Financial consequences of losing admixed tree species:

A new approach to value increased financial risks by ungulate browsing

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Abstract

The influence of ungulates on the growth of young trees is amply discussed in forestry literature, particularly game browsing. Although there are a few appraisal methods that consider negative long-term influences on forest regeneration, hitherto no approach has addressed the financial consequences of lost admixed tree species. A homogenised species composition may lead to an increased financial risk of a forest. Based on financial return and risk ratios of mixed forests, this paper derives the financial compensation that would be necessary to make acceptable the increased risk of pure forest for forest owners. In this conceptual case study we consider a two-species mixed forest (Norway spruce, *Picea abies* [L.] Karst. and European beech, *Fagus sylvatica* L.) and calculate a tree species composition with maximum financial return per unit of risk. The financial indicators were generated via 1,000 Monte Carlo scenarios, which consider natural hazard risks as well as timber price fluctuations. In case of an assumed reduction of European beech in different mixed forests by 30 percentage points, a compensation rate for ungulate browsing of between 16 and 23 € ha^{-1} yr^{-1} was estimated. Compared to the annual gains of mixed-forest between 89 and 113 € ha^{-1} yr^{-1} for admixtures of beech between 70 and 30 percent, we consider this amount substantial and conclude that the appraisal of game browsing effects should include the changed risk profiles between homogenised and mixed forests.

Keywords:

Game browsing; Demixing; Portfolio Theory; Financial risk; Sharpe-Ratio; Compensation

1 Introduction

In addition to many positive ecological aspects, some types of mixed forests (e. g. mixtures of broadleaves and conifers) stabilise the volatility of net revenues significantly. This effect occurs with variable intensity due to influencing the susceptibility of forests to natural hazard risks, such as wind-throw or insect calamities (see also Amacher *et al.* 2009). Therefore, mixed forests are generally considered more resistant (Mayer *et al.*, 2005; Schütz *et al.*, 2006; Griess and Knoke, accepted). If a forest consists of more than one tree species, it forms a portfolio of mixed natural assets when seen from a financial perspective, wherein the tree species represent natural capital assets. If the mixed tree species show uncorrelated risks, one species may suffer from natural hazards or even low timber prices, while the others don't. A mixture of tree species may thus lead to risk compensatory effects and lead to superior financial return and risk combinations. The concept is also known as diversification (Knoke *et al.* 2005). Furthermore, mixed forests may offer improved management flexibility, because they provide the opportunity to adjust the forest stand's species composition to changing environmental conditions during rotation (Lohmander, 1993). Mixed forests also provide diversity in social demands – a further aspect which justify the endeavours of forest conversion (cf. Wagner 2004, 2007). However, all of these benefits will be lost if young forests are homogenised due to intensive browsing.

Homogenisation is an ecological effect described in numerous studies - e.g. Eiberle and Bucher (1989) and Didion *et al.* (2009) describe it for Switzerland, Gill (1992) for north temperate forests, Ammer (1996) for Southern Germany, Horsley *et al.* (2003) and Long *et al.* (2007) for the northern hardwoods of the USA, Tremblay *et al.* (2007) for boreal forests and Pellerin *et al.* (2010) for France. Adapted game densities can clearly help to keep the damage to forests at an acceptable level (Putman, 1996). For example, Hothorn and Müller (2010) could statistically prove that adequate hunting can reduce the probability of a young tree of being browsed by 50 %. But if adapted hunting is omitted the resulting consequences may be severe.

Beginning in the early 20th century (Endres, 1911) various approaches have been developed for the appraisal of such situations. Existing studies employ various methods. For example, the loss of annual height growth due to browsing was used to assess the effects of postponed harvesting (e.g. Speidel, 1980; Kroth *et al.*, 1985), or similarly, calculations being carried out on the differences between browsed and undamaged forest stands in regards to their net present values (NPV – explanation see cp. 2.1) – see Ward *et al.* (2004), who also considered

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timber quality changes. An alternative option to the above mentioned future oriented methods is to use cost values which are altered by game browsing. Here the value of a forest stand is assumed to be equivalent to the present accumulated costs for stand establishment and maintenance (e. g. Pollanschütz and Neumann, 2005). Also, the average of the altered NPV and cost value has been used to estimate financial losses (Moog and Schaller, 2002). Gill (1992) summarizes the results of studies on north temperate forests and shows a range between £0.73 and £85.23 ha^{-1} yr^{-1}. The causes of the differences can be found in the region considered, the assumed damage and the valuation method. However, none of the existing approaches considers the changed risk profiles after intensive browsing, which may have an important influence on a forest's value for a risk-averse decision maker.

Certainly forest owners also have the possibility to protect regeneration, whereby demixing can be avoided. With assumed 3,000 € per hectare for fencing and 2% interest we would reduce the annualized NPV of a forest stand by 70 € per hectare if we are regarding a time span of 100 years (calculation of annuities see Eq. 6). This exceeds the possible annualized NPV of timber production in many places. Assuming single tree protection of at least 500 plants per hectare for € 1.50 each, we would have still annual costs of 17 € per hectare. Thus, the financial losses are of interest if we tolerate or have to tolerate browsing without any protective measures.

Here, our focus is to find an approach for financial valuation of an increased financial risk, which the owner of an already existing mixed forest is forced to bear by means of intensive deer browsing. Two research questions thus arise for the paper at hand: How is it possible to identify a financial balancing which compensates a risk-averse decision maker for the increase of risk due to the loss of one out of two species included in a mixed forest? And: Are the necessary compensations substantial; how would they relate to the financial gain by an undamaged, respectively adequately mixed forest? In the following we will describe our new valuation method and will illustrate it by means of a numerical example. Finally, the results of our simulation study - timber volume and financial assessment - and their derivation will be discussed.

2 Methods and data

2.1 Valuation approach

To obtain a more realistic valuation of the financial consequences of game browsing, the resulting changes in financial risk should be considered. The risk of an investment in a forest is understood as the standard deviation (SD) of all appropriately discounted and summed net revenues gained or caused by the management (called net present value, NPV, from here onwards). The SD as a commonly accepted measure of financial risk (Hirshleifer and Riley, 2003) is of course influenced by natural occurrences that lead to deviations from the expected NPV. Storm, insect calamities, snow or fire regularly cause a reduction of the actual NPV. Also, an adverse timber price development affects the operational result. These negative financial consequences can only be quantified with enhanced financial valuation and simulation principles (Thomson, 1991; Knoke and Wurm, 2006; Hildebrandt and Knoke, 2011). Please note that we use NPV as indicator for financial return only in the first step. Later we form annuities based on the simulated forest NPVs accounting for an infinite time horizon (Section 2.2 provides an explanation).

2.1.1 Impact of portfolio composition on financial risk and return

In the middle of the last century, Markowitz (1952) published his Portfolio-Selection-Theory, which supports optimal choices on mixed investments under uncertainty. His approach can explain how a mixed portfolio of investments leads to a lower risk compared to the sum of the single risks of each investment (see Figure 1).

If we assume normally distributed financial returns, *NPV ~ N(E(NPV), Var (NPV))*, we can compute the financial return, NPV_p, and standard deviation, σ_p, of a mixed portfolio consisting of two assets (A and B) as follows:

$$NPV_p = f_A NPV_A + f_B NPV_B$$
$$\sigma_p = \sqrt{f_A^2 \sigma_A^2 + f_B^2 \sigma_B^2 + 2 f_A f_B Cov_{A,B}}$$

(1)

$$f_A + f_B = 1$$
$$Cov_{A,B} = c_{A,B} \sigma_A \sigma_B$$

with *NPV* being the net present value, *f* the decimal fraction of one asset, σ the standard deviation, *Cov* the covariance and *c* the correlation coefficient. All combinations of 2 investments with the highest financial return for a given risk form the so called "efficient

frontier", displayed in Figure 1. A detailed description of this approach that also may considers more than two investment options and the use of correlation coefficients can be found in Elton *et al*. (2003), Poddig *et al*. (2005) or Spremann (2006).

2.1.2 Optimal composition of capital assets and compensation for homogenisation

The optimal composition of investments depends on the risk aversion of the investor (Elton *et al*., 2003; Spremann, 2006). A risk-averse investor has to decide which additional return (or compensation) is necessary to compensate for additional risk, which has to be accepted when investing in a risky portfolio of assets. The expected compensation is also known as the price for risk (Hirshleifer and Riley, 2003).

Tobin (1958) has shown that the structural composition of a risky portfolio of assets will be identical for all investors independent of their individual risk aversion, if their expectations are homogeneous and a risk free asset exists (e.g. short-term government bills). Note that we used 20 € ha^{-1} yr^{-1} as financial return of the risk free investment (see Eq. 2) and calculated as follows: We assumed the forest owner can also sell his forest for 4,000 € per hectare for reinvesting at the capital market. This value corresponds with average forest sales in Bavaria, Germany. For an assumed risk-free interest rate of 2.5 % (Wöhe and Döring 2010) less inflation of 2 % (German Federal Statistical Office 2011, average 1992-2010) the forest owner will receive the real interest rate of 0.5 % and thus the annual risk free return of 20 € ha^{-1} yr^{-1}.

Given the existence of a risk-free asset, the so-called capital allocation line (CAL) can be formed for combinations of the risk free asset and every risky investment (see Figure 1 for an example). With this consideration we have to maximise the following relation to find the optimal portfolio composition:

$$\max SR_p = \frac{NPV_p - NPV_{Risk-free}}{\sigma_p} \qquad (2)$$

Equation (2) is known as the "Sharpe Ratio" (also noted as Reward-to-Variability-Ratio), SR_P, (Sharpe, 1966), a quotient named after the economist and Nobel laureate William F. Sharpe. In ecosystem management "Sharpe Ratio" has been applied by Koellner and Schmitz (2006) to optimize grassland composition and by Knoke et al. (in press) to compute land-use

portfolios for tropical landscapes. Rearranging (2) helps us to find an adequate financial return for a given risk.

$$NPV_p = (max\ SR_P)\ \sigma_P + NPV_{Risk\text{-}free} \qquad \textbf{(3)}$$

Equation (3) forms a line with a slope equal to (max SR_P), while the intercept is $NPV_{Risk\text{-}free}$. It thus describes the optimal CAL exactly. For the case of a homogenised risky portfolio, for example indicated by 100 % of the most risky single investment, the CAL requires a much higher adequate financial return, which would be necessary to form the maximum SR_P, than actually achieved (see Figure 1). The difference between the adequate financial return for the single investment expressed by the CAL and the actually achieved financial return, given by the efficient frontier, expresses the compensation amount we are looking for. Only if the investor could receive this compensation in addition to the financial return of the single investment would he be willing to accept the risk involved with it.

In the following, in some examples we will describe how we calculated the compensation possibilities as shown in figure 1 and investigate what it means to lose European beech in a mixed forest with Norway spruce.

2.2 Generating data and modelling

As mentioned above, we exemplarily applied the described valuation approach to a Norway spruce / European beech forest located within the Bavarian growth district "Innerer Bayerischer Wald". The forest growth was simulated using the simulation model Silva 2.2 (Pretzsch *et al.*, 2002), based on average height development curves for various growth districts in Bavaria. As input variables we used as followed:

(*Table 1*)

The initial forest characteristics were obtained from suitable yield tables (Spruce: Assmann, 1965, mean yield level; Beech: Wiedemann, 1932, moderate thinning). The already high initial ages chosen for generating the start situation result from the experience that the used growth model shows a good parameterization for forest stands from these ages upwards. For every period of 10 years, the forest volume as well as the amount of timber harvested was

generated assuming a 100-year rotation period for Norway spruce and a 120-year rotation for European beech, adapted from longer rotation periods used for hardwood. A harvest of 100 m³ (gross volume inside bark) per hectare and decade was assumed as an upper limit and used as input variable for the growth simulations. Using the volume and grading program "BDat" (Kublin and Scharnagel, 1988), the timber amount was divided into common assortments in a final step. Note that net revenues for every age class were calculated out of the timber volume – explanation of net revenues follows later. As it is not possible to simulate correct data for stands younger than our starting age (25 years for Spruce and 45 years for Beech), we estimated net revenues for these ages. Furthermore, we assumed that Spruce is tended at age 20 and Beech at age 30 leading to costs of 500 € per hectare each.

Following the process chart displayed in Figure 2, we supposed an already existing mixed forest which is exposed to browsing, so that no establishment costs had to be considered, and we supposed a complete harvest after one rotation period. Since we assumed that browsing occurs in an already existing forest, all investments made before can be seen irrelevant (sunk costs), since our valuation is future-oriented. Threefold repeated growth simulations – we used the average to consider the possibility of different forest growth – were then carried out for single species stands of both Spruce and Beech on an area of 1 ha each. The results were then merged to calculate virtual mixed forest with different proportions of each species.

We calculated the survival probabilities of both Norway spruce and European beech based on survival functions published by Beinhofer (2009) that allow to estimate the probability of a forest to reach the rotation age.

$$SP_b = 0.990 + 9 \cdot 10^{-5} \cdot Age_b - 1 \cdot 10^{-7} \cdot Age_b^3$$
$$SP_s = 1 + 3 \cdot 10^{-4} \cdot Age_s - 4 \cdot 10^{-5} \cdot Age_s^2 + 6 \cdot 10^{-8} \cdot Age_s^3$$

$$(4)$$

SP = Survival probability; Age = Stand age; b = European beech; s = Norway spruce

We used the equations in (4) to derive conditional hazard probabilities as an input for a binomial distribution function to generate random numbers. During 1,000 Monte Carlo simulations this function resulted in simulated forest damage with a relative frequency that complied with the derived hazard probabilities. In younger age classes the survival probabilities of both tree species show a similar curve shape. Starting at age 50 the regressive

curve shape of Spruce is considerable: The survival probability of Spruce then amounts 0.923 and for Beech 0.982, developing into an even stronger difference at age 100 of 0.691 for Spruce and 0.899 for Beech. If damage was simulated, the financial return was calculated using simulated harvest revenues obtained until that moment plus half of the current felling value. This approach is based on Dieter (2001) and copes with the facts that in case of a calamity a considerable proportion of timber will be destroyed, cost for salvage logging will increase, some timber won't be saleable and timber prices will decline due to oversupply (see also Bright and Price 2000). Additional costs emerge from necessary plantings of a new generation after damage. The total amount depends on the age of the forest affected. In older stands, we assumed that an already existing understory reduces possible planting cost.

But not only hazards have strong influence on financial risks and return of forest investments. Fluctuating timber prices are also of high importance. Not only can they change the monetary valuation of a forest directly and therefore imply a specific uncertainty, they can also determine in part the risk correlation of different mixed tree species. At first we analysed an available data base on timber prices from 1975 till 2007, which was fed with data from the Bavarian State Forests (BayStMELF, 1975-2004; Bayerische Staatsforsten, 2005-2007). Then a mixed price made up of prices for different timber qualities was composed for every diameter class and year. We used the prices from year 2007 to determine the net revenues gained by harvesting the final forest volume and thinning harvests per decade, not considering administration expenses.

A simple process to generate the fluctuation of timber prices was applied (cf. Knoke *et al.* 2005). To obtain the variation of timber prices we used the mixed price distributions for saw logs of specific size classes, which represent the biggest timber volumes among all saw log size classes. These size classes were only used as reference value to initiate the fluctuation and range between 35 and 39 cm for European beech logs and between 25 through 29 cm for Norway spruce (Figure 3). Then we calculated the historical mean prices and their standard deviation for these size classes. While European beech resulted in an average historical price of 64.42 €, Norway spruce achieved 56.07 € per m³ over bark. The timber prices of Norway spruce featured a slightly higher standard deviation (10.03 €) than prices for European beech (9.84 €). Figure 4 and 5 show the corresponding price intervals for both tree species.

Next, based on the mean historical timber price and the standard deviation, we simulated the distribution of timber prices for Spruce only and drew random prices for every simulation run and every point in time when a harvest was assumed (generally every ten years). To include

the correlation of the different timber prices between Beech and Spruce, the price for European beech was simulated using a regression model – from historical price distribution – depending on the simulated Norway spruce timber price ($P_{Beech} = 0.1306\ P_{Spruce} + 57.10$). The standard deviation for Beech of the differences between historical timber prices and simulated prices of each year was about 9.61 € per m³ over bark. Thus, the random price for Beech was simulated using the regression model and the described standard deviation:

$$P_{Beech} = NORMINV\ (random\ number;\ 0.1306\ P_{Spruce} + 57.10;\ SD) \tag{5}$$

with P as price for Beech and Spruce, *NORMINV* as excel-based assumed normal distribution, and *SD* as standard deviation.

Finally, two quotients were generated based on the simulated random prices for Norway spruce and European beech as described by Knoke *et al.* (2005). The quotient considered an actual randomly generated timber price as the enumerator and the mean historical timber price as the denominator. Following, the net proceeds based on the price level of the year 2007, made up of harvesting and felling values were multiplied with the randomly fluctuating quotient. Thereby we obtained fluctuating timber prices for both tree species and every decade. The ratio of the revenues remains unchanged using the quotients.

For each of the 1,000 simulation scenarios generated with fluctuating net revenues, the NPV for an infinite time horizon (NPV_i) – also known as soil expectation value – and the annuity (a_i) as the annualized NPV were calculated using a moderate interest rate of 2 % as common for long term forest investments (Heal *et al.*, 1996; Herbohn and Harrison, 2001) in Central Europe. To consider an infinite time horizon we added the – appropriately discounted - average soil expectation value (SEV_g). We obtained SEV_g as the average NPV_T, formed by the individual NPVs of 1,000 scenarios computed over the production period T. Here, T is either the rotation or the time when the stand failure by natural hazard was simulated. Thereby, the average estimated NPV was multiplied by the eternity factor (cf. Eq. 6) with average rotation periods: 84 years for Spruce and 111years for Beech to finally obtain the average soil expectation value, SEV_g. If a simulation runs without hazard the estimated NPV was added at the end of rotation period and was then discounted together with the revenues. This amount and the sum of earlier discounted net revenues from thinnings and costs for tending resulted in the NPV_T. If hazard occurs, the estimated SEV_g was added to that period and was discounted with the age of damage occurrence. In a final step for every scenario the NPV_i was then multiplied by the interest rate:

$$NPV_i = NPV_T + SEV_g q^{(-T)}$$

$$NPV_T = \sum_{t=0}^{T} r_t q^{-t}$$

$$SEV_g = \overline{NPV_T} \frac{q^{\overline{T}}}{q^{\overline{T}} - 1} \qquad \textbf{(6)}$$

$$a_i = NPV_i \cdot i$$

$$q \neq 1$$

with i being the scenario, t the considered point in time, T the period of consideration (100 or 120 years, or when stand failure occurred), $\overline{T}$ the average age of Spruce or Beech, r_t the net revenues at a given point in time, q the discount factor (q=1+i, with i=0.02 being the decimal interest rate) and SEV_g the estimated soil expectation value.

For the final valuation the annuity was chosen as indicator for financial return. Applying this method an investment is advantageous if the annuity shows a positive value or is greater than the annuity of the alternative. In forest economics this financial ratio offers an adequate method for decision support (Möhring *et al.*, 2006).

To obtain the correlation of the annuities of both tree species the 1,000 times iteration of simulating forest life was necessary. We applied the Monte Carlo method according to Barreto and Howland (2006), where classes of computational algorithms that rely on repeated random sampling are used to compute results, in our case to repeatedly simulate net revenues under a changing environment. With the obtained financial returns, standard deviations and correlation coefficients it was possible to derive efficient tree species portfolios as well as SR_P's.

3 Results

3.1 Biophysical data

As known from other studies (e. g. Möhring, 2004), Norway spruce can achieve higher timber volumes than European beech during equivalent growth periods. Exclusive of considering hazard risks an average volume increment of 10.3 m³ ha⁻¹ yr⁻¹ was simulated for Norway spruce, while the value for European beech was only 6.2 m³ ha⁻¹ yr⁻¹ (Table 2).

3.2 Financial flows

The net felling values at age 100 and 120 respectively differed considerably between Norway spruce and European beech. While Norway spruce achieved 31,793 € ha^{-1} after 100 years, European beech reached only 16,867 € per hectare after 120 years. Average net revenues gained by thinnings are similar for both species. For Spruce we simulated an average of 1,104 € ha^{-1} per decade and for Beech 1,301 € ha^{-1}.

The 1,000 scenarios under different financial scenarios resulted in a correlation coefficient of -0.04 between the annuities of both tree species. This shows that the financial return of Norway spruce and European beech is neither positively dependent on each other, nor does it shows an opposing development. The causes may be sought at the different influence of the calamities which is comparable with the results of Beinhofer (2009). In contrast, an analysis of Hyytiäinen and Penttinen (2008) shows high correlations between different forest stands. The average annuity of Norway spruce was 131 € ha^{-1} yr^{-1} with a standard deviation of ± 31 €. European beech obtained a smaller annuity with 72 € ha^{-1} yr^{-1} yet at a much lower risk. The standard deviation for Beech was only ± 11 €. The simulated frequency distribution of annuities for both species (see Figure 6 and 7) and for a mixture of 50% Spruce and 50 % Beech (Figure 8) of the Monte Carlo simulation can be seen in the following:

Figure 6-8

If we see the two tree species as natural capital assets and parts of a portfolio, the financial risk-return relation of various portfolios will depend on the composition of tree species, including a single investment (Figure 9). Various mixtures between Beech and Spruce turn out to be efficient because of their advantageous risk-return relation. In contrast a pure Beech forest shows lower returns and higher risks than a portfolio with a small proportion of 10 to 20 % Spruce and 80 to 90 % Beech.

As illustrated in Table 3, different portfolio compositions result in different SR_P quotients implying the price demanded for an additional unit of risk. The highest quotient of 5.74 derives from a composition of 80 % Beech and 20 % Spruce.

An examination of all SR_P's leads to the conclusion, that a tree species composition made up by 80 % Beech and 20 % Spruce has the most favourable risk-return relation, whilst a pure Spruce forest show the lowest Sharpe Ratio of 3.57, which exposes them to have the most unfavourable risk-return relation. However, this holds only for the situation in which no investment costs for establishing the forest stands are considered, as is the case for example,

when using natural regeneration opportunities. If both tree species have to be planted thus requiring establishment costs, a composition of 50 % European beech and 50 % Norway spruce turns out to be the optimum. Thus it would be incorrect to assume that the initially selected species composition would have been 80 % Beech and 20 % Spruce for the forest owner. Rather, a mixture of 50 % Beech and 50 % Spruce (or even higher percentages of Spruce) seems a more realistic initial composition to consider in our browsing exposure scenarios, should establishment costs be a factor.

3.3 Necessary compensation to accept the risk of increased proportions of Norway spruce

The efficient frontier shown in Figure 9 shows all risk-return relations depending on the mixture of Spruce and Beech. According to our financial model, any risk averse forest owner would prefer one mixture of 80 % Beech and 20 % Spruce. This composition achieves the maximum SR_P. However, the mixture of species can change. A recent survey showed browsing probabilities of only 0.04 for the case of Norway spruce and 0.15 for European beech in Bavaria (BayStMELF, 2009). It is clear that selective browsing will lead to a shift in the composition of tree species. If regeneration consisting initially of 80 % European beech and 20 % Norway spruce stepwise develops into a pure Norway spruce forest whilst plants are at a height susceptible to browsing risk will increases for the coming years. Assuming that the forest will have a moderate reduction from 80 % to 50 % till the end of final harvest, the annuity will be about 101 € ha^{-1} yr^{-1} with a risk of ± 17 € ha^{-1} yr^{-1} (Table 3). The increased proportion of Norway spruce thus induces a higher risk. If we multiply the maximum SR_P (5.74) with the risk of ± 17 € ha^{-1} yr^{-1}, which has to be accepted when having a 50 to 50 mixture, according to Equation 3, we obtain the demanded annuity to accept this risk. Including the return for the risk free asset of 20 € ha^{-1} yr^{-1} this leads us to expect approximately 117 € ha^{-1} yr^{-1} as an adequate financial return. However, actually only 101 € ha^{-1} yr^{-1} can be obtained leading to the demanded 16 € ha^{-1} yr^{-1} to compensate the forest owner for the increased risk. We can also consider another example: Imagine you have invested in a mixture of 70 % Spruce and 30 % Beech. Although this mixture has not the favourable risk-return-relation (see Table 3) the SR_P is still better than that of a pure Spruce forest. In the case of a complete loss of the Beech admixture we would only accept the higher risk if we receive a compensation of approximately 20 € ha^{-1} yr^{-1}. This is derived by multiplying the SR_P (4.21) by the risk of a pure Spruce forest (± 31 € ha^{-1} yr^{-1}) plus 20 € for the risk free asset giving an

adequate financial return of approximately 151 € ha^{-1} yr^{-1} from which we must then subtract the actual obtainable amount of 131 € ha^{-1} yr^{-1} (return for 100 % of Spruce). Similarly, we have to demand a compensation of 23 € ha^{-1} yr^{-1} when we start with a mixture of 50 % Beech and 50 % Spruce and lose 30 percentage points of Beech so that we end up with a forest formed by 20 % Beech and 80 % Spruce. Here we multiply the initial *SR*$_P$ of 4.87 (50 to 50 mixtures) with the risk of a 20 % Beech / 80 % Spruce mixture (i.e. ± 25) with adding the risk free return. Thus we would require 142 € ha^{-1} yr^{-1} to accept this risk, but we obtain only 119 € ha^{-1} yr^{-1} (Table 3), therefore requiring an additional compensation of 23 € ha^{-1} yr^{-1}. We may conclude that a loss of 30 percentage points of Beech would require between 16 and 23 € ha^{-1} yr^{-1} as a compensation payment.

4. Discussion and Conclusion

The approach we apply depicts the possibility to evaluate aspects of demixing tree species when seen from a financial point of view, which was disregarded until today. It vividly shows the economic consequences that high ungulate densities may bring in comparison with possible annualized NPV of a mixed forest. Within the very long period of time a forest has to live through to reach its harvest age, calamities or timber price fluctuations influence the degree of risk significantly. If the valuation of this situation is done using conventional methods of dynamic investment appraisal with constant prices for timber sales and without considering natural risk, single species forests will turn out to be most profitable. Such calculations do not allow the consideration of a compensatory effect of admixed tree species, as their payments will show greater stability and they lead to no compensation for possible lower returns due to game browsing. Contrary to these conventional methods our approach shows how to derive financial compensation to make acceptable the increased risk of pure forests.

The amount of the compensation is depending on the degree of demixing. The occurrence of demixing due to ungulate browsing does exist, as proven by many studies. However, – as Weisberg and Bugmann (2003) show – these studies clarify shifts in species composition within a few decades, but long-term studies about shifts in species composition within one rotation period are unknown. But some forecast models can at least estimate the shifting. We assumed exemplary demixture of Beech up to a plant height of 1.30 - 1.50 meters – beyond this, plants are not endangered by browsing pressure (Prien and Müller 2010). But thinnings until the end of rotation period could develop into the initial composition if the browsing

effect was only moderate. In that case no compensation would be calculated. However, this thinnings could cause additional costs.

The growth characteristics of both species we used were generated applying a simulation based on pure forests. The virtual mixture was later composed using the regarded proportions of each species from the earlier simulation. For this reason possible interactions of tree species are not taken into account. But mixed species forests cannot be treated as a summation of the corresponding monocultures. If species interact because of ecological interdependence then the direct analogy to financial assets dissolves. However, studies which quantify possible impacts of mixtures are hard to find and most known studies relate to growth performance and disregard the fact that mixture can lead to higher stability and risk apportionment (Pretzsch and Schütze, 2009). Hence, it is to expect that a better integration of the ecological reality into models of mixed forests would substantially change the results towards higher financial amounts to compensate for demixing effects. A first attempt to estimate the consequences of interdependent tree species, mixed at the stand level, was undertaken by Knoke and Seifert (2008). This paper emphasized the great importance of stand resistance and timber quality in mixed stands according to financial parameters and could neglect the critique by Deegen *et al*. (1997), who claimed that the portfolio theory would not be useful to estimate diversification effects on trees, thus allowing further interactions between tree species. By combining all the effects that Knoke and Seifert (2008) considered, and integrating these interactions into the modeling, the risk-return relationship improves, thus increasing the compensation rate.

Modern financial theory based on the fundamentals of Markowitz, Tobin and Sharpe (see chs. 2.1.1 and 2.1.2) is used in many facets. The use of aspects of modern portfolio theory in forestry is still in its infancy and in particular has not been used in the valuation of browsing effects in any published work. Normally, the models are used to show market risks of assets traded at stock exchange. However, assumptions regarding return and risk of investing in timber are based on historical data. The long investment period of the asset class timber has to be discussed as well because willingness to accept risk can change over time. This makes forest investments hardly comparable to an investment in funds with a short-term investment strategy. Here, the computation of the capital allocation line (CAL) offers an opportunity for showing adequate return-risk-relations for a forest owner, in which the maximum obtainable price for accepted risk is determined by the specific species composition held in the tangential portfolio.

Although the models of financial theory have normative character, are easy to handle and are based on simplified assumptions (Schnelle, 2009), some critical comments about these assumptions have been published (Roll, 1977). The constant slope of the CAL, based on equivalent debit and credit rates, displays the assumption of a perfect market. In principle though, it is possible to earn higher returns than those achievable by holding asset combinations situated on the tangential portfolio. By increasing the total investment volume using borrowed money the asset composition will not change. However, the related risk will increase proportional to the related return. In the case of a long term investment in timber, interest rates have to be constant for the total investment period. Here, a constant risk free asset can be contested.

The portfolio selection theory is based upon the principle of normally distributed financial flows (e. g. the NPV). In this case Eq. (1) can be applied to calculate the standard deviation of the mean NPV. However, Figure 6 and 7 show in particular that the financial returns for Spruce and Beech that derive from our simulation are not normally distributed. Especially in the case of Spruce, we have very long left tails and may thus conclude that the assumption of a normal distribution led to an underestimation of the effects of risk. One can see that lower NPVs, displayed on the left side of the x-axis, occur more for Spruce than for Beech. This clearly shows that a higher failure probability leads to potentially lower NPVs. Regarding forestry, which is exposed to many biophysical risks, revenues differ from the normal distribution. Additionally Knoke and Wurm (2006) proved that assuming a normal distribution is adequate neither for European beech nor for Norway spruce or mixtures. The assumption of normally distributed revenues are criticized (Gotoh and Konno, 2000), in particular that the use of the SR_P with non-normal returns can result in misleading conclusions (Zakamouline and Koekebakker, 2009). This is why many researchers replace the standard deviation by an alternative risk measure. Alternative approaches such as considering aspects of Stochastic Dominance (Levy, 1998), the so called Downside-Risk models (Lee and Rao, 1988), or the calculation of robustness according to the Information-Gap Theory (Ben-Haim, 2006) may be used. In the described example above, the assumption of normal distribution and the use of the SR_P seem to be sufficient to show how important a shift in risk-return-relations may be. Even if alternative approaches would lead to changed results, financial compensation will still be necessary to adjust for the higher risk related with demixing of species. Only the height of the compensation rate would differ, which we certainly have estimated rather conservatively.

In most cases it is assumed that a special risk-benefit function and a risk preference have to be derived for an optimal portfolio. Risk aversion often depends on concrete decisions that may not be constant in their response to time (Post and Vliet, 2006). This limitation can be invalidated by implementation of a risk free investment alternative as shown above. However, the SR_P shows a high affinity to the less risky European beech. Only 20 % Norway spruce will be part of the risky portfolio. Hildebrandt *et al*. (2009) also used the SR_P to define optimal mixture of Rauli (*Nothofagus alpina*, P. et E., OERST.) and Douglas fir (*Pseudotsuga menziesii*, Mirb.). The less risky Rauli achieves maximal values of 80 %, in a similar relation for block mixtures and for single-tree mixtures.

The results show that derivations of optimal tree species mixtures are possible with methods of financial theory, even if there are some critical views of the assumptions and the long-running nature of a forest investment. The described model cannot forecast the future but it shows an important contribution to valuing the effects of ungulate browsing in terms of demixing and increased risk. According to the results shown here, these effects may be substantial and thus should not be neglected in future studies on the financial effects of ungulate browsing.
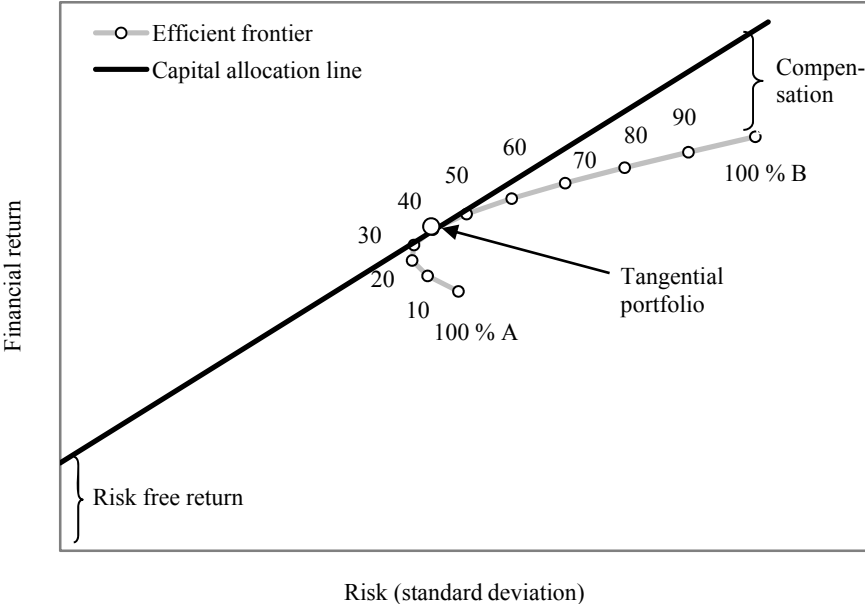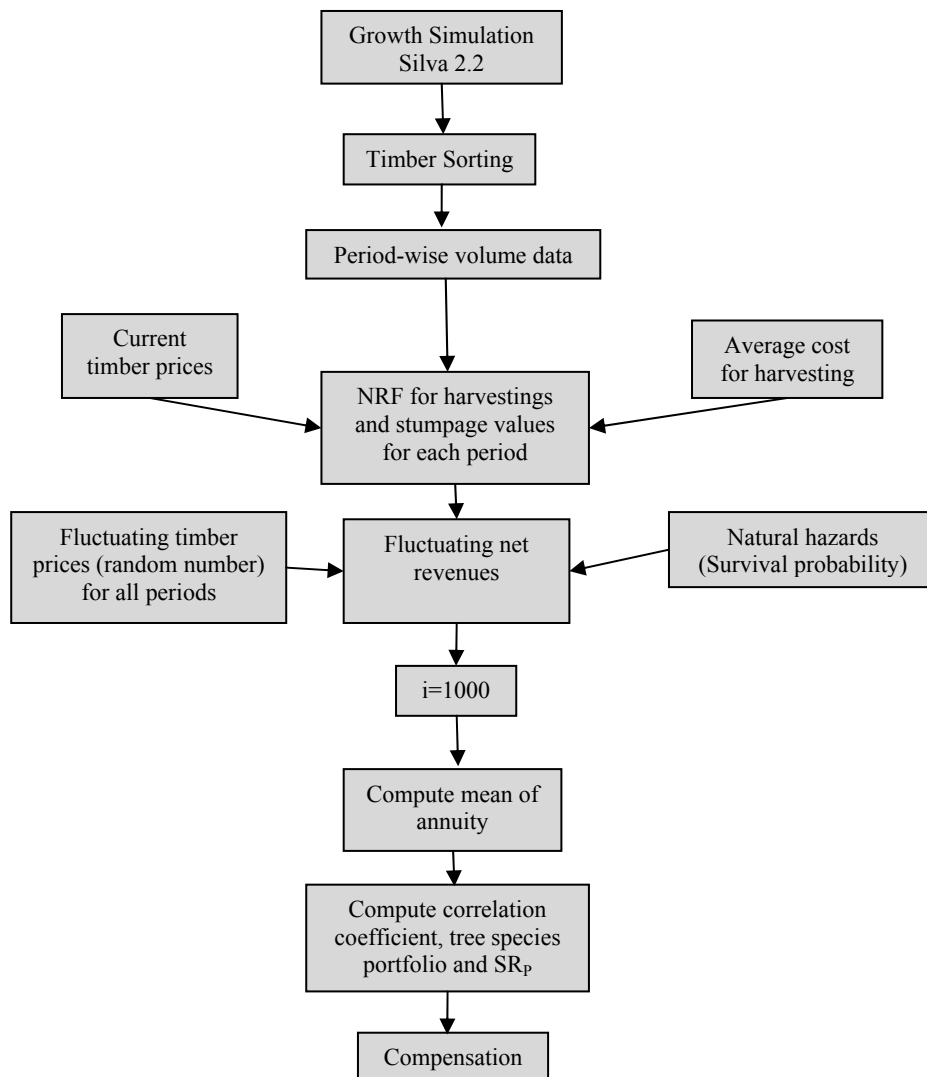
Figure 1

Figure 2

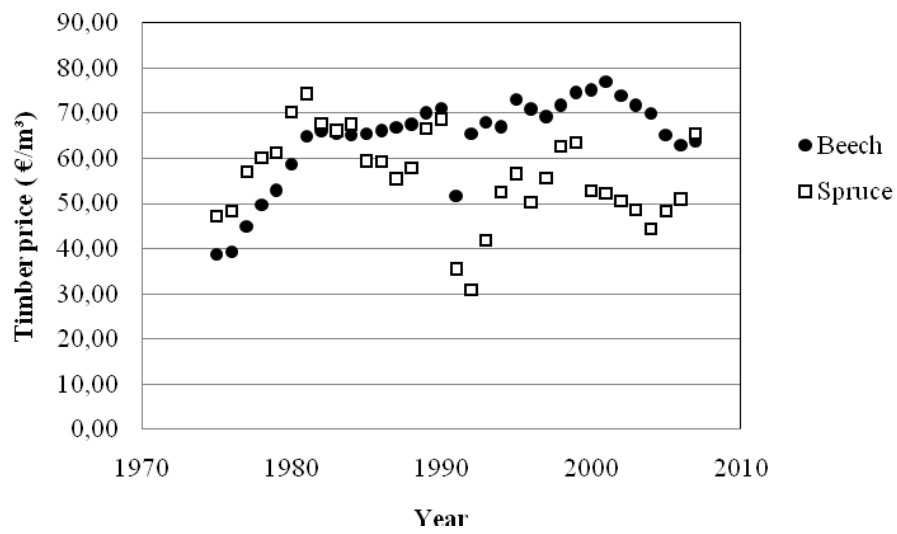NRF = Net revenue flow; i = Repetition with Monte Carlo simulation; CC = Correlation coefficient; SR_P = Sharpe Ratio
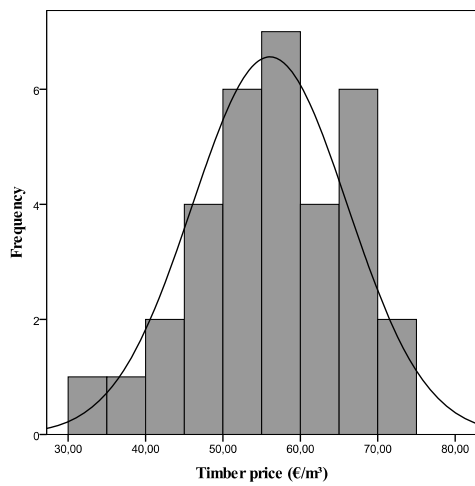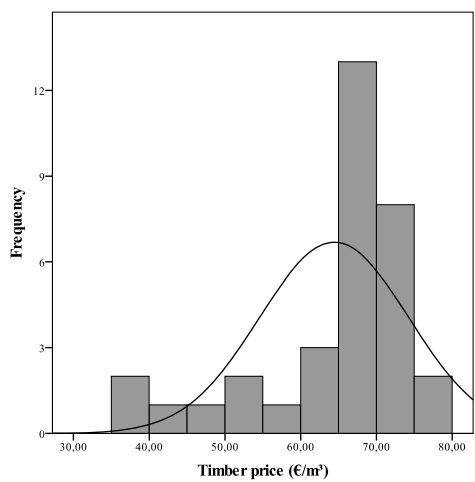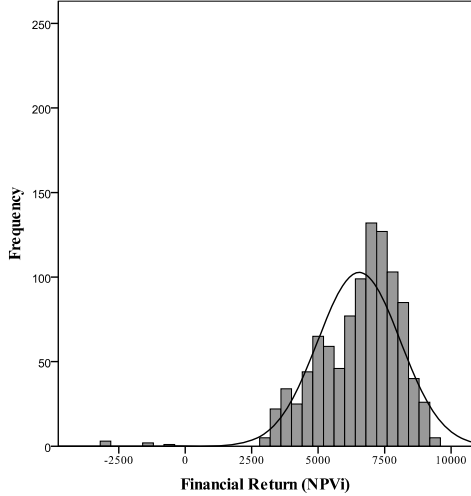
Figure 3
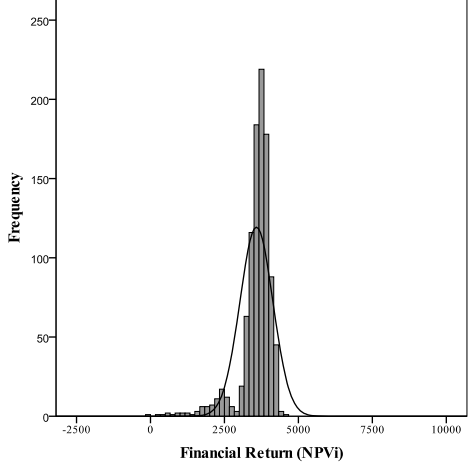

Figure 4

Figure 5

Figure 6
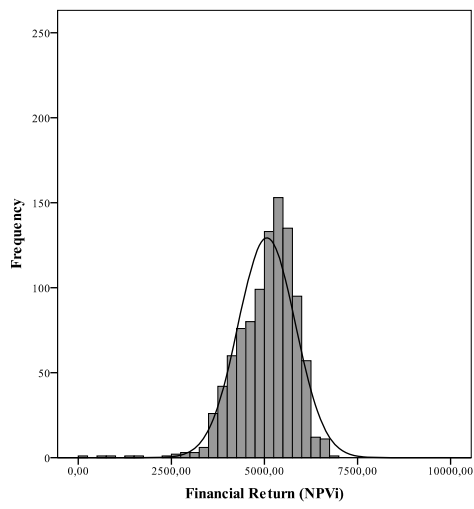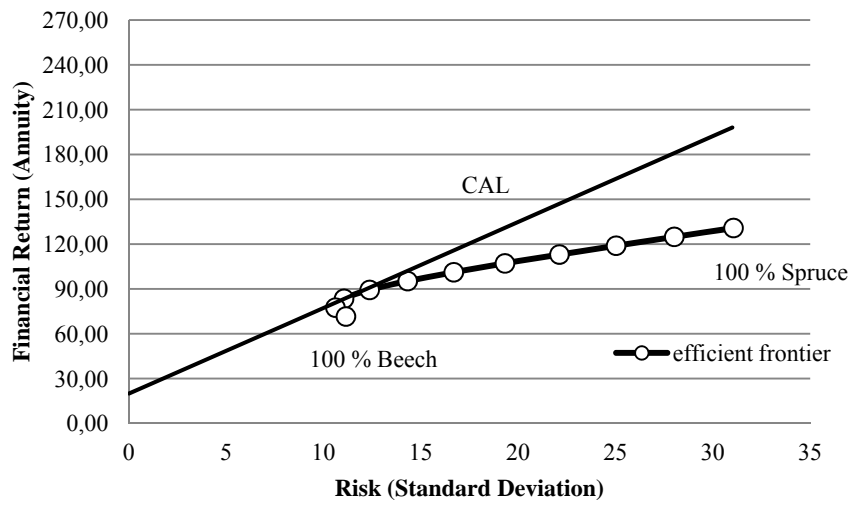

Figure 7

Figure 8

Figure 9

Figure 1 Efficient frontier, optimal capital allocation line, tangential portfolio and compensation (schematic diagram)

Figure 2 Simulation operations to calculate compensations

Figure 3 Timber price fluctuation of Spruce (diameter class: 25-29 cm) and Beech (diameter class: 35-39 cm) for mixed qualities

Figure 4 Frequency of Spruce timber prices 1975- 2007 (diameter class: 25-29 cm) for mixed qualities

Figure 5 Frequency of Beech timber prices 1975- 2007 (diameter class: 35-39 cm) for mixed qualities

Figure 6 Simulated frequencies of NPV for an infinite time horizon for pure Spruce forest

Figure 7 Simulated frequencies of NPV for an infinite time horizon for pure Beech forest

Figure 8 Simulated frequencies of NPV for an infinite time horizon for mixture of 50 % Spruce and 50 % Beech

Figure 9 Calculation of risk compensation

Table 1: Input variables from yield tables

Species (age)	Top height site class or relative site class according to yield tables	N [trees/ha]	Basal area [m²]
Spruce (25)	32	3,686	19.9
Beech (45)	3	3,476	20.3

Table 2: Simulated standing timber and harvesting volume for Norway spruce and European beech

Age (years)	Remaining standing volume after harvesting (m³/ha)		Harvested volume (m³/ha)	
	Norway spruce	European beech	Norway spruce	European beech
10	0	0	0	0
20	0	0	0	0
30	89	0	15	0
40	168	0	70	0
50	253	85	57	39
60	338	129	61	68
70	420	170	48	45
80	497	211	58	46
90	566	255	41	38
100	0	297	676	39
110	0	340	0	39
120	0	0	0	434

Table 3: Financial return and standard deviation for Norway spruce - European beech mixtures

Proportion Spruce/Beech	Financial return (Annuity)	Risk (Standard deviation)	SRp
100/0	130.83	31.06	3.57
90/10	124.91	28.01	3.75
80/20	118.98	25.02	3.96
70/30	113.06	22.11	4.21
60/40	107.14	19.31	4.51
50/50	101.21	16.68	4.87
40/60	95.29	14.32	5.26
30/70	89.36	12.36	5.61
20/80	83.44	11.04	5.74
10/90	77.52	10.60	5.42
0/100	71.59	11.14	4.63

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