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Comparison of various sources of uncertainty in stand level net present value estimates

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1 INTRODUCTION

- Value of forest - crucial information for landowners
  - real estate business
  - land divisions and exchanges
  - forestry investments

$$\max_{R} NPV = \sum_{t=1}^{\infty} \left(Timber_t + Amenity_t \right) e^{-rt}$$

R – decision variables: harvests, silvicultural operations, etc

Problem: NPV is subject to several sources of uncertainty

Several sources of uncertainty:
- economic parameters (prices, interest rate)
- natural hazards (windfalls, fire, insect damages)
- effects of climate change
- quality of the forest inventory data
- uncertainty related to the growth predictions and future production of products and services

Objective: Assess the relative importance of three important sources of uncertainty in forest NPV computations

(1) Variations in timber assortment prices

(2) Errors in inventory information (initial stand state)

(3) Random errors in growth and yield predictions

Definition of uncertainty in this study: variation in estimated forest NPVs caused by random variations in timber prices, quality of inventory information and growth predictions

2 METHOD AND DATA

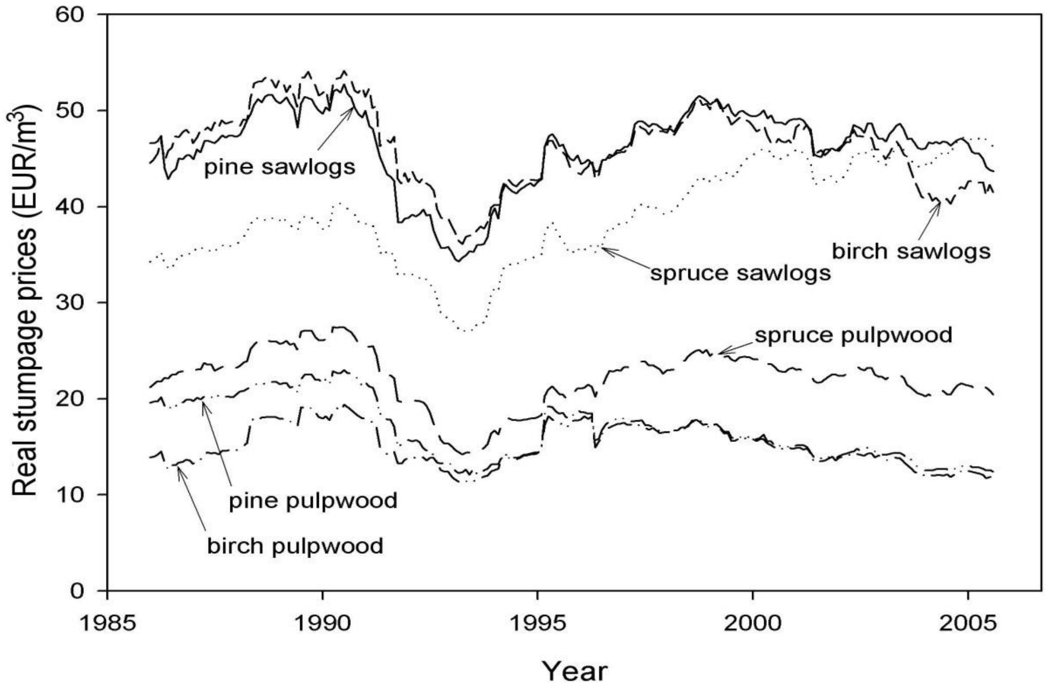
A case study forest estate consisting of 40 stands

Carry out Monte Carlo simulations for each stand in order to obtain probability distributions of NPV

- no uncertainty
- different combinations of three sources of uncertainty

100 iterations for each stand

Simulation of stochastic price developments



Geometric mean reverting process (cf. Insley 2002, Yoshimoto 2009)

$$dp = \eta\left(\bar{p} - p\right)dt + \sigma\, p\, dz$$

- η speed of reversion
- σ level of annual variation
- dz increment of the wiener process
- $\bar{p}$ long-run average price

Correlations: Cholesky decomposition of the variance-covariance matrix

Random variation in forest inventory data

- Including measurement and sampling error
- two datasets:
  (1) Field inventory of stand characteristics based on measurement of sample plots
  (2) Aerial Laser scanning tecniques
- Both datasets: reference plot measurements
  –> construct true values equations of forest properties
  –> generate random variation in initial stand state by comparing true values and observations
- Measured characteristics:
  . mean diameter (*DgM*),
  . mean height (*HgM*),
  . basal area (*G*),
  . number of stems per hectare (*N*)
  . total volume (*V*)

Simulation of random growth prediction errors

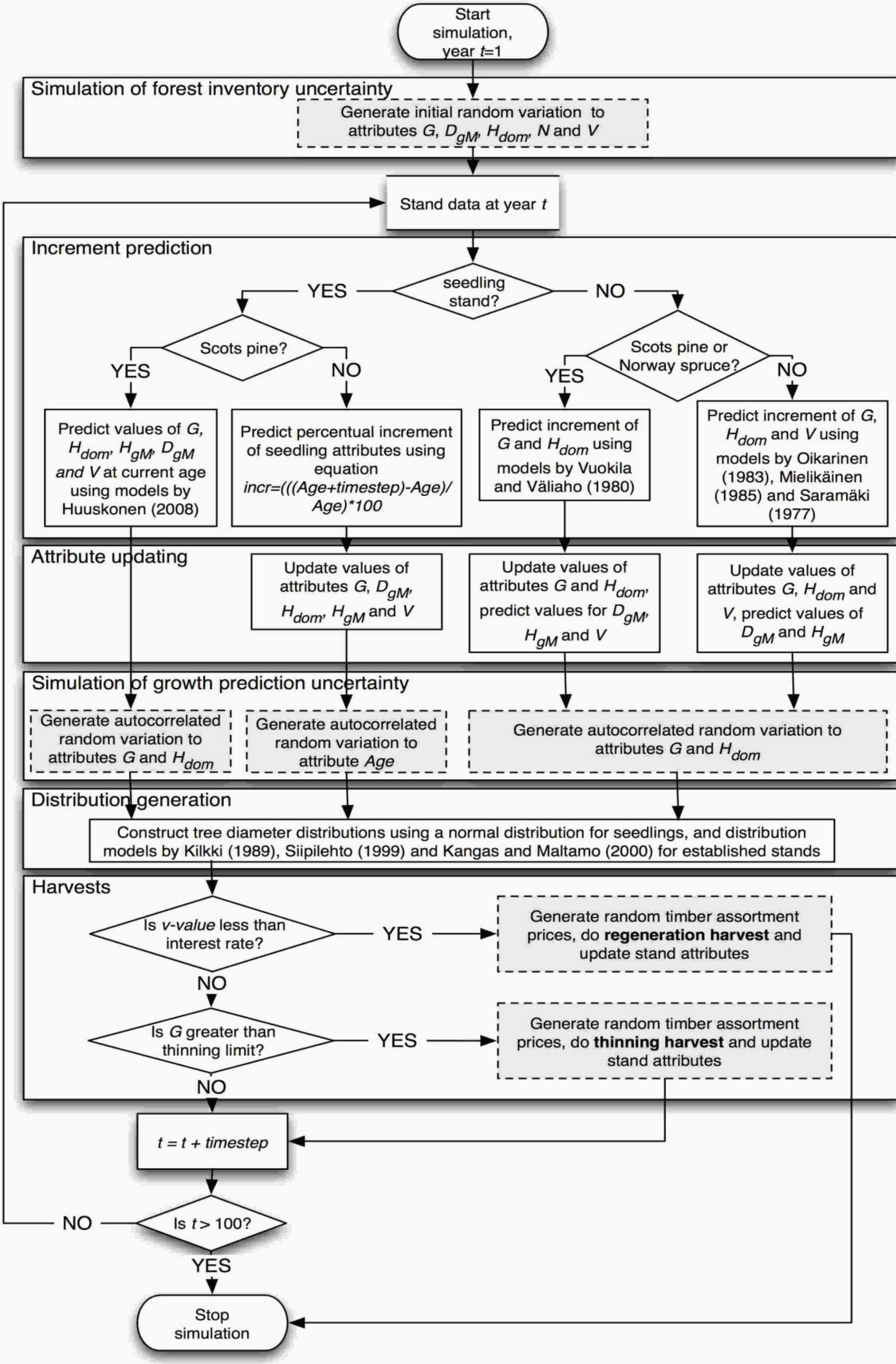
- whole stand models
- include random variation component in growth predictions
- two sources of random variation:

  (1) inter stand error *u*

  (2) intra stand variation e_t (annual variations in weather)

Total random error: $\mu_t = u + e_t$

The prediction errors for different attributes (H_{dom}, G, etc) between neighbouring stands correlate -> samling from multinormal distribution using the Cholesky decomposition and variance-covariance matrix


Start simulation, year t=1
Simulation of forest inventory uncertainty
Generate initial random variation to attributes G, DgM, Hdom, N and V
Stand data at year t
Increment prediction
seedling stand?
YES
NO
Scots pine?
YES
NO
Scots pine or Norway spruce?
YES
NO
Predict values of G, Hdom, HgM, DgM and V at current age using models by Huuskonen (2008)
Predict percentual increment of seedling attributes using equation incr=(((Age+timestep)-Age)/Age)*100
Predict increment of G and Hdom using models by Vuokila and Väliaho (1980)
Predict increment of G, Hdom and V using models by Oikarinen (1983), Mielikäinen (1985) and Saramäki (1977)
Attribute updating
Update values of attributes G, DgM, Hdom, HgM and V
Update values of attributes G and Hdom, predict values for DgM, HgM and V
Update values of attributes G, Hdom and V, predict values of DgM and HgM
Simulation of growth prediction uncertainty
Generate autocorrelated random variation to attributes G and Hdom
Generate autocorrelated random variation to attribute Age
Generate autocorrelated random variation to attributes G and Hdom
Distribution generation
Construct tree diameter distributions using a normal distribution for seedlings, and distribution models by Kilkki (1989), Siipilehto (1999) and Kangas and Maltamo (2000) for established stands
Harvests
Is v-value less than interest rate?
YES
Generate random timber assortment prices, do regeneration harvest and update stand attributes
NO
Is G greater than thinning limit?
YES
Generate random timber assortment prices, do thinning harvest and update stand attributes
NO
t = t + timestep
Is t > 100?
NO
YES
Stop simulation

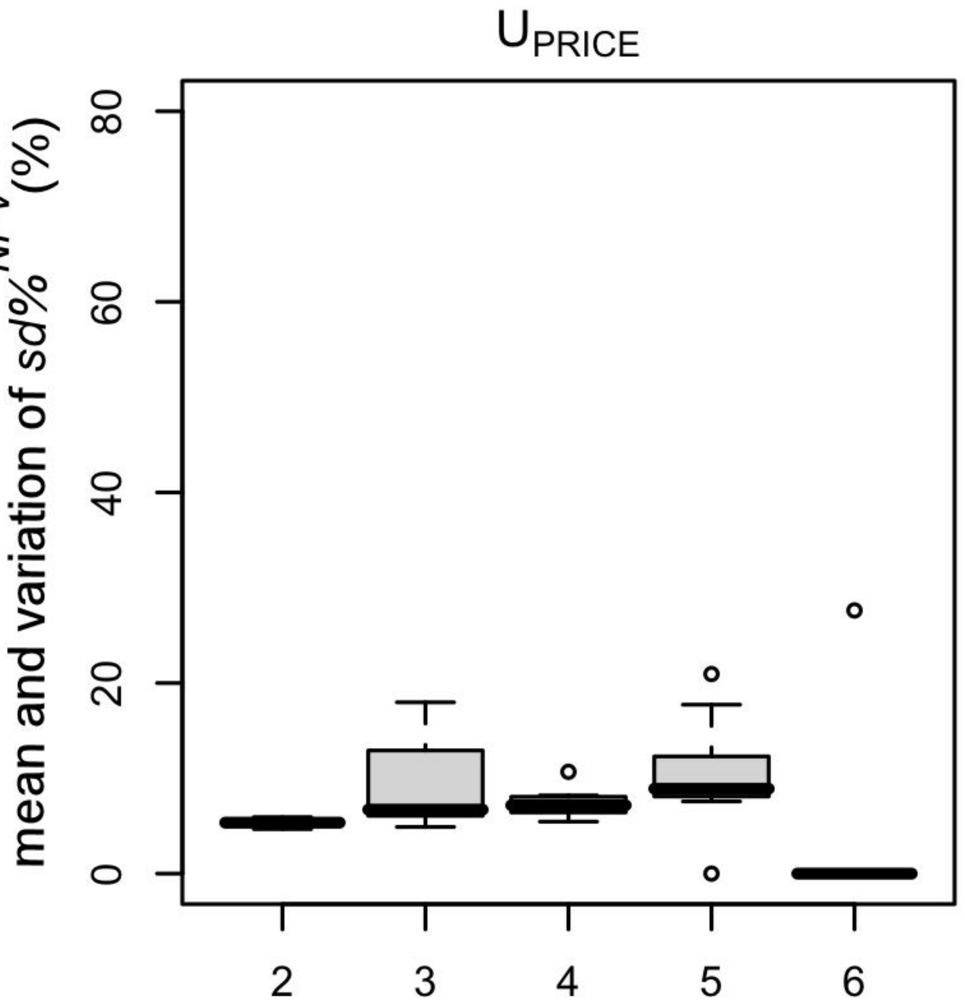
3 RESULTS

ACTIVE SOURCES OF UNCERTAINTY				AVERAGES	
U_{PRICE}	U_{FIELD}	U_{ALS}	U_{GROWTH}	$bias\%^{NPV}$	$sd\%^{NPV}$
o				-6.1	8.2
	o			-6.8	28.8
		o		1.7	26.5
			o	-9.5	33.2
o	o			-9.1	29
o		o		-1	27.4
o			o	-5.7	34.9
	o		o	-12.5	46.9
		o	o	-2.1	46.5
o	o		o	-9.2	47.4
o		o	o	0.1	46.5

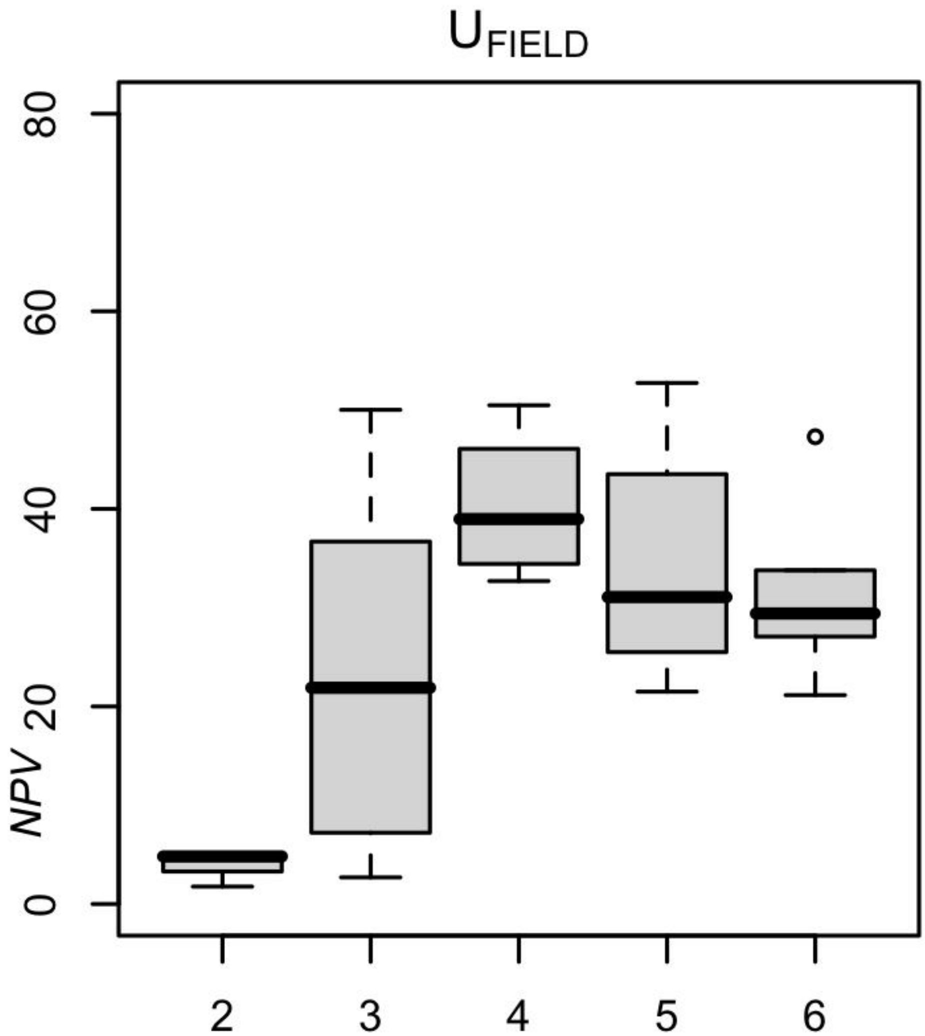
U_{PRICE} price uncertainty
U_{FIELD} inventory data uncertainty, field measurements
U_{ALS} inventory data uncertainty, aerial laser scanning techniques
U_{GROWTH} uncertain growth predictions

$$bias\%_i^{NPV} = \left(mean_i^{NPV} - npv_i^{REF}\right) / npv_i^{REF} \times 100$$

$$sd\%_i^{NPV} = \sqrt{\sum_{l=1}^{100}\left(\left(\frac{npv_{il} - mean_i^{NPV}}{mean_i^{NPV}}\right)\times 100\right)^2 \times \frac{1}{100}}$$



Development classes:
2 – young seedling stand
3 – advanced seedling stand
4 – young seedling stand
5 – advanced thinning stand
6 – mature stand



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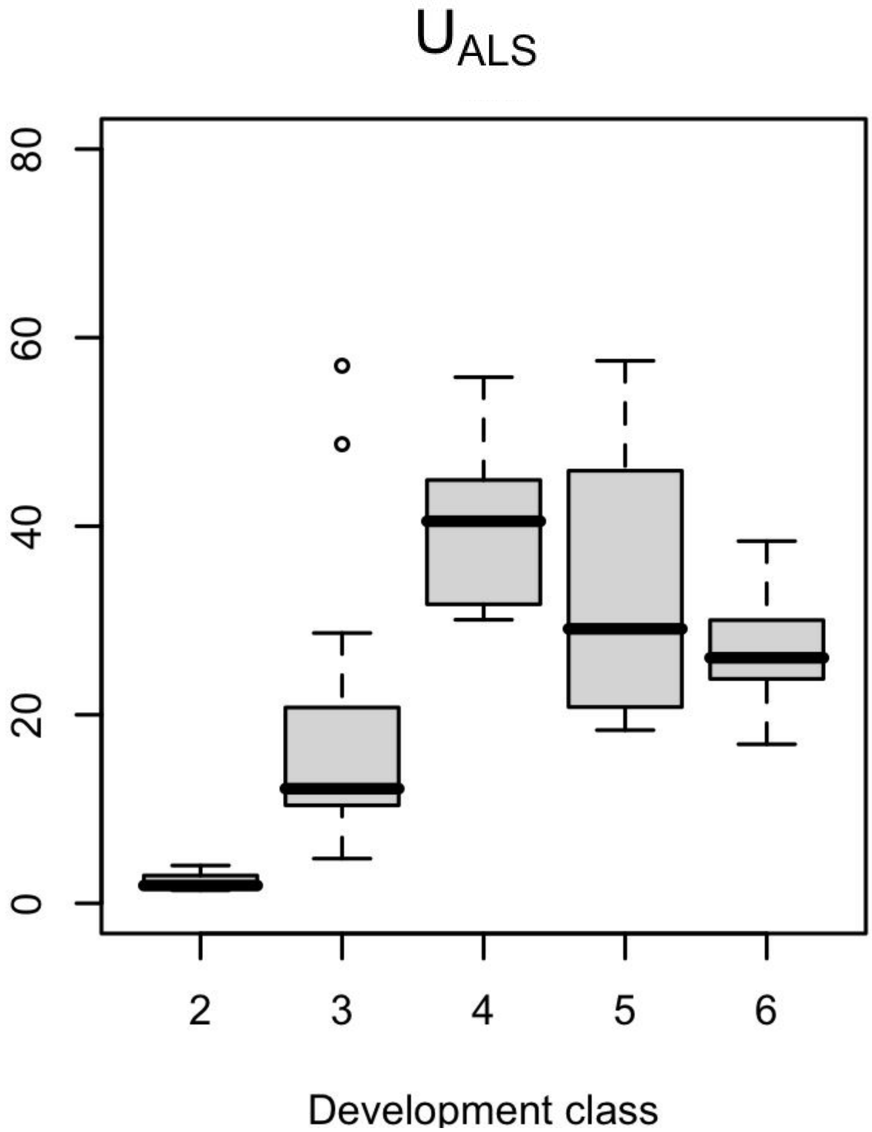

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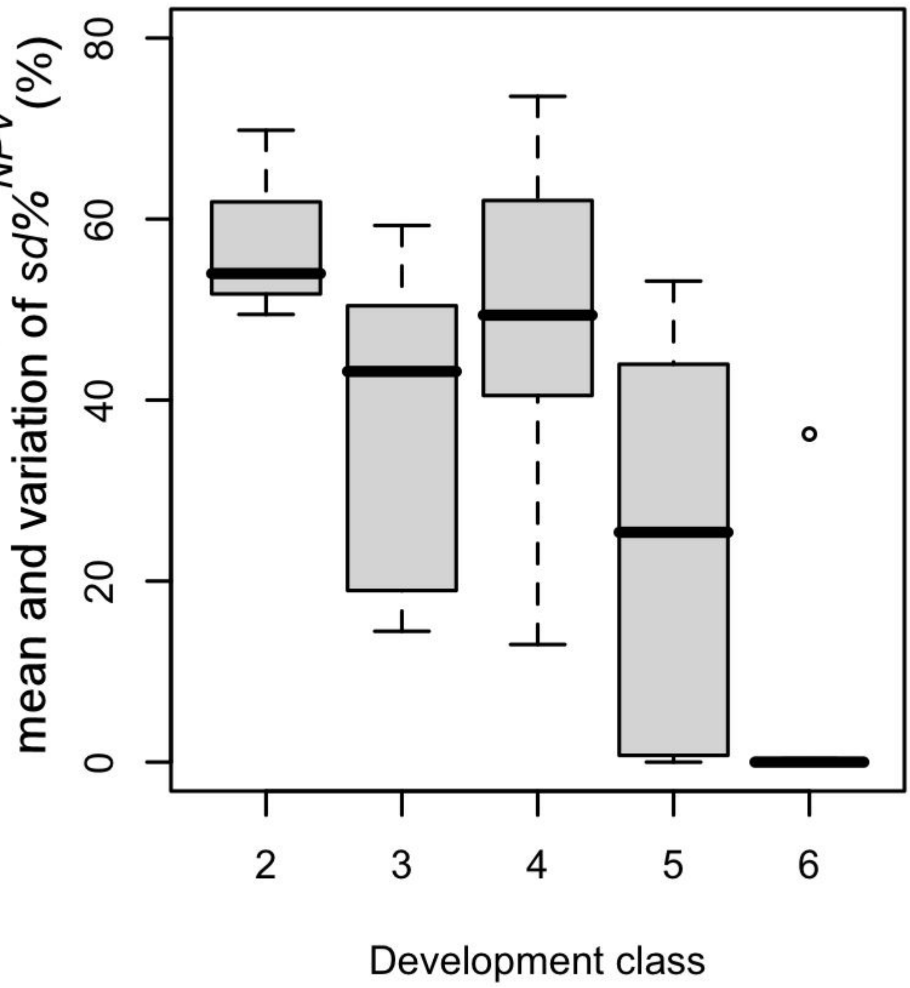
U_{GROWTH}



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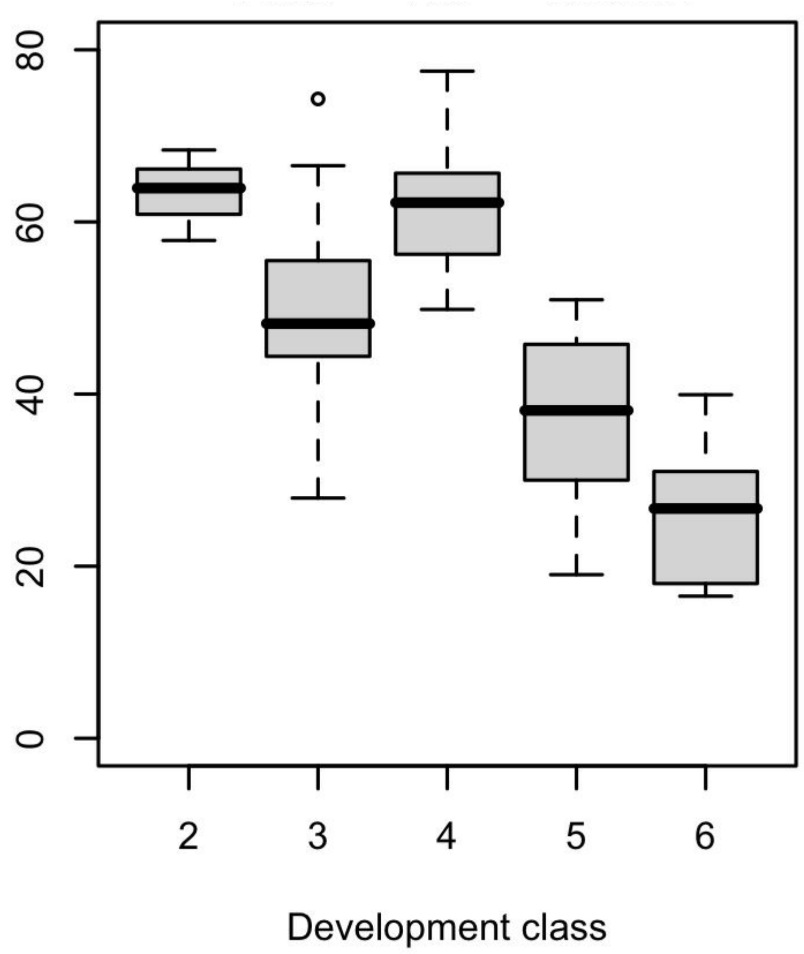
$U_{PRICE} + U_{ALS} + U_{GROWTH}$



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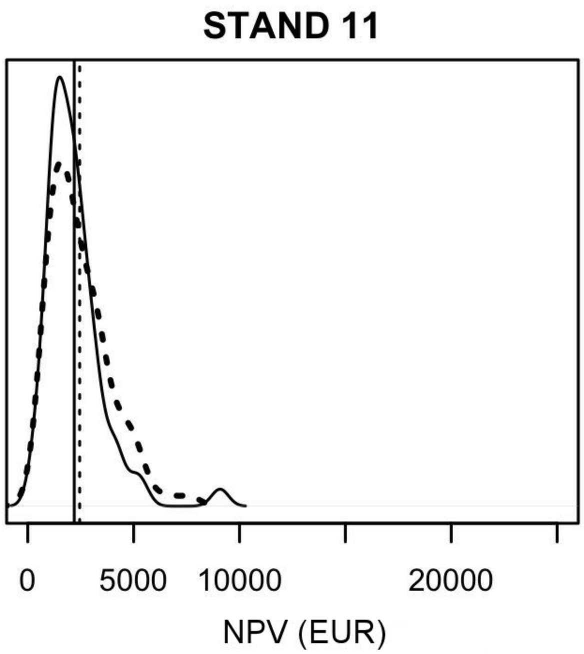
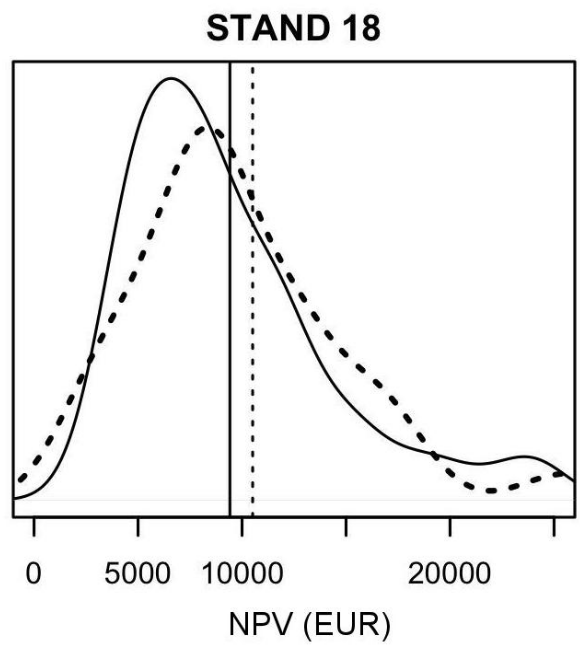
PROBABILITY DISTRIBUTIONS FOR NPV:

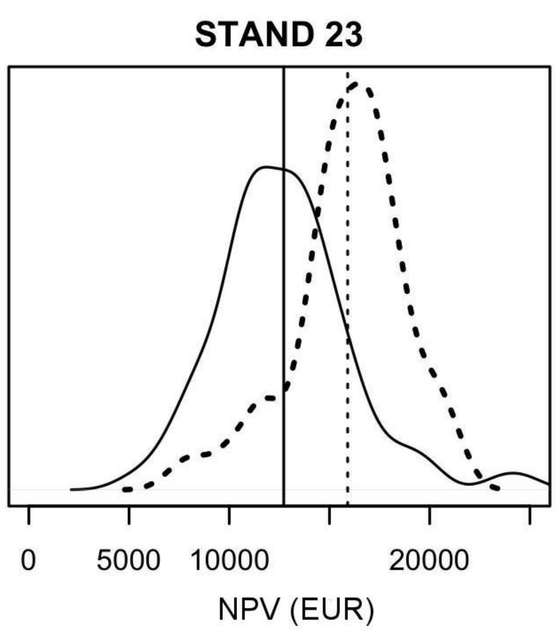
Young seedling stand:



Young thinning stand:



Mature stand:



Solid line=$U_{price}+U_{field}+U_{growth}$
Dotted line=$U_{price}+U_{als}+U_{growth}$

4 CONCLUSIONS

- All three sources of uncertainty all had significant effects on the probability distribution of the net present value of the stand

- The relative standard deviations (3% rate of interest)
  8% for stochastic timber price
  29% for errors in stand-wise field inventory data,
  26% for errors in airborne laser-scanning data
  33% for errors in growth projection models

- All three sources: 47.4% average standard deviation

- outcome: find out the most important source of uncertainty to focus

- Errors in the growth projections and the quality of inventory data contributed more than timber price
  -> assumption that forestry industry maintains its competitiveness in the long run

- implications to optimization: variations in NPV due to uncertainties are much higher than the differences between two near optimal solutions