analysing 17 years of transformation is not sufficient, data base was supplemented with data from simulations carried out using the distance dependent growth model SILVA (Kahn and Pretzsch 1997).

### 2.1 Growth data

The stand being investigated belongs to the forest area of Bavarian State Forest Service in Freising (Upper Bavaria, Germany), where highly productive sites dominate (brown earths and loess soils). The stand is located within the growing area 12.8 (Oberbayerisches Tertiärhügelland) in which the natural forest cover should consist of oak (Quercus robur L.) and beech (Fagus sylvatica L.) (Foerst and Kreutzer 1978). However, the current forest cover is dominated by spruce. The mean annual precipitation of 814 mm and the mean annual temperature of 7.7 $^{o}$C are representative for Bavaria. Assmann and Franz's yield table (BMFAF 1990) predicts mean annual increment (age 100 years) of about 12 $m^3$ $ha^{-1}$ $yr^{-1}$ for the stand under investigation.

#### 2.1.1 Transformation

##### 2.1.1.1 Data measurement

58-year-old transformation stand

Plusczyk (2000) established an experimental plot of 0.984 hectare, which comprised three groups of 15-year-old fir saplings (0.14 hectare). The main crops that are 58 years old consisted of 82 % spruce and 18 % admixed tree species.

In order to analyse the stand's state properly and to get reliable simulations, Plusczyk measured the following:

a) Spatial distribution of all trees and stumps of recently harvested trees,

b) dbh of 604 58-year-old trees,

c) total heights of 53 sample trees to derive regression equations for estimating tree height,

d) total heights and height increment during the last five years for 327 fir saplings that formed the regeneration.

To collect information on the last intervention conducted in the stand, the dbh of recently harvested trees based on stump diameters were estimated. Regression equations were employed to estimate the dbh.

Transformation stand at an age of 41

When transformation of the 41-year-old stand started, there was no existing record on the state of the stand. This was therefore supplemented by data collected during a survey of a thinning trial, carried out at a stand age of 41 years (Huss 1990, 1996). The location of this trial is close to the stand under investigation and the site conditions are comparable.

The area occupied by fir saplings (0.14 ha) served as a measure to estimate the extent that the snow breakage of 17 years ago opened up the stand. The gaps originally formed by snow breakage were assumed to be part of the early starting regeneration strategy. In addition, a selective thinning in areas between gaps was simulated.

**2.1.1.2 Growth simulation**

To complete the necessary data for transformation for the whole time period (77 years in this case), we simulated growth and interventions using the distance dependent growth model SILVA (version 2.2). Kahn and Pretzsch (1997) described underlying growth equations of the model and an extremely broad data base to estimate parameters of these growth equations. Simulations started with data from existing 58-year-old stand and ended after a period of 60 years, with the state of the stand at age 118 years. Transformation during 17 years and 60 years of simulations made up the transformation period of 77 years. As the growth model contains stochastic components that randomly influence tree growth, simulations were repeated three times.

The time interval for growth simulations comprised 10 years. Simulations of interventions took place at the end of every 10 years. Interventions were made based on information on the spatial distribution and dbh relations between trees depicted in the plot, showing the local positions of the trees. The interventions were aimed at opening the crown cover to promote fir regeneration, supporting the admixed species, and enhancing stability of dominant spruce. The mortality function was switched off, as test simulations showed poor results for the transformation stand.

The growth model SILVA has a deficiency of not being able to describe development of small trees sufficiently well. According to Schütz (1999), development of regeneration and recruitment is especially essential for a successful transformation. Therefore, a pragmatic approach was adopted to describe height development of firs. Results reported later (3.1.2) confirmed that height development of firs corresponded well to age-height equations generated by Kennel (1999) to simulate implications of browsing. Consequently, the height increment of fir saplings for the next 16 (first fir generation) and 9 years (second and third fir generation) was calculated according to Kennel's age-height equations. This means that the growth model was not used to control the fir's development until firs had attained the age of 31 years for the first generation and 24 years for the second and third generation.

### 2.1.2 Even-aged treatment

#### 2.1.2.1 Data measurement

58-year-old e-a stand

To meet the demands for comparison, the description of e-a silviculture was based on the data of 58-year-old stand, which also served as data base for transformation. The gap cuttings apparently enhanced the growth rates of the trees located close to the gaps. This effect is not expected in e-a stand management. Therefore, all trees probably promoted by the gap cuttings, which showed large crowns and dbh were excluded. As the growth model is able to generate trees and to fill up already existing stands we were able to create a new e-a stand, which was fully stocked in line with yield tables commonly used in Germany. That is to say that the basal area of the e-a stand corresponded perfectly to that predicted by the yield tables.

The simulation of the intervention was again based on a plot of stem foot positions. At this stand age, intervention still aimed at enhancing stand stability by promoting deciduous trees and dominant spruce.

E-a stand at an age of 41

In comparison to the procedure described for transformation treatment, data collected during the survey of the thinning trial in Freising served as data base used to describe the stand condition at age 41 years.

#### 2.1.2.2 Growth simulation

The simulation of further development of e-a stand started at age 58, using the stand data described above.

Light thinning formed the interventions at stand ages 68 and 78 years. After no intervention at stand age 88 years, the final clear-cut at stand age 98 years was simulated. The simulations ignored mortality for e-a silviculture, as it was ignored for transformation, too.

## 2.2 Economic analysis of silvicultural treatments

Interventions for both silvicultural strategies were based on the following timetable (table 1):

### 2.2.1 Assessment of economic returns and profitability

Quantification of economic consequences of transformation focused on the analysis of net present value (NPV). NPV is the total of all anticipated future income and expense, evaluated by a discount factor

$1/(1+i)^t$

where i is real interest rate and t is time.

The analysis of NPV was carried out for three different time horizons:

a) The value production of both treatments, which included the liquidation value of the final stand as a terminal income, was analysed during one e-a rotation. Starting with a 41-year-old stand that means 57 years were considered until the rotation age of 98 years was achieved.

b) The main emphasise, however, was placed on the analysis of the net income during the transformation period of 77 years.

c) Finally, we analysed the net income for both treatments assuming the time horizon was not limited.

#### *2.2.1.1 Analysis of the value production during one e-a rotation*

In order to solve limited time horizon problems, economists often consider the liquidation value of the final stand as a net income at the end of the analysed period assuming all remaining trees are harvested at this time (Haight et al. 1985, Haight und Monserud 1990 a). By limiting the consideration to a stand age of 98 years, when the final clear-cut takes place during the e-a silviculture regime, the value production of both treatments can be compared best. This analysis brings both treatments to a common state, and may become relevant if the forest manager decides to stop transformation and to clear-cut the transformation stand after one rotation.

However, it is not realistic, to assume a clear-cut at the end of transformation. Normally, the state of the stand at the end of transformation will be maintained in the future. Consequently, only the net income earned by the transformation intervention at the end of the considered period and not the liquidation value of the transformed stand should be integrated in the calculations.

### 2.2.1.2 Analysis of net income during the transformation period

From the point of view of a forest enterprise, short- or mid-term consequences of a chosen silvicultural treatment are probably more essential than those occurring far in future (Möhring 1994, Moog 1997). Furthermore, the information on growth and yield, stumpage price and logging expenses increasingly loses reliability when the analysed time horizon is not limited for both transformation and e-a silviculture. Therefore, we decided to limit the time horizon for the main analysis to 77 years.

By limiting the analysed time period for transformation phase to 77 years, financial consequences during the time after transformation were ignored. The NPV was described starting the calculation with a stand age of 41 years as follows:

$$J = \sum_{t=0,17,27,37,47,57,67,77} \frac{1}{(1+i)^t} R[v(t)] \qquad (1)$$

where

$J$ is the net present value

$t$ is the time when a specific intervention takes place ($t$=stand age – 41 years)

$R[v(t)]$ is the revenue (net income) earned by a specific intervention, depending on species, volume harvested, log size and quality structure of timber cut at time t (regeneration expense is incorporated as negative net income)

However, the calculations based on a limited time horizon are unsatisfactory from a scientific point of view. By ignoring the time after the transformation period, the assumption that nothing of consequence happens beyond this point is implicitly made. Therefore, in order to analyse the importance of the time period after transformation, additional calculations incorporating the unlimited time period after transformation were carried out.

### 2.2.1.3 Analysis of net income during an unlimited time period

Supposing the time horizon is not limited, we described the calculation of NPV by supplementing equation (1):

$$J = \sum_{t=0,17,27,37,47,57,67,77} \frac{1}{(1+i)^t} R[v(t)] + \left[ \sum_{t=87}^{\infty} \frac{1}{(1+i)^t} R[v(t)] \right] \qquad (2)$$

A steady state after transformation, where the u-a stand infinitely produces a sustainable net income of constant height for every intervention was assumed. The part of equation (2) in parentheses describes discounted net income during this period of time. The general equation (2) describes calculation of NPV for both, e-a and transformation treatment. A solution for the infinite time horizon problem, which is more conveniently calculated by incorporating the Faustmann approach (Faustmann 1849), is expressed by equations (3) and (4).

Transformation treatment:

$$J_{tr} = \sum_{t=0,17,27,37,47,57,67,77} \frac{1}{(1+i)^t} R[v(t)] + \left[ \left( \frac{1}{(1+i)^{cc}-1} R_s[v(t)] \right) \frac{1}{(1+i)^{77}} \right] \qquad (3)$$

where $cc$ is the cutting cycle and $R_s[v(t)]$ denotes the sustainable revenue (net income), constant over time.

E-a treatment:

$$J_{e-a} = \sum_{t=0,17,37,47,57} \frac{1}{(1+i)^t} R[v(t)] + \left[ \left( \frac{1}{(1+i)^{98}-1} \sum_{t=0}^{98} (1+i)^{98-t} R[v(t)] \right) \frac{1}{(1+i)^{57}} \right] \qquad (4)$$

where $t$ is the time when a specific intervention takes place.

Regarding the time period after transformation the calculations were based on long term cash flows, which were estimated according to the studies of Schütz (1985) and Knoke (1998 a, b).

### 2.2.2 Log classification, logging expenses, stumpage price and regeneration expenses

We classified logs for every intervention based on stem taper functions calculated by the programme for timber classification, BDAT, developed in the context of the German National Forest Inventory (Kublin and Scharnagl 1988). At stand ages up to 68 years, short logs were formed and expenses according to log size for mechanical logging by a timber harvester used for an earlier study were applied (Knoke 1998 b).

Starting with age 78 years, timber grading according to Heilbronn’s grading rule (a timber classification scheme commonly used in Bavaria) was carried out and logging by power chainsaw was assumed. In order to assess the financial returns, current (1999) stumpage prices and logging expenses typical for the Forest Station in Freising were used.

For the planting of firs at stand ages 41, 78 and 98, the calculations incorporated expenses (negative net incomes) of 800 DM $ha^{-1}$ for each fir generation. The e-a treatment contained expenses of 5,000 DM $ha^{-1}$ for regeneration of spruce.

## 3 Results

Table 2 contains basic growth and financial data incorporated in calculations reported below.

### 3.1 Growth data

#### 3.1.1 Growing stock and volume cut

The e-a stand showed a large growing stock of 865 $m^3$ $ha^{-1}$ at the end of rotation (tab. 2, fig. 2). The standard error of the growing stock amounted to ± 12 $m^3$ $ha^{-1}$. It expresses the random variation in growth of the trees implemented in the growth model SILVA. The calculation of the standard error was based on the three repetitions of simulations, which produced different growth predictions for every period.

Interventions carried out at stand ages 41 and 58 were relatively strong (volume cut: 78 and 90 $m^{-3}$ $ha^{-1}$, respectively). As the response of old spruces to release is usually poor (Abetz 1975, Spellmann 1997, Knoke 1998 b), only light or even no interventions took place at stand age 68 and above. This cutting regime produced a large volume increment (mean annual increment 11,1 $m^3$ $ha^{-1}$ $yr^{-1}$).

Unlike e-a treatment, transformation avoided accumulation of growing stock through continuous interventions, cutting relatively large volumes (between 89 und 129 $m^3$ $ha^{-1}$, tab. 2, fig. 2). This amount of volume cut ensued from establishment of fir generations, opening crown cover to promote fir regeneration, promotion of deciduous trees and dominant spruce. By means of transformation treatment, the whole increment volume was almost utilised. After 77 years of transformation, the final stand (stand age 118 years) showed a growing stock of 295 $m^3$ $ha^{-1}$ (± 1 $m^3$ $ha^{-1}$).

While e-a treatment yielded 1090 $m^3$ $ha^{-1}$ of timber, the transformation produced only 889 $m^3$ $ha^{-1}$ (82 %). Consequently, the difference in timber harvested between e-a treatment and transformation during 77 years amounted to 201 $m^3$ $ha^{-1}$ (± 13 $m^3$ $ha^{-1}$).

#### 3.1.2 Height growth of fir

The height development of fir saplings compared well with age-height curves (fig. 3) derived by Kennel (1999). While height of dominant firs developed approximately according to age-height curve in yield class 1 (Hausser’s yield table, BMFAF 1990), that of subdominant firs followed age-height curve in yield class 3. Hence, anticipation of height development according to age-height equations, as reported in chapter 2.1.1.2, seems a pragmatic solution to describe development of fir saplings.

Further simulations excluded suppressed firs (127 trees), as they probably would die in future.

### 3.1.3 Stem frequency distribution after 77 years of transformation

Similar to the model stand (fig. 1), trees of different age classes formed a stem frequency distribution that approximately showed a negative exponential slope, when the transformed stand was 118 years of age (fig. 4). The stem distribution, achieved by means of transformation interventions, showed merely small difference when compared with the target stem frequency distribution of a specific u-a forest at an area of the Bavarian Forest.

## 3.2 Financial return

### 3.2.1 Income

After one rotation of 98 years the mean annual increment value for e-a stand amounted to 1,496 DM $ha^{-1}$ $yr^{-1}$. For the same time period the transformation showed a mean annual increment value of 1,279 DM $ha^{-1}$ $yr^{-1}$ (85 %). Consequently, the e-a silviculture model was more profitable, if only increment value is taken into consideration.

During the whole transformation phase, the transformation treatment produced a net income that is 24,378 DM $ha^{-1}$ (± 2,390 DM $ha^{-1}$) smaller than that of e-a treatment. The net income earned amounted to 83 % compared with that of e-a treatment.

By means of the transformation treatment, net income of between 8.000 DM und 15.000 DM at stand ages between 41 and 88 was achieved at every intervention (fig. 5). In contrast to this fact, e-a silviculture only resulted to very small or even no income at stand ages between 68 and 88 years.

In reality, in forest management the capital available for investments is limited. Due to this fact, the mere consideration of increment value in which the e-a stand really performed better, is not sufficient. With regards to scarce finances, it is interesting to note at which costs a certain increment value can be produced. By e-a silviculture the main part of increment value is utilised by harvesting the final crop, but not earlier. Compared with transformation that means that a large amount of capital is fixed until the end of rotation. In the case of this study the question arises, how efficiently capital allocation by transformation as well as e-a silviculture worked. Given a certain interest, the efficiency of capital investments is indicated by the NPV.

### 3.2.2 Net present value

The NPV was calculated as the sum of all future net income and expenses as depicted in figure 5, evaluated by means of a discount factor according to the time when income or expenses occur. As mentioned earlier, the analysis of NPV was conducted for three different time horizons.

#### 3.2.2.1 Value production during one e-a rotation (time horizon 57 years)

The sum of all income produced by the transformation between age 41 and 98 years amounted to 125,342 DM, including the liquidation value at age 98 (64,045 ± 864 DM $ha^{-1}$, before intervention). It was 15 % smaller than that produced by e-a silviculture. However, the break-even point for transformation was already given, when an interest rate of 1.7 % was applied. This interest rate (break-even interest) resulted in a NPV of the transformation, which exceeded that of e-a stand management. Consequently, the reported result indicates that the heavy cutting regime alone was advantageous compared to a cutting regime, which maximises value increment, when assuming a comparatively low interest rate of 1.7 %. However, to clear-cut the transformation means to return to e-a silviculture. That underlines that the medium-term effects of transformation can also be achieved by e-a silviculture based on early and heavy crown thinning, as Knoke (1998 b) pointed out.

As the liquidation value of the transformation stand at age 98 years was seen as a net income, the reported consideration may become relevant if the forest owner decides to stop a current transformation and to return to e-a silviculture by harvesting the whole transformation stand after one rotation.

#### 3.2.2.2 NPV of net income during the transformation period (time horizon 77 years)

As it is not compatible with the purpose of transformation to harvest the whole stand at any time, the following analysis ignores the liquidation value of the transformed stand.

The ratio between NPV of transformation and NPV of e-a silviculture at different interest rates was used to assess differences in both regimes.

As depicted in figure 6, the break-even interest rate was about 2.5 %. Above this interest rate, the NPV of transformation exceeded that of e-a silviculture.

### 3.2.2.3 NPV of net income during an unlimited time period

Growth predictions by the model SILVA for u-a stands are not possible over very long periods because there is no regeneration model available. Additionally, the error of long-term growth estimations becomes intolerably large in u-a stands of complex structures. Therefore, results of existing studies were utilised to quantify the long-term cash flows, which can be expected from the transformed stand.

Knoke (1998 a) calculated a sustainable net revenue (net income) for a productive u-a model stand that amounted to 1,250 DM $ha^{-1}$ $yr^{-1}$. The stand structure and the volume increment of the transformed stand are similar to that of the model stand. As Knoke's calculations for the model stand were based on a wood price of 10 % less than that applied to this study, sustainable net revenue of 1,350 DM $ha^{-1}$ $yr^{-1}$ was assumed for the present study (tab. 3). This assumption is in line with results reported by Schütz (1985). The cash flows assumed for e-a silviculture are similar to those calculated for the first rotation (tab. 3).

Applying an unlimited time horizon improved the position of the transformation considerably. The NPV of the transformation was already equal to that of e-a silviculture, when an interest of 1.5 % was applied. Given an interest rate of 1.9 %, the NPV of transformation exceeded that of e-a silviculture by 1,060 DM $ha^{-1}$ (± 342 DM $ha^{-1}$).

This result is explained by the fact that u-a silviculture produced already 13.500 DM $ha^{-1}$ ten years after transformation, while the value increment of e-a stand could still not be utilised. Further on the net income of u-a silviculture was higher every ten years except for the intervention 78 years after finishing the transformation, when the e-a stand was clear-felled.

### 3.2.3 Variation of stumpage price and rotation length

### 3.2.3.1 Variation of stumpage price

As the investigated period of 77 years was long, it was essential to analyse the sensitivity of results for the stumpage price under different assumptions.

The changes in break-even interest rates with variation of stumpage price were very small and they were therefore of minor importance (tab. 4).

### 3.2.3.2 Variation of rotation length

As Chang (1998) observed, optimal harvest age (rotation length) has been subject to much studies. All studies showed that profitability of e-a silviculture heavily depends on rotation length. Therefore, the impact of variation on rotation length to the results obtained by this study was analysed for both the limited time horizon analysis and for the assumption of an unlimited time horizon.

Given a rotation length of 78 years, no interest rate between 0 and 10 % produced a significantly larger NPV for e-a silviculture. That means that profitability of transformation was at least as high as that of e-a treatment for any interest rate within this range. Both strategies showed identical profitability for an interest rate of 4 %. Almost identical results were obtained for the analysis of an unlimited time period. In this case the NPV of both treatments were equal between interest rates of 3.7 % and 4.2 %. As figure 7 shows, for all other interest rates transformation was found to be more profitable. However, the differences between both treatments were less than 5 % in NPV within a range of interest rates of 2.1 % and 6.2 %.

By shortening rotation age to 88 years, a higher NPV was achieved by transforming the stand at interest rates of 2.4 % and above (tab. 4). The consideration of an unlimited time horizon already led to a significantly higher NPV by u-a silviculture when interest rates of 0.8 % and above were applied.

In focussing only on the transformation period of 77 years, it is essential to emphasize that given an interest rate of at least 2.6 %, the profitability of transformation was equal or higher than that of e-a silviculture for any investigated stumpage price and rotation. The integration of the time after the end of transformation in the calculations generally improved the position of transformation considerably.

## 4 Discussion and conclusions

This study analysed essential economic differences between a transformation treatment and an e-a treatment. O’Hara (1998) pointed out the existence of numerous stand structure objectives for u-a stands. There are therefore a variety of transformation techniques to apply. It should be noticed that this study, in attempting to improve the knowledge on economic consequences of transformation, described and analysed just one method of transformation. Therefore, we cannot give a general answer to the question of economic consequences of transformation.

However, the data presented can form a quantitative basis for future discussions on transformation. It is obvious that the data base on transformation has to be supplemented by further studies.

The discussion of results obtained in this study is presented with regards to the hypotheses that were put forward at the beginning of the research work.

Investigations carried out on the first research hypothesis,

> „H1: A period of 77 years of transformation leads to an u-a stand structure that provides frequent and periodic income“,

revealed the following:

The transformation of an existing 58-year-old stand, where transformation process had started 17 years ago into a stand of irregular age structure was successful, at least by means of simulations. At an age of 118 years, stem frequency distribution of transformed stand corresponded to that of a specific u-a stand, which showed a negative exponential stem frequency distribution.

Consequently, the analysed transformation treatment is probably well suited to achieve an u-a stand structure.

However, the study ignored the risk, for example, of wind-blow during the transformation phase. While wind-blow is a constraint upon transformation at many sites in Scotland (Gardiner 1999), the wind-blow risk for young stands in Bavaria is rather small (Burschel and Huss 1997). In the medium term, a positive effect of transformation on stand stability is expected, as implementation of small gaps (smaller than 500 $m^2$) probably promotes stability of trees growing close to the gaps. Otto (1994) pointed out that small disturbances in forest ecosystems, like small gaps, reduce homogeneity of stands. Gaps also function as a brake against extensive damage to forest stand. Additionally, the forest service at the Kreuzberg municipal forest (Knoke 1999) observed a high resistance of u-a stands against bark beetle attacks.

However, the forester has to bear it in mind that the risk of damage by wind-blow immediately after intervention is high, especially in stands with top height above 20 meters (König 1995). As König’s model for risk quantification available for Germany is not able to take into account a higher stability of trees, showing low height-dbh ratios and high bark beetle resistance, we could not properly quantify risk for transformation. Economic studies carried out by Dieter (1997, 1999) showed implications of rather minor relevance after integration of wind-blow risk in economic calculations. Dieter started a conversion treatment in older stands consisting of tall trees, reducing stocking density to 75 % in one intervention (according to Assmann and Franz's yield table, this is equivalent to a volume cut of 166 $m^3$ $ha^{-1}$, BMFAF 1990).

With regards to the second research hypothesis,

> „H2: During the transformation period, volume cut as well as income earned by transformation are significantly less compared with that of the e-a treatment“,

the following results were obtained:

The amounts of timber and income provided by the transformation treatment were significantly smaller compared with that of e-a silviculture. With reference to the findings of Spellmann (1997) and Knoke (1998 b), this result was explained to conform to the fact that early harvests of trees that are still productive during transformation lead to losses in both increment volume and value. Larger growth rates of spruces neighbouring the harvested trees do not compensate for losses in production, as observed in the case of Fagus sylvatica L. (Freist 1962). However, the obtained results are specific for spruce dominated transformation stands. Presumably, the findings would be very different for beech dominated forests.

With regards to silvicultural treatments that strive for maximum value increment, which ignore the time when the forest owner is able to utilise the value increment, e-a treatment incorporating moderate or no intervention in older spruce stands (age above 58 years) was more profitable.

However, the time when silvicultural treatment provides income is essential for economic survival as well as for effective resource allocation (Klemperer 1976). Therefore, we investigated a third research hypothesis:

> „H3: Given a certain interest rate, the net present value (NPV) of transformation treatment exceeds that of e-a treatment, as transformation provides earlier income“

An interest rate of 2.6 % resulted in a NPV for transformation during a limited period of 77 years that was significantly larger than that of e-a silviculture.

This result agrees well with that achieved by a study that investigated a silvicultural treatment combining early, strong crown thinning and diameter limit cutting (Knoke 1998 b). The investigated silvicultural concept, which was based on single tree selection, was advantageous when compared with e-a stand management at an interest rate of 2.8 %. This result, which is almost identical to that calculated by the present study, was achieved even though no transformation was conducted and different stumpage prices as well as variant growth data were applied. This emphasises that medium-term effects of transformation can also be achieved by unconventional e-a silviculture concepts.

Consequently, early and relatively strong interventions carried out continuously over time, do not necessarily result in losses of profitability. When comparatively high interest rates of about 3 % and above - as measured by productivity of forests in Central Europe - were applied, higher profitability was calculated for transformation. Kroth (1967) and Möhring (1994) had already reported that full stocking density was not found to be optimal, when interest rates variant to zero were introduced. The cutting regime applied during transformation led to stocking density significantly less than that of e-a silviculture, by avoiding accumulation of growing stock. Even though growing stock of stand under transformation amounted just to 42 % (age 98 years) of that in e-a stand, transformation produced 85 % of increment value.

In contrast to the findings reported by German authors, Haight and Monserud (1990 b) reported no losses even in natural productivity by u-a management. Chang (1981) conducted a static optimisation at an interest rate of 3 % and reported profitability for an already existing u-a stand exceeding that of e-a stand.

However, it cannot be precisely stated whether these interest rates are appropriate for German forest enterprises. The answer to this question depends on internal rate of return on alternative investment, which is acceptable to the forest owner. Transformation might be an interesting treatment, particularly with regard to numerous forest enterprises in Germany managing small forest areas. It produces early and continuous income, even at the stand level. Once an u-a structure is achieved, flexibility of the forest owner increases, as liquidity greatly improves. In case a forest owner faces a great need for money, he is able to utilise large trees at any time. As an example, he can earn an additional income of 22,686 DM $ha^{-1}$ from the transformed stand at age 118 years, by cutting all trees of dbh larger than 40 cm. The remaining stand (growing stock 143 $m^3$ $ha^{-1}$) is still able to produce trees of dbh about 45 cm within the next ten years. In contrast to e-a silviculture, where no income will be earned after clear-felling for a long time, timber can be produced continuously.

The assumption of an unlimited time horizon further improved the position of transformation. This long-term consequence is a specific effect of transformation, which cannot be achieved by e-a silviculture. Once a stand has been clear-felled, a more or less long period of small or even no contribution from this area to the enterprise’s income will follow. This effect is avoided by the transformation, as it produces a continuous sequence of income over the time. It may be argued that a comparison at the stand level is of minor relevance regarding the level of a whole enterprise. However, transformation is a dynamic process, and it also changes the normal sequence of cash flows at the level of a forest enterprise. When starting transformation in a management unit consisting of a regular distribution of e-a stands managed with a rotation of 98 years, it will take 98 years until this process has begun in every stand. It will then take 77 further years until it has been finished in every stand. Each transformation stand will yield more income to the forest enterprise for the next 37 years than an e-a stand. Only in the year, when the e-a stand normally would be clear-felled, the income of the whole enterprise will be lower than in an enterprise, in which e-a management is maintained for every stand. Beyond this point, the transformation stand will enhance the profit of the enterprise again for 88 years. Consequently, the results obtained within this study have also relevance at the forest enterprise level.

With regard to the last research hypothesis,

> „H4: The rate of interest that produces a larger NPV for the transformation depends on the level of the <u>stumpage price</u> and the <u>rotation</u> applied to e-a silviculture“,

the following results were obtained:

Even when variant stumpage price or rotation length for e-a silviculture were applied, the interest rate, which produced a larger NPV for transformation did not change considerably. Accordingly, the interest rate that produces a larger NPV for transformation was relatively invariant with regards to changes in stumpage price and rotation length.

Conclusively, neither transformation nor e-a silviculture can generally be recommended from an economic point of view. However, the results showed that loss of increment value and volume was obviously not proportional to early reduction of stocking density by transformation. This finding can also be utilised to apply alternative e-a silviculture concepts, which are based on heavy crown thinning. Consequently, the forest owner has to decide whether increment volume and value absolutely higher for e-a silviculture would be preferable to him instead of earlier income provided by transformation or unconventional e-a silviculture concepts, which would be available for alternative and maybe more efficient investments. Indeed, the transformation has an additional positive effect on the NPV. Heavy interventions that produce considerable income during the transformation phase are combined with frequent and periodic income during the time after the transformation. During the latter time period, the u-a stand provides again earlier income than the e-a stand.

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Table 1. Timetable.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **TIME —>** | | | | |
| **stand age:** | **41** | **58** | **68** | **78** | **88** | **98** | **108** | **118 years** |
| | | | | **transformation** | | | | |
| **interven-tion:** | gap cuttings/ selective thinning | opening up/se-lective thinning | opening up/se-lective thinning | gap cuttings/ selective thinning | opening up/se-lective thinning | gap cuttings/ selective thinning | opening up/se-lective thinning | opening up/se-lective thinning |
| | planting of 500 firs | | | planting of 500 firs | | planting of 500 firs | | |
| | | | | **e-a treatment** | | | | |
| **interven-tion:** | selective thinning | | thinning from below | | | clear cut | | |
| | | | | | | planting of 3,000 spruces | | |

Table 2. Basic growth and financial data used for calculations (either $m^3$ $ha^{-1}$ or DM $ha^{-1}$, ± standard error resulting from different tree growth between three simulations in parentheses, exp. area=growth and yield experimental area, sim.=simulation)

| | transformation | | | | even-aged silviculture | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **time (yrs)** | **growing stock** | **volume harves-ted** | **net-income** | **regen. ex-penses** | **growing stock** | **volume harves-ted** | **net income** | **regen. ex-penses** | **source of growth data** |
| **0** | 221 | 114 | 8,488 | 800 | 257 | 78 | 5,282 | | exp. area |
| **17** | 344 | 89 | 8,492 | | 355 | 90 | 9,089 | | exp. area |
| **27** | 365 (± 1.7) | 129 (± 0.9) | 16,435 (± 106) | | 474 (± 10.9) | 13 (± 0.3) | 1,059 (± 22) | | sim. |
| **37** | 379 (± 5.1) | 104 (± 1.5) | 13,971 (± 203) | 800 | 580 (± 6.7) | 44 (± 0.7) | 2,039 (± 81) | | sim. |
| **47** | 387 (± 6.2) | 91 (± 1.2) | 13,214 (± 234) | | 728 (± 7.9) | 0 | 0 | | sim. |
| **57** | 362 (± 2.3) | 129 (± 1.5) | 21,539 (± 349) | 800 | 865 (± 12.4) | 865 (± 12.4) | 129,158 (± 2,267) | 5,000 | sim. |
| **67** | 344 (± 3.1) | 109 (± 0.9) | 18,759 (± 178) | | 0 | 0 | 0 | | sim. |
| **77** | 295 (± 0.9) | 126 (± 2.9) | 21,351 (± 106) | | 0 | 0 | 0 | | sim. |

Table 3. Assumptions for cash flows during the time after the end of transformation (DM $ha^{-1}$).

| time (years) | u-a silviculture | e-a silviculture |
|---|---|---|
| **87** | 13,500 | 0 |
| **97** | 13,500 | 5,000 |
| **107** | 13,500 | 6,000 |
| **117** | 13,500 | 7,000 |
| **127** | 13,500 | 1,060 |
| **137** | 13,500 | 2,040 |
| **147** | 13,500 | 0 |
| **155** | 0 | 129,158 |
| **157** | 13,500 | 0 |

Table 4. Changes of interest rates producing NPV for transformation, which exceeds that for e-a silviculture ensuing from variant stumpage prices and rotations (± standard error[1]).

| | **transformation period (77 years)** | | **unlimited time horizon** | |
|---|---|---|---|---|
| | **interest rate producing an NPV for transformation, which exceeds that for e-a silviculture (%)** | **difference of NPV between transforma-tion and e-a silviculture** | **interest rate producing an NPV for transformation, which exceeds that for e-a silviculture (%)** | **difference of NPV between transforma-tion and e-a silviculture** |
| **current wood price, rotation 98 years** | 2.6 | 344 ± 15 | 1.9 | 1060 ± 342 |
| **stumpage price + 25 %** | 2.7 | 467 ± 16 | 2.1 | 687 ± 138 |
| **stumpage price - 25 %** | 2.4 | 215 ± 14 | 1.8 | 427 ± 125 |
| **rotation 88 years** | 2.4 | 81 ± 16 | 0.8 | 1.905 ± 889 |
| **rotation 78 years** | all interest rates between 0 and 10 % | | all interest rates between 0 and 10 % | |

[1]The standard error for the NPV-difference was calculated on the basis of three repetitions of growth predictions, which allowed three different estimates of cash flows for each treatment.

**Figure captions:**

Fig. 1. Schematic age structure of an uneven-aged forest stand (according to Smith et al. 1997, with alterations).

Fig. 2. Development of growing stock and volume cut over time.

Fig. 3. Height development of fir saplings.

Fig. 4. Stem frequency distribution of transformed stand at age 118 years.

Fig. 5. Distribution of income and expenses over time for even-aged and transformation treatments.

Fig. 6. Ratio between net present value (NPV) produced by transformation and that produced by even-aged silviculture.

Fig. 7. NPV produced by transformation and that produced by e-a silviculture (rotation 78 years).