Product diversification in South Africa's commercial timber plantations.

A way to mitigate investment risk

Authors: Verena C. Griess^{a*} (verena.griess@ubc.ca)
Britta Uhde^b (uhde@forst.wzw.tum.de)
Cori Ham^c (cori@sun.ac.za)
Thomas Seifert^c (seifert@sun.ac.za)

*Corresponding author. Tel.: +1-604-827-0634 Fax +1-604-822-9106

Affiliation: ^a Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, Canada

^b Department of Forest and Wood Science, Stellenbosch University, South Africa

^c Institute of Forest Management, Department of Ecology and Ecosystem Management, Center of Life and Food Sciences, Weihenstephan, Technische Universität München, Germany

Address: ^a Forest Sciences Centre, 2424 Main Mall, Vancouver, British Columbia V6T1Z4, Canada

^b Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

^c Paul Sauer Building, Bosman Street, 7599 Stellenbosch, South Africa

Keywords: risk, mixed species, financial theory, diversification, economic resilience, portfolio analysis, *Eucalyptus grandis*, *Pinus patula*

Abstract

We used the portfolio method to examine how a forest company can lower investment risk by producing a mix of timber products. We derived optimum combinations of pine (*Pinus patula*) saw timber production and eucalypt (*Eucalyptus grandis*) pulpwood production at landscape level. Our results indicate that producing a product mix rather than a single product improves aggregated financial returns and lowers investment risk over multiple rotation periods. The optimum mixture depended on past timber price correlations for pulpwood and sawn timber in South Africa between 1980 and 2011. This ideal mixture is comprised of areal ratios of about 45% saw timber and 55% pulpwood.

Our example shows how economic risk of a forest investment can be reduced by creating a portfolio of a number of products. The risk that an investor has to accept for each monetary unit that is expected in return can be reduced by over 40% when comparing the risk –return combinations of a pure pine saw timber stand with that of a portfolio of forest products. The risk associated with the production can be reduced by 20% when growing a portfolio of products rather than eucalypt pulpwood only.

Introduction

The forest industry is regularly confronted with risks such as biotic and abiotic hazards (Seifert 2007, Griess and Knoke 2011, Rötzer *et al.* 2012, Odhiambo *et al.* 2014), fluctuating timber prices (Insee 2013) or even changing buyer preferences (Knoke *et al.* 2006). These risks lead to economic volatility that translates into a high degree of uncertainty regarding the profitability of forest operations. The existence of a successful insurance industry neatly displays the fact that human beings generally tend to be risk averse. From two investment opportunities with identical financial outcome we typically chose the one that is related with a lower risk. Risk averse decision makers are even willing to dispense with parts of the possible gain, if the related risk is decreased (De Pril 1979).

In forestry, the choice of a main product is a management decision that plays a crucial role regarding future risks. Relying on a single product in this context might prove an economically risky choice. Additionally, longer rotations required to - for example - grow saw timber of suitable diameters increases cumulative fire risk, or the probability of the occurrence of insect damages. Additionally, sawmills are exposed to market fluctuations in the construction industry which is – with a ratio of 73% in all lumber purchases – the most important buyer of timber products in South Africa (Crickmay & Associates 2015). This combination of biotic and abiotic risks as well as market risks associated with long rotations make investments in sawlog production less attractive than investments in assets from which returns are expected sooner and that are exposed to those risks for a shorter period of time, such as pulpwood production (Ham *et al.* 2010).

The higher cumulative risk associated with long rotations contributed towards an increase in the establishment of short rotation pulpwood plantations in South Africa since the 1980ies. Additionally, growing biomass for the use in bio-energy production is gaining momentum in the African context (Seifert *et al.* 2014). While the area under sawn timber has remained fairly constant new plantings focus predominantly on pulpwood production. As displayed in Table 1, in 1980, 43% of South Africa's total plantation forests were used for the production of sawlogs, 33% for the production of pulpwood, 19% for mining timber and 5% for the production of poles and other products. By 2010 the proportion of area used for pulpwood production had increased to 56% (Godsmark 2013).

Table 1: Change of production goal of South African forest plantations between 1980 – 2010 (adopted from Godsmark 2013)

Percentage of plantation area	Year			
	1980/81	1990/91	2000/01	2010/11
Sawlogs (%)	43	35	37	36
Pulpwood (%)	33	38	56	56
Mining timber (%)	19	22	4	4
Poles (%)	2	2	2	3
Other (%)	3	3	1	1
Total plantation area (ha)	1,095,157	1,295,531	1,351,760	1,273,357

While shorter rotations and focusing on a single core business (such as pulpwood or sawtimber) may appear to make business sense *prima facie*, focusing on a single product could increase risk as well. Between 2002 and 2011 on more than one third of the entire area under forest plantations severe damages caused by fire (71%) as well as insect pests and diseases (Godsmark 2013) were recorded. Over and above these environmental risks, companies dependent on a single product are exposed to intense market price fluctuations.

Figure 1: Northern Bleached Softwood Kraft Pulp price between 1990 and 2012 (adapted from Insee 2013)

Between 1990 and 2012 the *Northern Bleached Softwood Kraft Pulp* price fluctuated between as little as US\$ 400/tonne and US\$ 1,005/tonne around an average of US\$ 668/tonne. In only 41% of the years a price above average could be noted (Figure 1).

Accordingly, it can be questioned if a single species, single product business strategy is the best for South Africa's plantations. Markowitz (1952) was able to mathematically prove that by mixing assets certain risks can be considerably reduced or even excluded. He was furthermore able to show what factors influence this positive diversification effect, one of which being the correlation coefficient of market prices for different products over time. It is well known that market prices of different forest products are not necessarily highly correlated and their volatility can vary independently, as for example shown by an analysis of timber and wood chip prices (Groot *et al.* 2012). First approaches to applying financial calculations that integrated risk to

the problem sphere of tree species and hence product choice have received a rather critical feedback (Hostettler 2006). More recently though the portfolio theory seems to have found its way into forest economic planning (Hanewinkel *et al.* 2011) and scientific studies applying the concept to forest and investment economics become more and more frequent: Neuner *et al.* (2013) assessed financially optimal tree species compositions for forest enterprises, accounting for the risk of calamities and fluctuating timber prices. Apiolaza and Alzamora (2013) used portfolio theory to analyse the trade-offs between returns and performance instability of *Pinus radiata*. Roessiger *et al.* (2011) investigated whether or not clear-cutting and single species stands are optimal when risk is considered using a model that reflects a risk-avoiding attitude and builds upon portfolio theory and finally Hildebrandt and Knoke (2009) analysed optimal species composition in plantation forests for minimum risks using portfolio theory, just to name a few.

The use of portfolio approaches in industrial plantation forestry is a relatively new but highly promising application. In this study it will be applied to a South African dataset to investigate the potential benefits of a well-structured portfolio of forest products. In forestry, the choice of the products determines the choice of species and accordingly the silvicultural regime. If the establishment of a forest stand (or enterprise) is considered not only to be the creation of ecological, but also of economic assets, the basic principles of Markowitz's portfolio theory can be used to support the decision of what species and products to choose. Forest stands are then considered a long term investment that is associated with varying risks according to tree species and management regime. An evaluation of financial return of species is necessary to assess the potential of product diversification.

Accordingly, we will test the following hypothesis:

H_{0,1}: By mixing eucalypt (Eucalyptus grandis) pulpwood and pine (Pinus patula) sawn timber production in a South African commercial forest, no risk reduction can be achieved.

Materials and methods

Past data on timber price indices suggest that timber prices of South African sawn timber for construction purposes are negatively correlated with small sized timber sold as energy or pulpwood (Figure 2). The correlation coefficient between the two is $r = -0.3$. This relation points at an existing potential regarding hedging production risk by mixing the two and lead to the initial hypothesis “By mixing eucalypt pulpwood and pine sawn timber production in a South African commercial forest, no risk reduction can be achieved.”.

Figure 2: Development of timber prices for pulp and sawn timber in South Africa from 1980-2011 (Godsmark 2013).

To test our hypothesis whether or not a risk reduction can be achieved when applying the portfolio theory we investigated a virtual portfolio made up of pulpwood from *Eucalyptus grandis* and *Pinus patula* sawn timber.

Financial estimators

For the optimization of portfolios usually internal rates of return (IRR) are used. This would be possible within the example at hand, but due to the calculation of returns over a very long time period deriving an IRR would lead to logical problems (Schmalen 2002) such as assuming re-investing all returns – for example from thinnings – at the IRR. This assumption is discussed frequently. Accordingly, in our example the return associated with all investments is given as an annuity that facilitates the inclusion of cash flows that occur discontinuously in forest management with respect to discount rates.

The use of annuities allows the comparison of financial outcome of assets with a varying investment time, such as eucalypt pulpwood and pine sawtimber stands, that differ substantially in rotation time.

Annuity is calculated based in the following equation:

$$a = R * i * \frac{(1 + i)^t}{(1 + i)^t - 1}$$

Equation 1

Where R is the return, i is the decimal interest rate and t time.

As risk free asset we assume a hectare of forest land is sold at an average price of ZAR 3,500 and this return is invested at 6 % interest rate. Considering that land prices strongly vary depending on a number of factors such as distance to port or other available infrastructure, in this example is we use an illustrative average.

The financial data used for calculating annuities is displayed in Table 2. At the time of the study (August 2015) the US Dollar and the Euro converted 1:12.7 and 1:13.9 to the South African

Rand (ZAR) respectively. The optimum proportion of the risk free asset as well as the questions if eventually borrowing money is necessary to increase the funds available for the tree species portfolio shall be of no concern at this point. Exemplarily we are going to estimate if a mixture of both products is more beneficial under the given assumptions and if so, what species proportions of eucalypt pulp and pine sawlog production areas are recommendable.

Table 2: Financial data and hazard rates used as basis for assessing an optimum mixture of pine sawn timber and eucalypt pulpwood (adapted from Godsmark 2013).

	<i>Pinus patula</i>	<i>Eucalyptus grandis</i>
Establishment costs	-5,411	-4,220
Reduction factor salvage logging	0.4	0.6
Interest Rate	0.06	0.06
Age [years]	Hazard rate	
0	0	0
5	0.053	0.074
10	0.056	0.078
15	0.059	0.082
20	0.063	
25	0.067	
30	0.071	
Age [years]	Return [ZAR/ha]	
0	-5,411	-4,220
5	79	78,788
10	10,387	151,222
15	38,460	173,695
20	88,490	
25	132,924	
30	180,083	

Monte-Carlo Simulation

Monte-Carlo Simulations (MCS) were carried out for the two stand types or different working circles. The method is commonly used to analyse the effects of stochastic processes by using random numbers to incorporate the dispersion of expected values into a model (Vose 2008). The strength of MCS lies in its ability to integrate various sources of risk and how they affect

the dispersion of returns. Accordingly, the method is well suited to simulate options in forest management (eg. Griess *et al.* 2015).

Figure 3: Simplified schematic flow chart of Monte Carlo simulations (adopted from Griess and Knoke 2013).

For each stand type 2,500 simulation runs were carried out. The 2,500 scenarios comprised 6 periods of 5 years for pine leading to a total production time of 30 years and 3 periods of 5 years for eucalypt leading to a production time of 15 years. The process for one simulation run is schematically displayed in Figure 3. The simulation is started at age 0 for all stands. During

each 5 year period, failure (damage caused by hazards or pests) was possible. Occurrence of hazards was simulated using a binomial distribution indicating failure or no failure with the according probabilities as shown in Step 1 (Figure 3). Hazard rates for *Eucalyptus grandis* were adopted from a study by Dickel *et al.* (2010), those for *Pinus patula* from unpublished material that was made available by industry.

In step 2, the timber value was calculated. The yield volumes arose from the development of each stand and were dependent on the stand age at the time of any simulated failure. If a failure was simulated, the return for the timber at sale was reduced by 50 % using a ratio estimated by Dieter (2001). Furthermore, damaged stands were replanted assuming certain costs (eucalypt 4,220 ZAR/ha and pine 5,410 ZAR/ha) (FES 2012). The simulation was then reset to age 0 for damaged stands.

In step 3, random timber prices based on historic price developments that consider price correlations were determined for each period. The prices for eucalypt pulpwood and pine sawn timber were modelled based on historical timber prices provided by the South African timber industry (*unpublished information*). To consider correlation of prices between eucalypt and pine for each period in our simulation a random year between 1980 and 2011 was drawn and the according price pair was used for estimating financial return. Prices of both species were negatively and weakly correlated (see Figure 2). An increasing trend recognisable within the original price data was disregarded.

Finally, annuities were calculated using a 6 % interest rate (IR) (Step 4). The discount rate is a key variable of this process, and the IR of 6 % was chosen accordance with discount rates commonly applied in South Africa's industrial forest plantations (FES 2012).

Accordingly, for each stand type 2,500 varying scenarios were calculated that display fluctuating results. The high number of repetitions allows calculation of average results as well as their distribution and correlation. These estimators are used to draw the risk-return curve of all possible mixtures ranging from 100% of the one asset (pine sawlogs) to 100% of the second asset (eucalypt pulp wood). Finally, the Sharpe ratio is used to calculate risk-adjusted return and determine the optimum portfolio, or that mixture of the two assets under consideration with the best risk-return ratio (Zinkhan 1988). A detailed description on derivation of using transition probabilities and other methods of risk analysis can be found in Holthausen *et al.* (2004). A detailed description on the methodology of constructing MS EXCEL sheets for MCS and risk analysis can be found in Knoke *et al.* (2012).

Results

Growing pine and eucalypt (mixed in large blocks or grown in individual stands) for the production of the two products pulpwood and sawn timber leads to a clear diversification effect even at the very low correlation coefficient ($r = -0.3$) as displayed in Figure 2.

At first glance, unexpected risk-return relations seem to result from mixing the two assets. Initially, one would expect that not only return increases proportionally with the more profitable asset but also the related risk. If this would be the case, a mixture between pine and eucalypt would result in a straight line. The correlation coefficient as well as unrelated risks, however lead to the unique shape of the risk-return curve that is typical for a portfolio.

Figure 4: Risk-return curve for mixtures of *Pinus patula* sawtimber (PIN) and *Eucalyptus grandis* pulpwood (EUC) (smoothed).

In this case the diversification effect is allegorized by the efficient frontier or portfolio curve for various mixtures of pulpwood and sawn timber. The optimum portfolio is made up of proportions of 45% pine and 55% eucalypt, indicating that the most desirable risk-return combination is in fact that of a mixture of the 2 assets.

When starting from a pure pine production, with average annuities of ZAR 1,922 (y-axis) and a risk or standard deviation of ZAR 673 (x-axis), increasing the proportion of eucalypt pulpwood within the portfolio does not only lead to an increase in return (moving up on the y-axis), but also a decrease of risk (moving left on the x-axis). The benefits increase until the turning point, or in this case the optimum portfolio, is being reached. The portfolio yields average annuities of ZAR 2,653 and a risk of ZAR 543. Accordingly, the risk that the investor has to accept for each ZAR in revenue decreases by ZAR 0.15 when the optimum portfolio is compared with a pure pine plantation, and by ZAR 0.05 when compared to pure eucalypt plantations. A further increase of the proportion of eucalypt for pulpwood production in excess of the ratio suggested in the optimum portfolio leads to increased returns and increased risk. The increasing risk from this point onwards can be understood as a premium that an investor has to pay for the additional return. From a pure eucalypt biomass production perspective any increase in the pine component will lead to a substantial decrease in investment risk.

Compensation effects due to slightly correlated biophysical risks and a weak negative correlation regarding timber prices do apply in this specific portfolio.

Discussion & Conclusion

Our results display the financial benefits that can be achieved when aiming to produce more than one product, or respectively, growing more than one tree species. They allow us to successfully reject our hypothesis

“By mixing eucalypt pulpwood and pine sawn timber production in a South African commercial forest, no risk reduction can be achieved.”

In fact, the risk that an investor has to accept for each ZAR in financial revenue can be reduced by over 40% when comparing the risk-return combinations of a pure pine stand with that of the market portfolio. When coming from a pure eucalypt stand, risk related with each ZAR in return can be reduced by 20%.

Our case study shows the potential that mixing assets has when it comes to financial decision making in forest management. However, the related assumptions have to be carefully weighed when it comes to transferring these findings into practice. Application of the portfolio theory has to be expanded towards other products, tree species and their related production circles or rotation times to derive a complete set of information allowing the derivation of robust results for specific situations. Site conditions play an important role, so for a full evaluation of a real life situation those have to be taken into account as well.

Also, the diversity ultimately influencing the risk-return ratio of an investment can be achieved in various ways and can be introduced on different levels of production (Figure 5): the forest/plantation level, the stand level and the single tree level. Combinations of the different levels are also frequently found.

At the landscape, plantation or enterprise level decisions regarding tree species as well as regarding the working circles or rotation times for different blocks and stands have to be made. Under the precondition that different resulting products are used for different purposes this already creates diversity in the product portfolio but also in the production and risk distribution since rotation periods might be very different for different products. Examples are production of sawlogs from indigenous forests with rotation periods typically ranging from 20 to 200 years in the tropics and subtropics, or the typical plantation sawlog production in plantations with rotation periods from 20-40 years. Shorter rotation periods in pulpwood production (typically 6-12 years) or short rotation bio-energy plantations (typically 3-6 years) will create quite different products, reduce risk exposure and improve overall financial results (Bauhus *et al.* 2010).

Figure 5: Levels of product diversification in forestry and examples to achieve diversification at the various levels.

At stand level product diversification can be achieved by mixing tree species, or in mono-specific plantation stands by a temporal change in production throughout the rotation period. A good example is chipping first thinning for fuelwood, changing to poles and then finally to sawlogs. Accordingly, even in one working circle (which would be technically defined by the end product) several products can be produced by temporally staggering the different production goals (Ham *et al.* 2010). Another frequently found option at the stand level is a separation

of products based on quality at the harvest. Here, bad stem forms or knotty stems might not qualify for high value processing but might very well be a good fuelwood resource. Effective quality screening techniques to support this, such as terrestrial LiDAR in combination with modelling can check for stem quality in standing timber and are available (Seifert *et al.* 2010). Finally, at the tree or stem level different products can be scaled from one tree after felling such as pulpwood of very bottom, sawlogs from the pruned bottom log and chips for biomass from the branchy tree top of the stem. Accordingly, all those levels offer some potential for diversification and have to be further researched. Additionally, an optimum portfolio in reality will most likely comprise of more than just two species or products, display the urgent need of further research regarding production risk in the segment of forest science.

Other assumptions include that of a market in which producers can sell their entire production immediately. Possible market disturbances were not included in our scenarios and should be accounted for in future research. Also, changes in prices over the years, inflation or alternative interest rates were left unassessed and offer the potential for further research, to allow for a more precise projection of results in reality.

However, the results obtained illustrate that even a mixture of species in large blocks leads to benefits regarding risk diversification. Even buying existing forest stands to obtain a portfolio of a number of products or species can be financially beneficial. Weber (2002) shows in this context that acquisition of plantation forests on other continents can be advantageous to achieve a certain diversification.

We can conclude that the introduced method for the evaluation of benefits from diversity is not complete yet. It does so far not allow the inclusion of interspecific or inter-clone mixing effects

in one stand, which might be another factor positively influencing economic outcome. The question whether the use of small scale species or clonal mixtures in groups or clusters can compensate the benefits of economies of scale and the better timber quality from larger mixtures can only be answered if additional research is carried out. First approaches regarding these aspects show an existing potential for financial optimization (e.g. Griess *et al.* 2012, Griess & Knoke 2013, Griess *et al.* 2015). Assessing interspecific effects amongst different tree species that occur in more intimate mixtures is a research field of high potential and should be given priority considering that mixing different clones is becoming a popular alternative to monoclonal stands in commercial plantation forestry.

From a production perspective growing timber for bioenergy seems promising. The use of biomass for bio-energy production is gaining momentum in the African context (Seifert et al 2014). As part of larger product portfolios biomass offers an interesting avenue to diversify forestry companies and to gain resilience to production and market risks. Past data on timber price indices shows a negative correlation of various timber products. This displays existing opportunities regarding the further exploration of portfolio effects.

With the ongoing changes in South Africa's society plantation land holding ownership is becoming more fragmented. The area of larger plantations is declining as the number of smaller scale individual growers increases, who will seek value in a marketplace not tied to any one value chain. In this context our findings displays important information for both tree growers as well as policy makers to ensure the economic resilience of African forest plantations.

Acknowledgements

We thank Th. Knoke for providing valuable suggestions during the project, Laura Carlson for language editing and two anonymous reviewers for their comments. The EU project “Climate Fit Forests” was funded by the European Union under the Marie Curie Cost AP IRSES-GA-2011-295136 for international research staff exchange.

References

- Apiolaza LA, Alzamora RM. 2013. Building deployment portfolios for genotypes under performance instability. *Silva Fennica* 47: 901.
- Bauhus J, van der Meer P, Kanninen M. 2010. *Ecosystem Goods and Services from Plantation Forests*. Routledge, 272p.
- Crickmay & Associates 2015. *South African Lumber Index*. Dec 2014/ Jan 2015.
- De Pril N. 1979. Optimal claim decisions for a bonus-malus system: A continuous approach. *ASTIN Bull* 10 (2): 215-222.
- Dickel M, Kotze H, Gadow K, Zuchhini W. 2010. Growth and Survival of Eucalyptus Grandis — A Study Based on Modelling Lifetime Distributions. *International Journal of Mathematical and Computational Forestry & Natural Resource Sciences* 2 (2):86-96.
- Dieter M. 2001. Land expectation values for spruce and beech calculated with Monte Carlo modelling techniques. *Forest Policy and Economics* 2/2001: 157 166.
- Godsmark R. 2013. The South African Forestry and Forest Products Industry 2011. Industry Fact Files, Forestry South Africa. Available online at: <http://www.forestry.co.za> [accessed August 2015]
- FES, Forestry Economic Services 2012. Detailed analysis and cost benchmark report: Kwa-Zulu-Natal 2011/2012. Pietermaritzburg.
- Griess VC, Knoke T. 2011. Growth Performance, Wind-throw, Insects - Meta-Analyses of Economic Influence Factors for Mixed Species Stands in Boreal and Northern Temperate Biomes. *Canadian Journal of Forest Research* 41 (6), 1141-1159
- Griess VC, Acevedo R, Härtl F, Staupendahl K, Knoke T. 2012. Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce. *Forest Ecology and Management* 267: 284-296.

- Griess VC, Knoke T. 2013. Bioeconomic modelling of mixed Norway spruce - European beech stands: Economic consequences of considering ecological effects. *European Journal of Forest Research* 132 (3): 511-522.
- Griess VC, Panwar R, Cool J. 2015. The potential of mixing timber assets to financially offset negative effects of deer browsing on western redcedar. *The Forestry Chronicle*. Accepted.
- Groot HLF, Rademaekers K, Smith A, Svatikova K, Widerberg O, Obersteiner M, Marcarini A, Dumollard G, Strosser P, de Paoli G, Lise W. 2012. Mapping resource prices: the past and the future. *Report for the European Commission – DG Environment* (ENV.G.1/FRA/20410/0044), Rotterdam.
- Ham C, Ackerman P, de Wet J, du Toit B, Geldenhuys C, Ham H, Howard M, Mortimer J, Seifert T, Wessels B. 2010. Sawlog Strategy and Implementation Plan for South Africa. *Report compiled for the FAO National Forest Programme Facility and the Department of Agriculture, Forestry and Fisheries*. Department of Forest and Wood Science, Stellenbosch University: 103 pp.
- Hanewinkel M, Hummel S, Albrecht A. 2011. Assessing natural hazards in forestry for risk management: A review. *European Journal of Forest Research* 130: 329-351.
- Hildebrandt P, Knoke T. 2009. Optimizing the shares of native tree species in forest plantations with biased financial parameters. *Ecological Economics* 68: 2825-2833.
- Holthausen N, Hanewinkel M, Holec J. 2004. Risikomanagement in der Forstwirtschaft am Beispiel des Sturmrisikos. *Forstarchiv* 75: 149-157.
- Hostettler M. 2006. Discussion of the article: “Knoke, T.; Stimm, B.; Ammer, C. und Moog, M., 2005. Mixed forests reconsidered: A forest economics contribution to the discussion on natural diversity. *Forest Ecology and Management* 213: 102-116.” *Schweizer Zeitschrift für Forstwesen* 157: 64.
- Insee 2013. International prices of imported raw materials - Wood pulp - Northern Bleached Softwood Kraft (NBSK) - Price in US dollars per tonne - Series 001532276. Available online <http://www.bdm.insee.fr/bdm2/affichageSeries.action?id-bank=001532276&page=graphique&codeGroupe=298&recherche=criteres> [Accessed July 2015]
- Knoke T, Stang S, Remler N, Seifert T. 2006. Ranking the importance of quality variables for the price of high quality beech timber (*Fagus sylvatica* L.) *Ann. For. Sci.*, 63, 399 – 413.
- Knoke T, Griess VC, Hahn A, Rößiger J, Schneider T. 2012. *Forstbetriebsplanung als Entscheidungshilfe*. Ulmer, 408 S.
- Markowitz H. 1952. Portfolio Selection. *The Journal of Finance* 7: 77-91.
- Neuner S, Beinhofer B, Knoke T. 2013. The optimal tree species composition for a private forest enterprise - applying the theory of portfolio selection. *Scandinavian Journal of Forest Research* 28: 38-48.

- Odhiambo B, Meincken M, Seifert T. 2014. The protective role of bark against fire damage - a comparative study on selected introduced and indigenous tree species in the Western Cape, South Africa. *Trees* 28(2): 555-565.
- Roessiger J, Griess VC, Knoke T. 2011. May risk aversion lead to near-natural forestry? A simulation study. *Forestry* 84: 527-537.
- Rötzer T, Seifert T, Gayler S, Priesack E, Pretzsch H (2012) Effects of stress and defence allocation defence on tree growth: Simulation results at the tree and stand level. In: Matyssek R, Schnyder H, Ernst D, Munch J-C, Oßwald W, Pretzsch H (eds) *Growth and Defence in Plants: Resource Allocation at Multiple Scales. Ecological Studies* 220, Springer. 401-432.
- Seifert T. 2007. Simulating the extent of decay caused by *Heterobasidion annosum* s.l. in stems of Norway spruce. *Forest Ecology and Management*, 248: 95 – 106.
- Seifert T, Klemmt HJ, Seifert S, Kunneke A, Wessels B. 2010. Integrating terrestrial laser scanning based inventory with sawing simulation. *Precision Forestry Symposium: Developments in Precision Forestry since 2006*. Stellenbosch, 1-3. March 2010.
- Seifert T, Ackerman P, Chirwa P, von Doderer C, du Toit B, Görgens J, Ham C, Kunneke A, Meincken M. 2014. Bioenergy from wood in the tropics. In: Seifert T (ed.) *Bioenergy from Wood: Sustainable Production in the Tropics*. Springer, Managing Forest Ecosystems, 26, 1-10.
- Schmalen H. 2002. *Grundlagen und Probleme der Betriebswirtschaft*. Schaeffer-Poeschel 800p.
- Vose D. 2008. Risk Analysis, *A Quantitative Guide* (3rd ed.). Wiley, Chichester.
- Weber MW. 2002. *Portefeuille- und Optionspreis-Theorie und forstliche Entscheidungen*. Schriften zur Forstökonomie Volume 23. Frankfurt a.M.: Sauerländer's.
- Zinkhan FC. 1988. Forestry projects, modern portfolio theory, and discount rate selection. *Southern Journal of Applied Forestry* 12(2): 132-135.