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How economic performance of a stand increases due to decreased failure risk associated with the admixing of species

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ABSTRACT

A new modeling approach which combined survival probabilities for spruce with financial optimization showed a considerably reduction in financial risk in spruce (*Picea abies* [L.] Karst.) stands with an admixture of a 20% proportion of beech (*Fagus sylvatica* L.). The admixture enhanced the stability of the spruce component against natural hazards, such as storm or insect damage. Here, these new survival investigations were integrated into a bio-economic modeling approach called silvicultural economics. A new failure model which includes the benefits of ecological interactions for decreasing hazard risk for spruce was developed. The modeling technique is based on Monte-Carlo-Simulation and on simultaneous portfolio optimization of management strategies under risk. Area proportions were allocated as decision variables to each tree species and to regeneration harvests at various points in time in order to achieve the maximum financial return given a predefined, acceptable risk. The simultaneous optimization led to a mixed – and, through long regeneration periods – to an uneven-aged forest stand, for almost all predefined risk-levels. In addition, for a selection of possible even-aged tree species compositions, a stand-level mixture (including the species interactions of the new model) was compared with the same species proportion at the stand level, but consisting of two separated parts of spruce and beech (thus excluding species interactions). For all even-aged and interacting mixtures that were investigated, a higher expected return and a lower financial risk were achieved when compared to the identical even-aged mixture proportions without interactions. When the timing and distribution of regeneration harvests was also optimized (as opposed to using a clear-cut strategy) there was a slight loss in financial return, but the reduction in risk was even greater, given the same tree species proportion – especially in cases with a low beech admixture. Compared to the simulation which excluded the stabilizing effect of beech on spruce, the variant with interacting tree species allowed for higher spruce proportions and shorter regeneration cycles for the same acceptable risk.

1. Introduction

1.1. Bio-economic modeling

Silvicultural economics attempts to combine the ecological and biological aspects of silviculture (e.g. Cotta, 1828) with the financial yield and risk aspects of forestry (Endres, 1919) to achieve a more ecologically realistic representation of forest stand management (Knoke, 2010; Griess and Knoke, 2011). Reliable economic data is often available only for pure even-aged stands of particular tree species that have the potential to produce high economic yields, but that are also prone to high risks. Many traditional forest decision models considered yield, but not risks (Hartig, 1800; Faustmann, 1849, yield tables Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten, 1990). The goal of the work presented here is to combine economically relevant information regarding the yield as well as the risks of various forest management strategies that make use of natural processes to help avoid risks.

Existing silvicultural knowledge about the complex ecological and biological interactions in forest stands is often predominantly qualitative (Griess and Knoke, submitted for publication). Studies are also available which summarize information with regard to the effects of particular management strategies, for example, for the management of uneven-aged stands – sometimes referred to as continuous cover forestry (Hanewinkel, 2002; Rojo and Orois, 2005; O'Hara, 2009; Knoke, 2009, 2012; Chang and Gadow, 2010; Tahvonen et al., 2010; Diaci et al., 2011; Meilby and Nord-Larsen, 2012; Buongiorno et al., 2012); for possible benefits of

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mixed-species stands (Bartelink and Olsthoorn, 1999; Valkonen and Valsta, 2001; Kerr, 2004; Comeau et al., 2005; Pretzsch and Schütze, 2009; Griess and Knoke, 2011); as well as for various ways to reduce storm risk for forestry management (Hanewinkel et al., 2011; Albrecht et al., 2012). Although artificial implementation of mixed (Kerr, 2004; Comeau et al., 2005; Nichols et al., 2006) and uneven-aged (Hanewinkel, 2002; Rojo and Orois, 2005) forests is possible, most authors agree to call such systems close-to-nature forestry (Hanewinkel, 2002; Meilby and Nord-Larsen, 2012) or near-natural silviculture (O'Hara, 2009; Chang and Gadow, 2010; Meilby and Nord-Larsen, 2012), especially in Europe. The term ecological forestry is used for even-aged as well as for uneven-aged management (Hanson et al., 2012). Methodological approaches to the evaluation of the financial outcomes of such situations (Mendoza et al., 2000; Rojo and Orois, 2005; Knoke et al., 2005; Knoke and Seifert, 2008; Roessiger et al., 2011; Griess and Knoke, submitted for publication) show that there are potential economic benefits to be derived by designing forest management schemes which make use of natural processes and thus, from near-natural silviculture. A meta-analysis comparing the economic performance of mixed-species stands to that of pure stands proved the advantages of species mixtures – especially with regard to susceptibility to damage caused by insects and storms (Griess and Knoke, 2011).

Griess et al. (2012) were able to generate empirically sound survival models for mixed and pure spruce stands. For their study, they used long-term inventory data and analyzed it using the accelerated failure time method (Bradburn et al., 2003), while estimating the parameters of a Weibull function (Weibull, 1951) which was dependent on stand age, spruce proportion, and many other, mainly site-related, variables. The study of Griess et al. (2012) demonstrated a clear positive impact of a stand-level admixture of broadleaves, specifically, a decreased failure risk for spruce: for average site conditions in the German federal state Rhineland-Palatinate, the probability of a pure spruce stand reaching age 100 was estimated at 0.80, while an admixture of 50% broadleaves at the stand level (thus allowing for interactions between individual trees of the two species) decreased failure and increased the probability of spruce survival from 0.80 to 0.94 at a stand age of 100 years (Griess et al., 2012).

From an economic point of view, the ecological effect of risk-reduction also has a direct impact on the expected financial return, which increases considerably (Knoke and Seifert, 2008). We agree with the assertion of Koellner and Schmitz (2006) that ecological stabilization is a unique characteristic of ecosystems, in contrast to other investment options, for which there is no evidence of similar positive interactions when mixing purely financial assets. In addition to the reduction in risk associated with a stabilization effect, a forest of multiple species is comparable to a portfolio of assets as it provides financial diversification effects already, without consideration of the benefits of ecological interactions.

Levels of risk-aversion vary among individuals, but in general aversion to risk is common decision (Valkonen and Valsta, 2001), especially as it relates to long-time investment decisions like those required in forest management. The existence of an insurance branch proves the relevance of this attitude (Knoke and Wurm, 2006). From the perspective of a risk-averse decision maker, near-natural forestry would be advantageous even without beneficial ecological effects. A recent study (Roessiger et al., 2011) has shown that diversification effects alone may lead to near-natural forestry: although the expected financial return suffered under a near-natural silvicultural strategy, the large decrease in financial return was more than compensated by an even stronger reduction of financial risk. The above-mentioned effect of a reduction in failure risk in mixed stands translates to a clear economic superiority of mixed stands compared to artificially implemented monocultures of non-native species. Moreover, uneven-aged forests without clear-cuts are beneficial compared to even-aged rotation forest management approaches when economic risks are considered. Spruce is non-native and risky on most sites in Germany, but has often been planted where mixed or beech forests are the natural vegetation types. Therefore, mixed and uneven-aged forests can be defined as near-natural silviculture. Accordingly, the aim of this paper is to quantify the impact of a decrease in failure risk for spruce in mixed stands (as opposed to in monoculture) on the economic attractiveness of near-natural silviculture. We formulate the hypothesis to be tested and to be falsified in the fashion of a Null-hypothesis:

> "A more realistic modeling of failure risk of spruce stands by inclusion of a stand-level admixture of beech will not lead to higher financial returns of mixed silviculture"

The paper is structured as follows:

We first frame this study in the context of preliminary studies, followed by a general description of the new bio-economic model used here, including a short description of the model components previously described in Roessiger et al. (2011). We then describe the effect of beech admixture on spruce survival probability out of the study by Griess et al. (2012), and develop a model which includes the new survival probabilities. In the results section, we first show a risk-return diagram for stands with different forest management treatments resulting in different stand characteristics- mono- and mixed-species, even-aged and uneven-aged. For mixed stands, we show results for both mixtures without interaction between species, and those with interaction. Then we show the timber production per time unit and per species for examples of each of the silvicultural strategies. Finally, we discuss the diversification effects, on which the model is based, the importance of new spruce survival functions and prospects for further research.

1.2. State of the art of bio-economic approaches

This section describes previous studies that consider not only traditional financial risks but also quantify the effects of interaction between trees of different species that arise due to a more intense group-wise or single-tree mixture (described by and extended from Knoke (2011), see Fig. 1).

Near-natural forestry can be interpreted as a combination of different management strategies that together form an approach that is similar to traditional economic portfolio management. Such portfolio concepts allow one to hypothesize about and consider future uncertainty (Hildebrandt and Knoke, 2009). Integration of portfolio diversification into forest investment decision making is not new. Approaches were developed for example, by Mills and Hoover (1982), Redmond and Cubbage (1988), Thomson (1991), Deegen et al. (1997), Moog and Weber (2001), Wippermann and Möhring (2001), Heikkinen (2002, 2003) and Healey et al. (2005). Beinhofer (2009) was able to develop a model for diversification of different timber products in a forest enterprise. Simultaneous optimization enables analyzing decisions which include not only one, but multiple forest management considerations at the same time, for example, species proportion, number and timing of thinnings, age of final cut (Schreuder, 1971; Kao and Brodie, 1980; Volkov, 1980; Salminen, 1993; Hyytiäinen and Tahvonen, 2002), or proportions of a stand to be finally cut at a particular ages (Roessiger et al., 2011). These studies demonstrate that it is possible to interpret parts of different ecological strategies as portfolio fractions. Near-natural forestry approaches take advantage of the ecological processes that occur when different management strategies are located close to one another in relatively small area units – meaning at the stand level, and not only in large, separate units