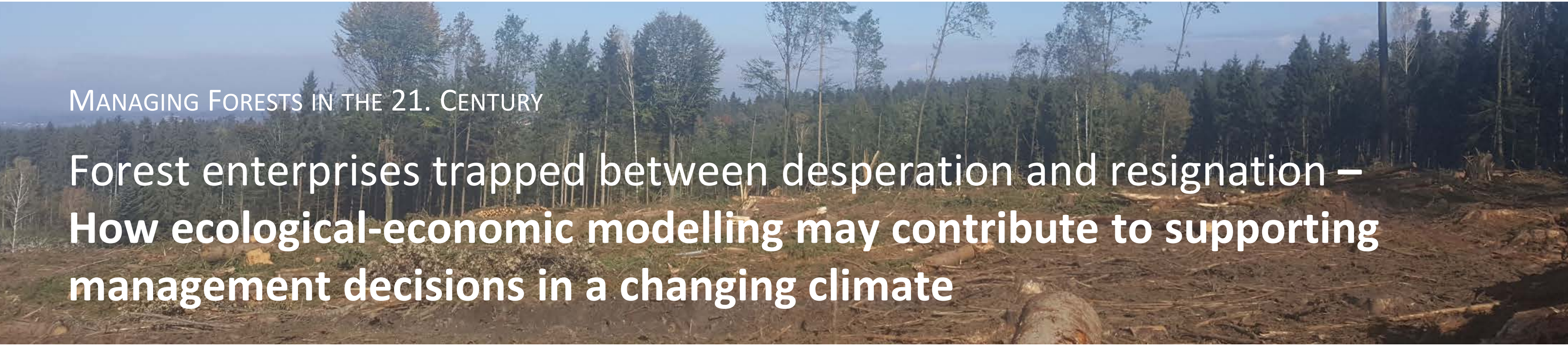

Managing Forests in the 21. Century

Forest enterprises trapped between desperation and resignation – **How ecological-economic modelling may contribute to supporting management decisions in a changing climate**

Carola Paul[1], Jasper Fuchs[1], Nils Benfer[1], Susanne Brandl[2], Claudia Chreptun[3], Fabian Härtl[3], Thomas Knoke[3]

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Forest enterprises trapped between desperation and resignation

How can science contribute?

How can ecological-economic modelling contribute?

Guiding questions

How can we quantify and model climate-change related economic consequences at the forest enterprise level? What are the main challenges?

How could we improve ecological-economic modelling to contribute to supporting management decisions in a changing climate?

What are the key factors driving economic mitigation potential?

Modelling economic effects of climate change at the forest enterprise level

Changing climate → **Management scenario** → **Biophysical consequences** → **Economic consequences** → **Compare Scenarios**

Management scenario
- **Species distribution**/mixture
- **Harvesting** and thinning schedule
- **Scenarios**: BAU and alternatives, derived from **Stakeholder** workshops

Biophysical consequences
- Changing **disturbance** patterns
- Forest **growth**
- **Species distributions**

Economic consequences

Short term
- Loss of **standing stock**
- Decrease in **wood prices**
- Increase in **harvesting costs**
- Increase in **monitoring costs**
- **Liquidity**

Long term
- **Premature** harvest
- Changes in **species composition**?
- Future **growth and survival**?
- Wood price **fluctuations**?
- Increased **monitoring** costs?

→ Changes in mean returns and their uncertainty

Main challenges

1. Include uncertainty in future returns in decision-making
2. Limits of scenario analysis

Guiding questions

How can we quantify and model climate-change related economic consequences at the forest enterprise level? What are the main challenges?

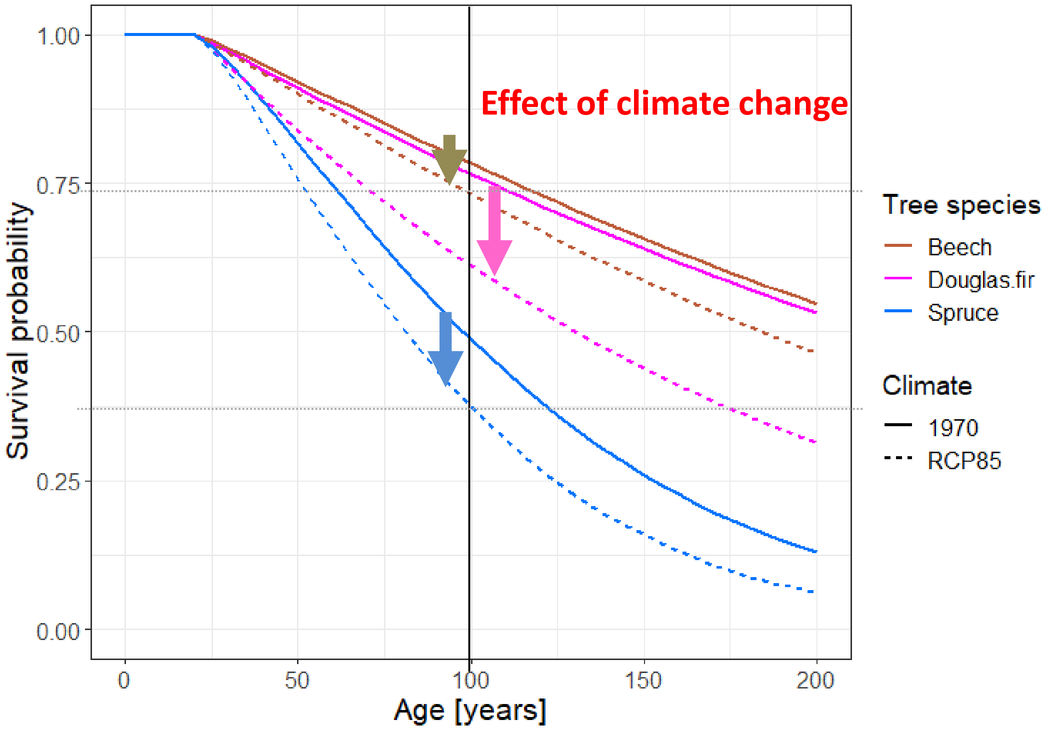
1. Include uncertainty in decision-making
2. Limits of scenario analysis

How could we improve ecological-economic modelling to contribute to supporting management decisions in a changing climate?

The example of tree species selection under climate change

What are the key factors driving economic mitigation potential?

Example application: Quantifying changes in survival probabilites



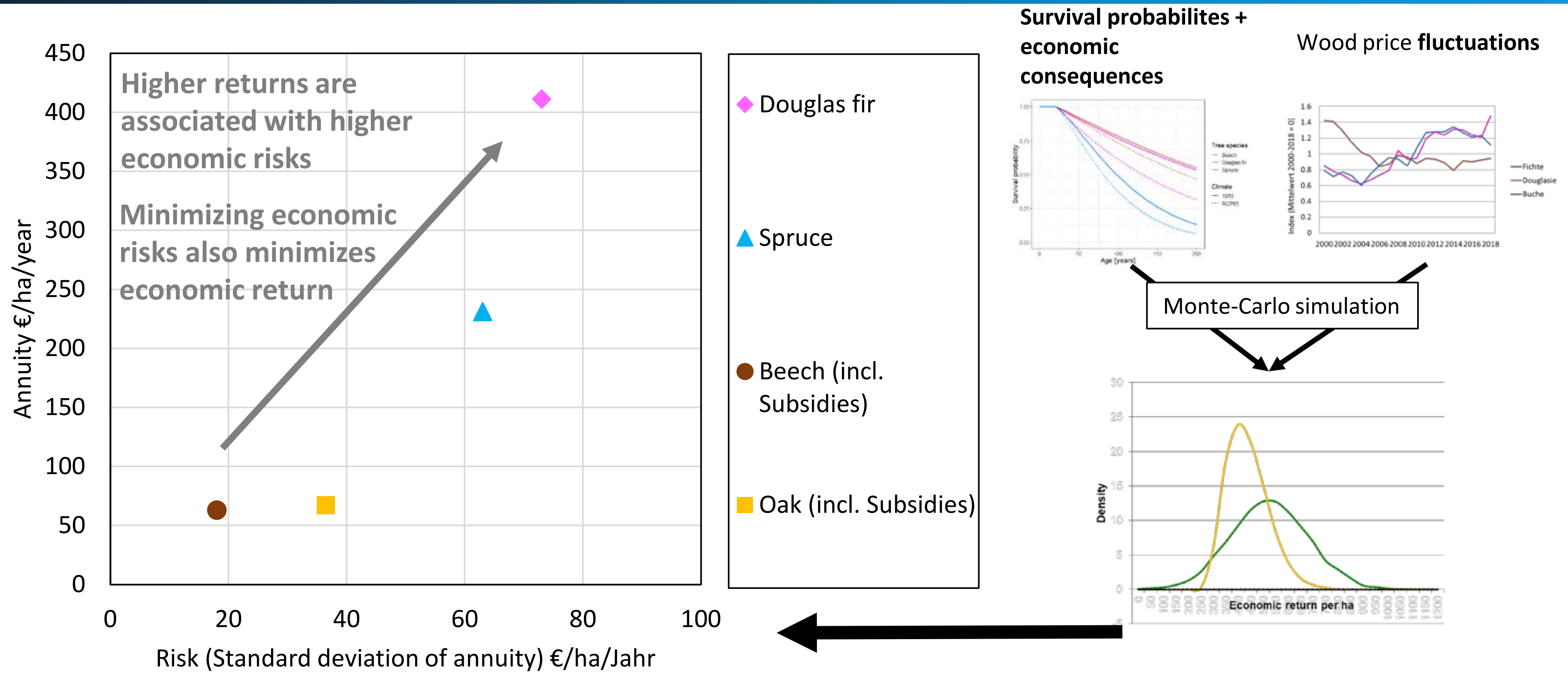
- Dataset: Level I+II ICP Data, German Crown Condition Survey
- Method: Survival time analysis using Weibull distribution parametrized by Accelerated failure time model
- Example application for Northwestern Germany (1.100 mm mean annual precipitation and 7.1°C mean annual temperatur)

Project **SURVIVAL-KW**

Waldklimafonds
Gefördert durch:
Bundesministerium für Ernährung und Landwirtschaft
Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit
aufgrund eines Beschlusses des Deutschen Bundestages

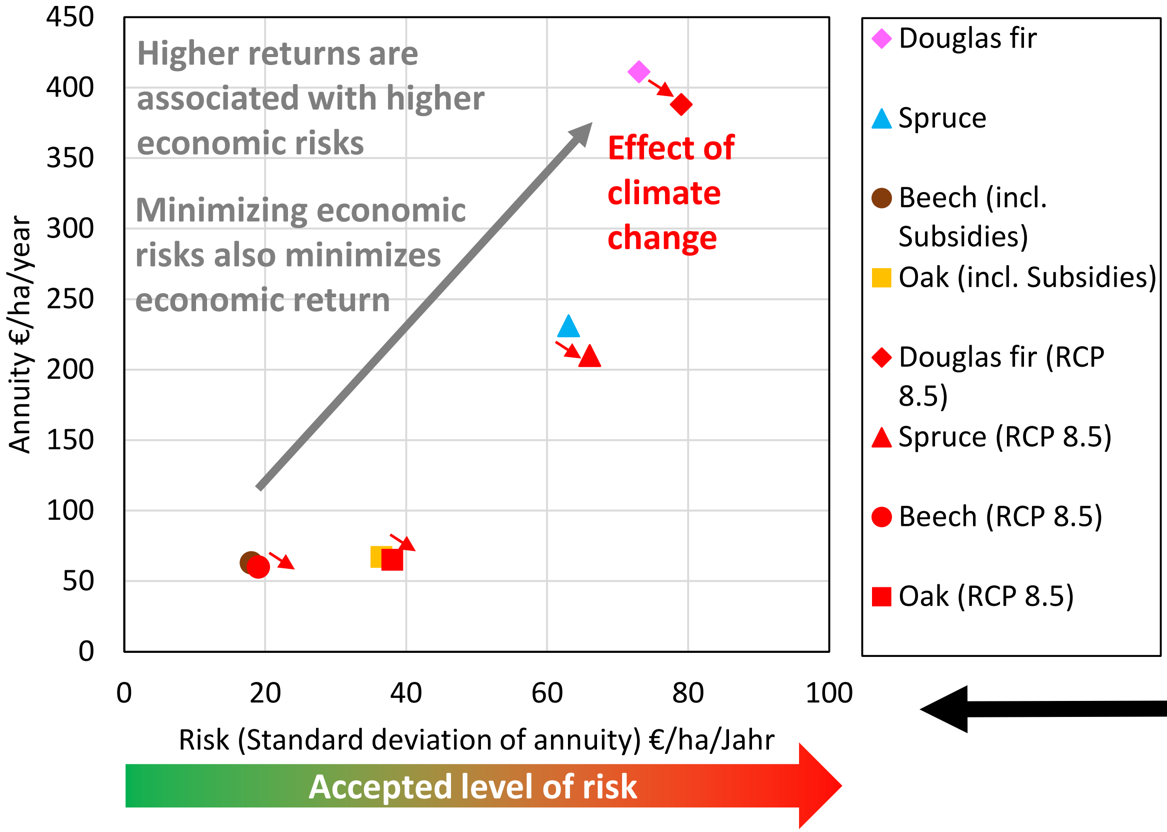
Brandl et al. (2020) Forest Ecology and Management 458, 117652.

Example application: Incorporating risks into tree species selection under climate change



Data taken from Paul and Benfer (2019): AFZ Der Wald, Example site: North-Western Germany, Discount rate 1.5%

Example application: Incorporating risks into tree species selection under climate change



- It is not so much about reducing economic risks but rather about balancing risks and returns
- Species selection depends on risk attitude of the decision-maker
- Open question: What is a desirable species composition to balance risk and returns?

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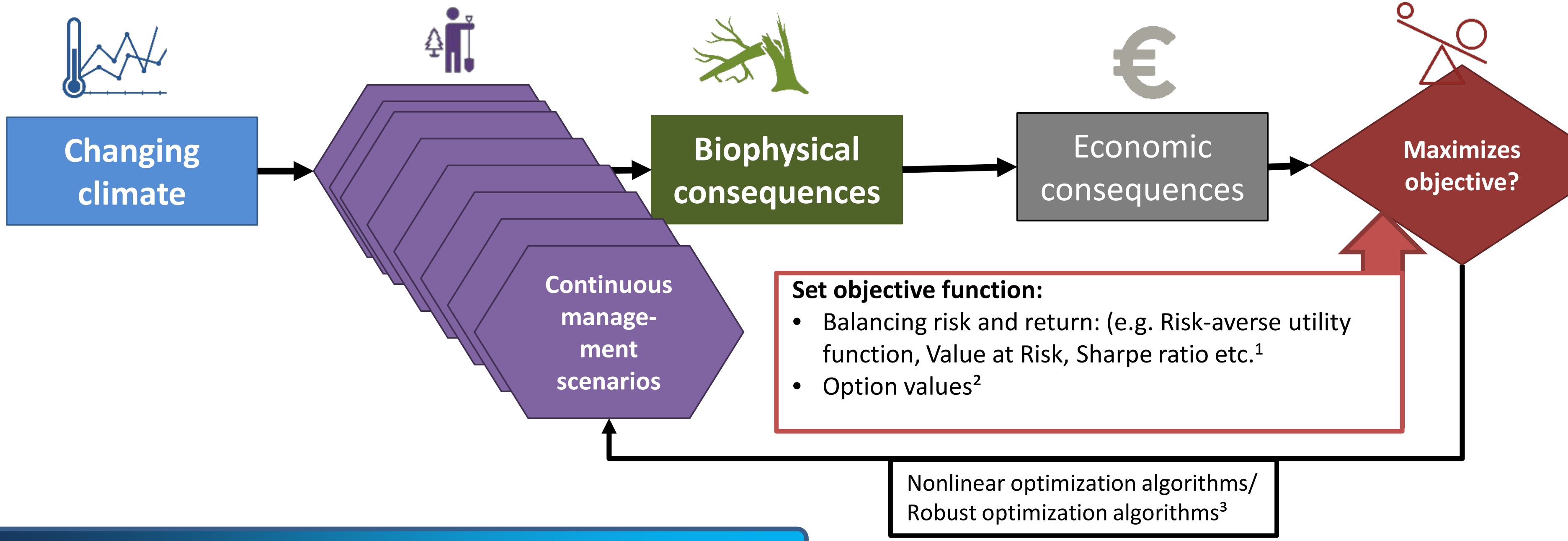
Example taken from Paul and Benfer (2019): AFZ Der Wald, Example site: North-Western Germany, Discount rate 1.5%

Normative modelling as a complement to scenario analysis



Main challenges

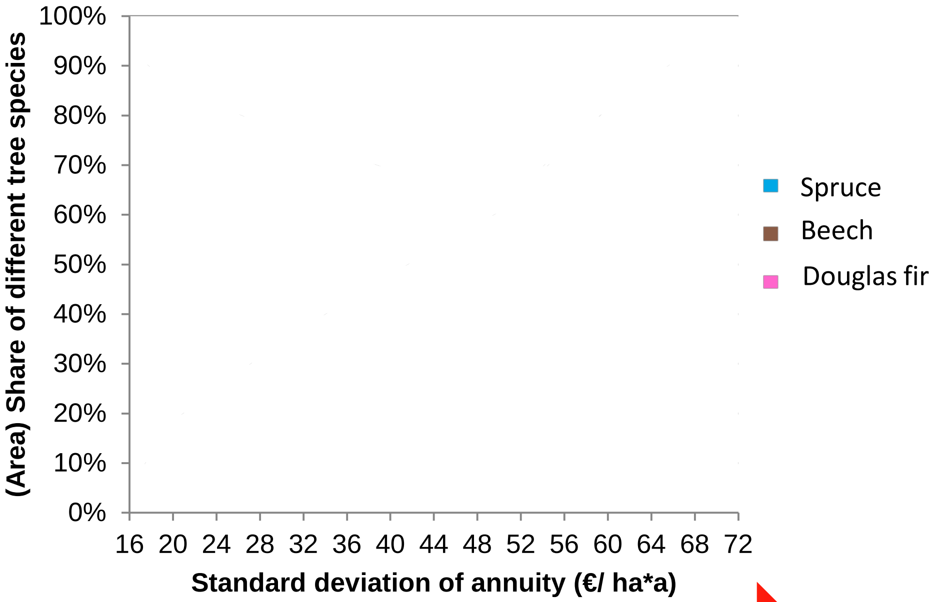
1. Include uncertainty in decision-making
2. Limits of scenario analysis

[1] Matthies et al. (2019) JEM 231: 926–939
[2] Schou et al. (2015) For. Pol. Econ. 50, 11–19
[3] Paul et al. (2019) Ann. For. Sc. 76:14
Knoke et al. (2017) Curr. For. Rep. 2(3): 93-106

Example application: The importance of tree species mixtures for reducing economic risks

Optimized species compositions for different risk levels

Current climate

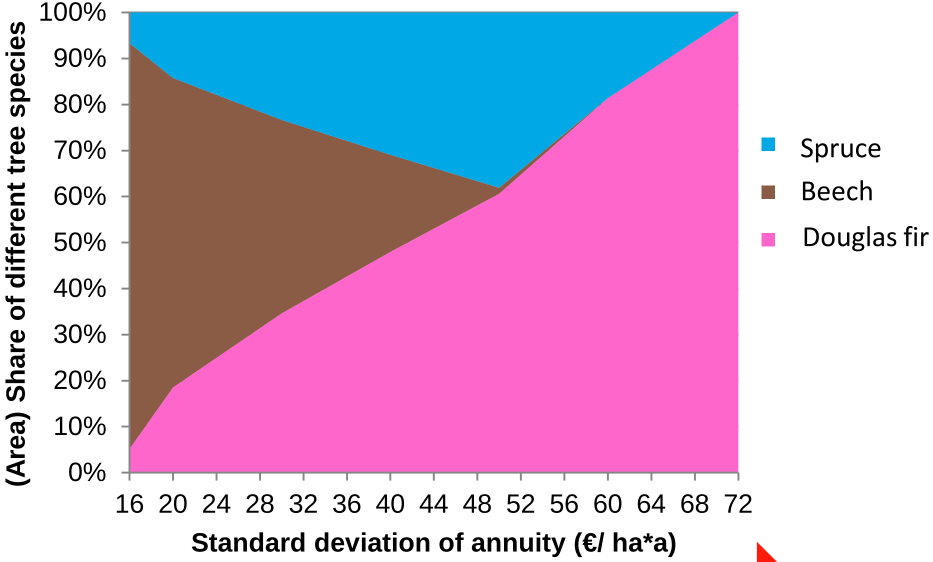


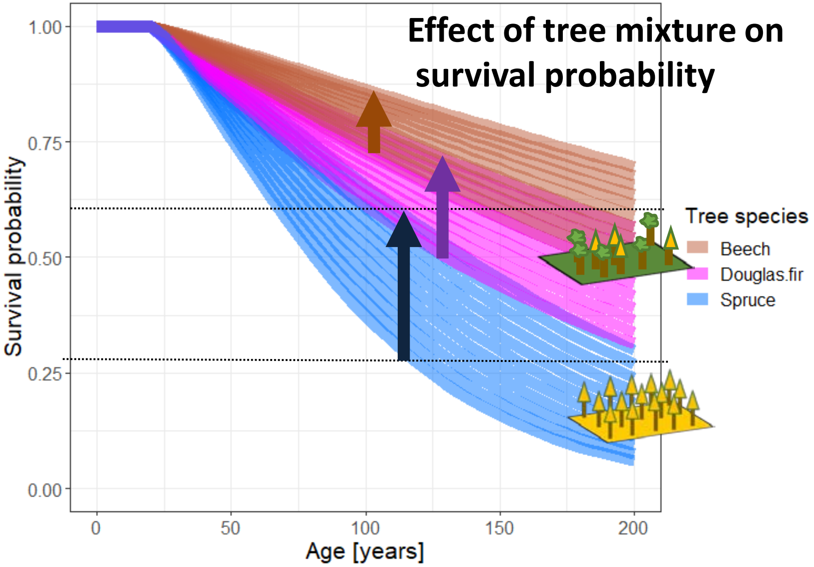
Accepted level of risk

Example application: The importance of tree species mixtures for reducing economic risks

Optimized species compositions for different risk levels

“Pure stands portfolio” (Block mixture)
Current climate

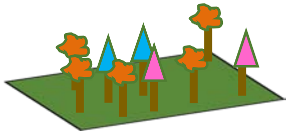




Accepted level of risk

Accepted level of risk

+



- 70% Doug, 10% Sp, 20% Be
- 50% Doug, 30% Sp, 20% Be
- 40% Doug, 40% Sp, 20% Be
- 10% Doug, 20% Sp, 70% Be

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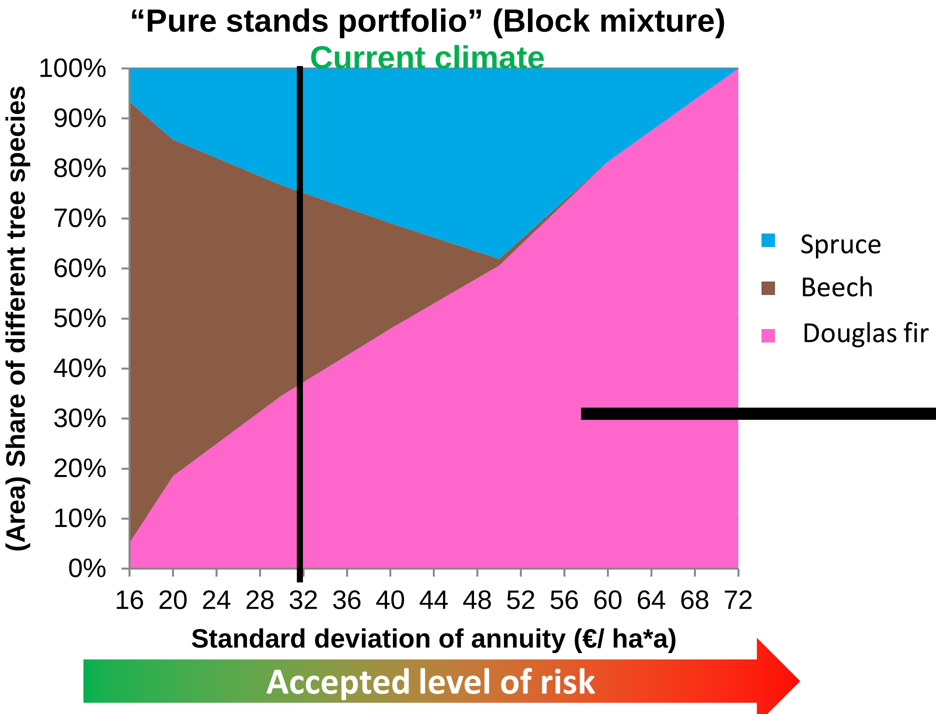
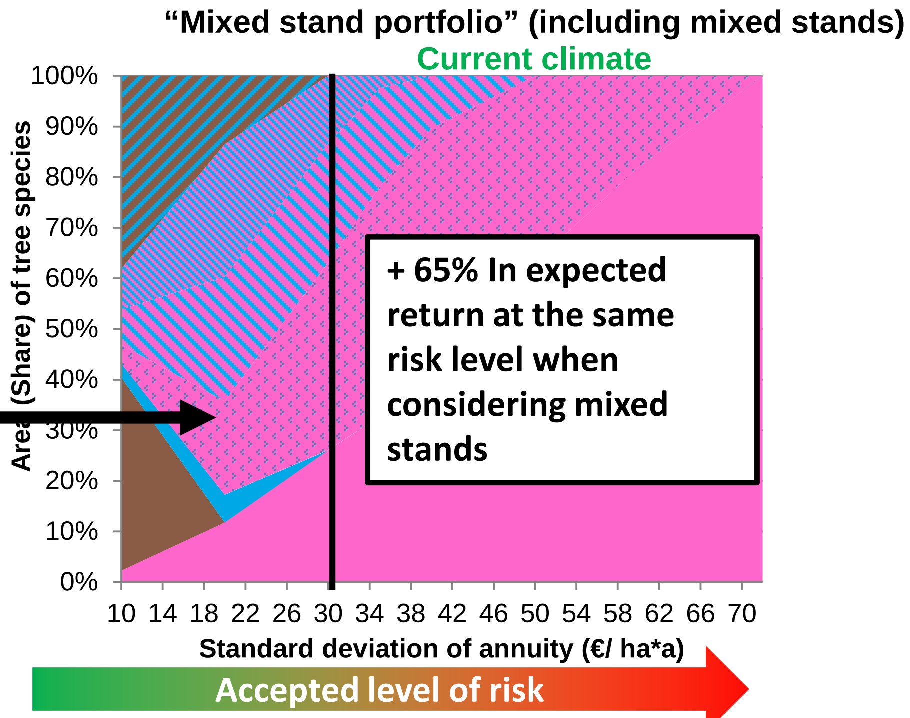
Unpublished data based on method by Paul et al. (2019) Ann For Sc 76:14

Example application: The importance of tree species mixtures for reducing economic risks

Optimized species compositions for different risk levels





Species mixtures are essential to reduce economic risks

⇒ How to select the level of accepted risk?

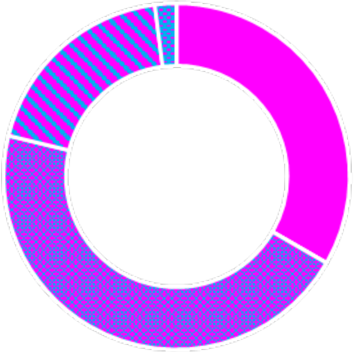
⇒ What is the effect of climate change on such an optimized portfolio?

Example application: Effects of climate change on desirable species compositions

Optimized species compositions of a risk-averse decision-maker under climate change

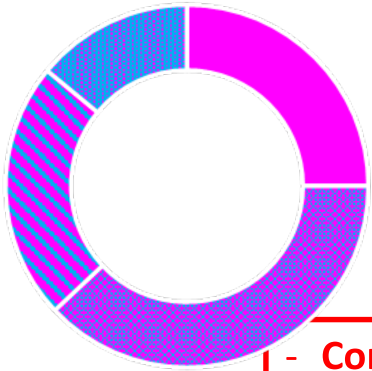
- **Objective: Maximize Value at Risk = Maximize return that is exceeded in 99% of the simulated cases**

Current climate



75% Doug
13% Beech
12% Spruce

RCP 8.5



69% Doug
18% Beech
13% Spruce

Expected „robust return“ -8%

But -17% if considering pure stands only

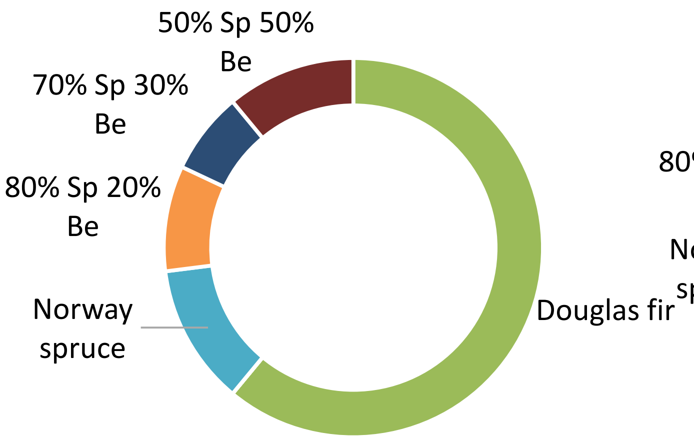
- Conifers
- Pure stands
+ Broadleaves
+ Mixed stands with equal shares

⇒ **Normative modelling offers an objective selection out of a continous set of options, irrespective of „what there is“**

⇒ **Not useful as an ultimate „recommendation“ but rather to reveal generalizable effects**

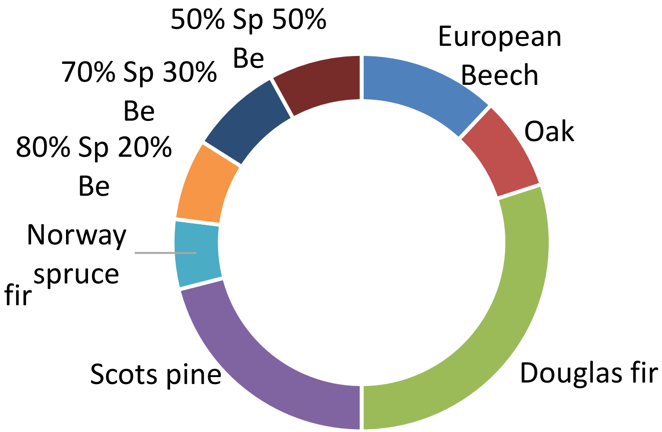
Optimized species compositions of a risk-averse decision-maker considering multiple functions

Economic objective only



Economic effects of diversification (but only economic indicator)

Multiple ecosystem services



Considering multiple ecological and economic indicators and their uncertainty *(Annuity, Carbon stock, deadwood, annual increment)*

See Poster Session 4(5)
Claudia Chreptun
FOREXCLIM

Knoke, T.; Messerer, K.; Paul, C. (2017): Current Forestry Reports 2(3): 93-106.

Guiding questions

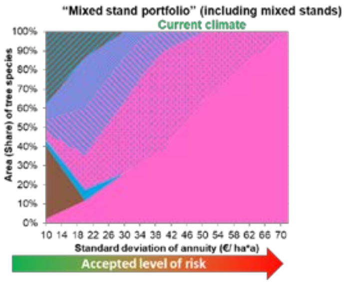
How can we quantify and model climate-change related economic consequences at the forest enterprise level? What are the main challenges?

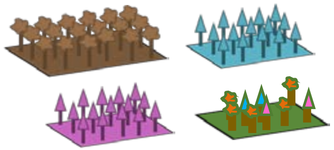
How could we improve ecological-economic modelling to contribute to supporting management decisions in a changing climate?

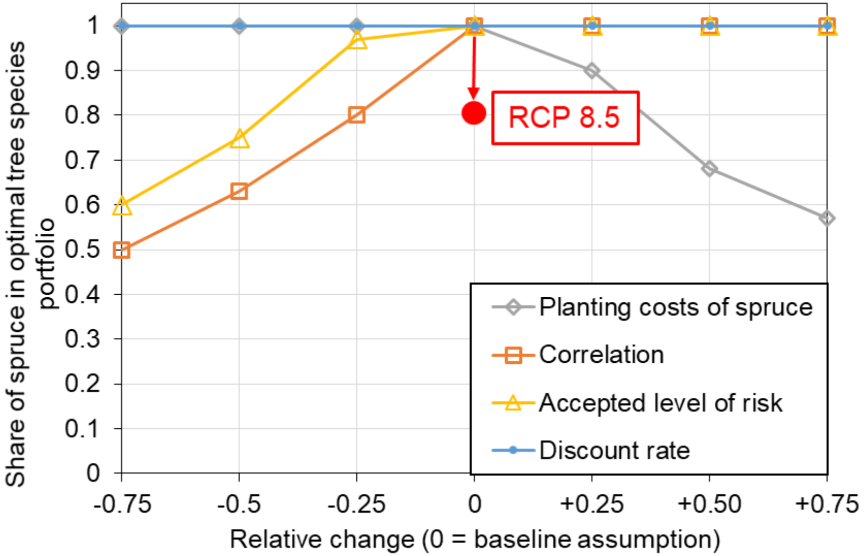
What are the key factors driving economic mitigation potential?

The example of species selection – lessons learned
What are the key factors driving economic mitigation potential?

- **Objective function of the normative model**
- **Alternatives** offered to the model
- Individual **risk attitude**
- **Classic economic coefficients**
  - ⟹ Planting costs: What are the upper limits for a species for inclusion in the optimized portfolio?
- **Wood prices and fluctuations**
  - ⟹ What are the lower limits for inclusion in the optimized tree species portfolio?
- **Combinations of mitigation options?**



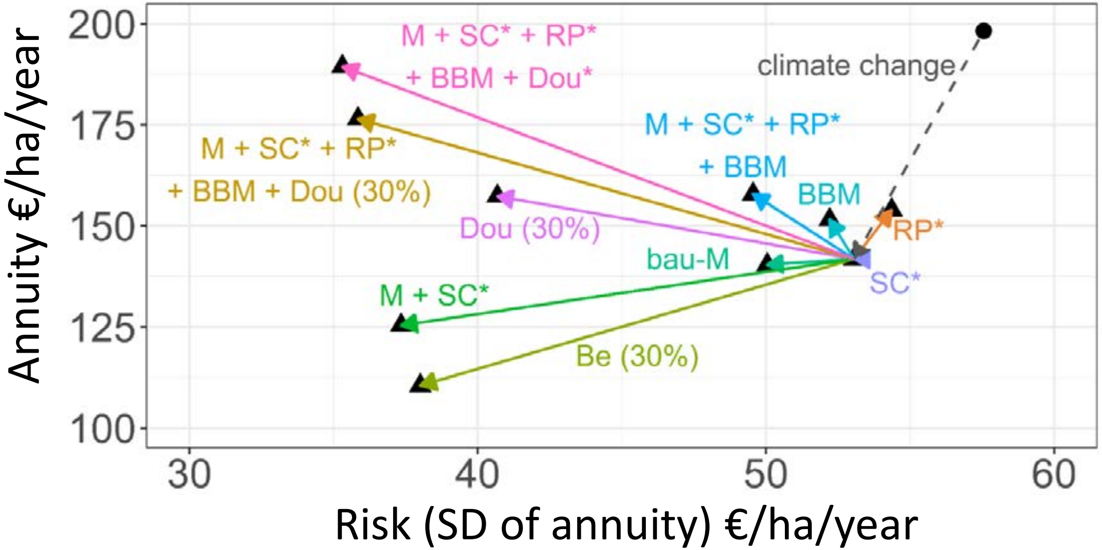




Paul et al. (2019) Ann For Sc 76:14

What are the key factors driving economic mitigation potentials?
The importance of combining mitigation options

- Risk and return of different optimized species compositions under different mitigation options



bau:	business-as-usual
M:	mixed stands (with species interaction)
Be (30%):	admixing 30 % beech
SC*:	optimized species composition
RP*:	optimized rotation period
BBM:	bark beetle management
Dou (30%):	admixing 30 % Douglas fir
Dou*:	optimized share of Douglas fir (here: 65 %)
+:	combinations of management responses

See Poster
Session 4(2)
Jasper Fuchs

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Fuchs et al. (in prep.)

Conclusions and lessons learned

- **Normative models using optimization approaches are an important complement to scenario analysis**

  – *Key questions: "At what magnitude do conditions need to change to severely affect my desired outcome and management strategy"?*

- **Incorporating uncertainties in ecological-economic modelling is methodologically challenging but crucial for supporting management decisions**

The road ahead:

- Robust optimization
  (Knoke et al. 2017, Curr. For. Rep. 2(3): 93-106, Etemad et al. (2019) J For. Sc.
- Dynamic approaches
  (Härtl and Knoke Forests 10, 504)
- Spatial approach (spatial correlation, site heterogeneity)

- **Resilient forest enterprises are key for resilient forest management**

Forest enterprises trapped between desperation and resignation

Acknowledgements and Contact

Co-authors:
Jasper Fuchs, Nils Benfer, Susanne Brandl, Claudia Chreptun, Fabian Härtl, Thomas Knoke

All colleagues in SURVIVAL-KW and FOREXCLIM Project

TUM Fachgebiet für Waldinventur und nachhaltige Nutzung
LWF Bayerische Landesanstalt für Wald und Forstwirtschaft
FVA Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg
THÜNEN
Landesforsten Rheinland-Pfalz – Wald. Werte. Wahren.

This research was funded by

Waldklimafonds

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Bundesministerium für Ernährung und Landwirtschaft
Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit
aufgrund eines Beschlusses des Deutschen Bundestages

DFG Deutsche Forschungsgemeinschaft

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Twitter: @Carola__Paul
@GoeFelaP

Sustainable yield planning at enterprise level

- **YAFO** model developed by ***Fabian Härtl at Technical Unviersity of Munich***
- Solves an allocation problem – allocating silvicultural measures (harvesting) to stands (or share of area within the stand) and planning period (E.g. 5 year period for next 50 years)
- How should Forest Management look like to maximize a specific objective Here: maximize **Robust Net Present Value (NPV)** of the entire enterprise under a certain accepted

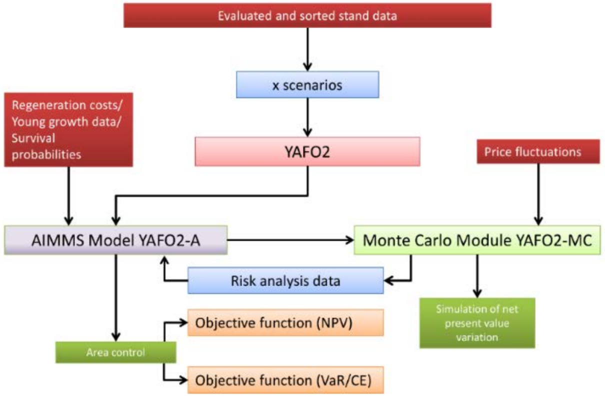
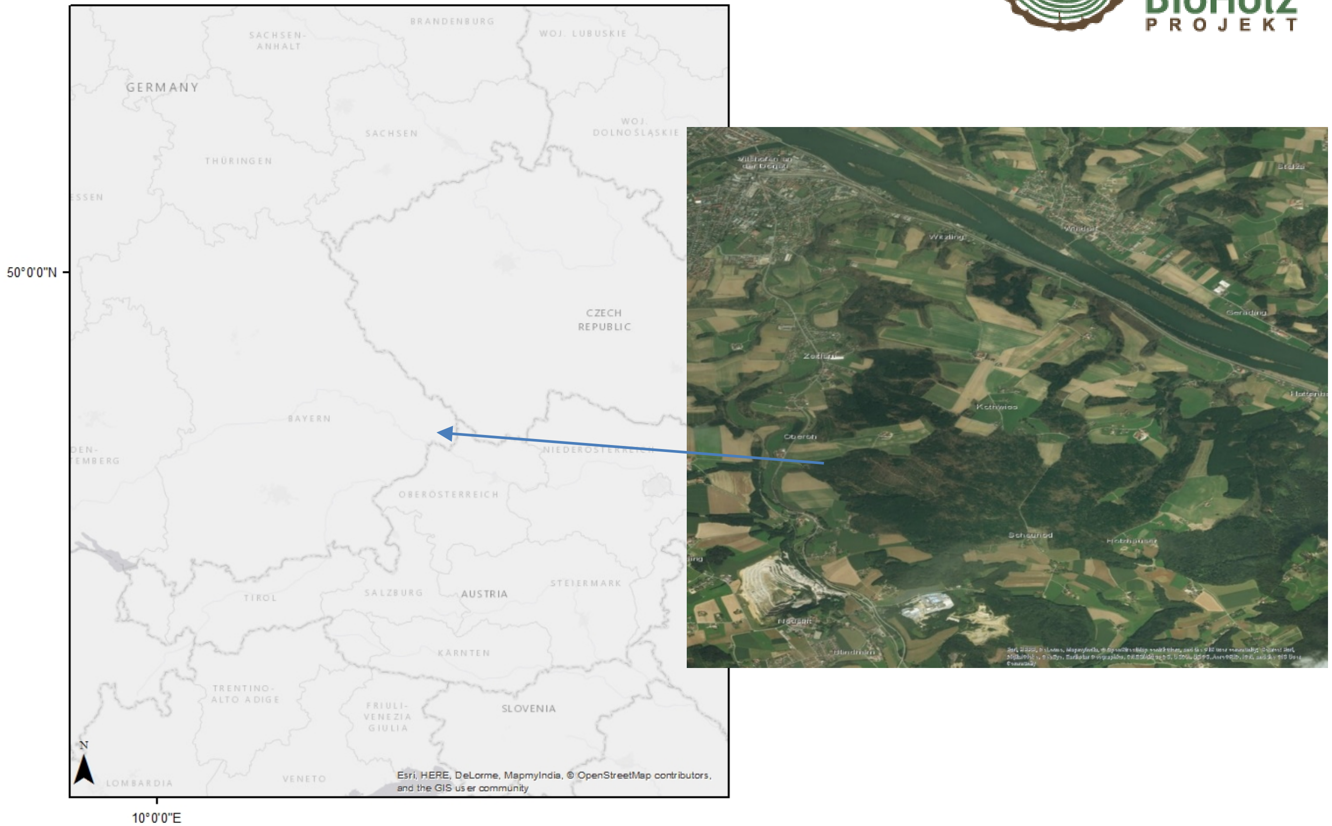


Abbildung: Fabian Härtl

Space	Time					
Stand	Periode 1	Periode 2	Periode 3	Periode 4	Periode 5	Periode 6
1	Area	Area	Area	Area	Area	Area
2	Area	Area	Area	Area	Area	Area
3	Area	Area	Area	Area	Area	Area
4	Area	Area	Area	Area	Area	Area
5	Area	Area	Area	Area	Area	Area
6	Area	Area	Area	Area	Area	Area
7	Area	Area	Area	Area	Area	Area
8	Area	Area	Area	Area	Area	Area
9	Area	Area	Area	Area	Area	Area
10	Area	Area	Area	Area	Area	Area

Example enterprise



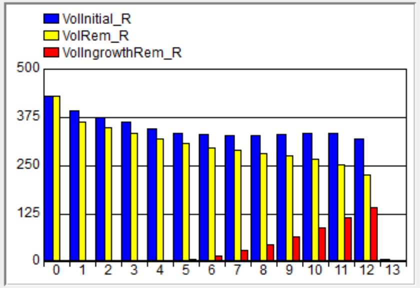
Example enterprise (by F. Härtl)

Volume development

Current climate

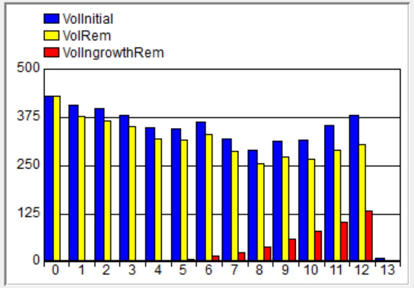
NPV = 4,709,064 [EUR]
NPV.robust = 3,656,209 [EUR]
AnnuityRO = 422.882 [EUR/(y*ha)]

Robust Solution



Periode (á 5 Jahre)

NPV only



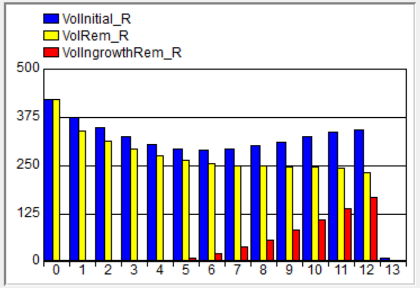
Periode (á 5 Jahre)

- 8%

Climate change
(RCP 8.5 MPI-ESM-LR)

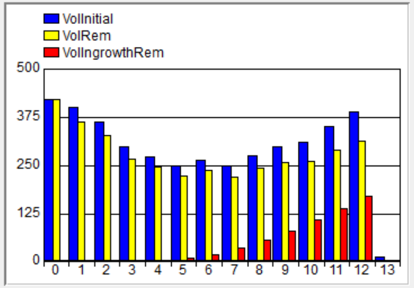
NPV = 4,497,499 [EUR]
NPV.robust = 3,353,748 [EUR]
AnnuityRO = 387.899 [EUR/(y*ha)]

Robust Solution



Periode (á 5 Jahre)

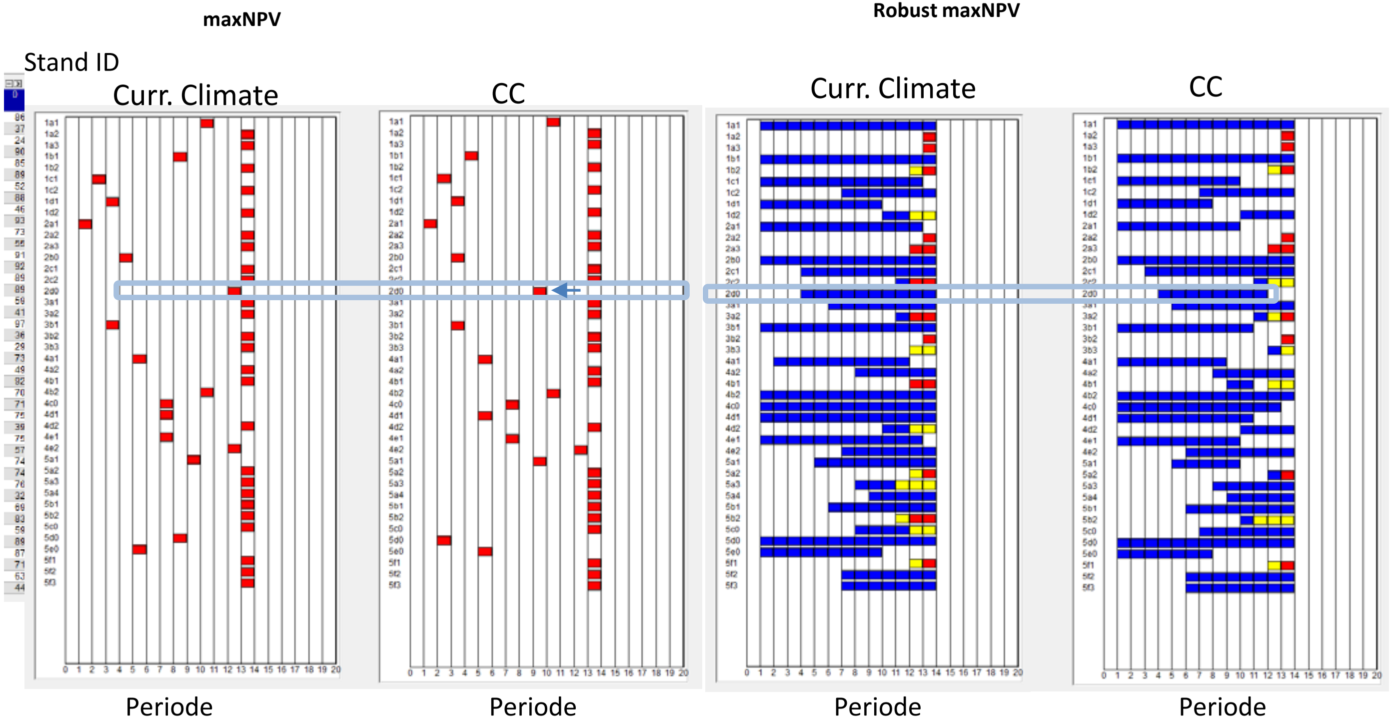
NPV only



Periode (á 5 Jahre)

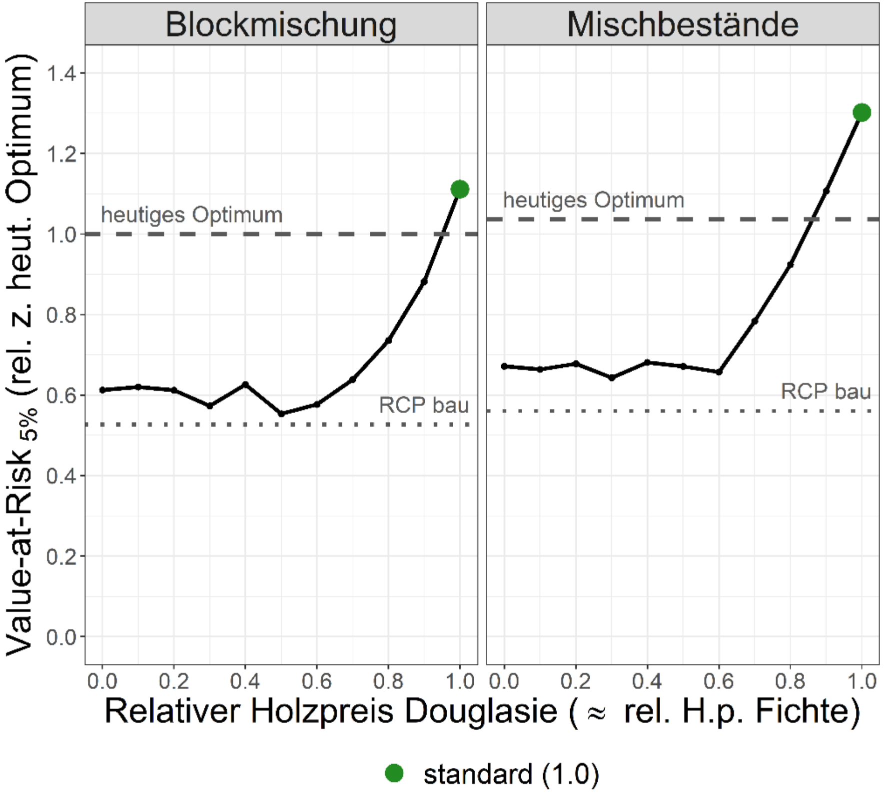
Example enterprise (by F. Härtl)

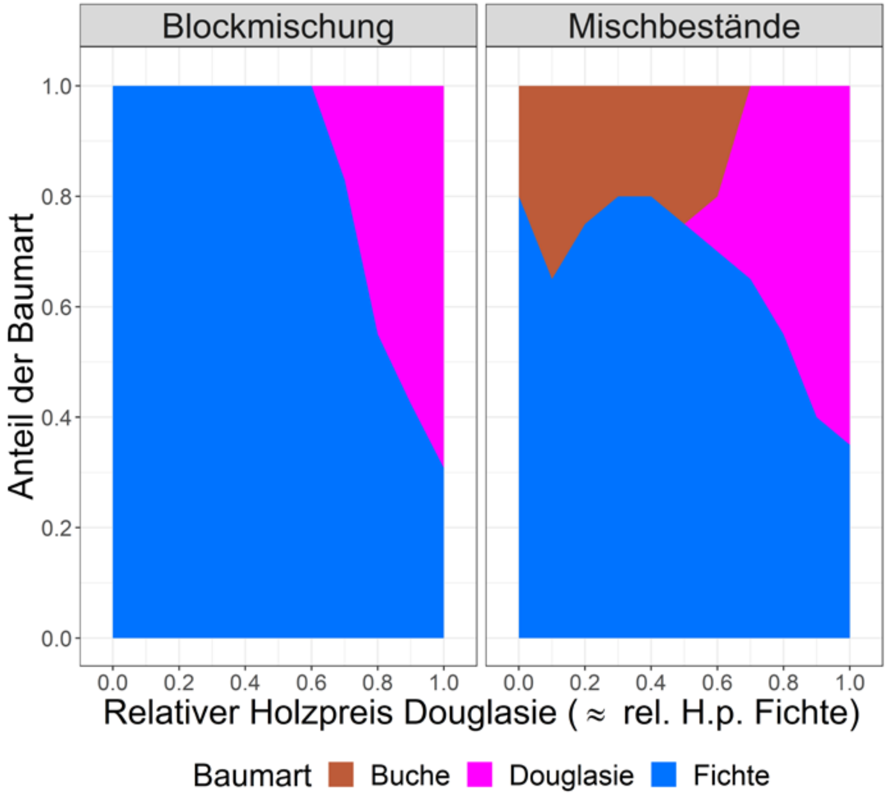
Harvesting schedule



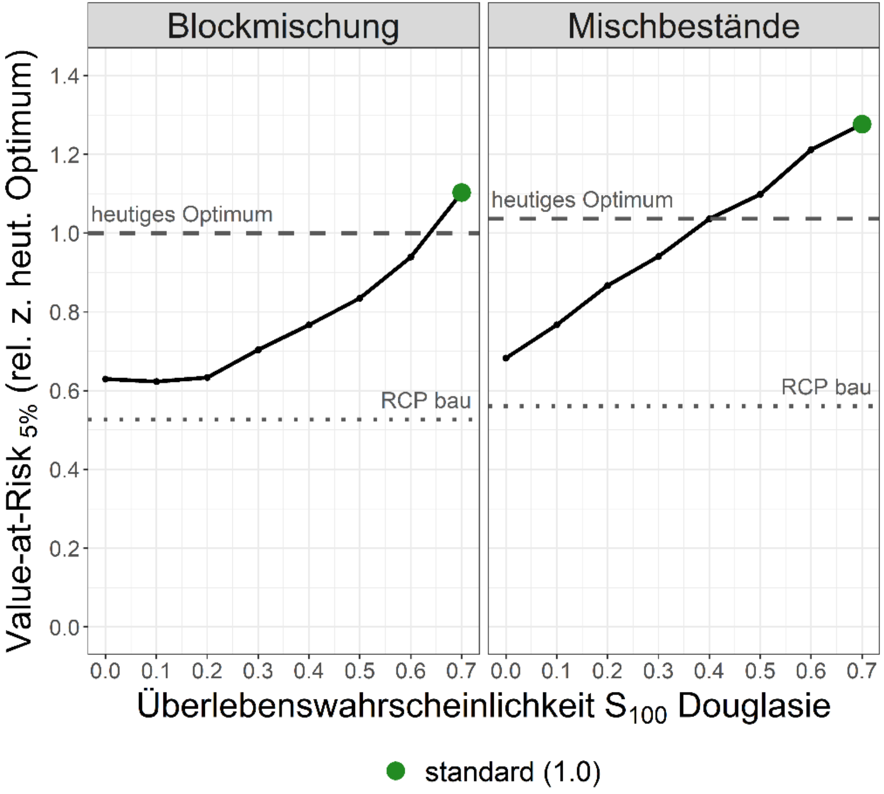
Harvesting (blue: <15% of stand area, yellow: >=15%, red: >=25%)

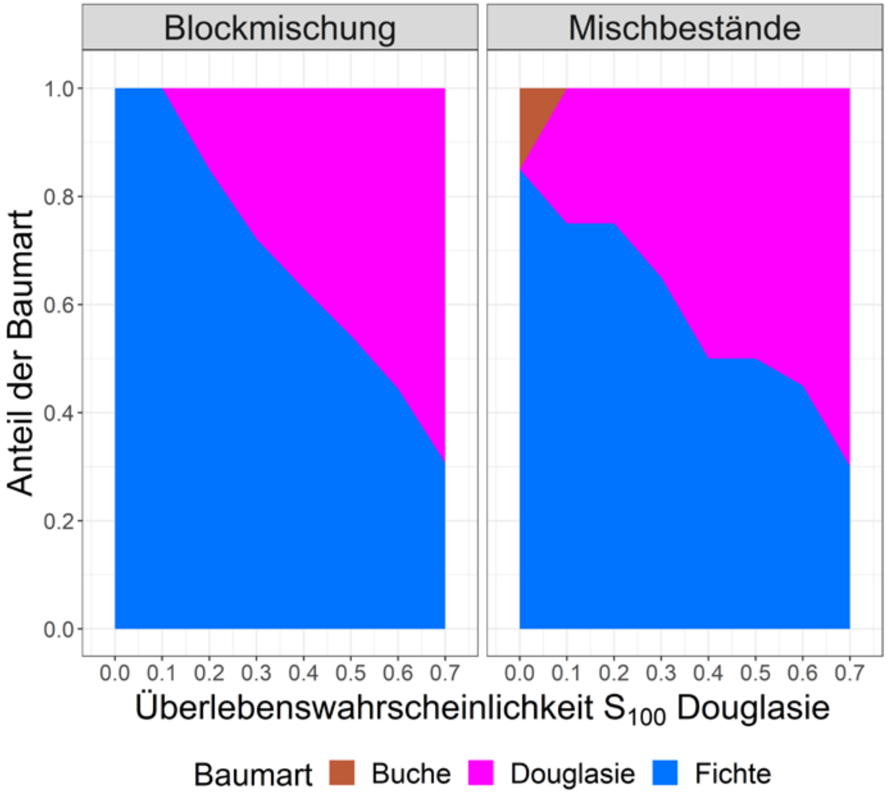
Ergebnisse: Anbau alternativer Baumarten - Holzpreise





Ergebnisse: Anbau alternativer Baumarten - Risiken





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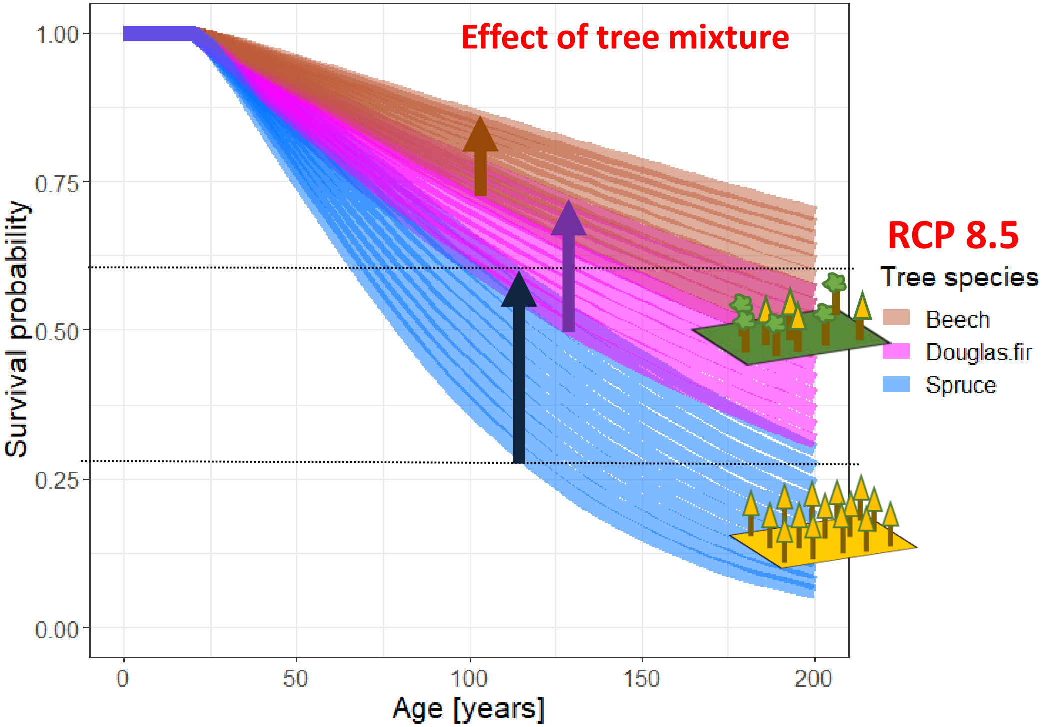
Example application: Quantifying changes in survival probabilites



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- Method: Survival time analysis using Weibull distribution parametrized by Accelerated failure time model, accounting for censored and left-truncated data
- Project **SURVIVAL-KW** funded by „Waldklimafonds“
- Example for Northwestern Germany (1.100 mm mean annual precipitation and 7.1°C mean annual temperatur)

Brandl et al. (2020) Forest Ecology and Management 458, 117652.

Waldklimafonds
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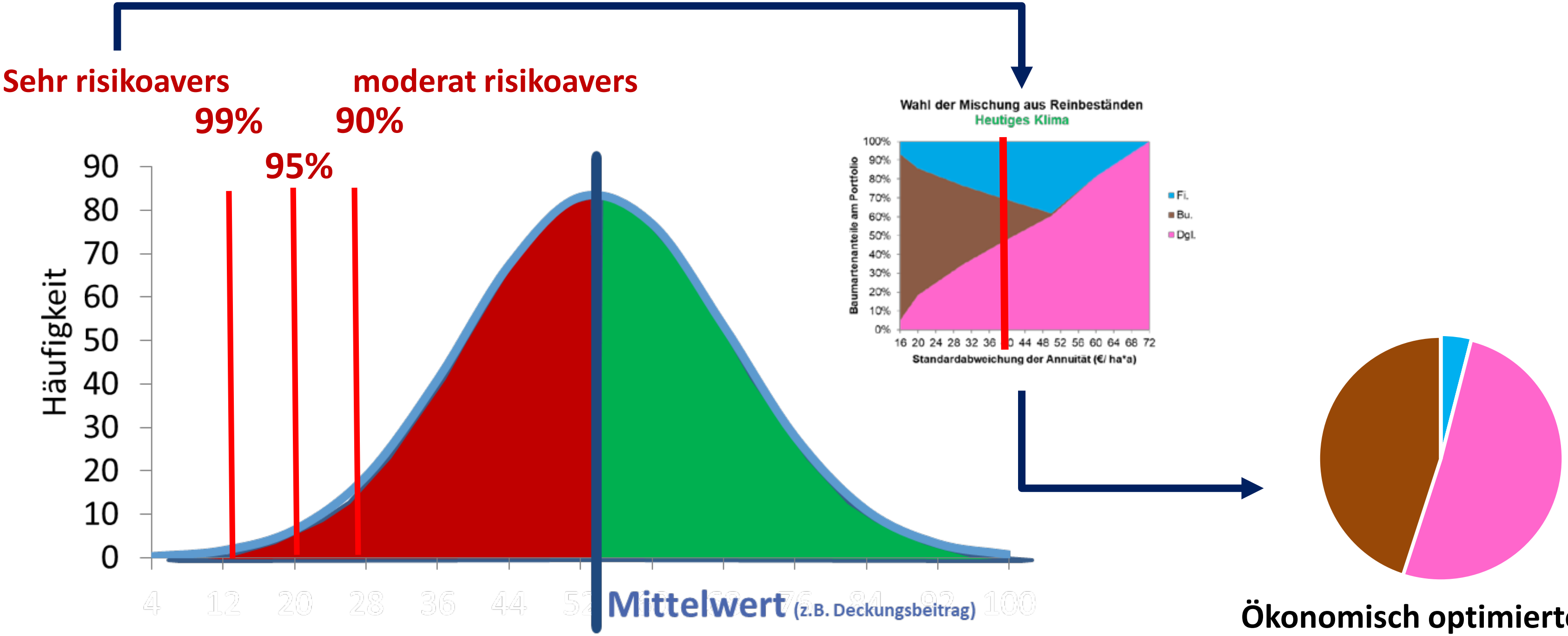
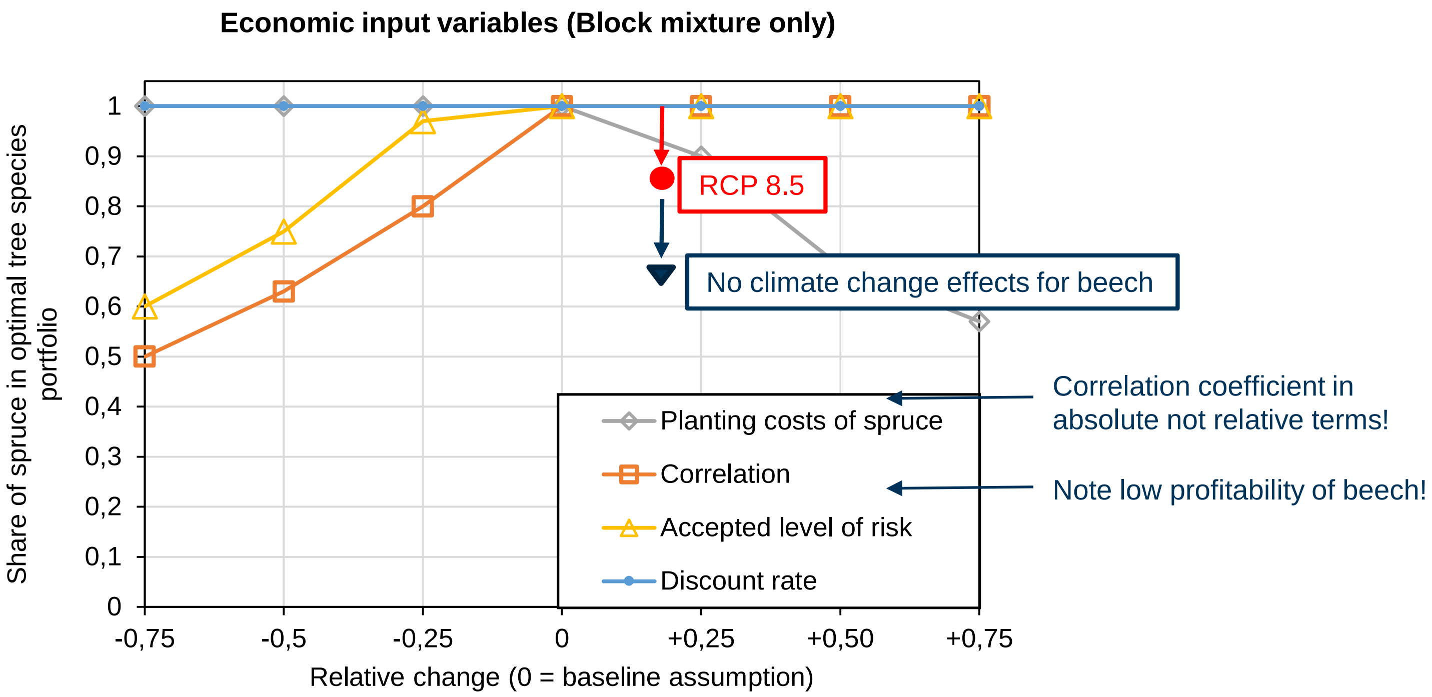
The Value at Risk as decision criteria



Ökonomisch optimierte Baumartenzusammensetzung

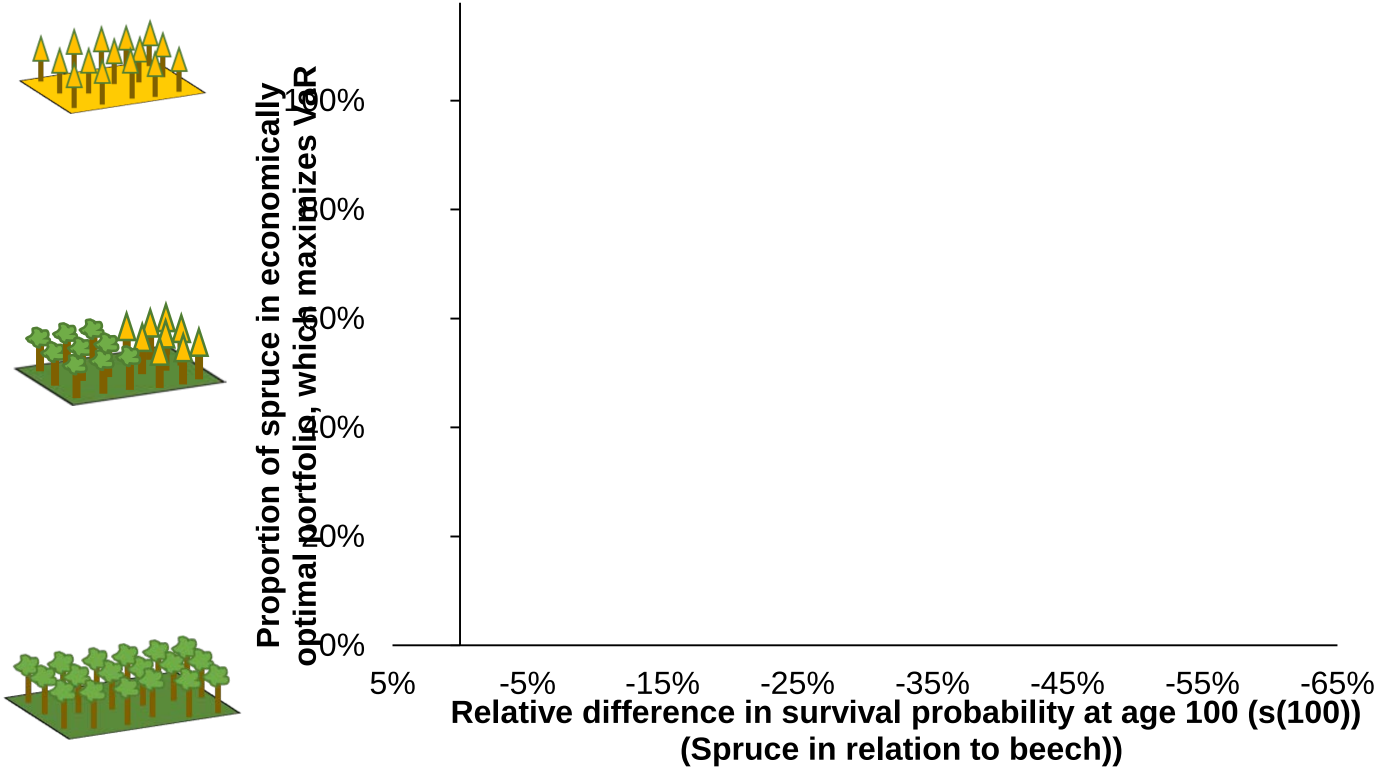
Sensitivity analysis



Survival analysis

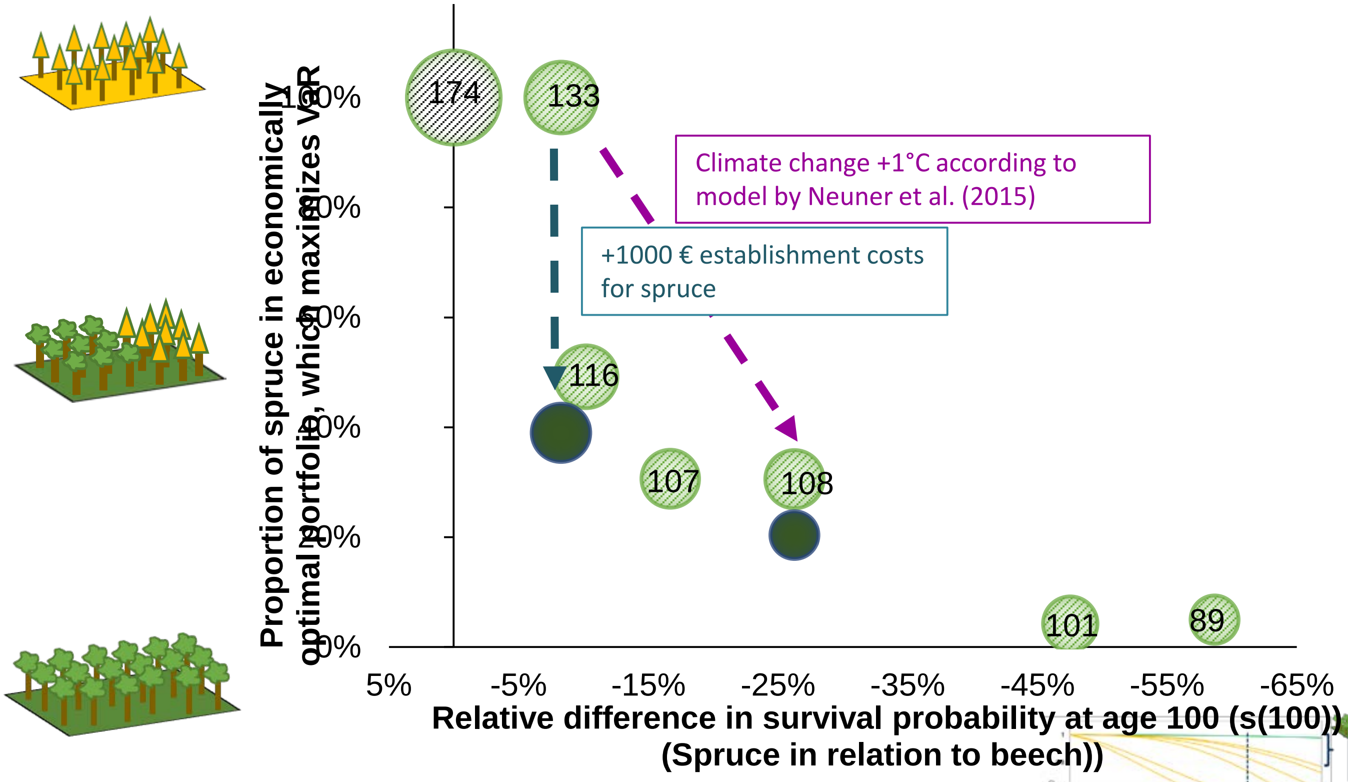
- No climate change effect for beech
- Share of Spruce would only fall below 50% if S(100) of beech was by 45 percentage points higher than that of spruce

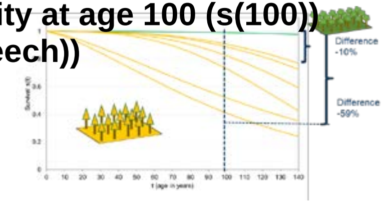
Results (1): Effect of survival probabilites on optimal share of spruce in the economically optimal tree-species composition (based on VaR)



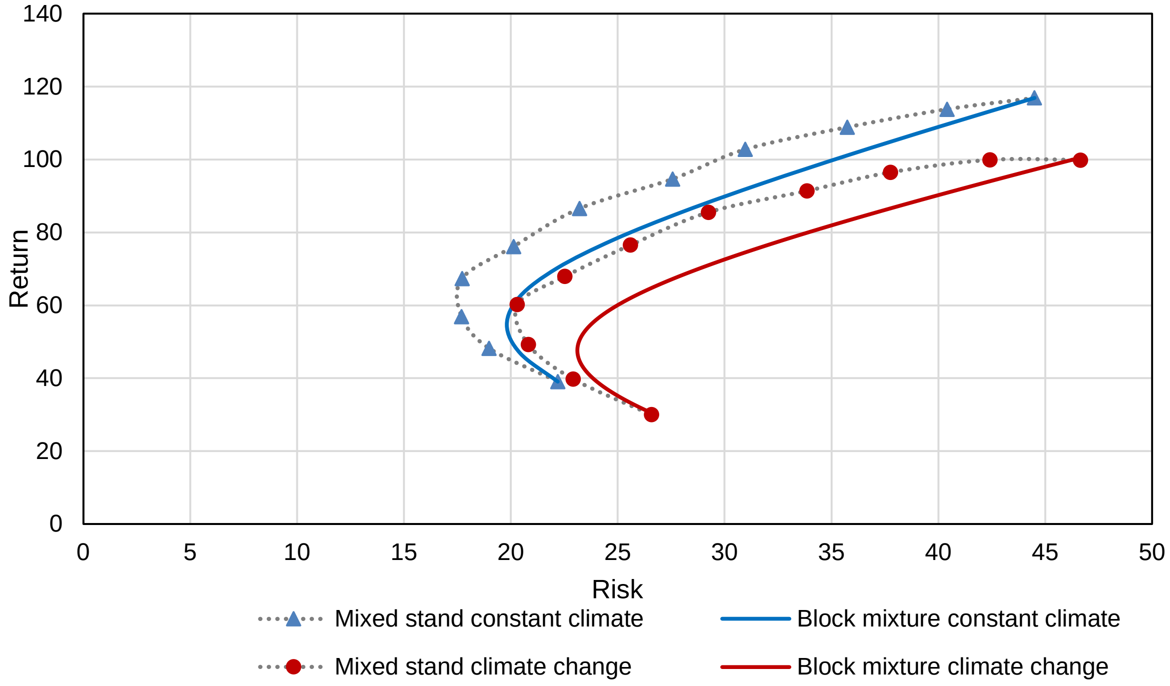
Size of circles and values denote VaR of optimized tree-species portfolios

Results (1): Economic effects of altered survival probabilities compared to other management decisions





Size of circles and values denote VaR of optimized tree-species portfolios



140
120
100
80
60
40
20
0
Return
0
5
10
15
20
25
30
35
40
45
50
Risk
Mixed stand constant climate
Block mixture constant climate
Mixed stand climate change
Block mixture climate change