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ORIGINAL PAPER

Mixed species plantations in Southern Chile and the risk of timber price fluctuation

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Abstract Financial assessment in forestry is characterized by considerable impacts of risk factors due to large time horizons. Accounting for the risk of timber price fluctuation mixtures of Rauli (*Nothofagus alpina,* P. et E., OERST.) and Douglas fir (*Pseudotsuga menziesii*, Mirb.) have been evaluated by different approaches. The data were taken from plantations in Southern Chile between 39°10′ and 39°50′ south latitude. Increments have been modelled in order to calculate possible financial returns and changed volume growth has been taken into consideration for mixtures of large blocks and single-tree mixtures of both species. The optimum proportions of both species varied depending on the different perspectives of the financial assessment: first, the effects of diversification shown by classical portfolio approach were low; second, the integration of moderate risk aversion of the decision maker resulted in predominance of stands with high proportions of Douglas fir, but optimum proportions of Rauli increased with higher degrees of risk aversion. The maximization of the expected surplus in relation to the fluctuation of net present values (NPVs) (Sharpe ratio) resulted in even higher optimum proportions of Rauli. However, mixed stands proved more advantageous in contrast to the financial assessment without consideration of the risk factor timber price fluctuation (maximization of NPV). Finally, the integration of further risk factors can have impacts on the results as well as the integration of further effects of single-tree mixtures. Both lacks of information should be investigated for more extensive assessments in the future.

Keywords Mixed species plantations · Single-tree mixtures · Risk integration · Diversification · Portfolio · Sharpe ratio

Introduction

Production periods in forestry are extremely larger compared to agricultural or industrial production. This leads to greater uncertainty in decision making because of a multitude of risks, which can decrease future returns and thus have to be taken into consideration. A differentiation between natural and market induced risks can be done: On one hand, hazards like storms, fire or insects for example often cause serious damages that might impair future yields; on the other hand timber price fluctuations brought about by the market can occur during the production period and reduce expected returns. As the impacts of natural hazards on forestry are quite low in Chile and there is no data available about the sensitivity of different species, timber price fluctuations were considered as the only source of investment risk. The significance of investment risks in forestry already has been investigated by various authors: some calculated the opportunities of risk-reduction for combinations of forestry and non-forestry related investments (e.g. Zinkhan et al. 1992; Lönnstedt and Svensson

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2000; Wippermann and Möhring 2001; Zinkhan and Cubbage 2003; Penttinen and Lausti 2004); others focused on investigating the effects of diversification for mixtures of different species (e.g. Thomson 1991; Deegen et al. 1997; Weber 2002; Knoke et al. 2005; Knoke and Wurm 2006; Knoke and Hahn 2007) or mixtures of different assortments (Beinhofer 2009). However, the evaluation of mixed stands has not yet been developed completely. Interactions of different species, which can occur in the case of single-tree mixtures, have been evaluated theoretically so far (Knoke and Seifert 2008). Therefore, the effects of changed volume growth and the impact on single-tree-mixtures and block-mixtures for plantations of Rauli (*Nothofagus alpina*, P. et E., OERST.) and Douglas fir (*Pseudotsuga menziesii*, Mirb.) have been chosen as the subject of the present investigation. Furthermore the mixture of these two species with different profitability potentials will be assessed in conjunction with the risk of timber price fluctuation. The latter is formulated by the following hypothesis.

H_1 The integration of timber price fluctuation does not affect the optimum proportions for mixtures of both species

The second hypothesis is focused on differences between single-tree-mixtures and block mixtures. Theoretically, volume growth can be reduced or increased for both species in single-tree-mixtures or the effects for both species are opposed. Therefore, we will test the second hypothesis.

H_2 Changed volume growth has no impact on the decision between single-tree- and block-mixtures

This study builds upon empirical data from plantations in Southern Chile, which were collected by Instituto Forestal (INFOR, Chile). In the following paragraph, we explain the calculation of expected timber returns and their deviations for single-tree and block-mixtures. Subsequently the financial assessment with and without integration of timber price fluctuation is demonstrated. Later, we present the results for timber volumes of different mixtures and financial assessment and finally the results and their derivation are discussed.

Materials and methods

To evaluate the different mixture types, yields of both species have first been calculated. The volumes have been sorted between stem wood, which was supposed to be sold as saw–wood, and the remaining wood, which was supposed to be sold as fuel–wood. Afterwards returns and costs for different yields have been computed to finally assess the expected net present values (NPV) and their fluctuation depending on varying timber prices.

Increments

The calculation of future yields has been done for a rotation period of 40 years[1] for both species. At first the increments and stand volumes have been computed for pure stands and mixed stands. The equations which have been used to calculate the diameter- and height-development of different mixtures have been developed by Kirchlechner (2007).

Diameter development

The data for diameter- and height-development were taken from mixed species plantations and have been collected in line with the project "*semi-natural forests: a technical option for rehabilitation of natural forests*" (INFOR, Chile). These plantations consisted of different mixtures of native *Nothofagus*-species (*N. alpina*, *N. obliqua*, *N. dombeyi*) and Douglas fir aged between 10 and 32 years. Kirchlechner (2007) introduced for all species indicator variables (Sps 1–3) to differentiate between the strongest competitor species and created variables to describe the effect of the interdependency of the strongest competitor species and tree age on diameter increment. Sps 1 was used to establish whether Douglas fir or *Nothofagus* spp. was the strongest competitor, while Sps 2 was used to differentiate between the strongest competitors of Rauli or another *Nothofagus* species. As we modeled the diameter development of Rauli and Douglas fir, the interdependency variables served to differentiate between neighbors of the same species and neighbors of the other species.

Hence, the mean diameter of pure stands or mixtures of large blocks after 40 years was calculated for both species with the strongest competitors of the same species. For single-tree (or row mixtures) we supposed that the strongest competitor was from the other species, respectively.

The diameter development was modeled in the following general Eq. 1 (Kirchlechner 2007):

$$\mathrm{DBH} = B_0 + B_1 v_1 + B_2 v_2 + B_3 v_3 + B_4 v_4 + B_5 v_5 \qquad (1)$$

DBH, Diameter at breast height (1.3 m) [cm].

Table 1 shows the values of the parameters B_0–B_5 and the corresponding variables v_1–v_5 of the diameter development models for Rauli and Douglas fir.

The variable competition index (CI) was introduced to describe the competition of the nearest seven trees according to Hegyi (1974) as the sum of the diameters of the neighbor trees divided by the sum of their distances to the central tree.

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[1] Donoso et al. (1999) described possible rotation periods of 35–40 years for plantations of Rauli on adequate sites; Quiroz and Rojas (2003) recommended rotation periods of 35–40 years for intensive managed Douglas fir-stands as well.

Table 1 Parameters of diameter development models for Rauli and Douglas fir Kirchlechner 2007

Variable		Parameter	Rauli	Douglas fir
	Constant	B_0	12.85383	12.76774
v_1	Age	B_1	0.56489	1.31702
v_2	Competition index	B_2	−0.09861	−0.46399
v_3	Sea level	B_3	−0.00703	
v_4	Interdependency 1[a]	B_4	0.05083	0.07314
v_5	Interdependency 2[b]	B_5	0.0474	

[a] Interdependency 1 = Sps 1 ∗ age

[b] Interdependency 2 = Sps 2 ∗ age

To model the diameter development, the competition index CI was calculated depending on tree age by linear regression (Eq. 2):

$$\mathrm{CI} = 23.54947 + 0.60358\mathrm{age} \tag{2}$$

CI, competition index.

In Kirchlechner's (2007) model the effects of the variables interdependency 2 and sea level have not been significant for the diameter development of Douglas fir; to model the diameter development of Rauli the variable sea level was set to a mean value for all considered plots of 430 m NN.

Figure 1 shows the diameter development for Rauli and Douglas fir in pure and mixed stands subject to the mentioned conditions:

Tree number

According to Reineke (1933), the stand density depends for stands with no thinning intervention on the mean dbh of the stand. Most of the stands, which were used for data collection, have not been thinned yet, but the tree numbers at the time of plantation varied. Consequently, the mean tree number per hectare was calculated by linear regression depending on the mean diameter and the tree number per hectare at the time of plantation (Eq. 3):

$$\ln(N) = 9.23108 - 1.03076\ln(dg) + 0.00028813\mathrm{N}(t_0) \tag{3}$$

In(N), natural logarithm of tree number/ha; ln(dg), natural logarithm of mean dbh; N(t_0), tree number/ha at time of plantation.

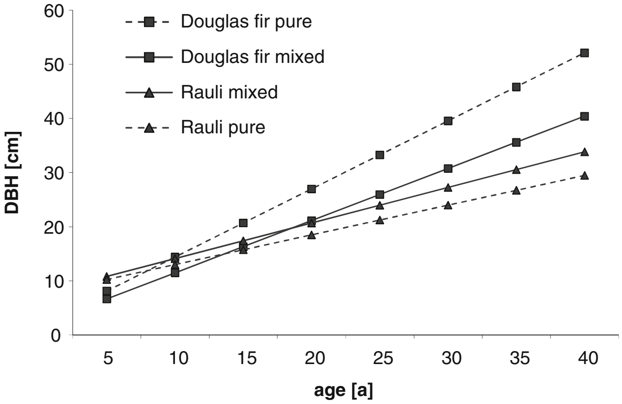

Fig. 1 Diameter development for Rauli and Douglas fir in pure and mixed stands

Thereby, it was possible to calculate the development of tree numbers depending on the predicted diameter development for single-tree mixtures and block-mixtures (or pure stands).

The stand volumes were calculated by multiplying the volume of the mean basal area trees and tree numbers per hectare. Volumes of block mixed stands with different proportions of species have been calculated by linear interpolation between stand volumes of pure stands of both species. For single-tree mixtures the stand volumes with different proportions of species have been calculated by linear interpolation between stand volumes of single-tree mixed stands and pure stands of both species (cp. Knoke 2007). Thus it was possible to consider the effect of changed volume growth for single-tree mixtures.

Tree height

The models to predict the tree height have been developed by Kirchlechner (2007) as well. The tree height development was modeled in the following general Eq. 4:

$$\ln(h) = C_0 + C_1 v_1^{0.25} + C_2 v_2^{0.25} + C_3 v_3 + C_4 v_4 + C_5 v_5^{0.25} \tag{4}$$

Table 2 shows the values of the parameters C_0–C_5 and the corresponding variables v_1–v_5 of the tree height development models for Rauli and Douglas fir.

The variables Scl1 and Scl2 served for differentiation of three social classes (dominant, co-dominant and remaining trees). For our calculations we assumed co-dominant trees for both species.

Table 2 Parameters of tree height development models for Rauli and Douglas fir (Kirchlechner 2007)

Variable		Parameter	Rauli	Douglas fir
	Constant	C_0	0.49334	1.07106
v_1	DBH	C_1	1.80045	2.04517
v_2	Sea level	C_2	0.02634	−0.03894
v_3	Scl1	C_3	0.05424	0.0591
v_4	Scl2	C_4	0.06971	0.08354
v_5	DBH/age	C_5	−1.80832	−2.70351

Volume

Compact wood The following model (INFOR 1997) was used to calculate the volume of individual trees of the tree species Rauli (Eq. 5):

$$V = 0.001508 + 7.018 \times 10^{-6}\mathrm{DBH}^2 + 5.25 \times 10^{-43}\mathrm{DBH}^2 h + 0.000051\mathrm{DBH}h^2 - 0.000148h^2 \quad (5)$$

V, Volume [m^3]; DBH, Diameter at breast height (1.3 m) [cm]; h, Height [m].

The following model (Grosse 1988) was used for the tree species Douglas-fir (Eq. 6):

$$V = 0.030764 + 0.000028\mathrm{DBH}^2 h \quad (6)$$

V, Volume [m^3]; DBH, Diameter at breast height (1.3 m) [cm]; h, Height [m].

Residual wood To derive the volume of residual wood, the stem wood share was determined, which was then subtracted from the volume of compact wood. The following procedure was used to calculate the stem wood share: Using linear regression, the crown base height was modeled for both tree species. For the tree species Rauli the model determined was (Eq. 7):

$$\mathrm{Cbh} = 3.16432 + 0.05297\mathrm{DBH} + 0.10061h \quad (7)$$

Cbh, Crown base height [m]; DBH, Diameter at breast height (1.3 m) [cm]; h, Height [m].

Out of 796 measurements, 46 were eliminated as outliers; 21% of the distribution of the measured crown base heights could be explained by the model. A residual distribution with an average of ±1.56 remained unexplained.

Similarly, the crown base height was modeled for Douglas-fir (Eq. 8):

$$\mathrm{Cbh} = 1.93853 + 0.04634\mathrm{DBH} + 0.08733h \quad (8)$$

Cbh, Crown base height [m]; DBH, Diameter at breast height (1.3 m) [cm]; h, Height [m].

In the case of the Douglas-fir, 30 measurements out of a total 1,129 were eliminated as outliers; 17% of the distribution of the measured crown base height could be explained by the model. A residual distribution with an average of ±1.47 remained unexplained.

The height of the mid diameter for the sorting stem log afterwards was determined for both tree species using (Eq. 9):

$$h(\mathrm{m}) = \left(\frac{\mathrm{Cbh} - 0.2}{2}\right) - 0.2 \quad (9)$$

h(m), Height of the mid diameter [m]; Cbh, Crown base height [m].

A stump height of 20 cm was assumed.

Thus, the mid diameter of the tree species Rauli was determined through the taper in relation to the DBH using values for Central European beech stands found by Knoke (2003). The following equation was used (Eq. 10):

$$md = \mathrm{DBH} - ((h - 1.3)a) \quad (10)$$

md, Mid diameter [cm]; a, variable additional factor.

The following values, depending on the DBH and the height of the mid diameter, were used for a (Table 3).

The mid diameter for the Douglas-fir was determined using a taper curve model by Schmidt et al. (2001). For both tree species, depending on the mid diameter, the bark was subtracted before calculating the stem wood volume (Table 4).

The stem wood volume of the average stem was calculated using the following formula and then multiplied with the stem number of the pure and mixed stands (Eq. 11).

$$Vst = \frac{md^2\pi}{40{,}000}(\mathrm{Cbh} - 0.2) \quad (11)$$

Table 3 Values for the variable additional factor a in relation to the height of the mid diameter to determine the taper

DBH	$h(\mathrm{m}) < 1.3$	$1.3 \le h(\mathrm{m}) < 2.0$	$2.0 \le h(\mathrm{m}) < 3.0$	$3.0 \le h(\mathrm{m}) < 5.0$	$h(\mathrm{m}) \ge 5.0$
18–21	0	0.5	0.5	1.04	1.2
22–25	0	0.5	0.5	1.16	1.28
26–29	0	0.5	0.7	1.28	1.35
30–33	0	0.5	0.95	1.39	1.43
34–37	0	0.5	1.2	1.51	1.51
38–41	0	0.5	1.46	1.63	1.58
42–45	0	0.78	1.71	1.74	1.66
46–49	0	1.21	1.97	1.86	1.73
50–53	0	1.65	2.22	1.98	1.81
54–57	0	2.08	2.47	2.09	1.88
58–61	0	2.51	2.73	2.21	1.96
≥62	0	2.94	2.98	2.33	2.04

Table 4 Bark subtraction depending on the mid diameter

Mid diameter (cm)	Bark subtraction (cm)
<20	−1
20–37	−2
38–53	−3
54–70	−4
>70	−5

Vst, Stem wood volume [m^3]; *md*, Mid diameter [cm]; Cbh, Crown base height [m].

For the stem wood, the mixed stands with different tree shares were calculated using linear interpolation of the values as for compact wood.

Expenditures

The expenditures were calculated using the following assumptions:

Stand establishment

Data for stand establishment was courteously provided by a forest company being partner of the project (27.05.2006) which was used to calculate the investment costs (Table 5).

The cited plant numbers refer to the corresponding pure stands; the respective shares for mixed stands were calculated. Additional 10% administrative costs were added for planting, replacement and tending.

Expenditures on harvest, processing and transport

The work time required for harvesting and processing was calculated using a model (Eq. 12) of Cruz Madariaga (1993):

$$T = 50.03161 + 27.56265\text{DBH} \tag{12}$$

T, Work time for harvest and processing with two workers [sec].

Using the diameter of the mean basal area tree and the stem number per hectare, the work time for harvesting and processing could be calculated specifically for each share of tree species.

A cautious 16.70 US \$/day was assumed to calculate wage expenditures; 5 US \$/m^3 were estimated for hauling costs.

Since the price data used did not include delivery, the costs of transportation had to be subtracted from the returns. For this purpose, an average transportation distance of 100 km and a mean value of 13.78 US \$/m^3/100 km were used in the calculations.

Basis for the calculation of timber returns

The division of the timber assortments was simplified by classifying the stem wood as saw logs and the remaining timber as fire wood. Taking into consideration timber price fluctuations, time series data from June 2003 to September 2007 were used, originating from the timber price statistics of INFOR (Boletín de precios forestales, June 2003–September 2007). Since time series of fire wood prices are available neither for Rauli nor for Douglas-fir, a default value of 30.00 US \$/m^3 (excluding delivery) was assumed, and a time series for both species was constructed using the standard deviation of fire wood prices for Eucalyptus (Boletín de precios forestales).

The prices used for the returns calculation were (Table 6).

With the assumptions mentioned above, the expected returns (excluding harvesting costs) and their standard deviations for large- and small-area mixtures of different tree species were calculated. The following procedure was used (Eq. 13):

$$E = VstPs + VrPf - (Vst + Vr)C \tag{13}$$

E, Expected returns (excluding harvesting costs); *Vst*, Volume of stem wood; *Vr*, Volume of remaining wood; *Ps*, Price of saw logs; *Pf*, Price of fire wood; *C*, Costs for preparation, transport and delivery.

Table 5 Basics of the cost calculation of the stand management

	Cost item	Quantity	Unit	Cost/Unit (US \$)	Total (US \$/ha)
Plantation	Area preparation	1	ha	593.51	593.51
	Plantmat. Rauli	1,600	Items	0.34	551.23
	Plantmat. Douglas-fir	1,600	Items	0.30	477.73
	Work time	20	Days	11.48	229.68
Replacement	Plantmat. Rauli	240	Items	0.34	82.68
	Plantmat. Douglas-fir	240	Items	0.30	71.66
	Work hours	1.2	Days	11.48	13.78
Tending	Work hours	3	ha	125.28	375.84

Table 6 Timber price statistics (INFOR: Boletin de precios forestales, June 2003–September 2007)

Product	Species	Mean (US $/m^3)	Standard deviation (US $/m^3)
Sawwood	Rauli	65.43	8.64
	Douglas fir	59.97	22.03
Fuelwood	Rauli	30.00	3.61
	Douglas fir	30.00	3.61

The expected returns of large-area mixtures were calculated using growth values of pure stands. In contrast to this, the interpolated growth values of the respective tree species were used for calculating the expected returns of small-area mixed stands.

Afterward, the financial evaluation of the different stands was carried out using the calculated expected returns.

Financial evaluation

Net present value and internal rate of return

The NPV of an investment can be calculated using the sum of the discounted returns, minus the investment expenditure (Eq. 14). Different interest rates of 3, 5 and 7% were used for the discounting.

$$\mathrm{NPV} = -IE + \sum_{t=1}^{T} \frac{Rt}{(1+i)^t} \tag{14}$$

NPV, Capital value; *IE*, Investment expenditure; *I*, Interest rate; *Rt*, Expected returns at time *T*.

The internal rate of return is the one that results in a NPV of 0. Thus, the profitability of different investments can be compared; the higher the value, the higher the profitability.

Risk assessment

Portfolio-theory The Portfolio-theory was developed by Markowitz (1952) and compares the risk in terms of standard deviation of the returns of different investment alternatives and their mean values. Taking into account the slightly different costs for stand establishment, the risk assessment was carried out using the NPV of the individual mixtures. The standard deviations were calculated using the following equation, valid for portfolios with only two investment possibilities (Eq. 15)

$$S_p = \sqrt{a_1^2 s_1^2 + a_2^2 s_2^2 + 2k_{1,2} a_1 a_2 s_1 s_2} \tag{15}$$

S_p, Standard deviation of the NPV of the portfolios; $a_{1,2}$, Share of tree species 1 or 2; $s_{1,2}$, Standard deviation of the NPV of tree species 1 or 2; $k_{1,2}$, Coefficient of correlation of the NPV of tree species 1 and 2.

Taking into account the different growth values for large- and small-area mixed stands, the standard deviations for large-area mixed stands were calculated using the standard deviations of the NPV of pure stands, while the standard deviations of the NPV of the respective tree shares were used for the small-area mixed stands. Thus, weighting the tree species shares ($a_{1,2}$) was not necessary when calculating the standard deviations of the small-area mixed stands.

Analogously, the mean values of large- and small-area mixed stands were calculated using the following Eq. 16:

$$M_P = a_1 m_1 + a_2 m_2 \tag{16}$$

M_P, Mean value of the NPV of the portfolio; $a_{1,2}$, Share of tree species 1 or 2; $m_{1,2}$, Mean value of the NPV of tree species 1 or 2.

It should be taken into account that the mean values of NPV of tree species 1 and 2 were different for large- and small-area mixed stands, since different stand volumes were predicted depending on each type of mixture.

When comparing different portfolios using their standard deviations and mean values, the investor's risk aversion plays an important role. It describes how inclined a person is in preferring a smaller, certain return to a higher, riskier return. This type of precautionary thinking is said to be very common (e.g. Spremann 1996; Valkonen and Valsta 2001) and is supported by the existence of numerous insurance companies. Considering this effect in our portfolio assessment, a certainty equivalent of the different mixtures was calculated (Eq. 17):

$$\mathrm{CE} = M_P - \alpha \frac{S_P^2}{2} \tag{17}$$

CE, Certainty equivalent; M_P, Mean value of the NPV of the portfolio; $S_P{}^2$, Variance of NPV; α, Degree of risk aversion.

In this equation, the mean values and dispersion of the respective mixtures are combined, whereas the variance is weighted by the factor α. It describes the risk aversion of the investor and is calculated using this quotient (Eq. 18):

$$\alpha = \frac{a}{I} \tag{18}$$

a, Relative risk aversion; *I*, Investment expenditure.

The higher the value of *a*, which describes the risk aversion of the investor, the higher his risk aversion is. When evaluating the mixtures, *a* value of 1 was used at first, which was regarded as moderate risk aversion in investment analysis (Knoke and Wurm 2006).

By maximizing the certainty equivalent CE, an optimization of the tree species shares could be carried out, which takes into account the amount of the expected return, its uncertainty, the necessary investment expenditures and an aversion to increasing risk, present in most cases.

Sharpe ratio Another estimate in investment analysis is the so-called Sharpe Ratio (Sharpe 1966). It describes the expected excess return in relation to the risk and is calculated as follows (Eq. 19):

$$\mathrm{SR} = \frac{M_\mathrm{P} - R_\mathrm{f}}{S_\mathrm{P}} \tag{19}$$

SR, Sharpe ratio; M_P, Mean value of the NPV of the portfolio; R_f, Risk free rate of return; S_P, Standard deviation of the NPV of the portfolio.

The risk free rate of return R_f describes the size of returns that could be achieved using an alternative form of investment with no or minimal risk (e.g. government bonds). In this case the Sharpe ratio was calculated for the portfolios of the NPV of different mixtures, so that the risk free return, per definition, is equal to 0.

The associated risk is calculated using the standard deviations of the individual mixtures. Ultimately, the Sharpe ratio describes whether a risky investment will be rewarded, but cannot make a direct statement about the risk itself (higher returns in connection with higher risks can, for example, result in the same Sharpe Ratio as lower returns with lower risks).

Results

Volume

Stand volumes have been calculated for pure stands and single-tree mixtures with different proportions of tree species. Pure stands of Douglas fir achieve about 611 m^3 after a rotation period of 40 years, pure stands of Rauli about 341 m^3. Mixed stands with 50% Douglas fir and 50% Rauli achieve about 406 m^3. Figure 2 illustrates the volumes of pure stands and mixtures with different proportions:

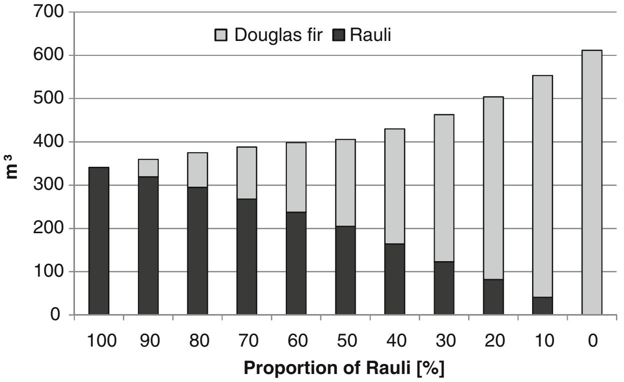

Fig. 2 Volumes of pure stands and single-tree mixtures with different proportions of Rauli (age = 40 years)

Financial return

After calculating costs for harvesting, yarding and transport depending on harvest-volumes, the net revenue flows at the age of 40 years and their variations have been computed. As expected, due to relatively high stand volumes the means of financial returns of pure stands of Douglas fir are considerably higher than those of pure Rauli stands. However, because of higher timber price fluctuations, the standard deviations of the expected financial returns of Douglas fir are considerably high as well (Table 7).

Table 7 Means and standard deviations of financial returns [US $/ha] for different proportions of Rauli

Financial return (US $/ha)	Mean		Standard deviation	
Proportion of Rauli	Rauli	Douglas fir	Rauli	Douglas fir
1	8,522	0	1,451	0
0.9	8,001	997	1,359	451
0.8	7,407	1,994	1,256	902
0.7	6,739	2,992	1,141	1,353
0.6	5,998	3,989	1,013	1,803
0.5	5,184	4,986	874	2,254
0.4	4,147	6,618	699	2,976
0.3	3,110	8,464	525	3,789
0.2	2,074	10,525	350	4,691
0.1	1,037	12,800	175	5,684
0	0	15,291	0	6,768

Net present value and internal rate of return

Net present values have been computed for discount rates of 3.0, 5.0 and 7.0%. As the expected returns for Douglas fir are quite high and the difference in plantation costs between both species are low, the NPV in general is increasing with the proportion of Douglas fir. The differentiation between single-tree and block-mixtures shows that the effects of changed volume growth for single-tree mixtures altogether have negative influence on the profitability of mixtures of Rauli and Douglas fir. Higher increments of Rauli cannot compensate, in financial terms, for the reduction of increments for Douglas fir (Fig. 3).

The difference between NPVs of single-tree and block mixtures is not very significant for Douglas fir in proportions of ≤20% whereas block mixtures of more or less equal proportions of both species have considerable higher NPVs.

The comparison of NPV for different discount rates already shows the amount of the particular internal rate of

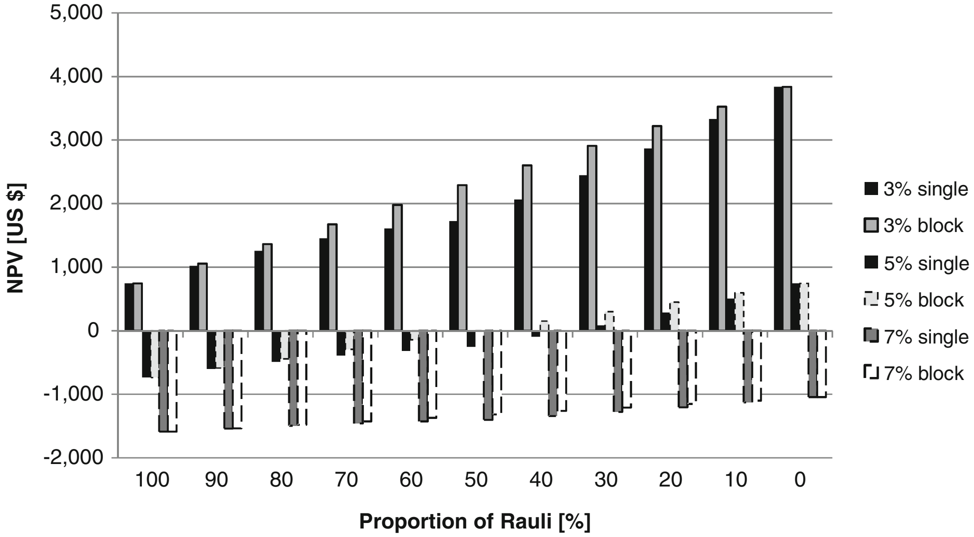

Fig. 3 NPV [US $] with discount rates of 3%, 5% and 7% for single-tree and block mixtures

return. Pure stands of Rauli see their NPVs equal to 0 for an internal discount rate of 3.81%, while pure stands of Douglas fir attain a rate of 5.87%. Correspondingly results the internal rates of return for different mixtures of both species (Fig. 4):

Likewise the internal rates of return tend to be higher for block mixtures than for single-tree mixtures and the difference is increasing for equal proportions of both species.

These values result from expected financial returns and as shown in Table 7, these expected returns possess quite different standard deviations due to varying timber price fluctuations. This kind of investment risk is taken into account in the following assessments.

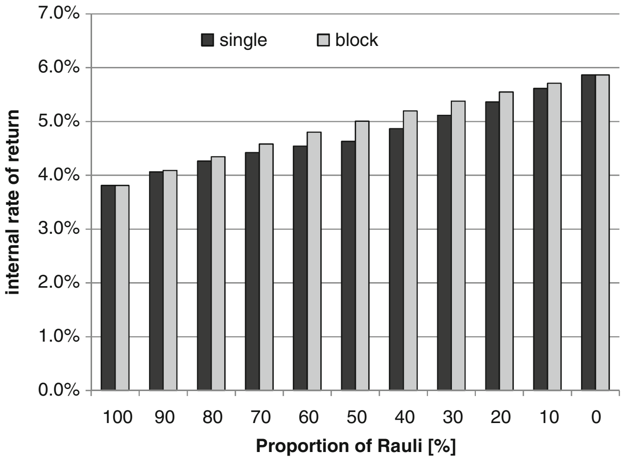

Fig. 4 Internal rates of return for single-tree mixtures and block mixtures

Risk assessment

Portfolio approach

If the standard deviations of NPVs are involved into the assessment, the results concerning the optimal proportions and the optimal kind of mixture of species change more or less drastically. Figure 5 shows the risk in terms of standard deviations of NPVs and the returns in terms of NPVs for different proportions of species (left side: 100% Rauli; right side: 100% Douglas fir) and both kinds of mixtures (single-tree mixtures: dotted line; block mixtures: solid line). The expected NPVs of pure Douglas fir stands and their standard deviations are considered as maximum values of 100% and compared with the percentages of other mixtures. As the correlation of timber prices was unknown, the calculations have been done for slightly negative timber price correlation ($k = -0.3$), no timber price correlation ($k = 0$) and slightly positive timber price correlation ($k = 0.3$). For Fig. 5 no correlation is assumed.

Comparing the risk-return relations between both pure stands, it becomes evident that Rauli stands achieve about 20% of the returns of pure Douglas fir stands and the deviation of returns amounts to 20% as well. Effects of diversification thus appear, however, the shapes are quite weak and depend on the correlation of timber prices and the kind of mixture as well.

Regarding the differences between single-tree mixtures and block mixtures, it is apparent that single-tree mixtures, particularly with higher proportions of Douglas fir ($\geq$50%), hold higher financial risks compared to block mixtures. Even if mixtures with equal proportions cannot be compared directly in this form due to different returns and risks, for stands with higher proportions of Douglas fir it is always possible to identify a block mixture with lower risk than a single-tree mixture and equal return.

For higher proportions of Rauli ($\geq$50%) the differences between block mixtures and single-tree mixtures are less present, but some effects of diversification can be identified:

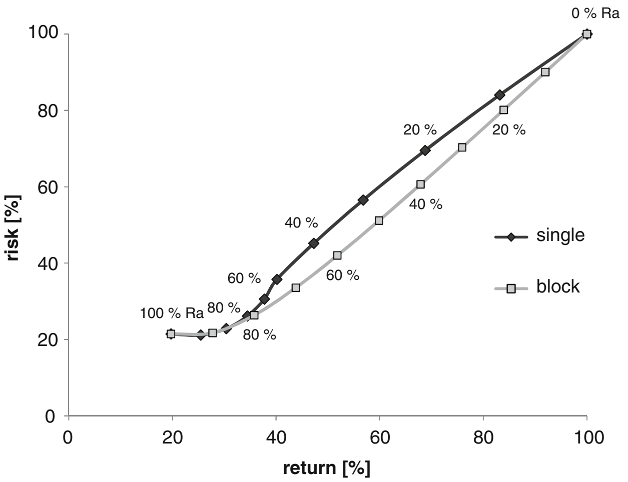

Fig. 5 Risk-return table for single-tree and block mixtures with different proportions of species (k = 0)

Admixtures of Douglas fir up to 30% for single-tree mixtures and 20% for block mixtures lead to a considerable increase (15%) of returns meanwhile the financial risk increases only slightly (5%), but further admixtures of Douglas fir until 50% flatten the effects of diversification for single-tree mixtures.

All in all this can be explained by an augmented volume increment of Rauli in connection with lower increment of Douglas fir for single-tree mixtures. Thereby the fraction of higher financial risk of Douglas fir is decreasing with the volume increment.

If we suppose moderate risk aversion for the decision maker ($a = 1$), the certainty equivalent CE becomes maximal for pure stands of Douglas fir or block mixtures with fractions of around 10% of Rauli (Fig. 6). For every block mixture the CE is higher than the corresponding single-tree mixture.

However if we augment the degree of risk aversion of the decision maker, as expected the optimal fraction of Rauli increases as well: the optimum proportion of Rauli increases earlier for block mixtures but the influence of the type of mixture is decreasing with higher degrees of risk aversion as well. At least for extremely high risk aversion ($a = 2.2$ for block mixtures and $a = 2.4$ for single-tree mixtures) the optimum proportion of Rauli exceeds 50% (Fig. 7).

Sharpe ratio

Mixtures with higher proportions of Rauli appear more advantageous for calculations of Sharpe ratios. For block mixtures and for single-tree mixtures the relations between expected NPVs and their dispersions achieve maximal values with proportions of 80% of Rauli (Fig. 8). In this case the Sharpe ratios is almost 50% higher than for pure Rauli or Douglas fir stands.

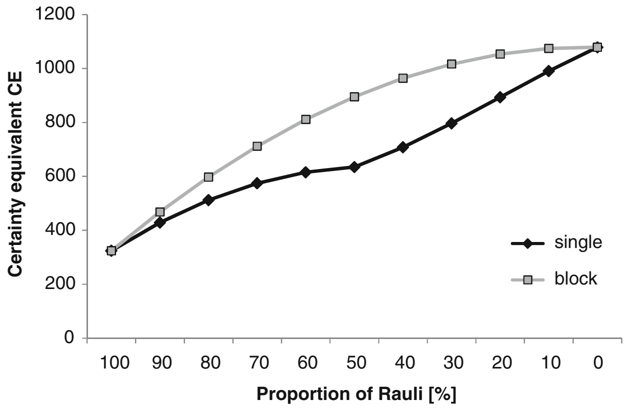

Fig. 6 Certainty equivalent CE of single-tree mixtures and block mixtures

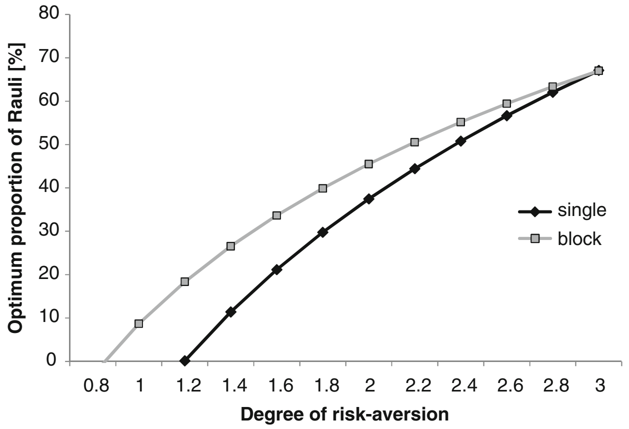

Fig. 7 Optimum proportions of Rauli for different degrees of risk aversion

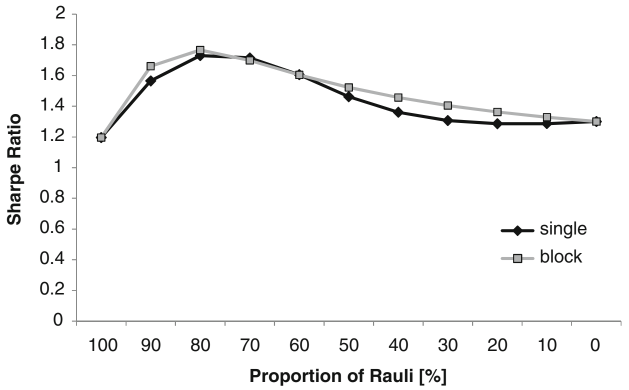

Fig. 8 Sharpe Ratios for single-tree mixtures and block mixtures

Comparisons of both kinds of mixtures show almost higher values for block mixtures while only proportions of 60–70% of Rauli seem to be more advantageous with single-tree mixtures.

Discussion and conclusions

Different approaches for financial assessment of mixed species plantations of Rauli and Douglas fir have been presented. According to the assumptions of risk integration and risk aversion, the results vary quite intensely. As a matter of fact, the selected fundamentals of valuation are crucial as well. The predictions of volume development as well as the supposed timber prices for example have both great influences on optimization.

The models for calculations of volume development are based on data, which were collected in different sites in Southern Chile (IX. and X. Region) in line with the project "*semi-natural forests: a technical option for rehabilitation of natural forests*" (INFOR, Chile). Regional differences of increments can influence the results of the financial assessment greatly. However, the data can be taken as mean values for the considered regions.

The computed annual mean diameter increment for Douglas fir at the age of 40 was 1.45 cm/a for block mixtures or pure stands and 1.15 cm/a for single-tree mixtures. These values are comparable with results from other studies but are also relatively high: annual increments of 0.61–1.34 cm/a have been described for the IX. and X. Region, although these results have been calculated for younger stands with higher tree densities. For stands at the age of 18 and 22 years in the IX. Region (Villarica) increments of 1.17–1.32 cm/a have been computed; in this case the upper limit was calculated for stands with similar tree densities as those based in this study. Furthermore for the VIII. Region (Collipulli) annual increments of 1.22–1.42 cm/a for stands at the age of 20 and 22 years have been noted (Quiroz and Rojas 2003).

The modeled annual height increments for Douglas fir were 0.91 m/a for block mixtures and 0.79 m/a for single-tree mixtures at the age of 40 years. These results are comparable to anterior studies as well: a range of 0.44–1.14 m/a has been noted for the IX. and X. Region; other studies calculated mean annual increment rates of 0.83–0.9 m/a for stands in the IX. Region (Quiroz and Rojas 2003).

Therefore, the calculated mean annual volume increment for Douglas fir (block mixtures: 18.1 m^3/ha/a; single-tree mixtures: 12.5 m^3/ha/a) certainly corresponds with comparable previous studies: mean annual volume increments of 14.4–18.9 m^3/ha/a have been indicated for the IX. Region; for stands at the age of 29 years increments of 14.0–24.0 m^3/ha/a have been computed in the VIII. and IX. Region (Quiroz and Rojas 2003).

Mean annual diameter increments of Rauli at age 40 were estimated at 0.88 cm/a for single-tree mixtures and 0.77 cm/a for block mixtures. These values are quite high compared to previous studies in Chile, but studies about plantations of Rauli are still scarce: Espinosa et al. (1988) for example indicated a culmination of mean annual diameter increment of 0.9 cm/a for plantations of Rauli at age 27-31 years. However, the mean annual height increments of 0.37-0.39 m/a have been considerably lower than the results of the present study (block mixtures: 0.6 m/a; single-tree mixtures: 0.65 m/a).

The mean annual volume increments for Rauli were 8.9 m^3/ha/a (block mixtures) or 10.7 m^3/ha/a (single-tree mixtures). Espinosa et al. (1988) computed mean annual volume increments of 5.1 m^3/ha/a for plantations at the age of 34 years and tree density of 800 trees/ha. Beside site class varieties the higher increment rates could be caused by mixture effects as well as different silvicultural concepts: However, the volume development used for financial assessment was comparable to the results of anterior studies, modern intensive management concepts with low tree densities and high thinning rates show higher increment rates for Rauli plantations (e.g. Tuley 1980; Mujica 1997; Grosse et. al. 2006; Müller-Using et al. 2008). Therefore, shorter rotation periods (25–35 years) are possible and the results of financial assessment would change in favor of higher optimum proportions of Rauli. Longer rotation periods result in comparatively higher increments of Douglas fir. In order to include single-tree mixtures of both species and the conventional silvicultural concept, we assumed an equal rotation period of 40 years for both species. This presumption might not be applicable for every situation but it is nevertheless definitely realistic. Calculations of saw-wood proportions were done by considering crown base heights as a limit for saw-wood. This can lead to slight overestimations of saw-wood proportions in the case of Rauli, especially if no thinning is assumed.

A further important variable for the financial assessment is the development of timber prices. Those were taken from statistics of INFOR (Boletín de precios forestales, June 2003–September 2007). Prices for saw–wood from Rauli are mean values for the IX. Region, Malleco and prices for saw–wood of Douglas fir mean values for the IX. Region, Cautin. Even in this case regional differences cannot be excluded. Moreover, estimated costs for transport (or harvest and processing) can differ depending on regional circumstances. Considering lower absolute transport costs for fuel–wood could slightly increase optimum fractions of Rauli because of higher proportions of fuel–wood. Nevertheless a crucial point considering the analysis of timber prices is the development of prices for Douglas fir. Until now the time horizon of data available was quite short and conclusions about fluctuation and correlation with timber prices of further species are still difficult to establish. However, the present dataset indicated intense fluctuations of saw–wood prices and a relatively strong price increase. Therefore, the fluctuation of prices can be overestimated, but the valuation was geared toward carefulness, which justifies a possible overestimation of risks. However, the price fluctuation for saw–wood from Douglas fir was considerably stronger than for Rauli, which might be an effect of a current establishment process in the timber market. Timber price fluctuations for Douglas fir might decrease in the future after being progressively established and higher proportions of this species might become recommendable from a financial point of view.

As the assortment of products has been considered in a simplified character, the NPVs could increase for a higher diversity of products. Nevertheless this is valid for both species and depends on regional timber market situations as well. Considering possible earlier returns from thinning would have similar effects but it has to be noted that the NPVs of Douglas fir would increase even more than those of Rauli because of higher growth rates.

Therefore, the results of the financial assessment obviously have a preliminary character and can vary depending on regional conditions like site conditions, timber prices and so on. Anyhow it becomes obvious that depending on different approaches the results can vary, but pure stands are almost only recommendable for decision makers which want to maximize the NPVs without consideration of risks (or decision makers with low risk aversion). The integration of the risk of timber price fluctuation already resulted in shifting optimum species proportions towards Rauli. Thus, our first hypothesis ("The integration of timber price fluctuation does not affect the optimum proportions for mixtures of both species") has to be rejected.

Differences between the optimum proportions by maximization of CE and maximization of SR are caused by different perspectives of both approaches: Beside the expected NPV and its variance, the results of maximization of CE depend on the degree of absolute risk aversion (which has an individual character and probably is not constant over time) and different investment expenditures. The expected NPV is punished by a value proportional to its variance. For almost equal investment expenditures (like in this case) and equal risk aversion, the CE can increase with higher expected NPV and proportionally higher variances. On the other hand, SR considers the relation between the expected excess return (or expected NPV in this case, as the risk free return was equal to 0) and the standard deviation of expected NPV. Therefore, SR increases (or decreases) for disproportionate changes of expected NPV and risks or remains equal for proportional increases (or decreases) of expected NPV and risks (with a risk free rate of return equal to 0). One unit of expected NPV is related to one unit of standard deviation. This emphasizes risk very much and leads to integration of low risk alternatives even if the latter show low NPV. Risk aversion is only generally assumed but its degree has no influence on the decision. The information provided by SR is the relation between expected NPV and risk or the expected reward of running a risk meanwhile CE has more individual character and depends on the absolute amount of expected NPV and risks as well.

Comparing the different approaches of financial assessment, is becomes obvious as well, that block mixtures finally have slight financial advantages in relation to single-tree-mixtures. Decreased volume growth for Douglas fir in single-tree-mixtures is not compensated by the increase of volume growth for Rauli. Thus, the results of financial assessment with and without the integration of timber price fluctuation generally favor block mixtures of both species and our second hypothesis ("Changed volume growth has no impact on the decision between single-tree- and block mixtures") can be rejected as well.

Nevertheless, further risk factors and uncertainties exist in addition to the fluctuation of timber prices. These can vary in relation with stand mixtures and should be considered as well. A higher resistance against natural hazards for example has been indicated by several studies for European mixed stands (e.g. Schütz et al. 2006) and further effects on timber quality, caused by single-tree-mixtures, can also be included in financial assessments (e.g. Knoke and Seifert 2008).

Finally, we have to note that severe future uncertainty is probably not defined sufficiently by reflections of the past. Technological innovations for example can change the conditions for timber markets or natural hazards can emerge, which have not been registered in the considered period. These unregistered uncertainties are lack of information and may lead to unexpected losses or gains; anyway, they will change the results of portfolio optimization. Robust worst-case optimization (e.g. Ben-Tal and Nemirovski 1998; Goldfarb and Iyengar 2003; Ben-Haim 2006; Hildebrandt and Knoke 2008) integrates severe future uncertainties into optimization problems and the maximization of robustness against unexpected losses might be an adequate approach for assessment of long term investment like forest plantations.

Indeed there are still open questions concerning financial assessment of investments in forestry. This paper focuses on a possible integration of single-tree mixtures into portfolio optimization as well as the comparison of different assessment approaches (with and without integration of risk, individual risk attitude, relation return-risk) and their results for mixtures of Rauli and Douglas fir in Southern Chile. The first aspect might be a further step to more comprehensive application of existing approaches, even if the reliability of the results is not yet optimal as the integration of further effects of single-tree mixtures is still missing. The second aspect demonstrates the impact of risk integration and the sensitivity of optimum portfolios to estimated parameters and applied approaches. The latter as well as the recognition of severe future uncertainty call for more robust optimization techniques in forestry.

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