Waldwachstum Systemanalyse

TECHNISCHE UNIVERSITÄT MÜNCHEN

Analyzing mixing effects on forest stand level

Hans Pretzsch
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http://www.wwk.forst.wzw.tum.de/info/presentations/

Lecture given on March 12th, 2012 at SLU, Alnarp, Sweden

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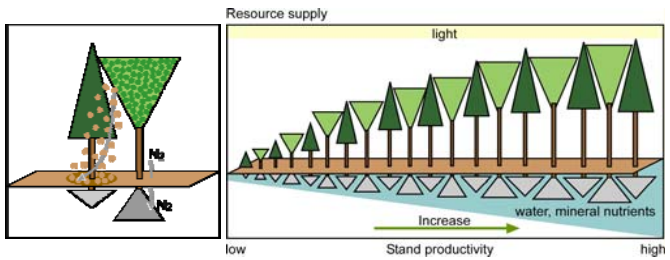
Production Ecology Equation by Monteith (1977) as a start

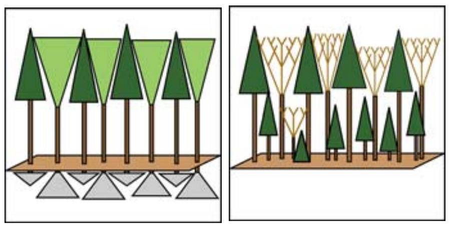
Gross primary productivity = resource supply
× proportion of resource captured
× efficiency of resource use

Mixing effects may be caused by change in

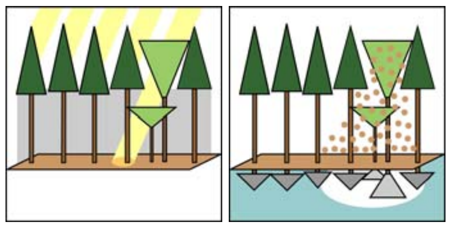
resource supply



resource capture



resource use efficiency



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1 Mixed vs. pure on total stand level

2 Analyses on species level

3 Allometric correction before causal analysis

4 Covariance analysis on species level

5 Components: Density, mean tree productivity

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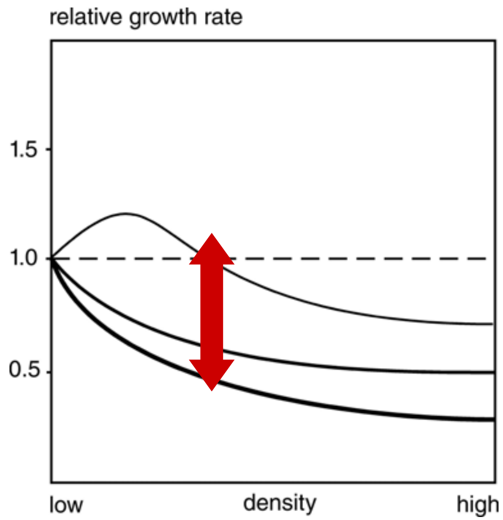
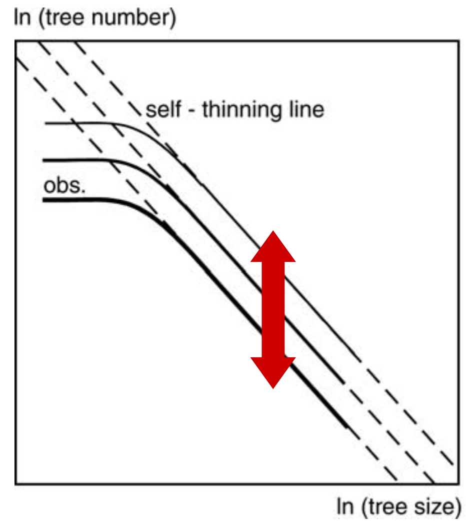
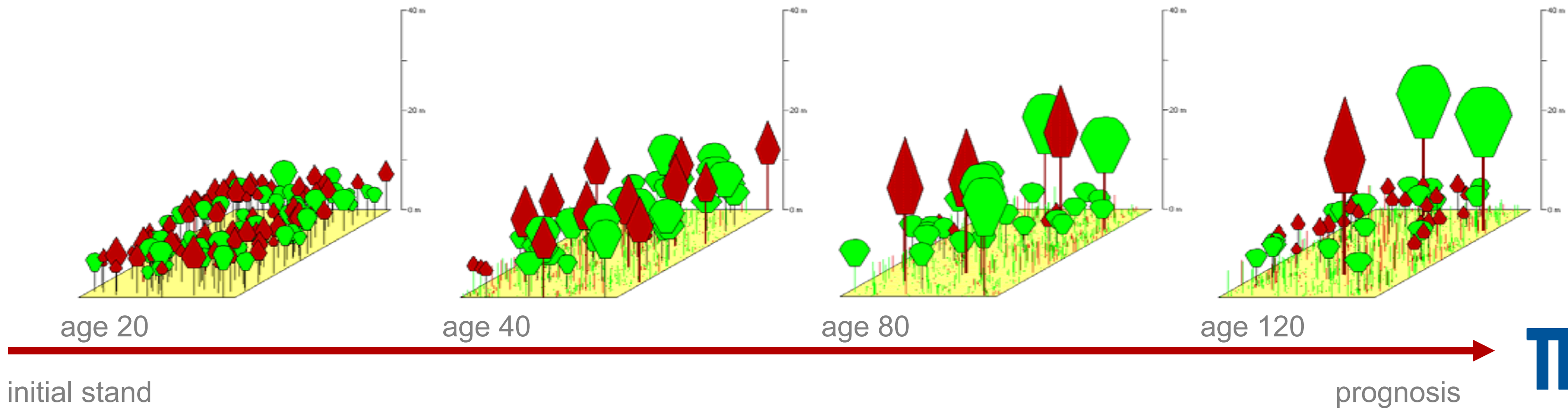
Understanding and improved consideration of mixing effects in individual tree models







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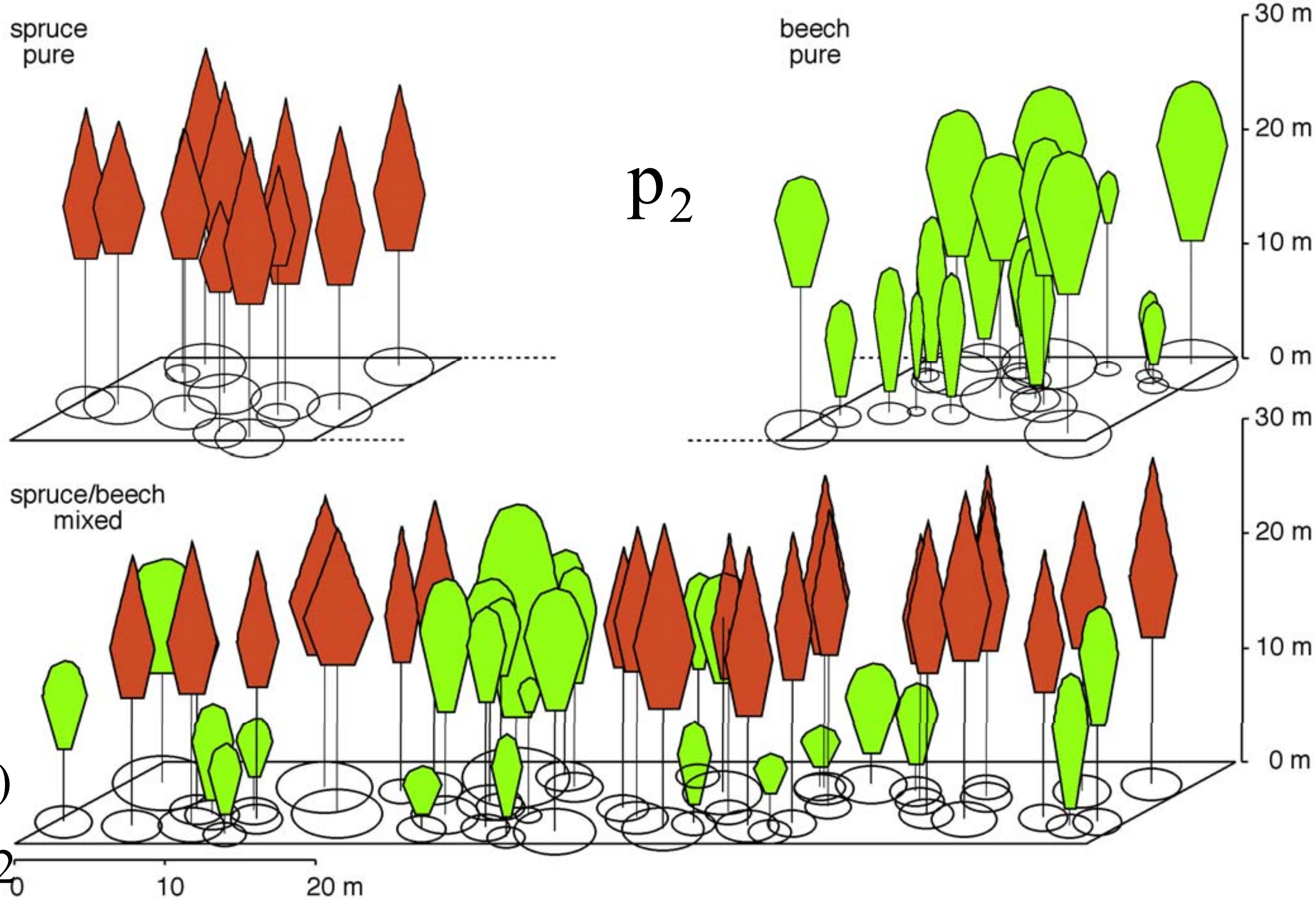
Experimental setup for scrutiny of mixing effects Zwiesel 111/3,4,5 Bavarian Forest

p_1 p_2



$p_{1,2}$
m_1
m_2
$pp_{1,(2)}$
$pp_{(1),2}$
$$p_{1,2} = pp_{1,(2)} + pp_{(1),2}$$

Pretzsch (2009) Forest Dynamics, Growth and Yield, Springer, 653 p.

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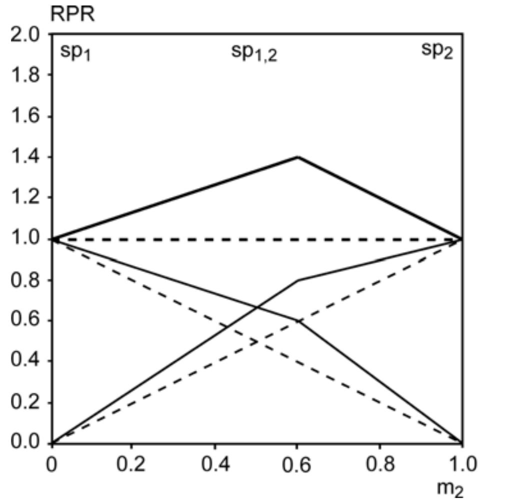
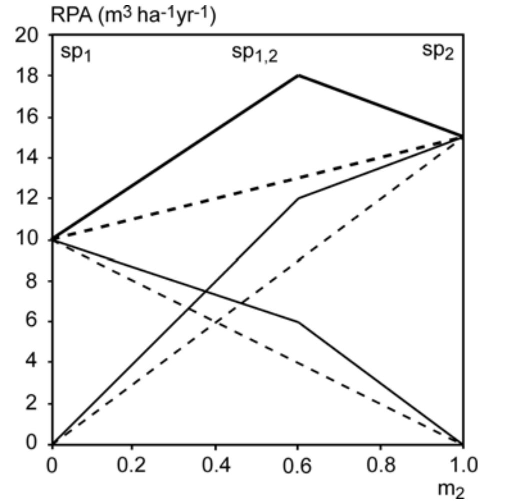
Ratio productivity RPR “with plant’s-eye view” and ratio productivity RPA “forester’s-eye view”





$$RPR_{1,2} = \frac{pp_{1,(2)}}{p_1} + \frac{pp_{(1),2}}{p_2}$$

$$RPA_{1,2} = \frac{pp_{1,(2)} + pp_{(1),2}}{p_1 \times m_1 + p_2 \times m_2}$$

the species' productivity share in mixture

$pp_{(1),2}, pp_{1,(2)}$

$p_{1,2} = pp_{(1),2} + pp_{1,(2)}$

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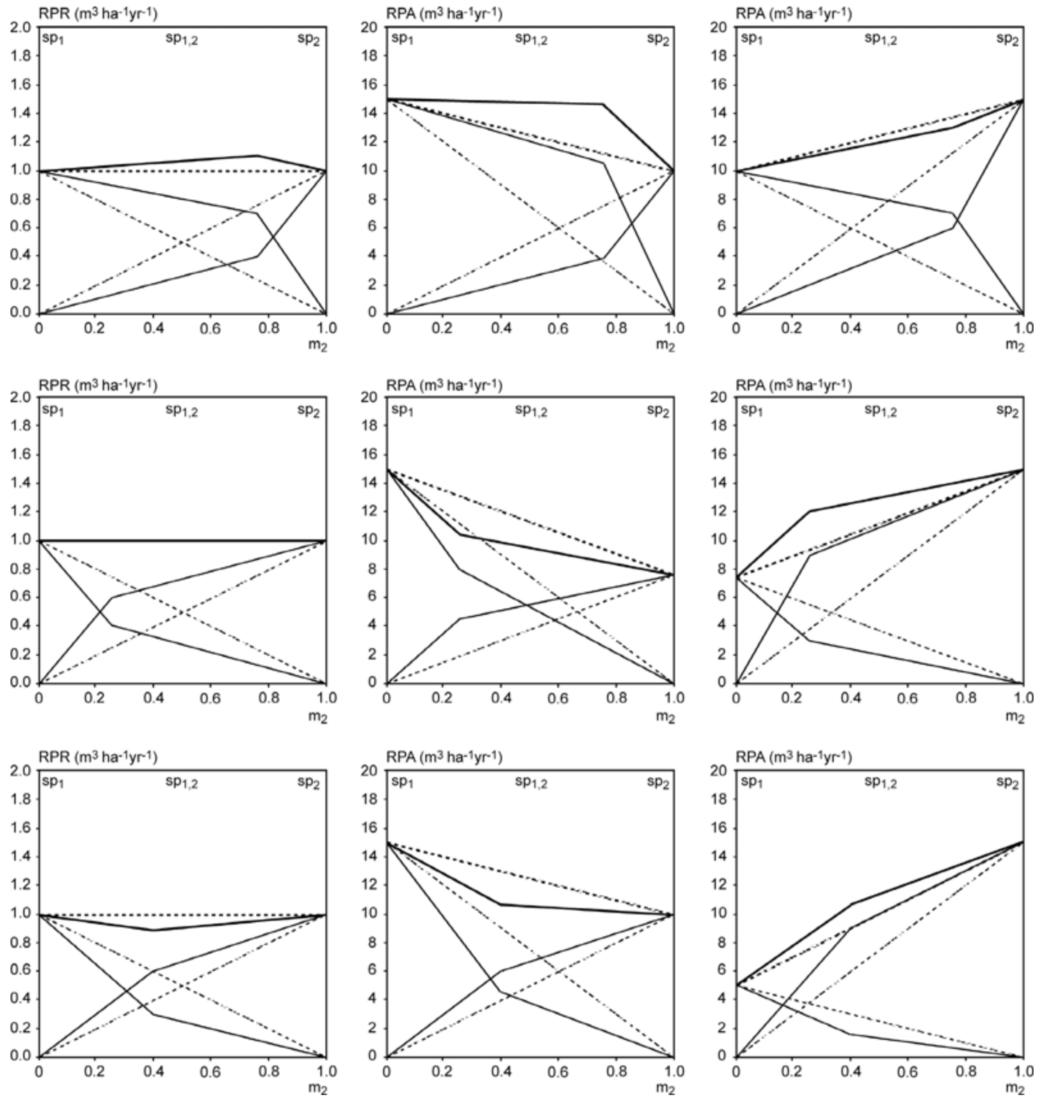
Relationship between RPR and RPA depending on mixing portions and species productivity



Comparison between RPR and RPA for model stand

p_1 (t ha^{-1} yr^{-1})	p_2 (t ha^{-1} yr^{-1})	m_1	$pp_{1,(2)}$ (t ha^{-1} yr^{-1})	m_2	$pp_{(1),2}$ (t ha^{-1} yr^{-1})	$RPR_{1,2}$	$RPA_{1,2}$
10	10	0.25	5.0	0.75	6.0	1.100	1.100
7	8	0.50	6.0	0.50	7.0	1.732	1.733
15	10	0.25	10.5	0.75	4.0	1.100	1.289
10	15	0.25	7.0	0.75	6.0	1.100	0.945
15	8	0.75	6.0	0.25	4.5	1.000	0.800
8	15	0.75	3.0	0.25	9.0	1.000	1.280
15	10	0.60	4.5	0.40	6.0	0.900	0.808
5	15	0.60	1.5	0.40	9.0	0.900	1.167

$$RPR_{1,2} = \frac{pp_{1,(2)}}{p_1} + \frac{pp_{(1),2}}{p_2}$$

$$RPA_{1,2} = \frac{pp_{1,(2)} + pp_{(1),2}}{p_1 \times m_1 + p_2 \times m_2}$$

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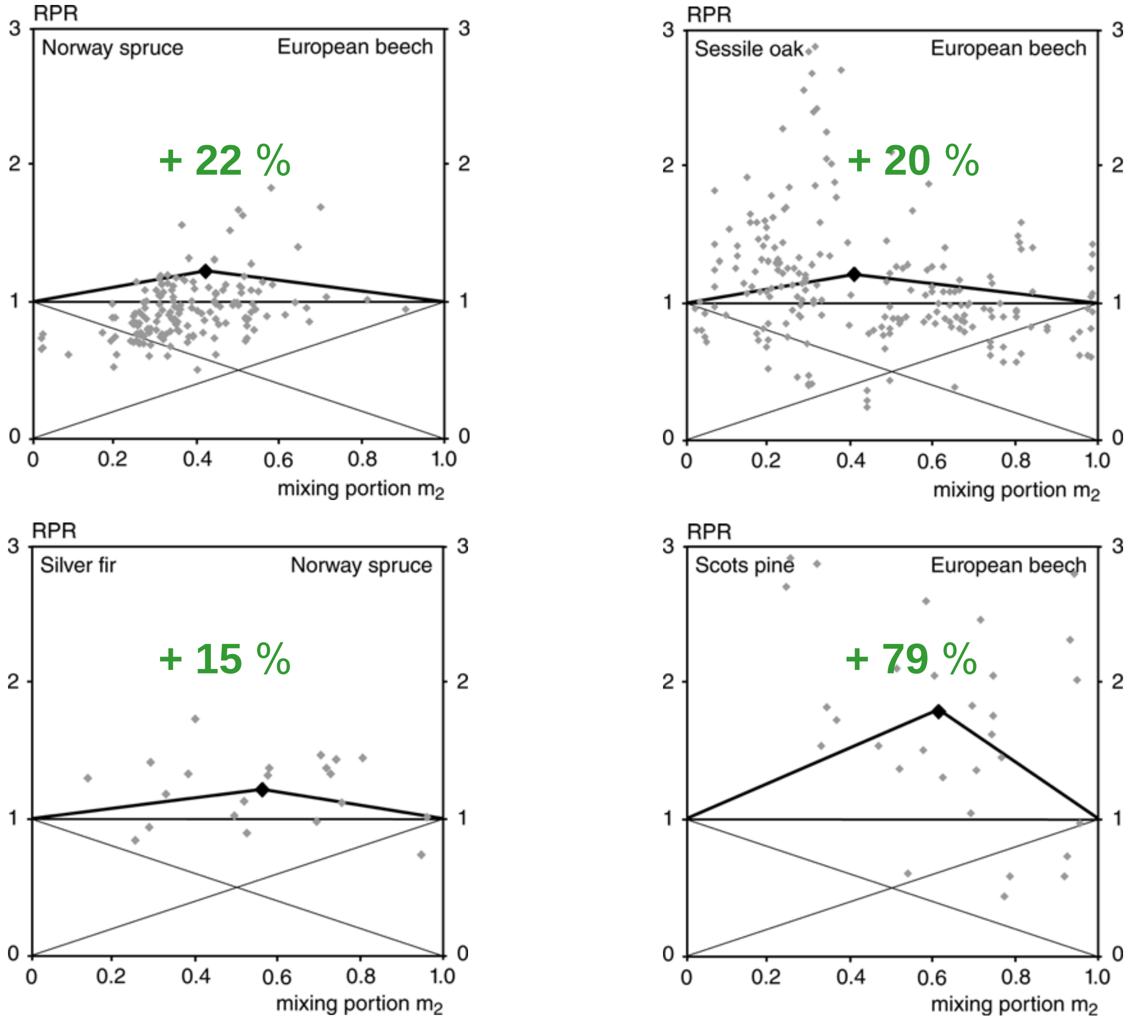
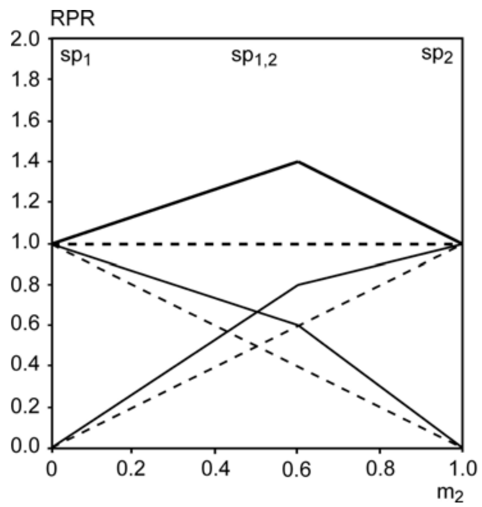
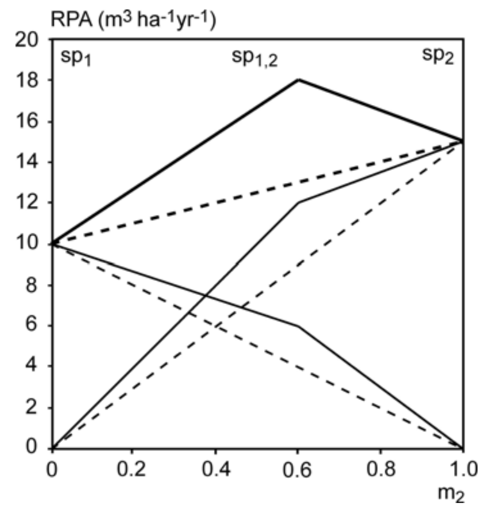
Productivity (t ha^{-1} yr^{-1}) of mixed compared with pure stands in Central Europe



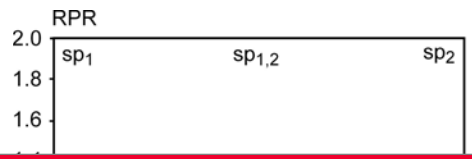
Productivity of mixed versus pure stands for mixtures of spruce, beech, oak, and fir

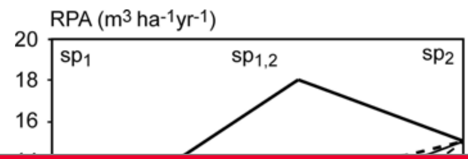




Species composition	n	$RPR_{1,2}$ ./.	$RPR_{1,(2)}$ ./.	$RPR_{(1),2}$ ./.	$RPA_{1,2}$ ./.	Δ mass a.g. ($t\ ha^{-1}\ yr^{-1}$)
N. spruce/E. beech	213	1.22 ±*0.03*	1.15 ±*0.04*	1.46 ±*0.05*	1.18 ±*0.03*	1.22 ±*0.23*
S. oak/E. beech	217	1.20 ±*0.04*	1.24 ±*0.03*	1.17 ±*0.04*	1.17 ±*0.03*	1.50 ±*0.32*
S. fir/N. spruce	27	1.15 ±*0.05*	1.25 ±*0.11*	1.13 ±*0.06*	1.14 ±*0.05*	1.01 ±*0.35*
S. pine/E. beech	33	1.80 ±*0.14*	2.19 ±*0.27*	1.65 ±*0.12*	1.78 ±*0.14*	3.64 ±*0.64*

Productivity of mixed versus pure stands for mixtures of spruce, beech, oak, and fir





Summary 1:

- RPR and RPA deliver slightly different information
- RPR ref. to plant‘s-eye view, RPA to forester‘s-eye
- on average RPR and RPA > 1.0

Species composition	n	$RPR_{1,2}$ ./.	$RPR_{1,(2)}$ ./.	$RPR_{(1),2}$ ./.	$RPA_{1,2}$ ./.	Δ mass a.g. ($t\ ha^{-1}\ yr^{-1}$)
N. spruce/E. beech	213	1.22 ±*0.03*	1.15 ±*0.04*	1.46 ±*0.05*	1.18 ±*0.03*	1.22 ±*0.23*
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S. fir/N. spruce	27	1.15 ±*0.05*	1.25 ±*0.11*	1.13 ±*0.06*	1.14 ±*0.05*	1.01 ±*0.35*
S. pine/E. beech	33	1.80 ±*0.14*	2.19 ±*0.27*	1.65 ±*0.12*	1.78 ±*0.14*	3.64 ±*0.64*

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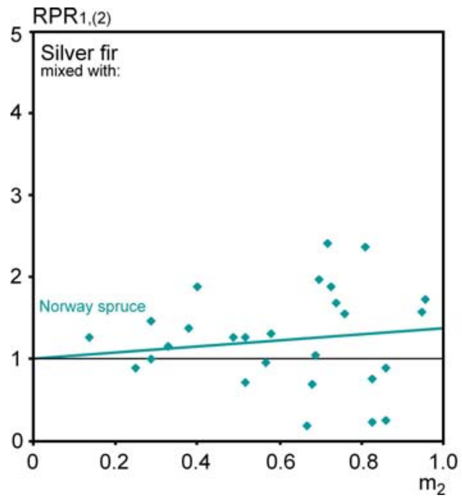
Ratio in terms of relative productivity RPR on species level



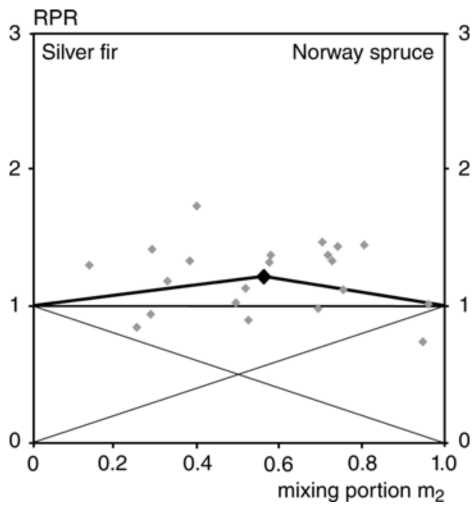
$$pp_{1,(2)}, pp_{(1),2}$$

$$p_{1,2} = pp_{1,(2)} + pp_{(1),2}$$

$$p_1, p_2$$

$$m_1, m_2$$

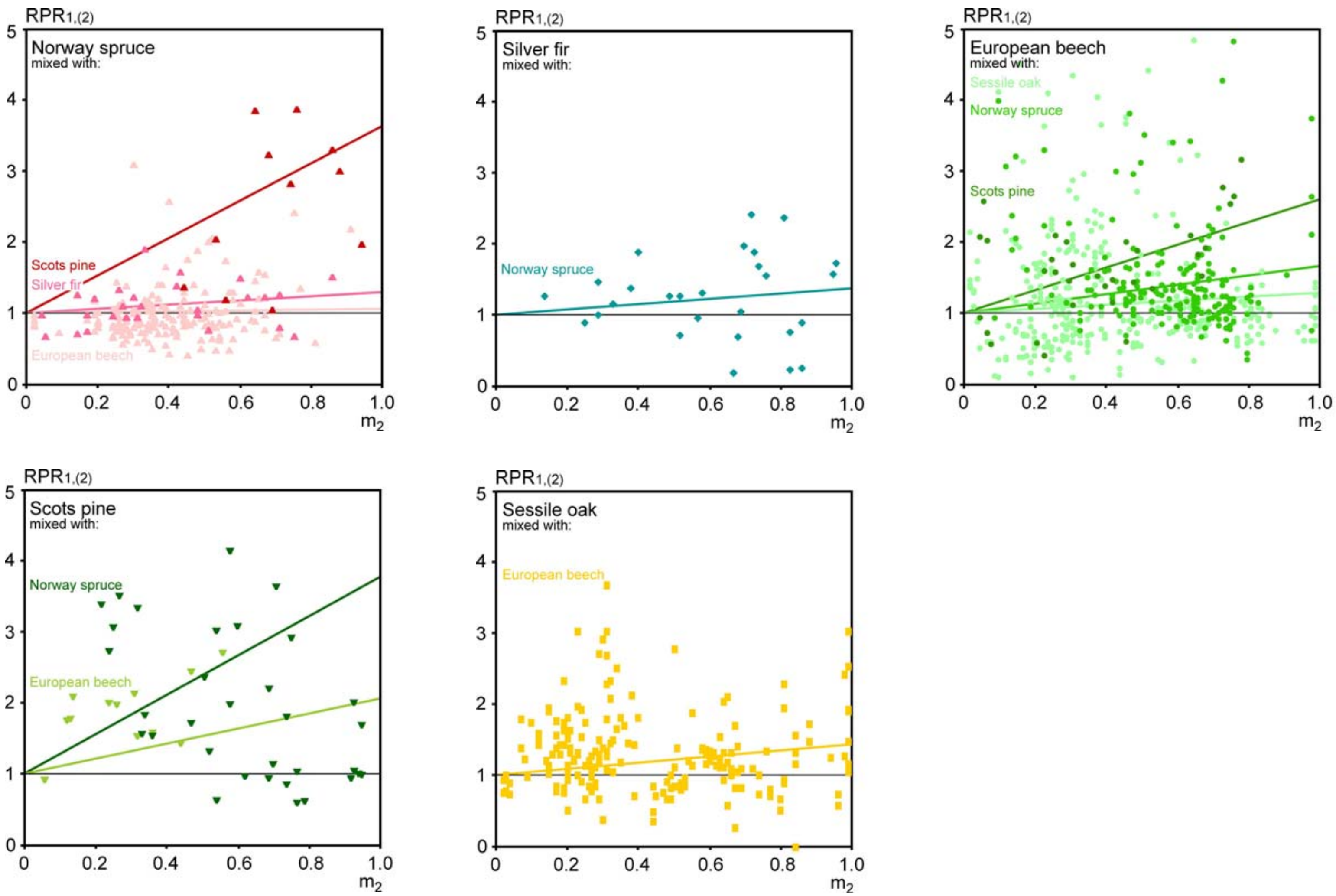
$$RPR_{1,(2)} = \frac{pp_{1,(2)} / m_1}{p_1}, \quad RPR_{(1),2} = \frac{pp_{(1),2} / m_2}{p_2}$$



$$RPR_{1,2} = \frac{pp_{1,(2)}}{p_1} + \frac{pp_{(1),2}}{p_2}$$

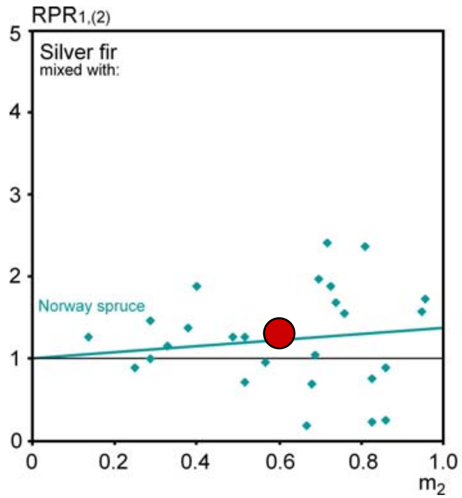
$$RPR_{1,2} = RPR_{1,(2)} \times m_1 + RPR_{(1),2} \times m_2$$

RPR depending on the admixed species and their portions: Shown for spruce, fir, beech, pine, and oak



Ratio in terms of relative productivity RPR on species level

$Species_1$	$Species_2$	sample size n	$\overline{RPR}_{1,(2)} \pm SE$	$\overline{m}_2$
Norway spruce	European beech	184	0.99 ± 0.03	0.39
	Silver fir	27	**1.13** ± 0.06	0.38
	Scots pine	12	**2.84** ± 0.42	0.72
European beech	Norway spruce	198	**1.46** ± 0.05	0.58
	Sessile oak	422	**1.17** ± 0.04	0.59
	Scots pine	33	**1.65** ± 0.12	0.39
Sessile oak	European beech	215	**1.28** ± 0.04	0.44
Scots pine	European beech	37	**1.92** ± 0.18	0.59
	Norway spruce	12	**1.88** ± 0.14	0.28
Silver fir	Norway spruce	32	**1.35** ± 0.11	0.59



Mixing reactions RPR of the two species in a stand are mostly positively correlated: Indication for mutualism

$Species_1$	$Species_2$	Pearson correlation $RPR_{1,(2)} \times RPR_{(1),2}$	sample size n	p-value
Norway spruce	E. be., S. fir, S. pine	+ 0.02	205	0.823
European beech	N. sp., S. oak, S. pine	**+ 0.13**	411	0.011
Sessile oak	E. be.	**+ 0.39**	207	0.001
Scots pine	E. be., N. sp.	**+ 0.28**	49	0.048
Silver fir	N. sp.	**+ 0.37**	32	0.036

Mixing reactions RPR of the two species in a stand are mostly positively correlated: Indication for mutualism

$Species_1$	$Species_2$	Pearson correlation	sample size n	p-value

Summary 2:

- RPR on species level mostly positive,
- level depending on species combination,
- e. g. effect of be neutral in sp, but positive in pine.

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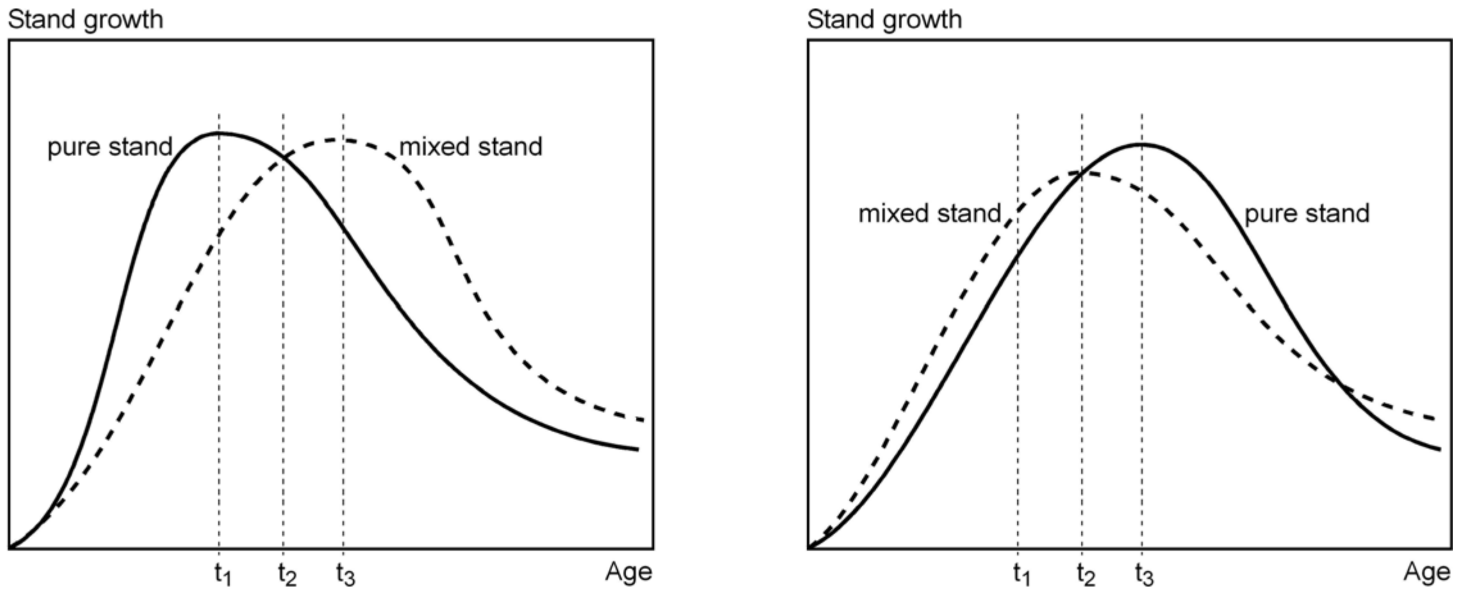
Growth curve in mixed vs. pure stands in schematic representation: slowing down (left) and acceleration (right)



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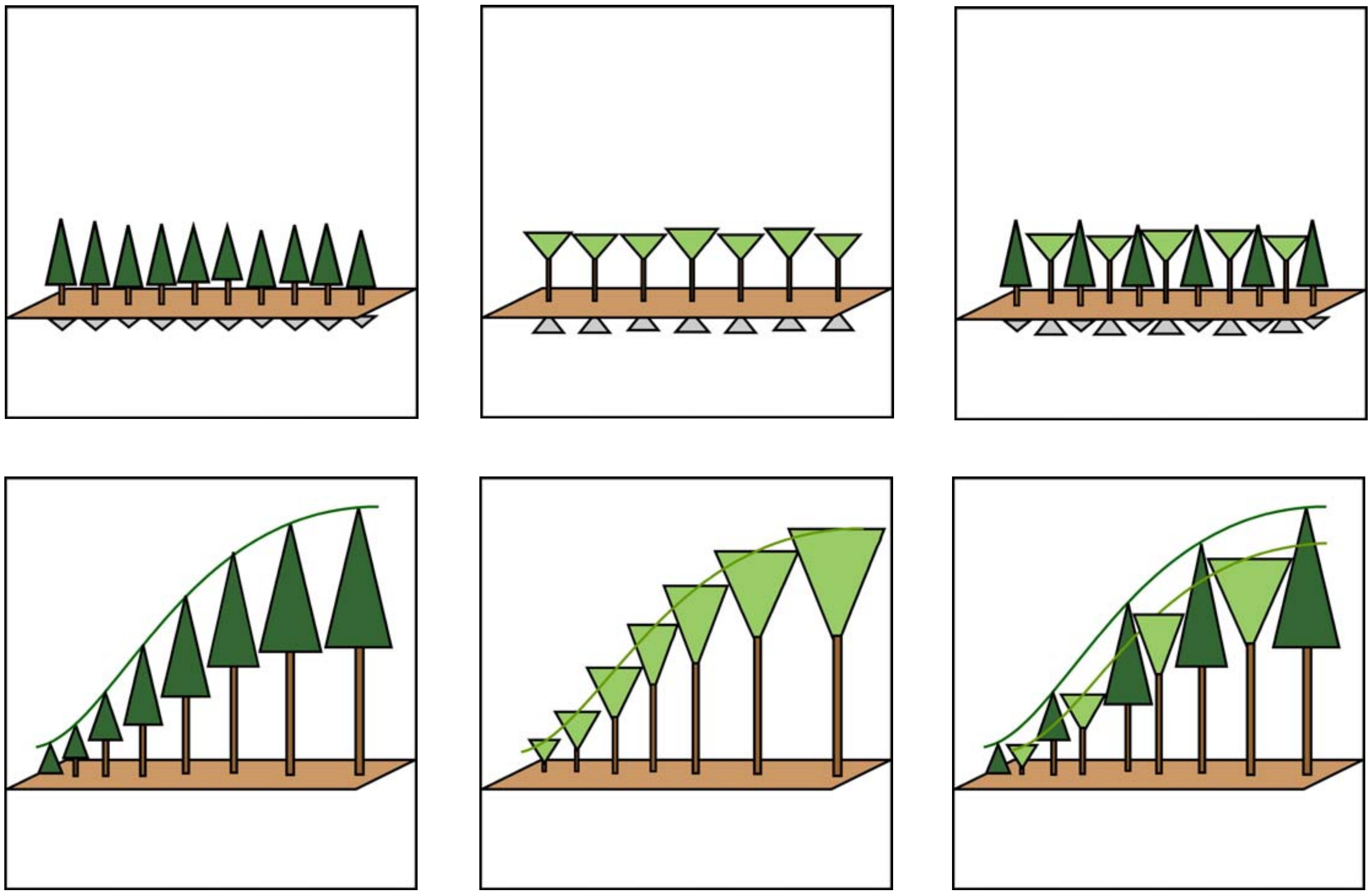
Diminishing validity of the pure reference plots for a causal analysis of mixing effects



Interspecific effect on course of growth, site index, and size development

Mischbestand: Mischbestandstafel	Umtriebszeit (Jahre)	Ertragsklasse der einzelnen Holzarten mit .... Jahren	30	60	100	120 bzw. 140	dGZ des Mischbestandes (fm)	Reinbestand: Ertragstafel	Umtriebszeit (Jahre)	Ständige Ertragsklasse	dGZ des Reinbestandes (fm)
a.											
Eiche/Buche 1939	140	Eiche	I	I	I	I	2,9	Eiche 1920	140	I	6,9
I. Ertragsklasse		Buche [1]	0,5	II,5	III,1	III,0	4,6	Buche 1931	140	I	8,9
		Summe					7,5	Buche 1931	140	II	7,4
b.											
Kiefer Fichte 1939	120	Kiefer	I	I	I	I	4,2	Kiefer 1908	120	I	7,5
I. Ertragsklasse		Fichte	III,6	II,6	II,6	II,6	4,3	Fichte 1936/42	120	I	11,9
		Summe					8,5	〃	120	II	9,3
								〃	120	III	7,4
c.											
Kiefer/Buche 1939	140	Kiefer	I	I	I	I	5,7	Kiefer 1908	140	I	7,0
I. Ertragsklasse		Buche [2]	–	III,6	III,9	III,6	2,5	Buche 1931	140	I	8,9
		Summe					8,2	〃	140	II	7,4
d.											
Fichte/Buche 1942	120	Fichte	0,9	I,1	0,9	I	8,0	Fichte 1936/42	120	I	11,9
mit gleichwüchsiger Buche		Buche	0,5	0,7	I,2	I,3	3,6	Buche 1931	120	I	8,9
		Summe					11,6	〃	120	II	7,4
I. Ertragsklasse								〃	120	III	5,6
e.											
Fichte/Buche 1942	120	Fichte	0,8	0,9	0,9	I	8,3	Fichte 1936/42	120	I	11.9
mit mattwüchsiger Buche		Buche [2]	I,3	I,8	II,2	II,4	1,6	Buche 1931	120	I	8,9
		Summe					9,9	〃	120	II	7,4
I. Ertragsklasse								〃	120	III	5,6

[1]) Verschlechterung der Ertragsklasse durch Aushieb herrschender Buchen
[2]) Schlechtes Wachstum durch übermäßige Konkurrenz der Nadelhölzer

Wiedemann, E. (1951, p 132) Ertragskundliche und waldbauliche Grundlagen der Forstwirtschaft. Frankfurt, J. D. Sauerländer's Verlag

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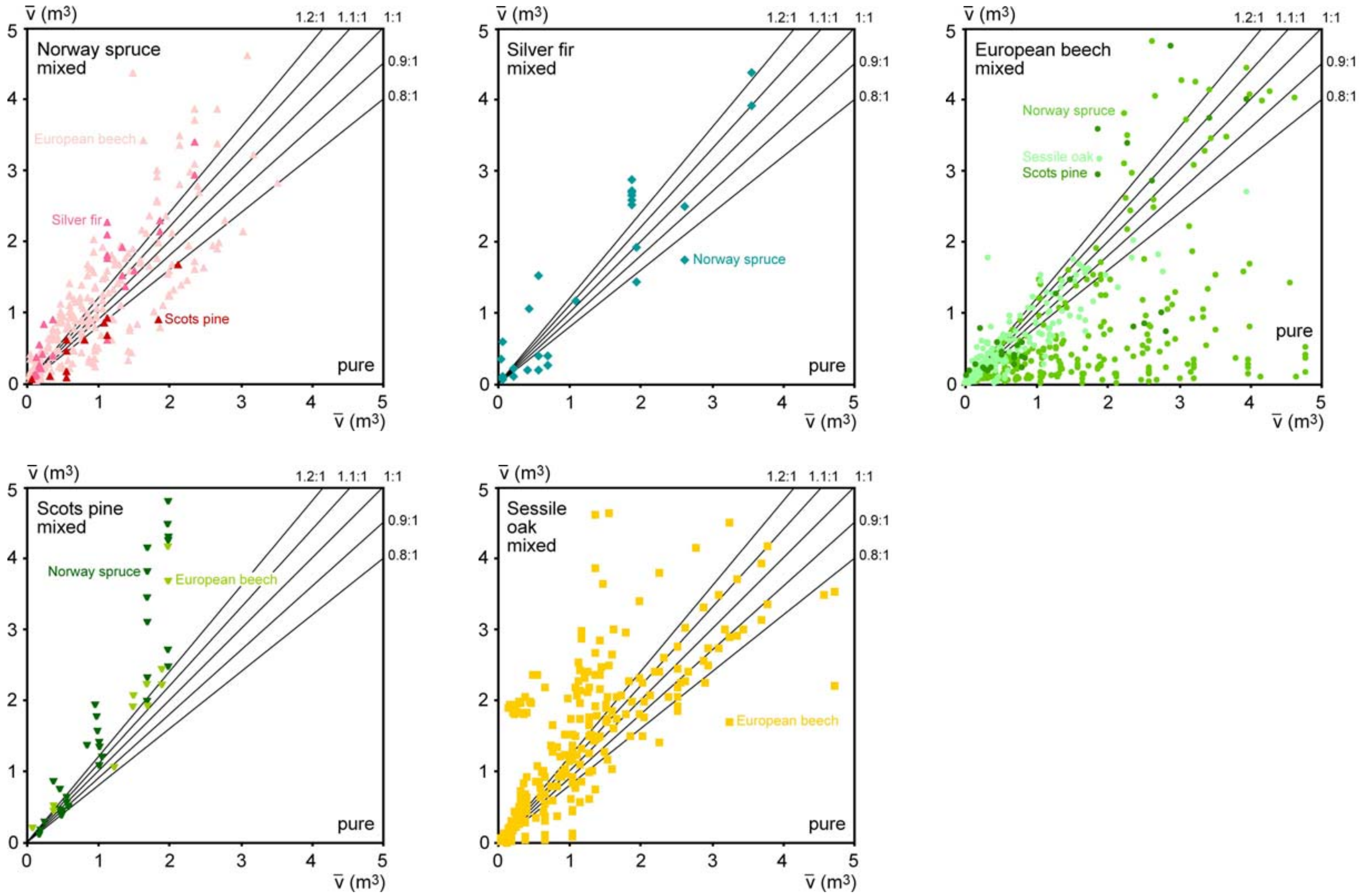
Mean tree volume in mixed versus pure stands: Shown for spruce, fir, beech, pine, and oak



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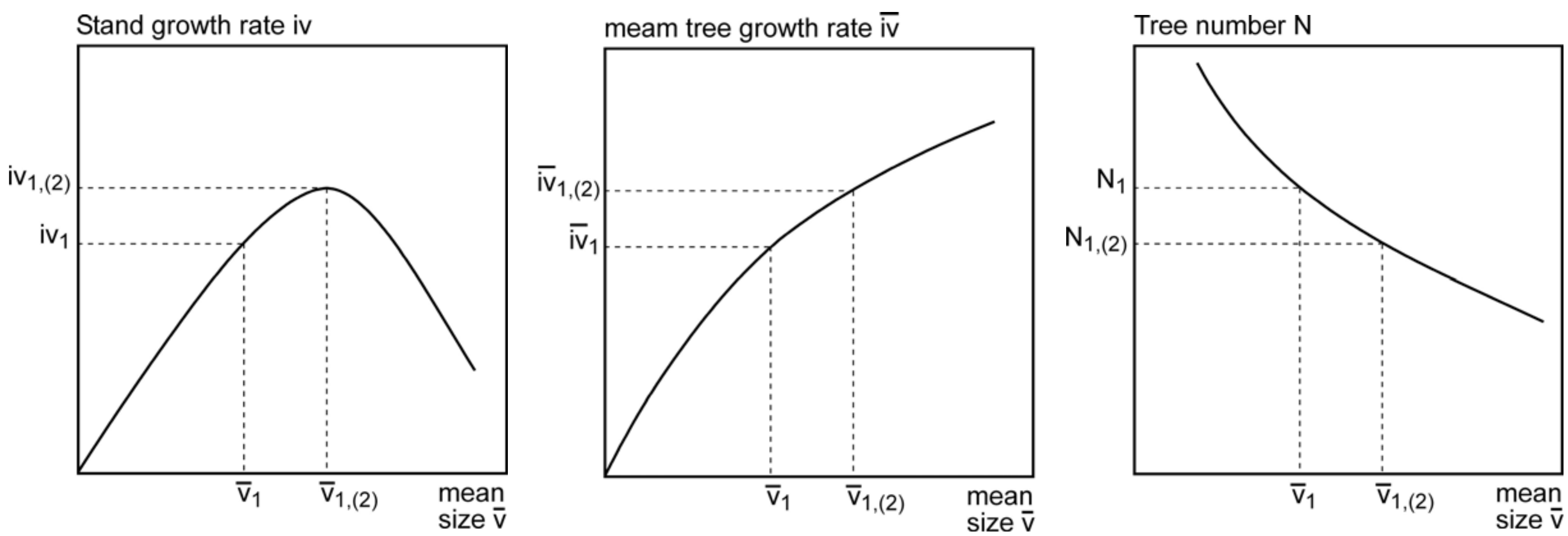
Development of stand growth, tree growth and tree number in dependence on mean tree size: The problem of included allometric drift



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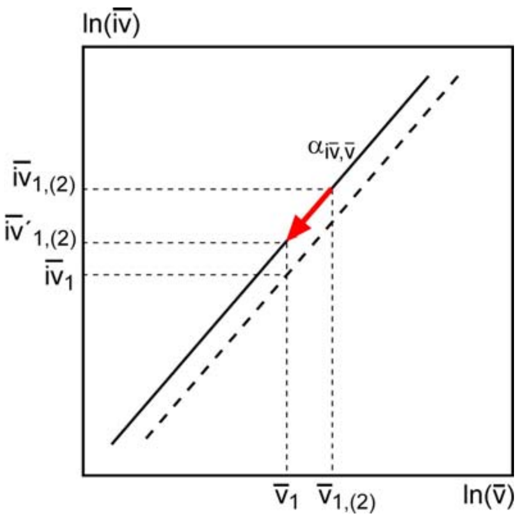
Elimination od allometric drift for comparing mixed vs. pure stand attributes



$\overline{iv} \propto \overline{v}^{\,\alpha_1}$

$\alpha_1 = 0.42, 0.61, 0.44, 0{,}59, 0.58$

for

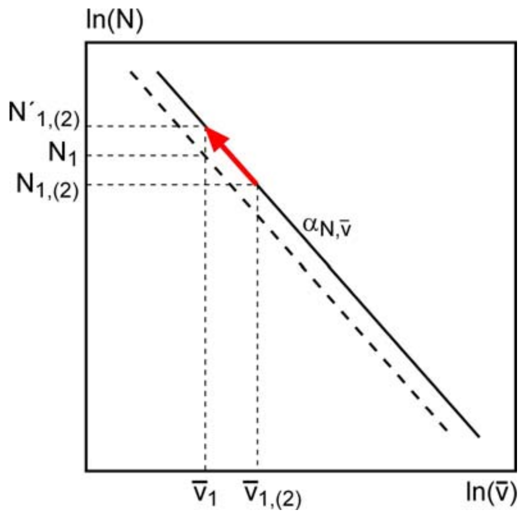
Norway spruce

Silver fir

Scots pine

Europeanbeech

Sessile/Common oak



$N \propto \overline{v}^{\,\alpha_2}$

$\alpha_2 = -0.62, -0.62, -0.68, -0.69, -0.54$

for

Norway spruce

Silver fir

Scots pine

European beech

Sessile/Common oak

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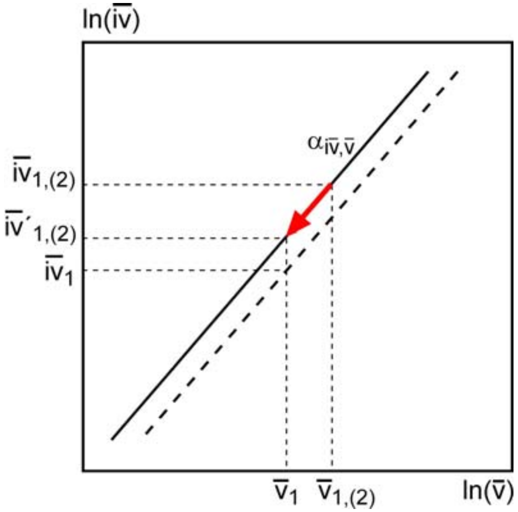
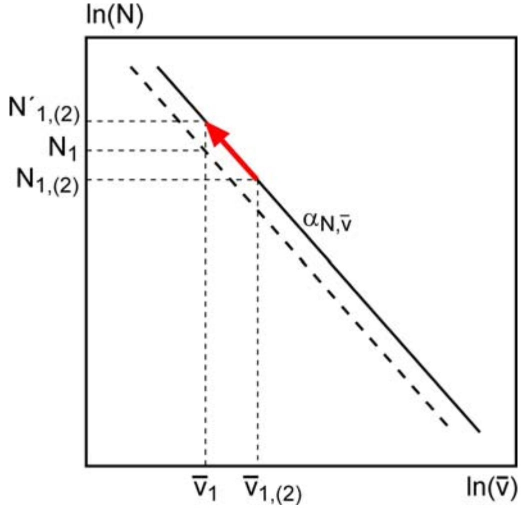
Elimination od allometric drift for comparing mixed vs. pure stand attributes





unadjusted:

$$r\overline{iv}_{1,(2)} = \frac{\overline{iv}_{1,(2)}}{\overline{iv}_1}$$

$$rN_{1,(2)} = \frac{N_{1,(2)}}{N_1}$$

$$riv_{1,(2)} = iv_{1,(2)} / iv_1$$

adjusted:

$$r\overline{iv}'_{1,(2)} = \frac{\overline{iv}'_{1,(2)}}{\overline{iv}_1} \qquad \overline{iv}'_{1,(2)} = \overline{iv}^{obs}_{1,(2)} \times \left(\frac{\bar{v}_1}{\bar{v}_{1,(2)}}\right)^{\alpha_2}$$

$$rN'_{1,(2)} = \frac{N'_{1,(2)}}{N_1} \qquad N'_{1,(2)} = N^{obs}_{1,(2)} \times \left(\frac{\bar{v}_1}{\bar{v}_{1,(2)}}\right)^{\alpha_1}$$

$$riv'_{1,(2)} = N^{obs}_{1,(2)} \times \overline{iv}^{obs}_{1,(2)} \times (\bar{v}_1 / \bar{v}_{1,(2)})^{\alpha_1+\alpha_2} \Big/ iv_1$$

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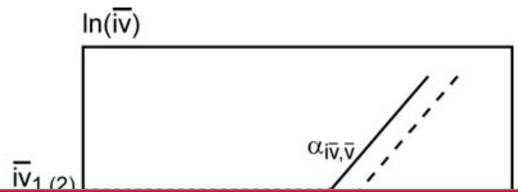
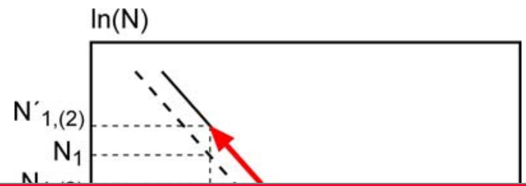
Elimination od allometric drift for comparing mixed vs. pure stand attributes





Summary 3:

- descriptive vs. causal analysis of mixing effects,
- size effect should be separated from mixing effects,
- allometric theory provides methods for adjustment.

unadjusted:

$$r\overline{iv}_{1,(2)} = \frac{\overline{iv}_{1,(2)}}{\overline{iv}_1}$$

$$rN_{1,(2)} = \frac{N_{1,(2)}}{N_1}$$

$$riv_{1,(2)} = iv_{1,(2)} / iv_1$$

adjusted:

$$r\overline{iv}'_{1,(2)} = \frac{\overline{iv}'_{1,(2)}}{\overline{iv}_1} \qquad \overline{iv}'_{1,(2)} = \overline{iv}^{obs}_{1,(2)} \times \left(\frac{\overline{v}_1}{\overline{v}_{1,(2)}}\right)^{\alpha_2}$$

$$rN'_{1,(2)} = \frac{N'_{1,(2)}}{N_1} \qquad N'_{1,(2)} = N^{obs}_{1,(2)} \times \left(\frac{\overline{v}_1}{\overline{v}_{1,(2)}}\right)^{\alpha_1}$$

$$riv'_{1,(2)} = N^{obs}_{1,(2)} \times \overline{iv}^{obs}_{1,(2)} \times (\overline{v}_1 / \overline{v}_{1,(2)})^{\alpha_1+\alpha_2} \Big/ iv_1$$

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Use of the allometric adjusted productivities for further analysis of mixing effects

$$rN'_{1,(2)} = N'_{1,(2)} \big/ N_1$$

$$r\overline{p}'_{1,(2)} = \overline{p}'_{1,(2)} \big/ \overline{p}_{\,1}$$

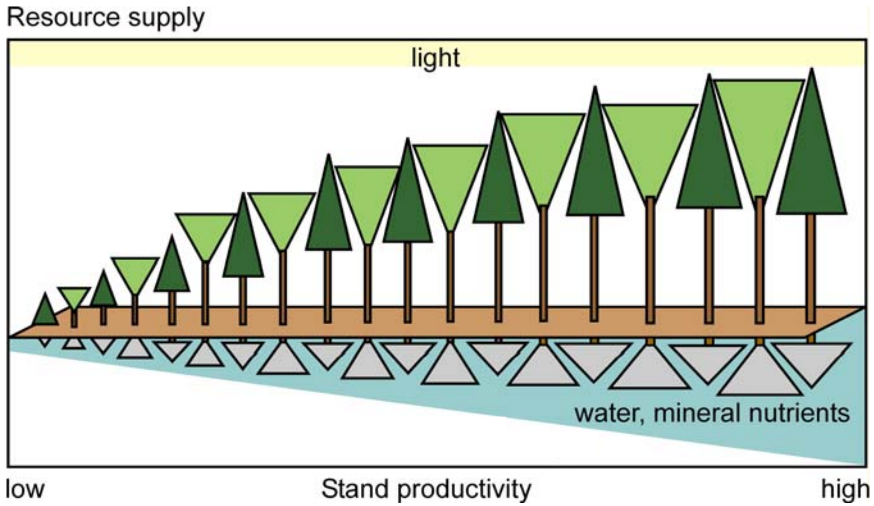
$$rp'_{1,(2)} = rN'_{1,(2)} \times r\overline{p}'_{1,(2)}$$

$$rp'_{1,2} = rp'_{1,(2)} \times m_1 + rp'_{(1),2} \times m_2$$

Over- and underyielding on species level depending on covariates

Target species sp_1 Admixed species sp_2, sp_3, sp_4	**N. spruce** S. fir, E. be S. pine	**E. beech** S. oak, N. sp, S. pine	**S. oak** E. be	**S. pine** N. sp, S. pine	**S. fir** N. sp
$rp'_{1,(2)}$					
intercept	1.54	-0.03	1.84	4.45	3.30
m_2	0.88	1.42	-0.33	-1.82	1.02
hq_1	-	0.02	0.02	-	-
hq_1/hq_2	-	1.01	-	-	-
site index sp_1	-0.03	-0.31	-0.03	-0.07	-0.10
dummy sp_3	0.10	0.33	-	0.32	-
dummy sp_4	1.19	0.60	-	-	-
n total	223	648	215	49	32
whole model R^2	0.38	0.18	0.14	0.24	0.42

Site dependeny of mixing effects: the poorer the site conditions the higher the benefit from mixing



facilitation ↔ competition

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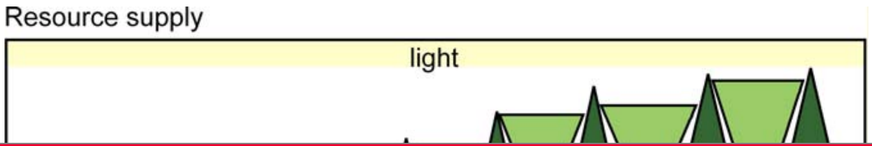
Site dependeny of mixing effects: the poorer the site conditions the higher the benefit from mixing



Summary 4:

- causal analysis based on adjusted productivity,
- species specific covariables,
- SGH: the poorer the stronger the mixing effect.

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TECHNISCHE UNIVERSITÄT MÜNCHEN

Analyzing mixing effects on forest stand level

Hans Pretzsch
Chair for Forest Growth and Yield Science
Technische Universität München

1 Mixed vs. pure on total stand level

2 Analyses on species level

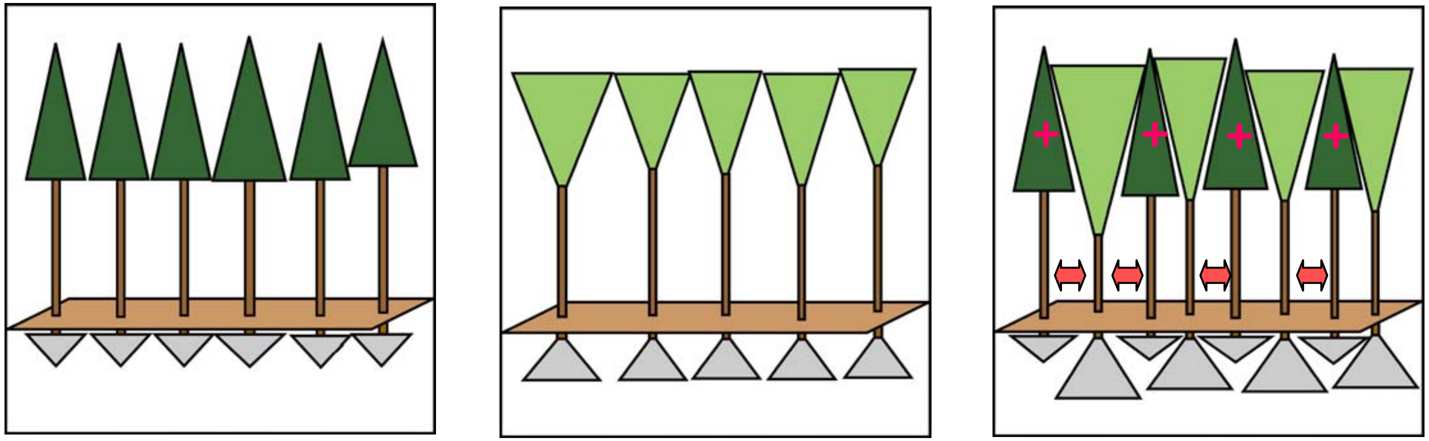
3 Allometric correction before causal analysis

4 Covariance analysis on species level

5 Components: Density, mean tree productivity

Lecture given on March 12th, 2012 at SLU, Alnarp, Sweden

Analyzing the components of mixing effects: Change in stand density and/or growth of trees



⇔ Change in stand density → higher/lower carrying capacity → **indicates change in resource supply or resource capture**. Usage requires adaptation of stand density management (e.g., SDMD).

\+ Change in growth of mean tree → slower/faster growth → **indicates change in resource use efficiency**. Usage requires adaptation in thinning intensity (e.g., return intervals).

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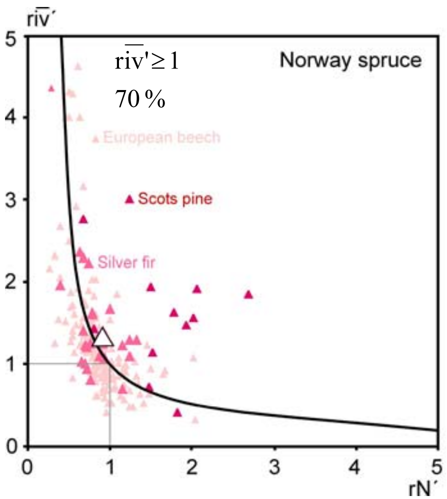
Effect of mixing on stand density rN' and mean tree volume growth $\overline{riv}$' of Norway spruce and European beech

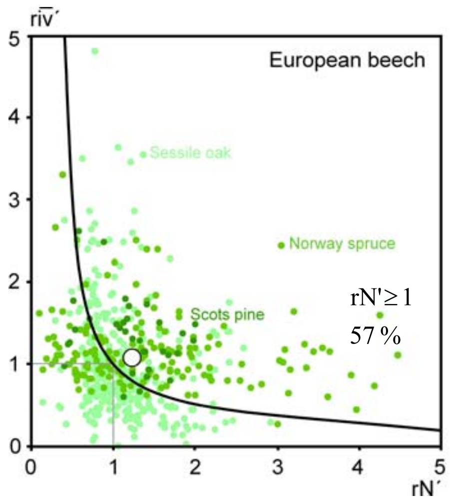
$$riv' = \overline{riv}' \times rN'$$



Norway spruce

$rN' = 0.92$

$\overline{riv}' = 1.32$



European beech

$rN' = 1.23$

$\overline{riv}' = 1.09$

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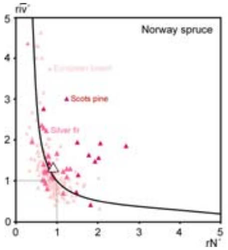
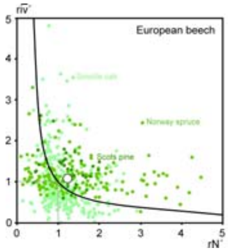
Density and productivity effects: Correlation with selected covariates



Norway spruce

Variable n=223	$rN'_{1,(2)}$	$r\bar{p}'_{1,(2)}$	site index sp_1	$h_q\ sp_1$	$h_q\ sp_1/h_q\ sp_2$	m_2
$rN'_{1,(2)}$	1	-0.355**	-0.052	-0.020	-0.491**	+0.412**
$r\bar{p}'_{1,(2)}$	-0.355**	1	-0.259**	-0.150*	-0.004	+0.175**

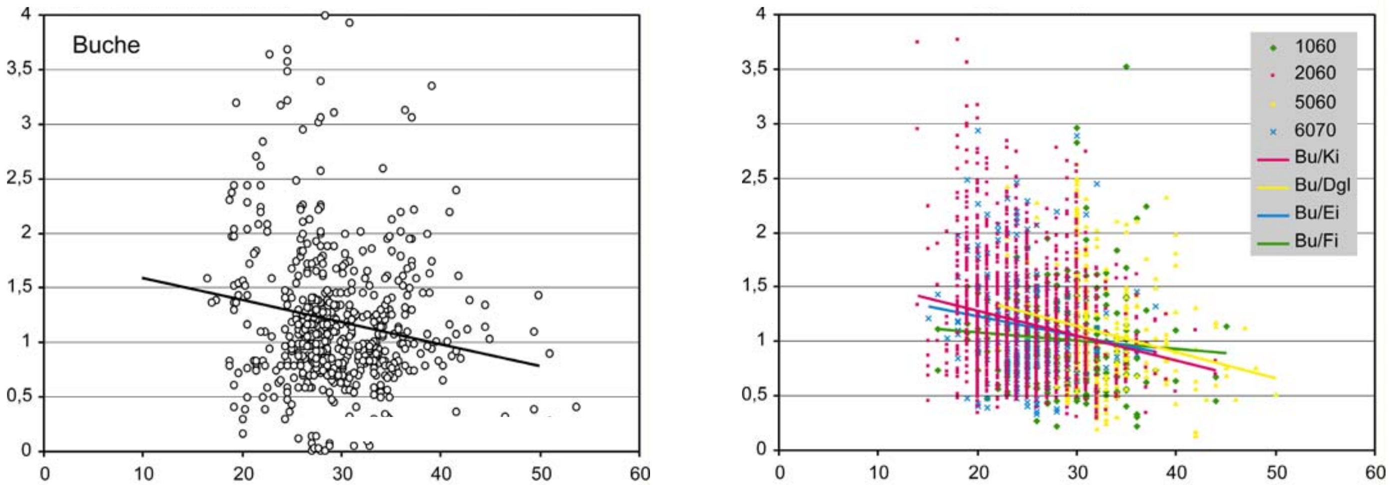


European beech

Variable n=652	$rN'_{1,(2)}$	$r\bar{p}'_{1,(2)}$	site index sp_1	$h_q\ sp_1$	$h_q\ sp_1/h_q\ sp_2$	m_2
$rN'_{1,(2)}$	1	-0.185**	-0.170**	-0.036	-0.042	+0.186**
$r\bar{p}'_{1,(2)}$	-0.185**	1	-0.056	+0.184**	+0.110**	+0.037

Relative stand density over site index for beech with different interspecific competition: left: long-terms plots - right: inventory plots

Relative stand density



Site index (dominant height in meters at age 100)

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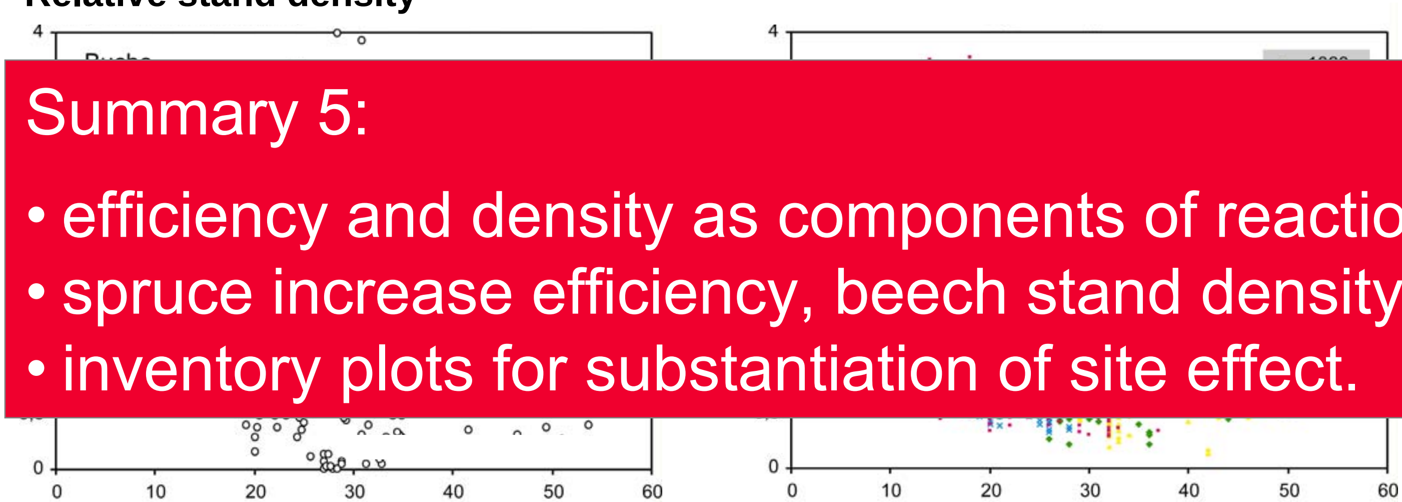
Relative stand density over site index for beech with different interspecific competition: left: long-terms plots - right: inventory plots

Relative stand density



Summary 5:

- efficiency and density as components of reaction,
- spruce increase efficiency, beech stand density,
- inventory plots for substantiation of site effect.

Site index (dominant height in meters at age 100)

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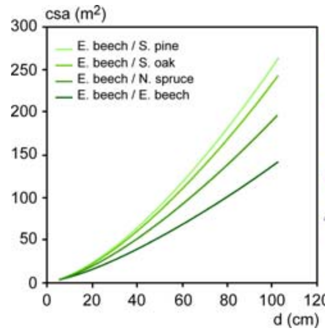
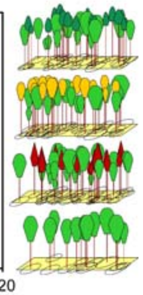
Summary

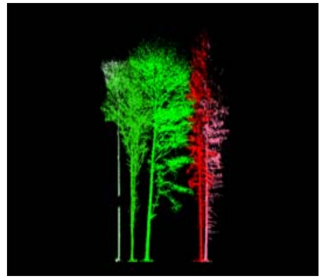
- *Overyielding of mixed versus pure stands on average; wide variation around this mean trend.*
- *The extent of a species benefit/loss depends mainly on the admixed species.*
- *Causal analyses require allometric adjustment when mixed and pure stands differ in mean tree size.*
- *Decrease of overyielding from poor to fertile sites as general trend (SGH).*
- *Change in density (e.g., beech) or efficiency (e.g., spruce) as species-specific strategies of coping with mixing.*

Conclusions and Perspective

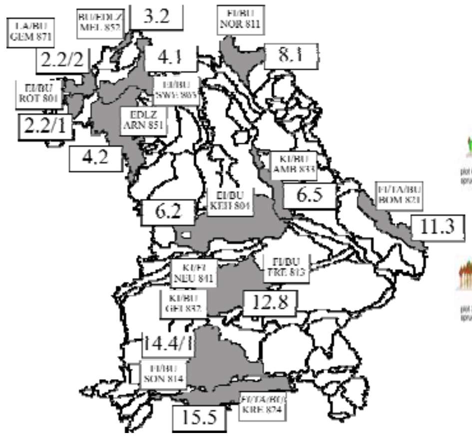
- *Tracing of mixing effects from stand to tree to branch to leaf level.*

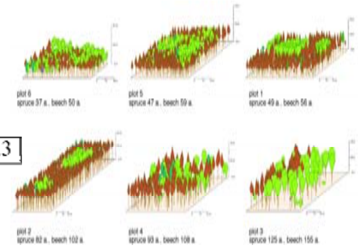




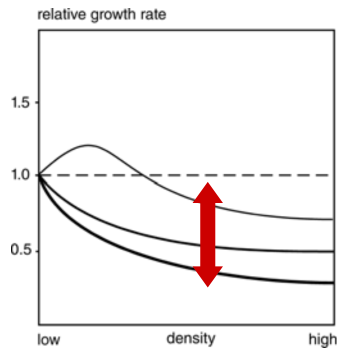


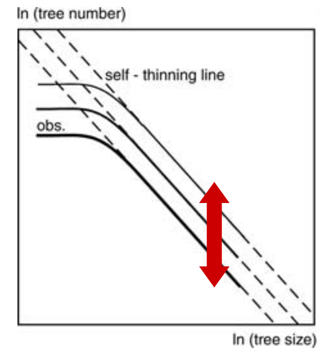
- *Analyses along ecological gradients.*





- *Improved integration of mixing effects in models*



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