Waldwachstum Systemanalyse

TECHNISCHE UNIVERSITÄT MÜNCHEN

Growth and yield of mixed-species versus pure forest stands

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

Seminar held on June 6th, 2013 at the University of Palencia, Spain

Fotos: Leonhard Steinacker

Criteria and indicators for sustainable forest management. Helsinki 1993, Lisbon 1998, Vienna 2003, Warsaw 2007

Criteria for sustainable forest management	Indicators
Forest resources	timber resources, area of forest, extension of area
Health and vitality	stability, fitness, elasticity
Productive functions	growth, yield, net return
Biological diversity	habitat quality, richness flora/fauna, conservation
Protective functions	soil, water, climate, noise, protection
Socio-economic functions	employment, recreation, esthetics, proximity to nature

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Growth and yield of mixed-species versus pure forest stands

1 Introduction: Experimental set-up, data, evaluation

2 Overview of mixing effects in temperate forests

3 Spatial and temporal variation of mixing effects

4 Effects on stand density or tree growth efficiency

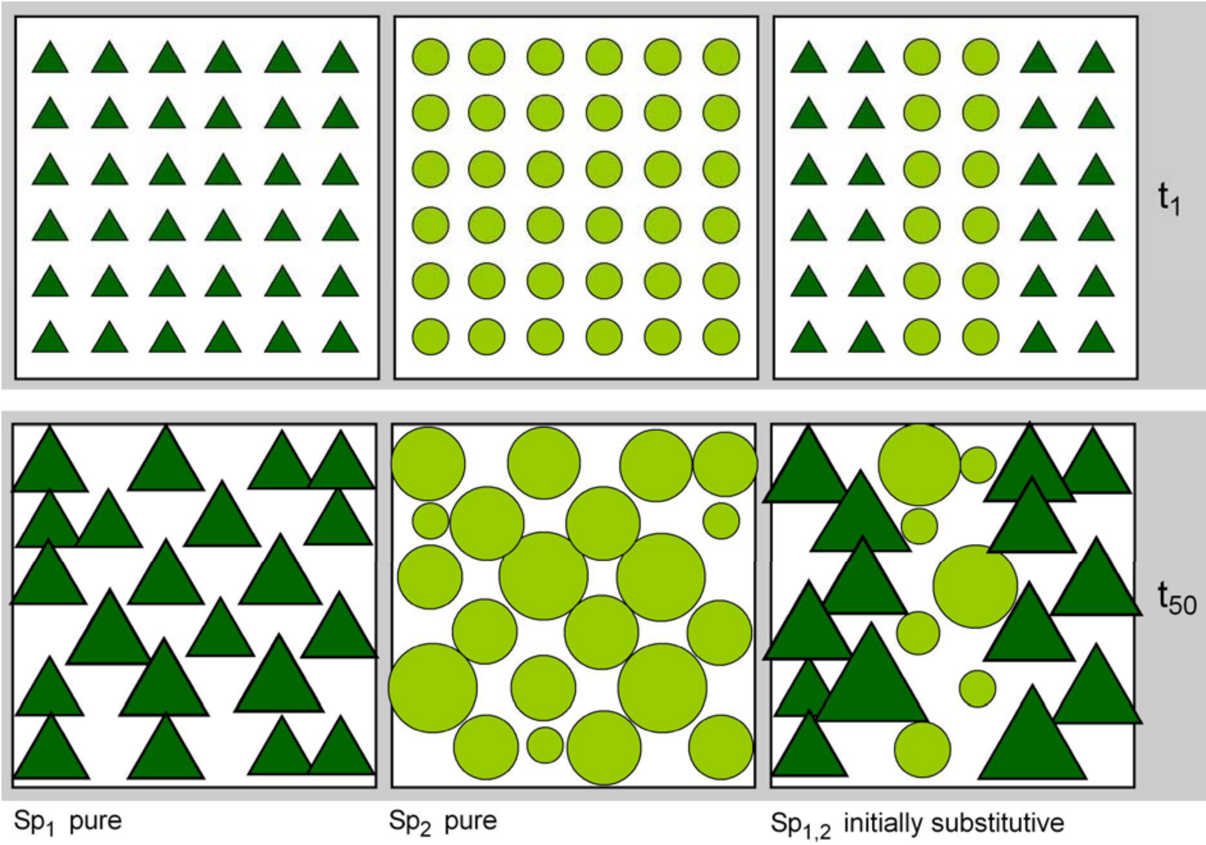
5 Tracing mixing effects from stand to tree level

Summary and perspective

Seminar held on June 6th, 2013 at the University of Palencia, Spain

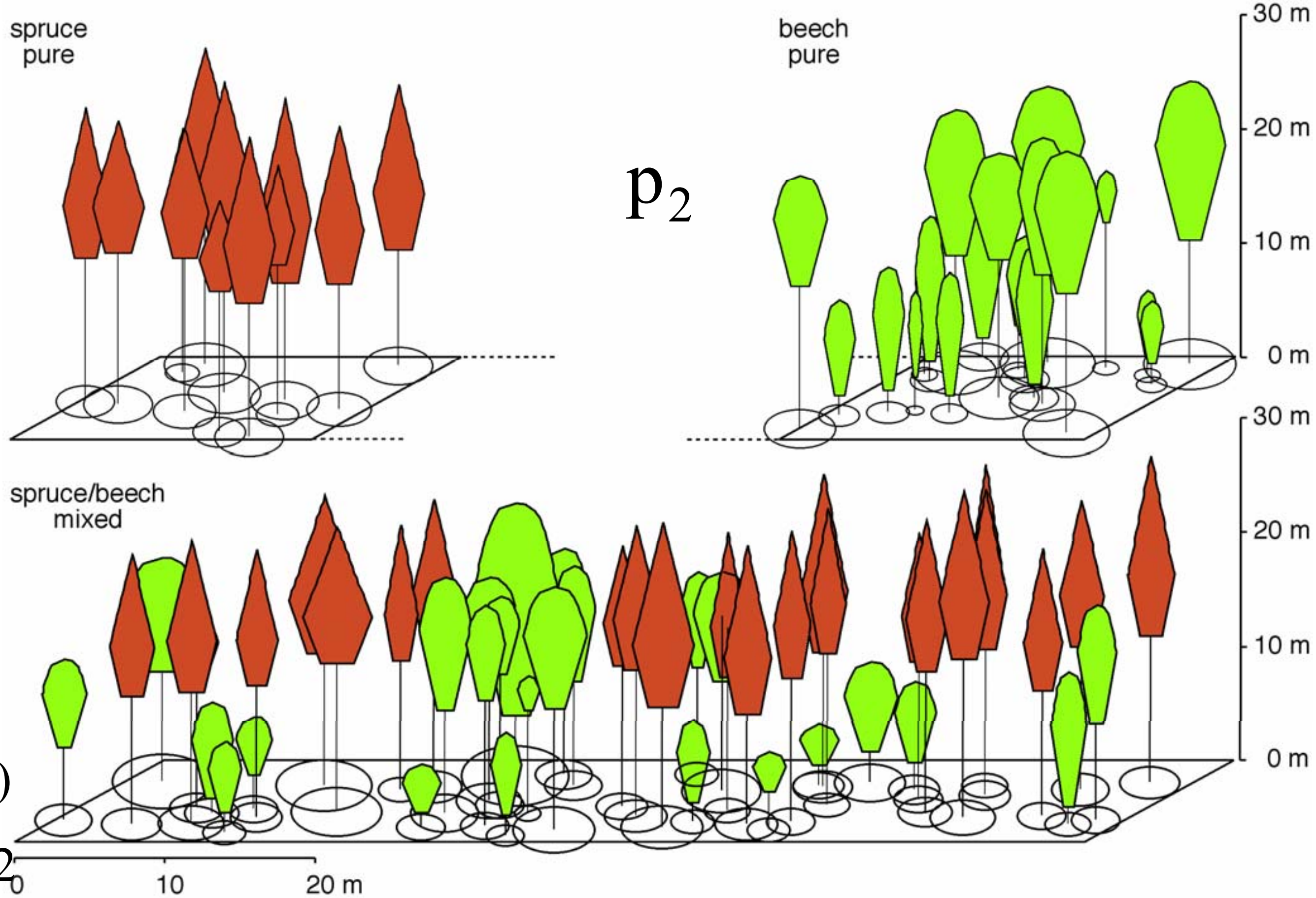
Growth and yield of mixed-species versus pure forest stands

1 Experimental set-up, data, evaluation substitutive resp. initially substitutive design



1 Experimental set-up, data, evaluation

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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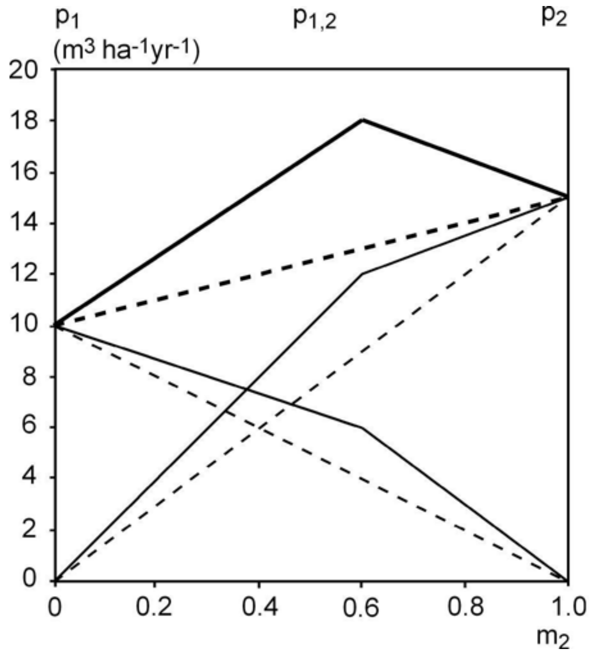
1 Experimental set-up, data, evaluation ratio of productivity in terms of absolute performance



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

$$RPA_{1,(2)} = pp_{1,(2)} / m_1 / p_1$$

$$RPA_{(1),2} = pp_{(1),2} / m_2 / p_2$$

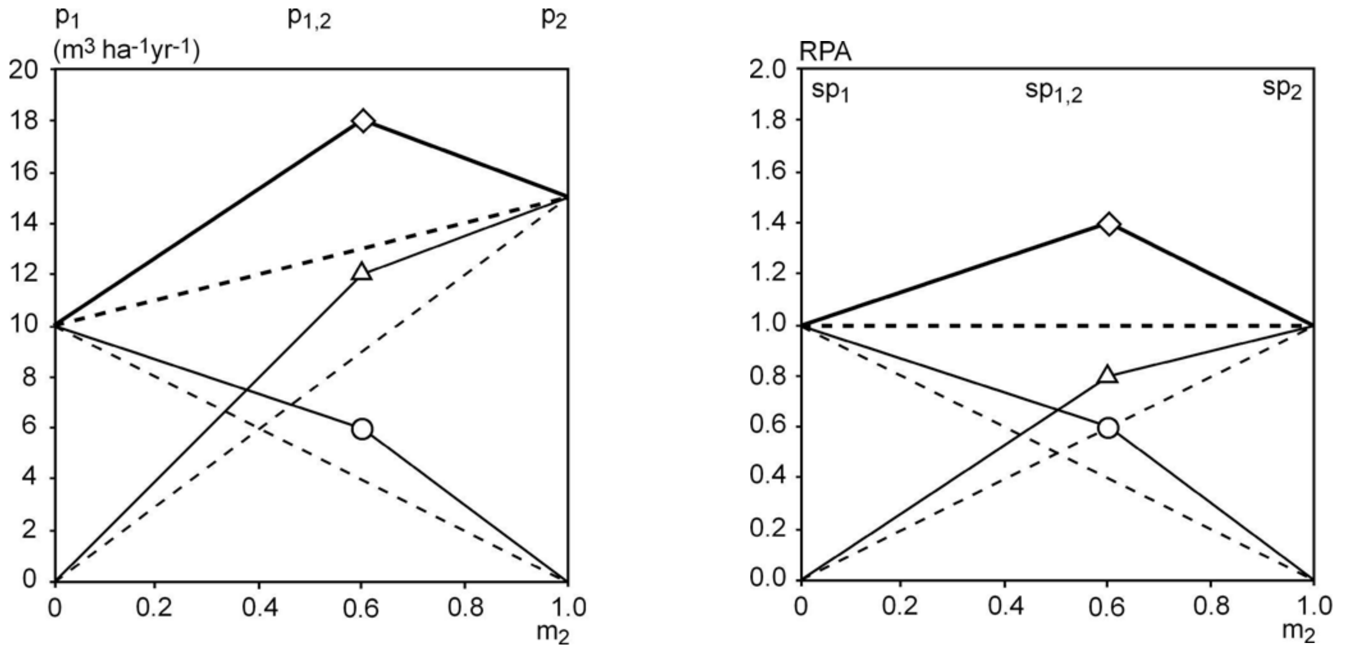
productivity in the mixed stand : $pp_{(1),2}, pp_{1,(2)}$, mit $p_{1,2} = pp_{(1),2} + pp_{1,(2)}$

mixing proportions : m_1, m_2

productivity of pure stands : p_1, p_2

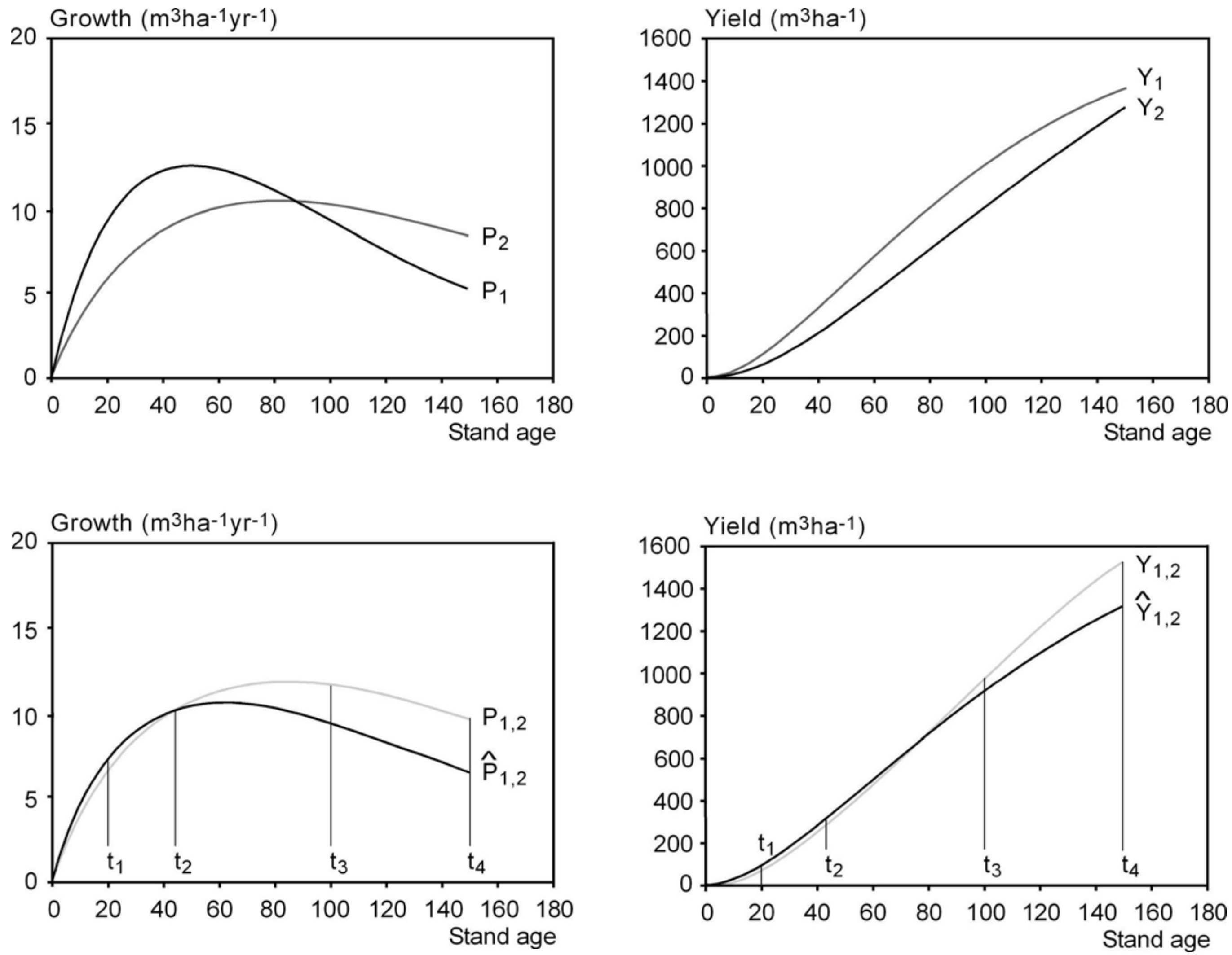
Pretzsch, H., Block, J., Dieler, J., Dong, P. H., Kohnle, U., Nagel, J., Spellmann, H., and Zingg, A. (2010): Comparison between the productivity of pure and mixed stands of Norway spruce and European beech along an ecological gradient. Annals of Forest Science, 67, DOI:10.1051/forest/2010037

1 Experimental set-up, data, evaluation cross diagrams: productivity (left) and ratio of productivity (right)

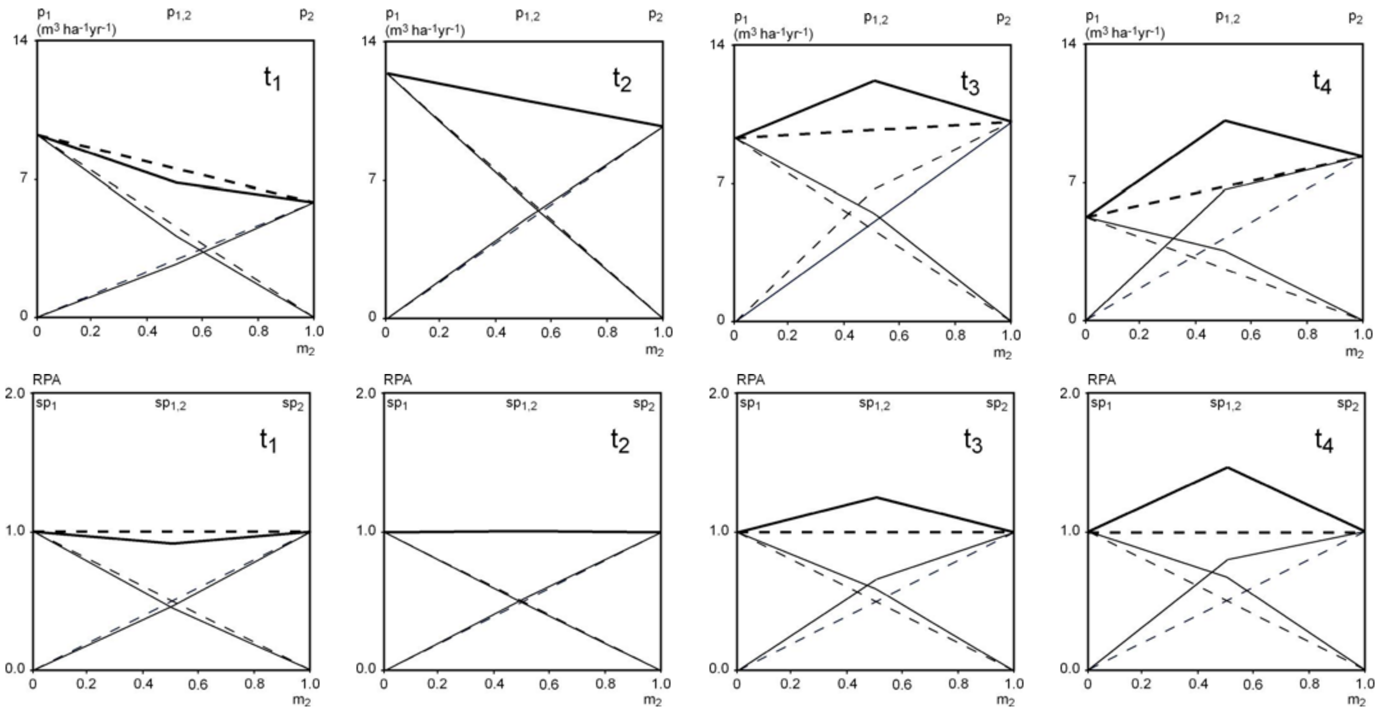


Pretzsch, H., Block, J., Dieler, J., Dong, P. H., Kohnle, U., Nagel, J., Spellmann, H., and Zingg, A. (2010): Comparison between the productivity of pure and mixed stands of Norway spruce and European beech along an ecological gradient. Annals of Forest Science, 67, DOI:10.1051/forest/2010037

1 Experimental set-up, data, evaluation



1 Experimental set-up, data, evaluation variation of mixing effects during stand development



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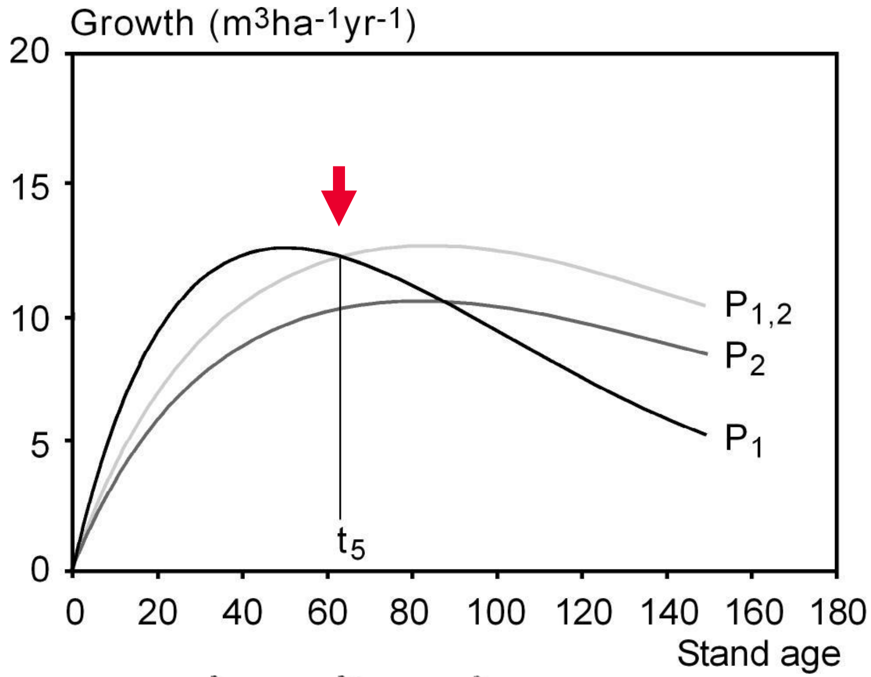
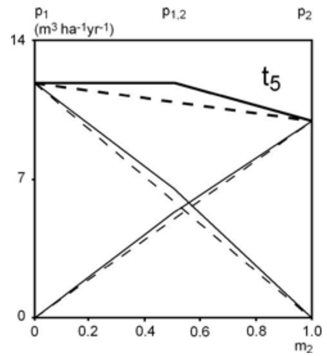
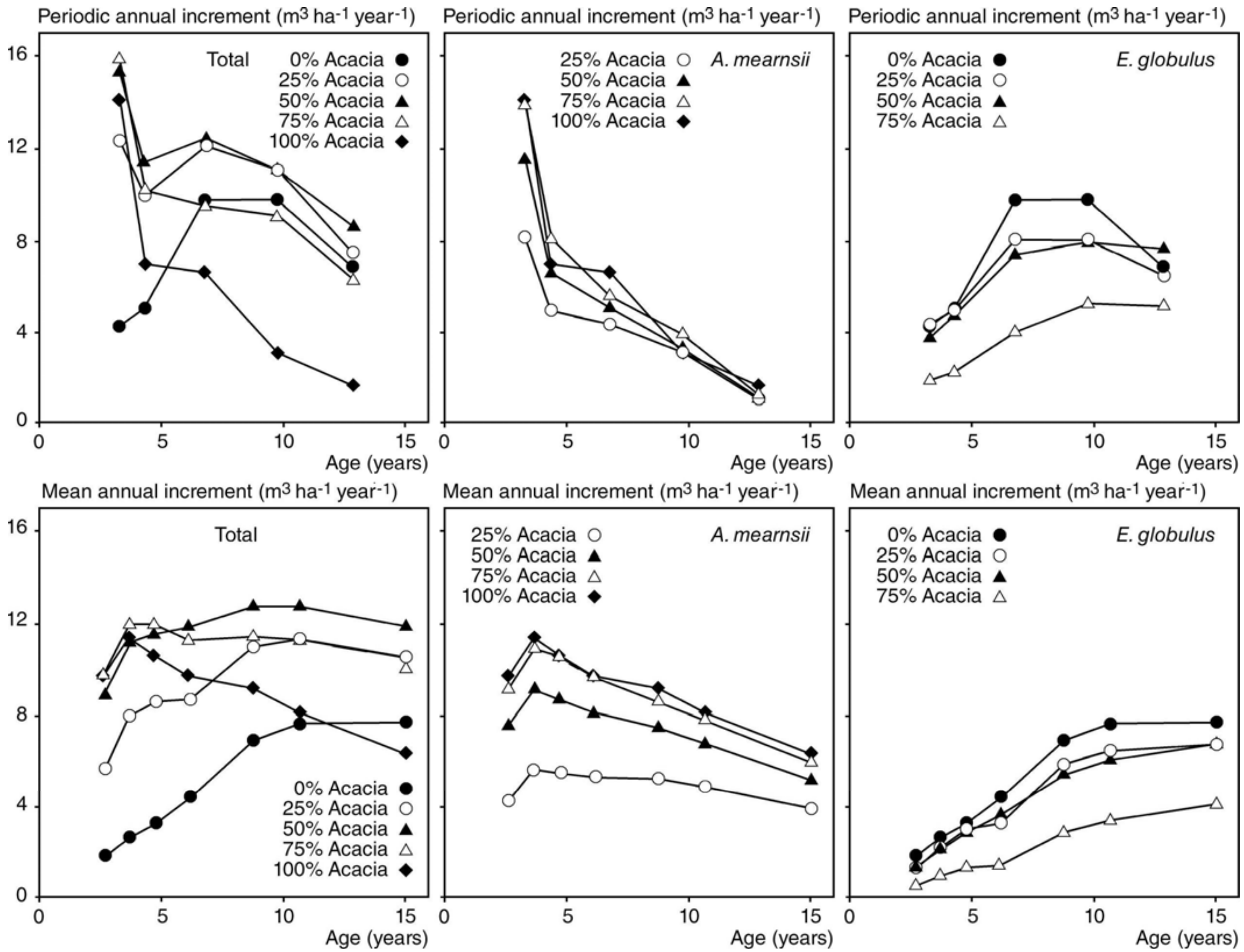
1 Experimental set-up, data, evaluation overyielding, transgressive overyielding



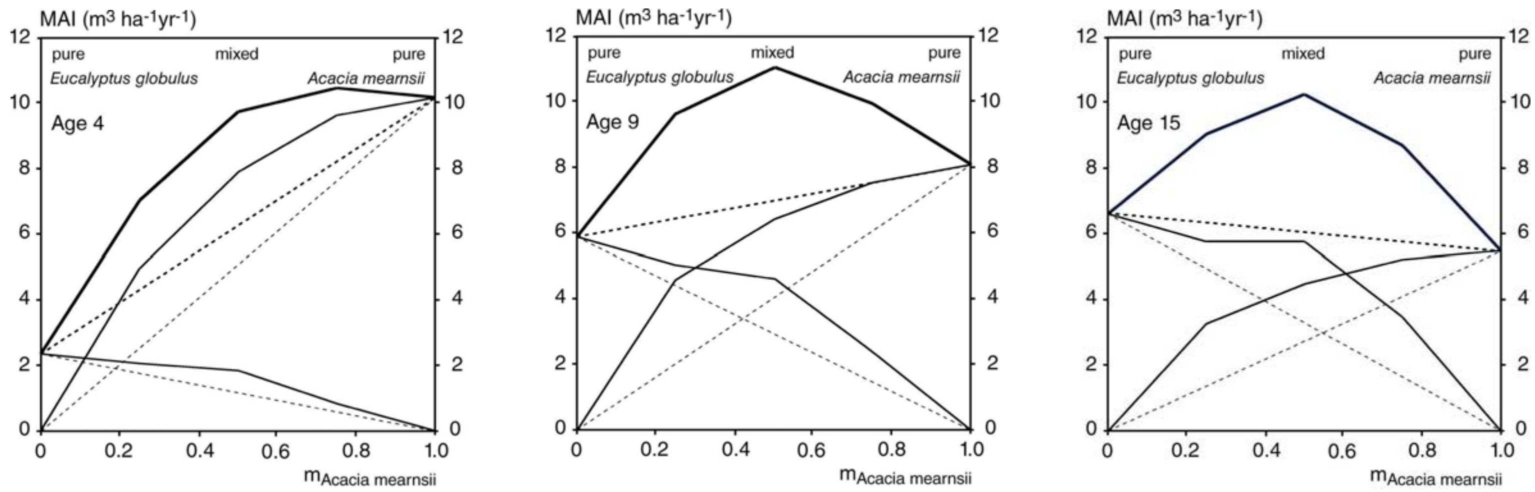


1 Experimental set-up, data, evaluation



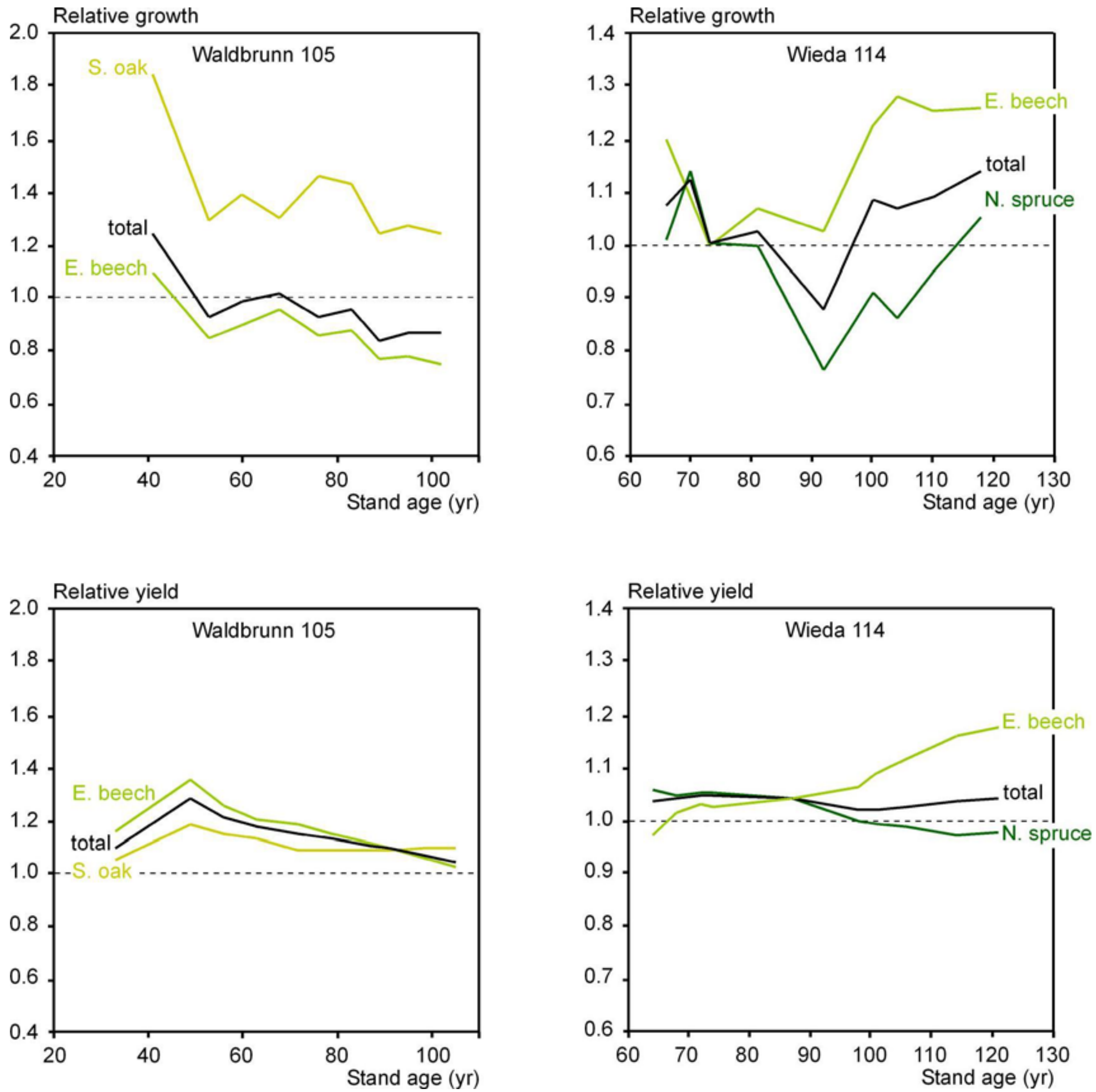
Forrester et al. (2006) Mixed-species plantations of *Eucalyptus* …, Forest Ecology and Management 233:211-230
Forrester, unpublished data from Cann River Exp., precip. 850 mm yr^{-1}, mean temp. 14.4 °C, Southeastern Australia

1 Experimental set-up, data, evaluation



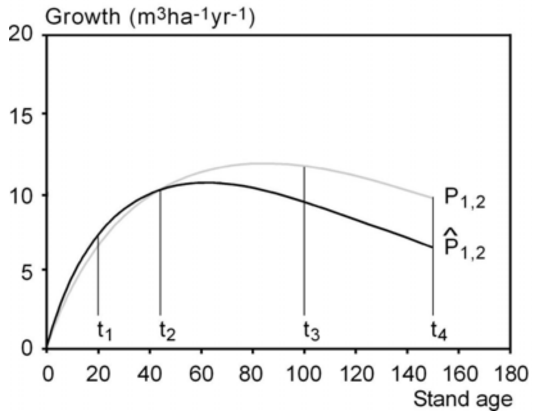
Forrester et al. (2006) Mixed-species plantations of *Eucalyptus* …, Forest Ecology and Management 233:211-230
Forrester, unpublished data from Cann River Exp., precip. 850 mm yr^{-1}, mean temp. 14.4 °C, Southeastern Australia

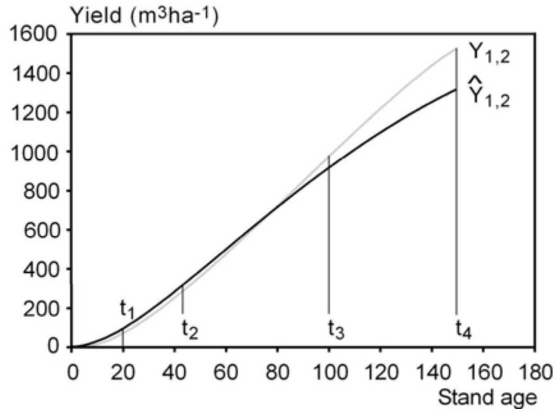
1 Experimental set-up, data, evaluation
Survey over 50-100 years as exception



1 Experimental set-up, data, evaluation growth versus yield for evaluation

Trial	Age first - last survey year	sur-veys n	Relative growth RPA					Relative total yield RYA			
		n	mean	min	age	max	age	final	age	min	max
WAB 105											
S. oak	33-105	10	1.38	1.24	105	1.84	49	1.10	105	1.05	1.18
E. beech	33-105	10	0.87	0.75	105	1.10	49	1.02	105	1.02	1.35
total	33-105	10	0.95	0.84	91	1.24	49	1.04	105	1.04	1.28
WAB 106											
S. oak	44-116	10	1.04	0.92	60	1.20	109	0.92	116	0.81	0.92
E. beech	44-116	10	0.85	0.76	102	0.95	60	0.96	116	0.96	1.14
total	44-116	10	0.92	0.85	102	0.95	116	0.94	116	0.94	0.95
WIE 114											
N. spruce	46-103	10	0.96	0.76	80	1.14	54	0.97	103	0.97	1.05
E. beech	64-121	10	1.16	1.00	74	1.28	106	1.17	121	0.97	1.17
total		10	1.05	0.88	98	1.14	121	1.04	121	1.02	1.05
MIT 101											
N. spruce	50-123	7	1.03	0.86	57	1.60	123	0.92	123	0.92	1.05
E. beech	50-123	7	1.01	0.91	57	1.08	69	1.32	123	1.06	1.34
total	50-123	7	0.98	0.88	57	1.07	117	1.14	123	1.05	1.14
ZWI 111/1											
N. spruce	59-113	9	1.01	0.79	74	1.43	102	1.03	113	1.02	1.12
E. beech	78-132	9	1.14	0.97	93	1.42	111	1.11	132	1.07	1.12
total		9	1.05	0.85	74	1.35	102	1.06	132	1.03	1.12





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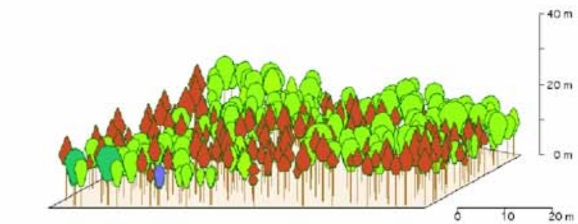
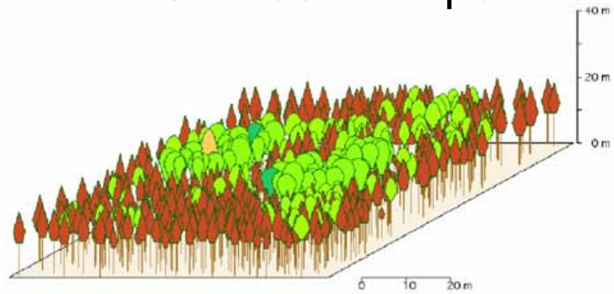
1 Artificial age series FRE 813 in mixed Norway spruce and European beech stands

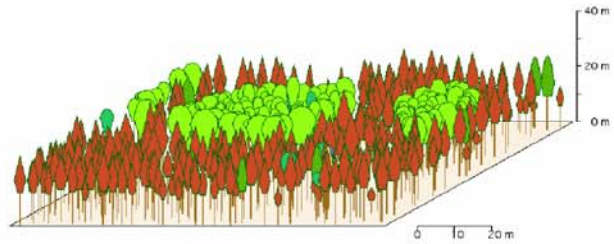
(plot 1 = SFB 607 - Experiment)



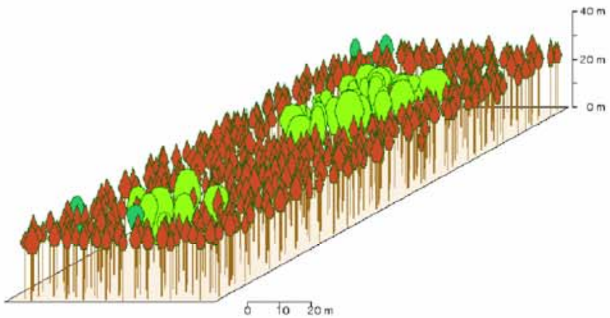
plot 6
spruce 37 a., beech 50 a.



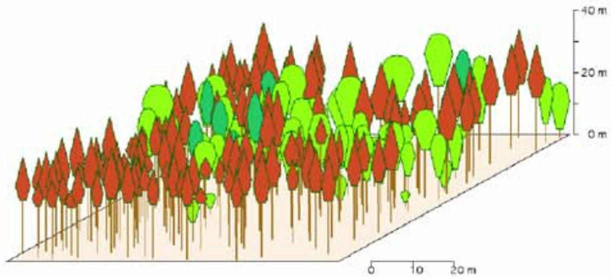
plot 5
spruce 47 a., beech 59 a.



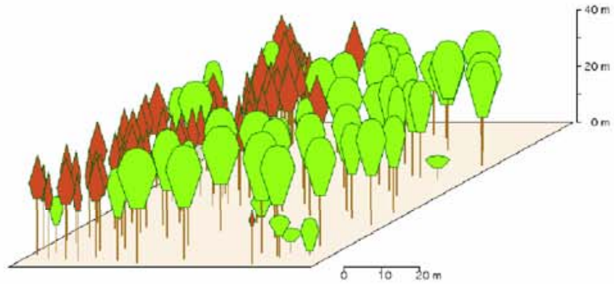
plot 1
spruce 49 a., beech 56 a.



plot 2
spruce 82 a., beech 102 a.

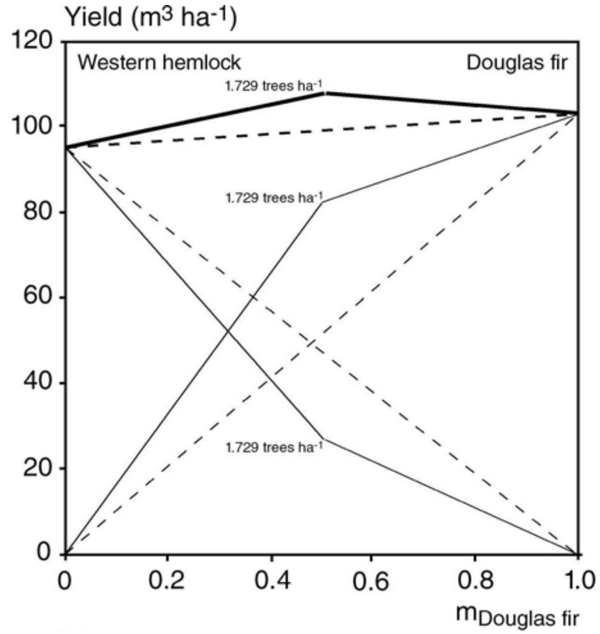


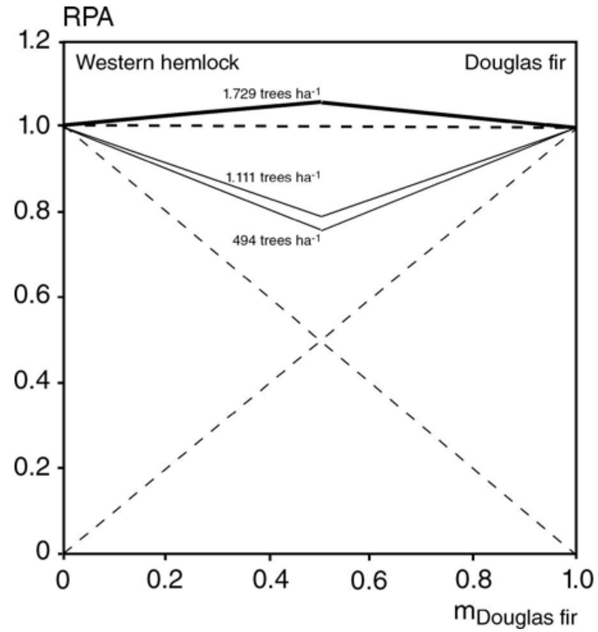
plot 4
spruce 93 a., beech 108 a.



plot 3
spruce 125 a., beech 155 a.

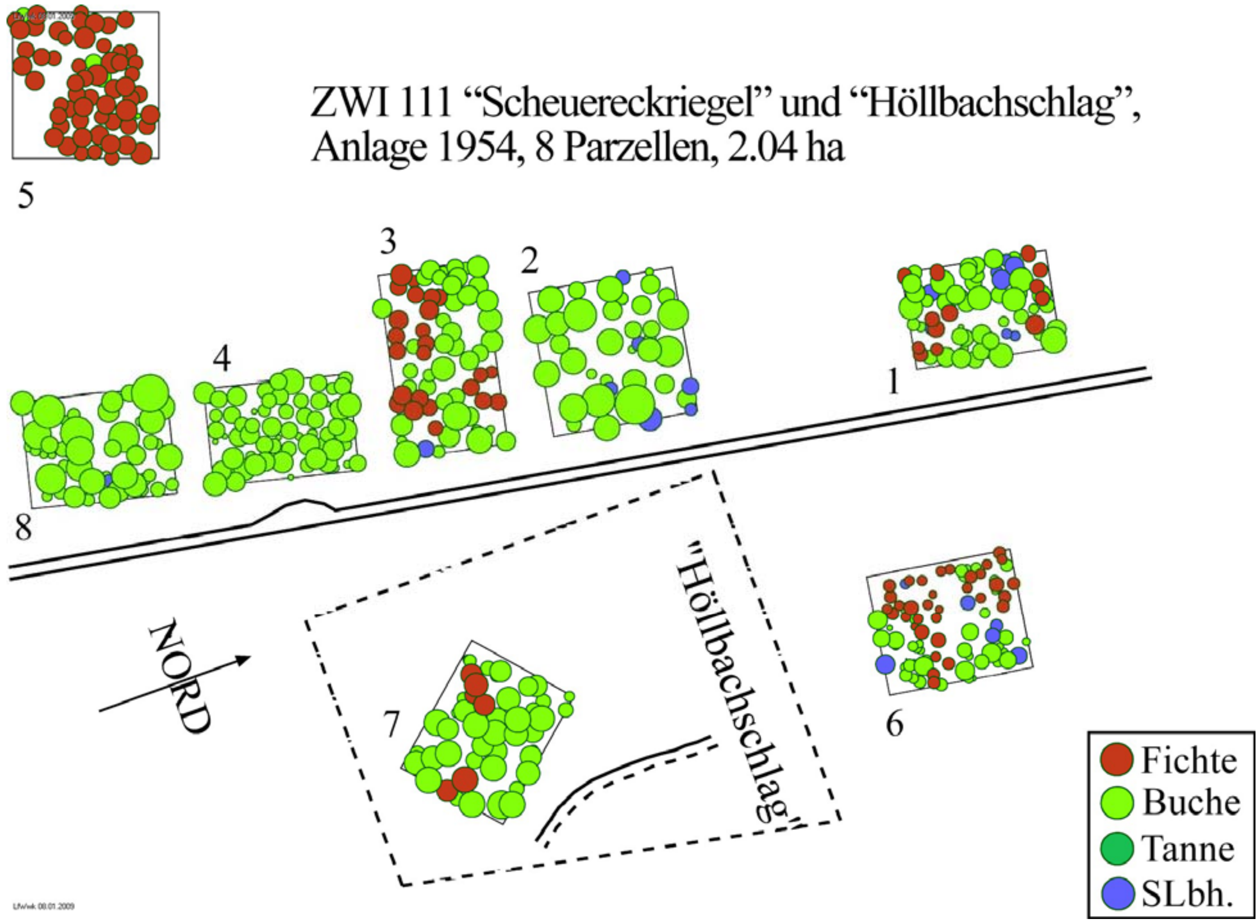
1 Experimental set-up, data, evaluation
Mixing effects may become obvious especially in fully stocked stands





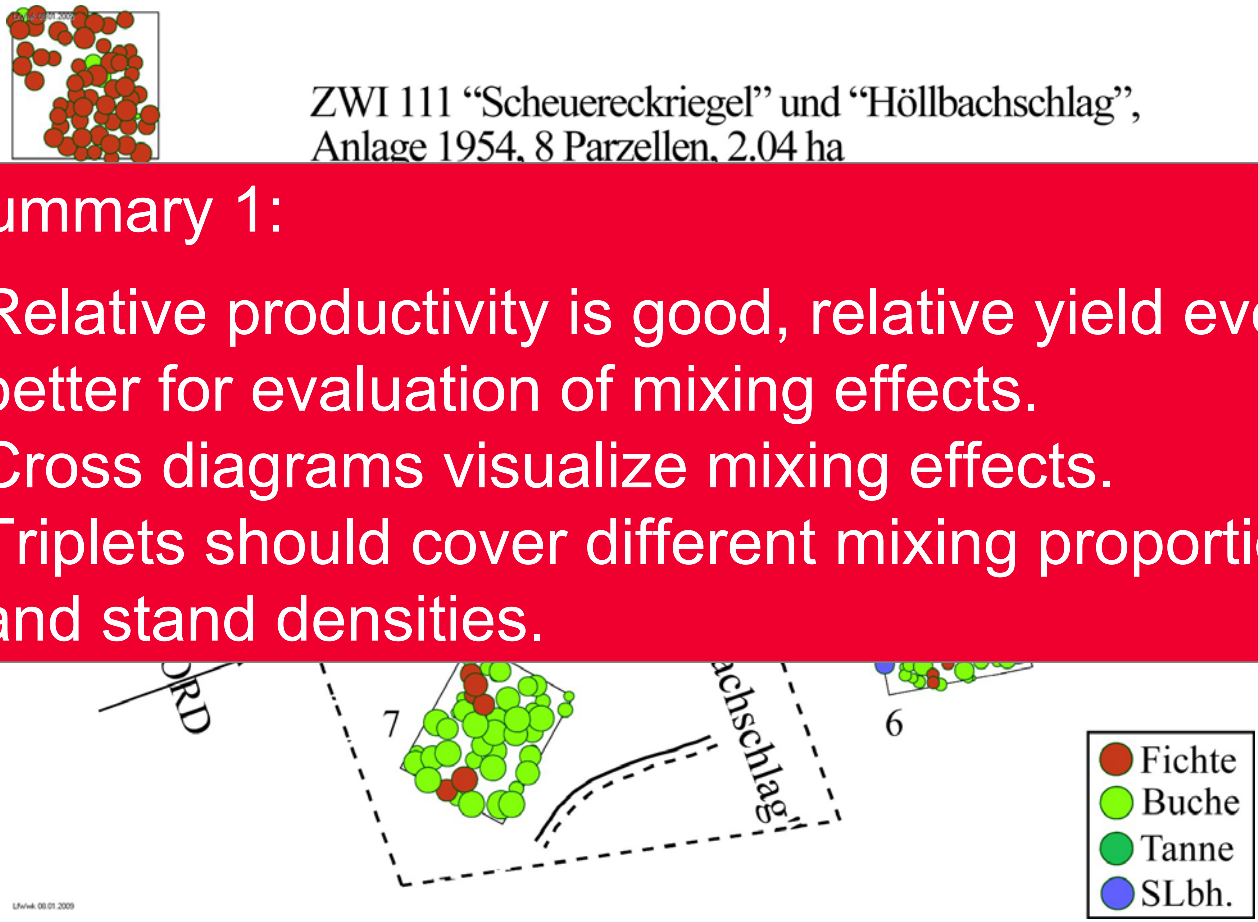
Amorosos M. M. and Turnblom, E. C. (2006) Comparing productivity of pure and mixed Douglas-fir and western hemlock plantations in the Pacific Northwest, Can. J. For. Res. 36:1484-1496

1 Design of the long-term mixing experiment in Norway spruce and European beech Zwiesel 111/1-8



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

1 Design of the long-term mixing experiment in Norway spruce and European beech Zwiesel 111/1-8



Summary 1:

- Relative productivity is good, relative yield even better for evaluation of mixing effects.
- Cross diagrams visualize mixing effects.
- Triplets should cover different mixing proportions and stand densities.

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

Growth and yield of mixed-species versus pure forest stands

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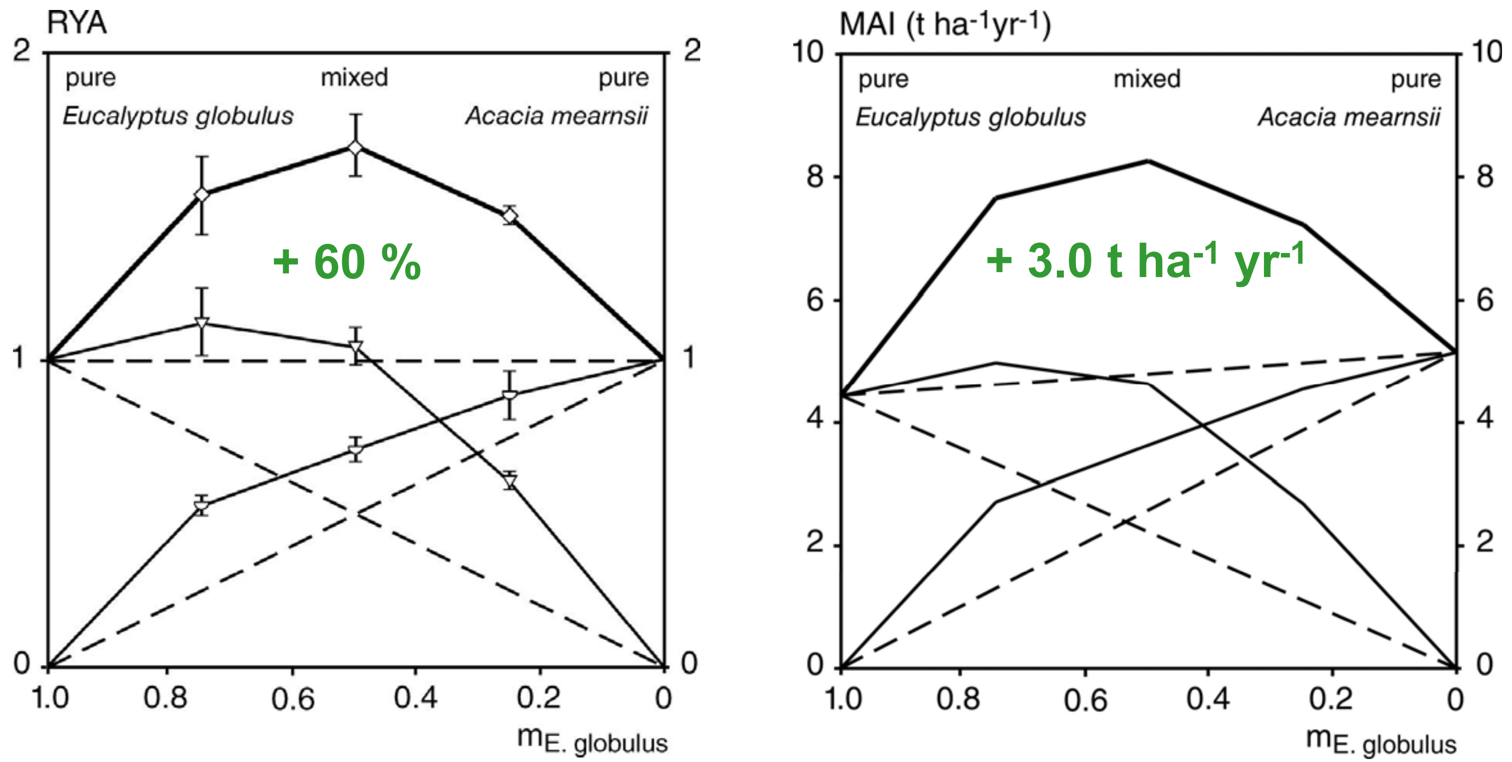
2 Overyielding in mixed versus pure stands of *Eucalyptus globulus* Labill and *Acacia mearnsii* De Wild.



Forrester et al. (2006) Mixed-species plantations of *Eucalyptus* …, Forest Ecology and Management 233:211-230
Forrester, unpublished data from Cann River Exp., precip. 850 mm yr^{-1}, mean temp. 14.4 °C, Southeastern Australia

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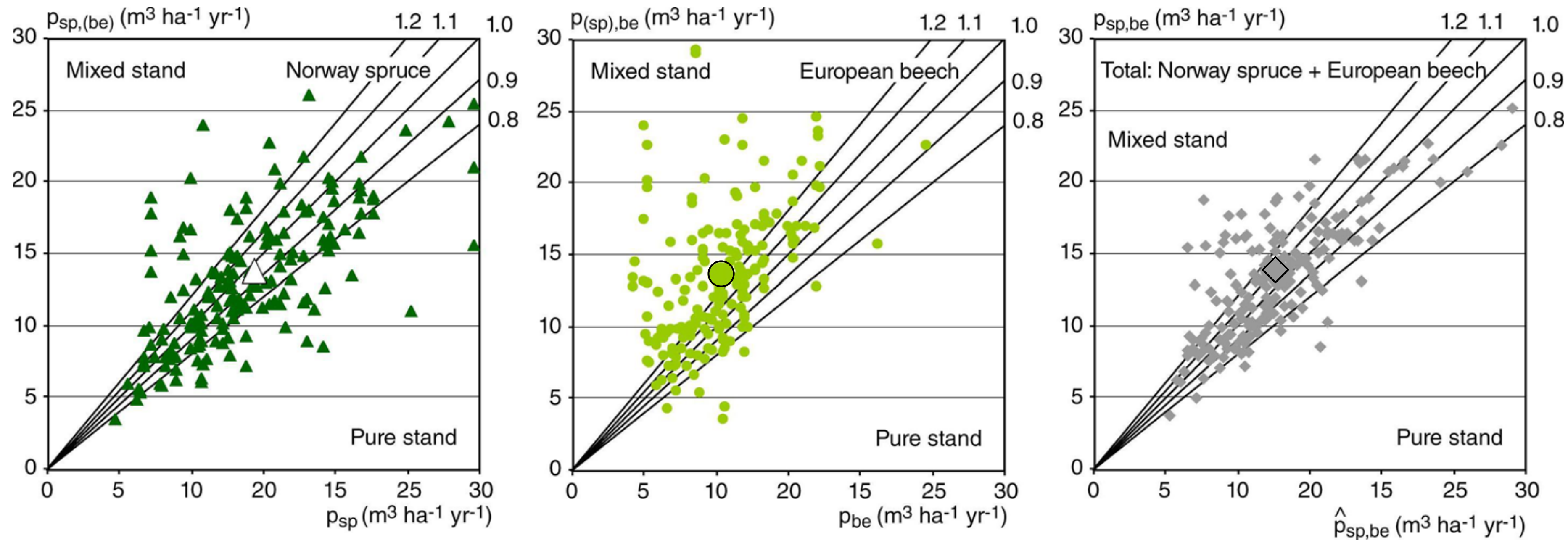
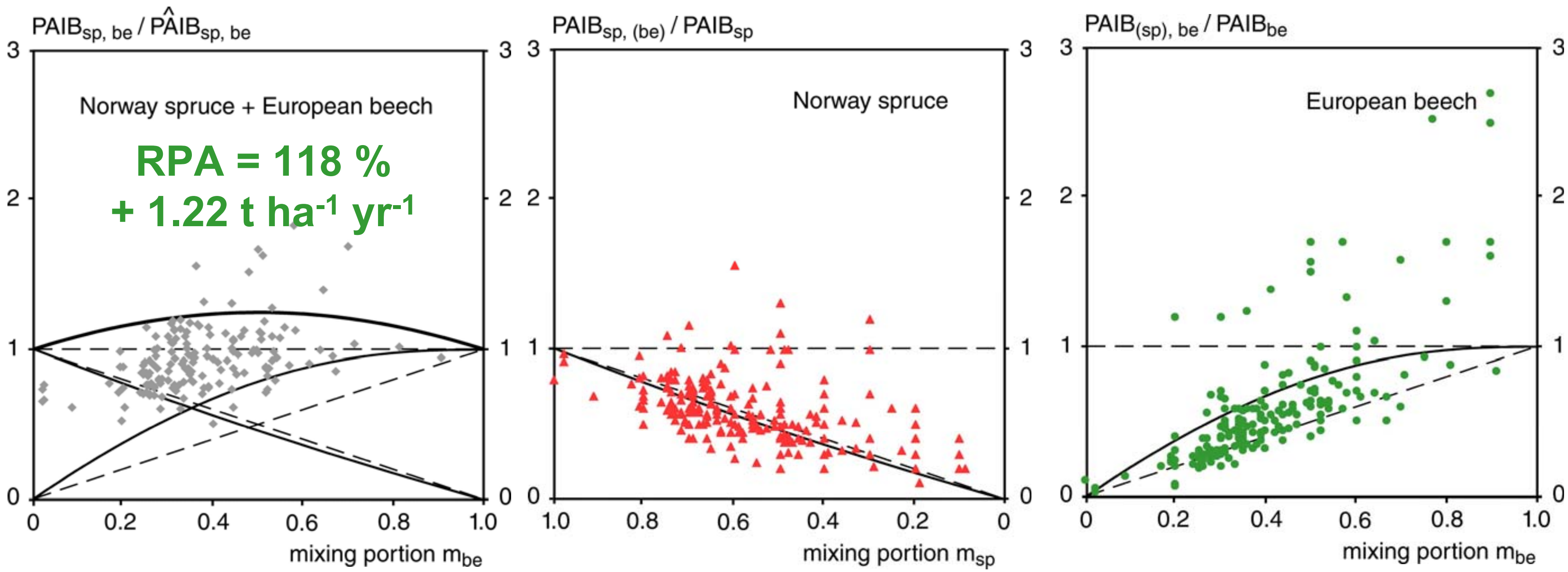
2 Overview of mixing effects in temperate forests



2 Relative productivity of mixed Norway spruce/ European beech versus pure stands



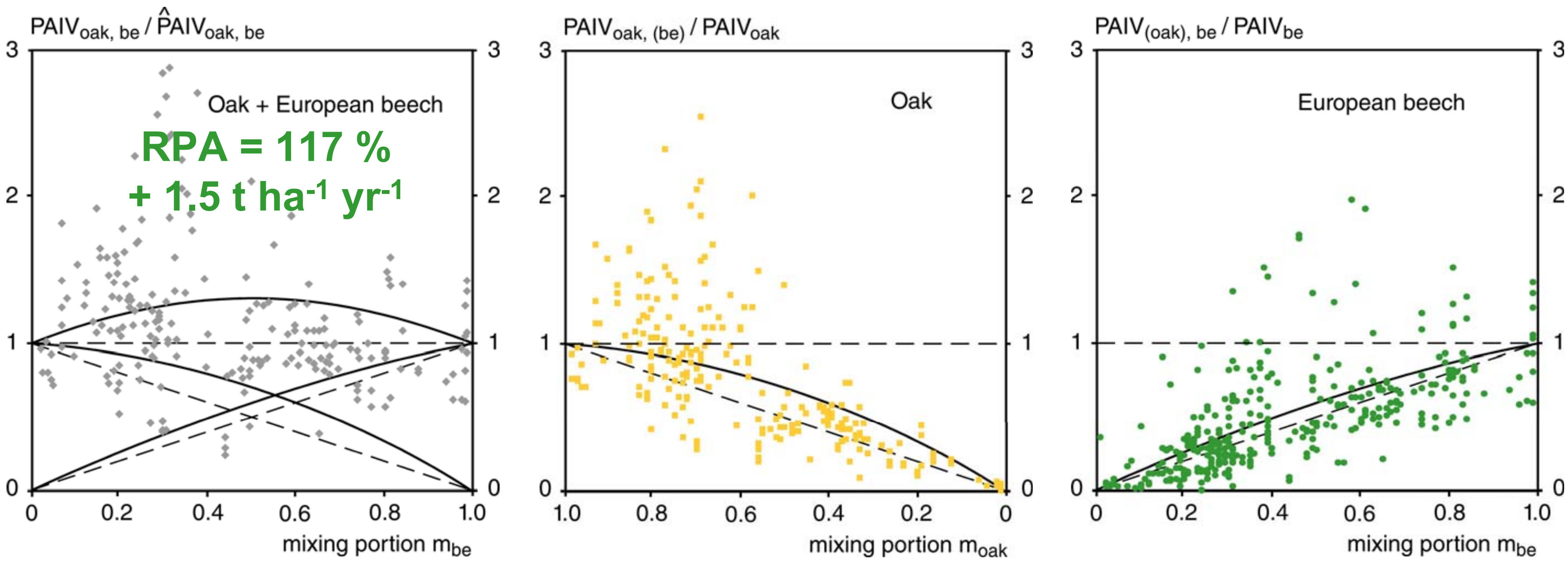
$RP_{sp,be} = RPP_{sp,(be)} + RPP_{(sp),be}$

$RPP_{sp,(be)} = m_{sp} \times (1 - 0.013 \times m_{be})$, $n = 236$, $R^2 = 0.12$, $p<0.05$

$RPP_{(sp),be} = m_{be} \times (1 + 1.115 \times m_{sp})$, $n = 221$, $R^2 = 0.33$, $p<0.001$

Pretzsch (2005) Ecological Studies 176
Pretzsch et al. (2010) Ann. For. Sci. 67

2 Relative productivity of mixed oak/ beech versus pure stands



Pretzsch et al. (2013) Productivity of mixed versus pure stands of oak and European beech
Eur J Forest Res, DOI 10.1007/s10342-012-0673-y

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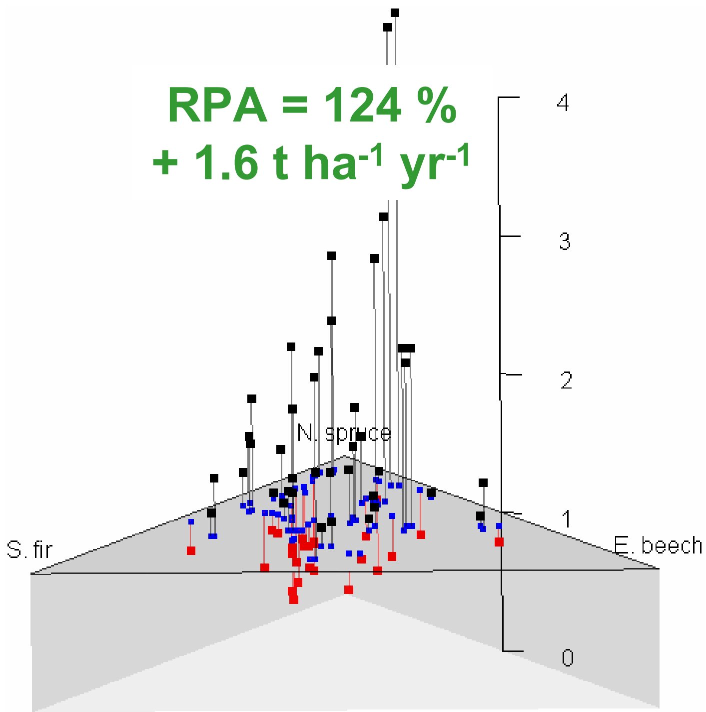
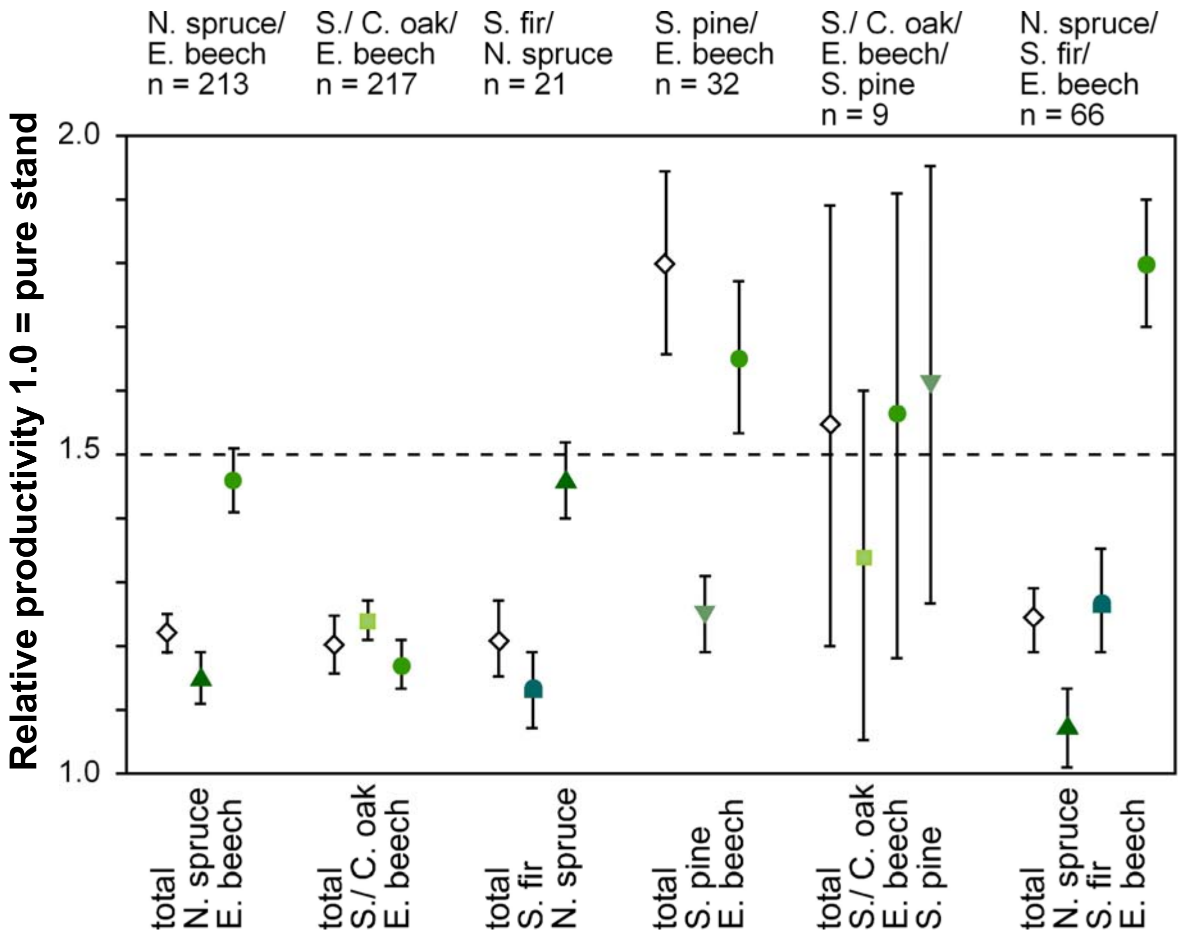
2 Productivity of mixed stands with three species versus pure stands
Norway spruce, Silver fir, and European beech



RP: sp/fir/be 1.24 (± 0.05)
AP: sp/fir/be 1.60 t ha^{-1} yr^{-1}

2 Overyielding of mixed stands compared with pure stands of spruce, pine, fir beech, and, oak



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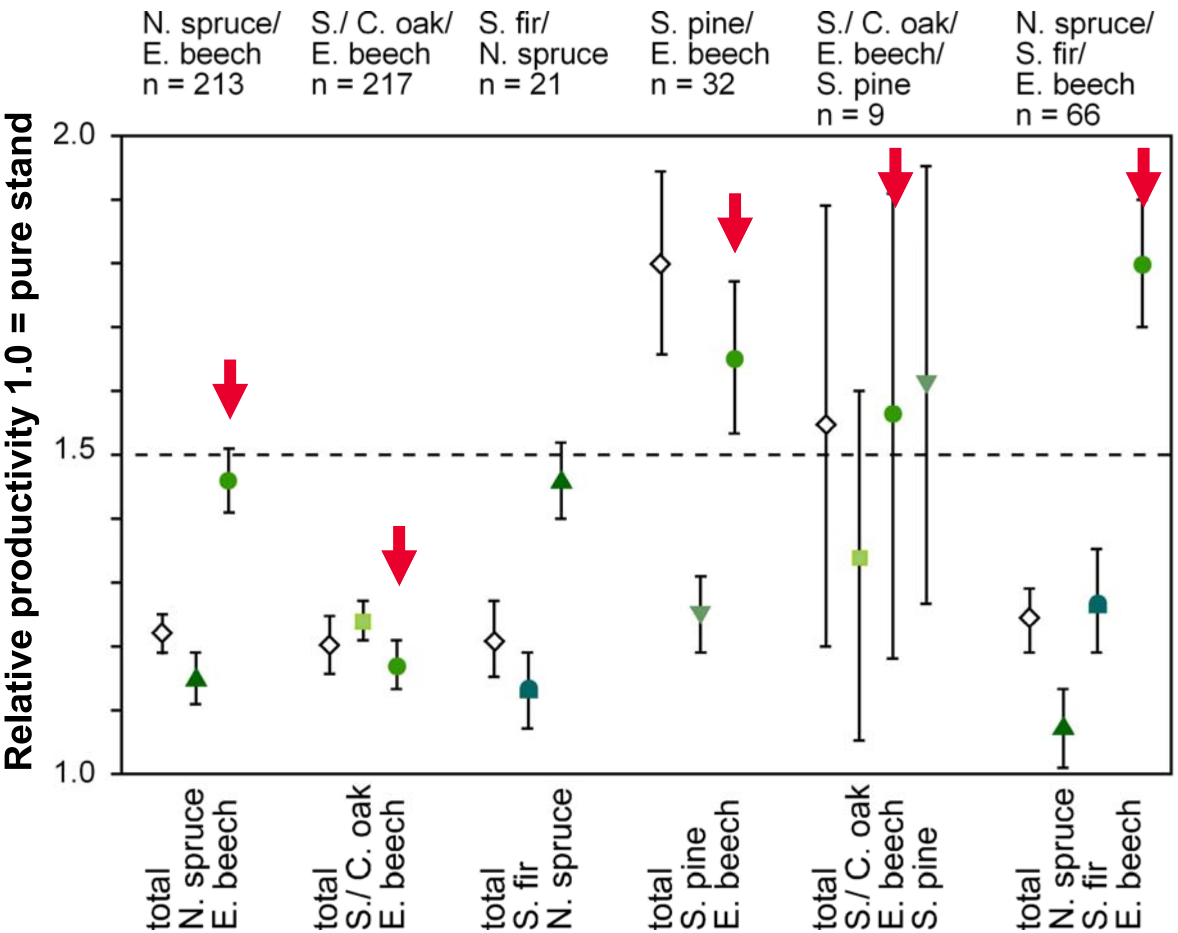
2 Notorious overyielding of beech in mixture



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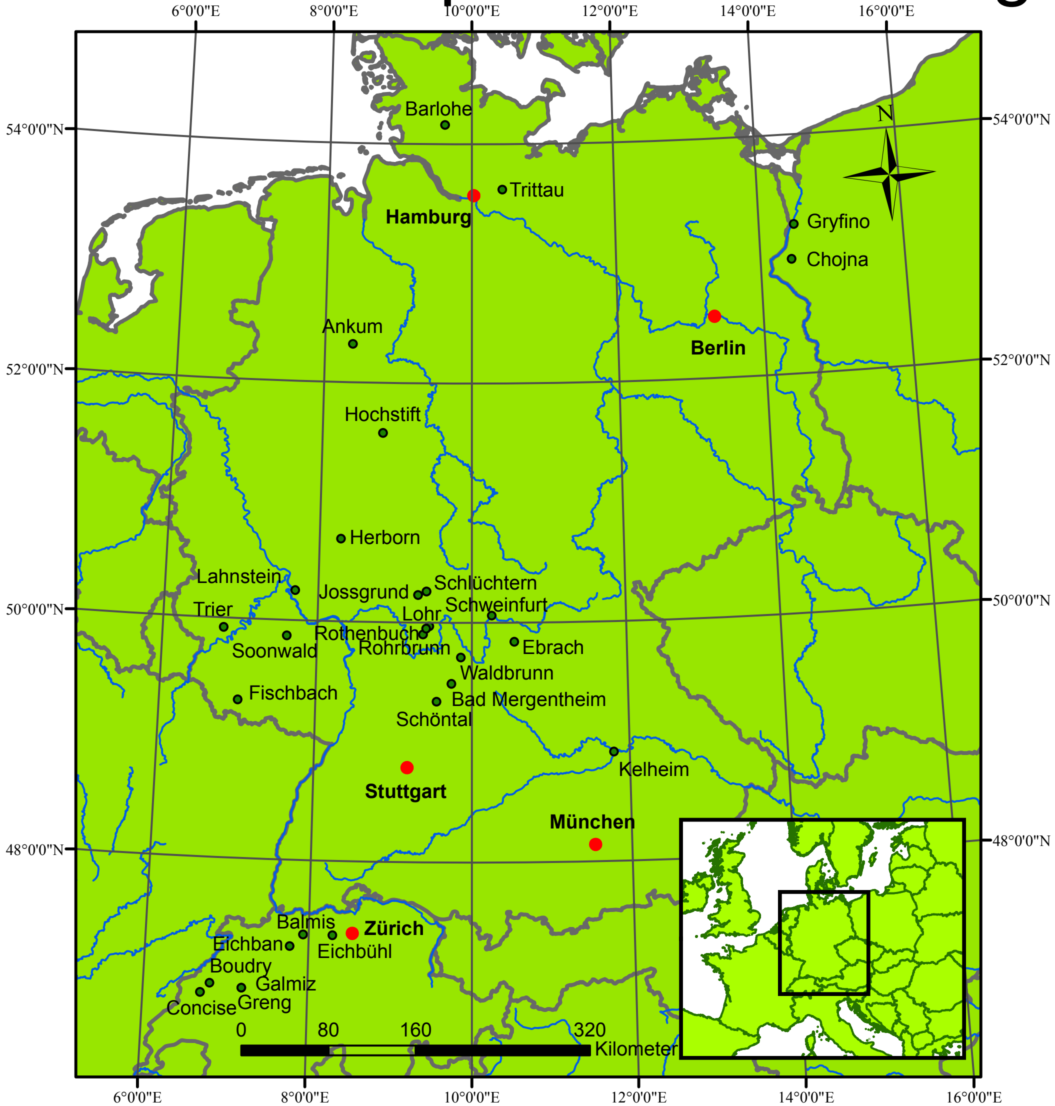
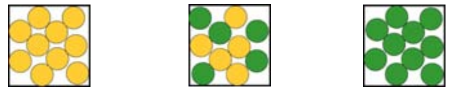
2 Pure and mixed species stands of Sessile/Common oak and European beech along an ecological transect





29 experiments
65 triplets
525 surveys

time span: 1890 - 2011

stand age: 17- 217

mean temp (°C): 6.0 - 9.5
precip (myr^{-1}): 550 - 1120
nut. supp.: acid - alcaline

from m_{oak} / m_{be}: 0.05:0.95
to m_{be} / m_{oaki}: 0.95:0.05

from: unthinned
to: heavily thinned

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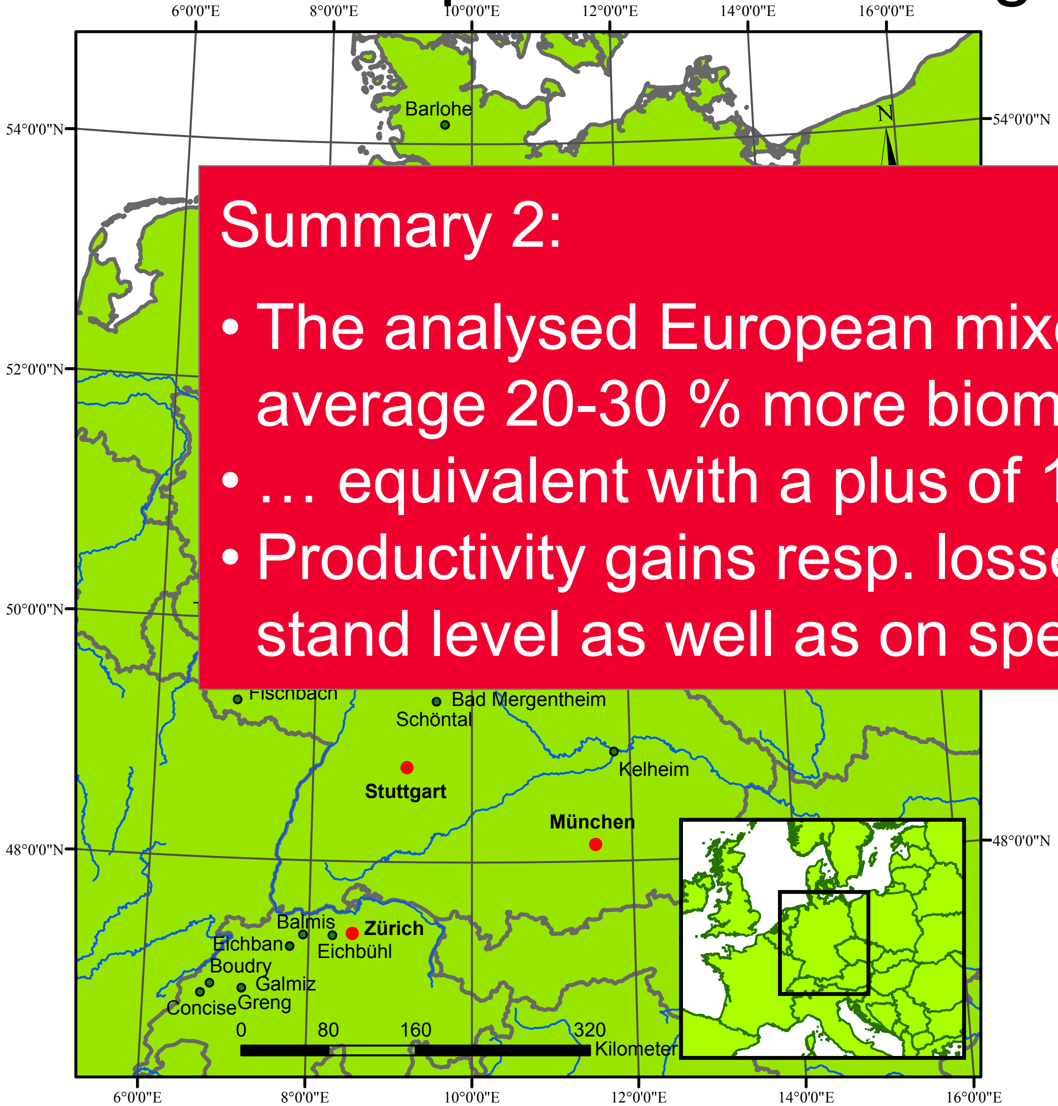
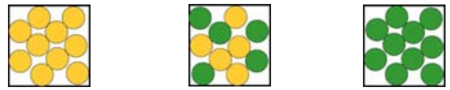
2 Pure and mixed species stands of Sessile/Common oak and European beech along an ecological transect





Summary 2:

- The analysed European mixed stands produce on average 20-30 % more biomass than pure stands …
- … equivalent with a plus of 1.5-2.0 t ha^{-1} yr^{-1} .
- Productivity gains resp. losses vary strongly on stand level as well as on species level.

from m_{oak} / m_{be}: 0.05:0.95
to m_{be} / m_{oaki}: 0.95:0.05

from: unthinned
to: heavily thinned

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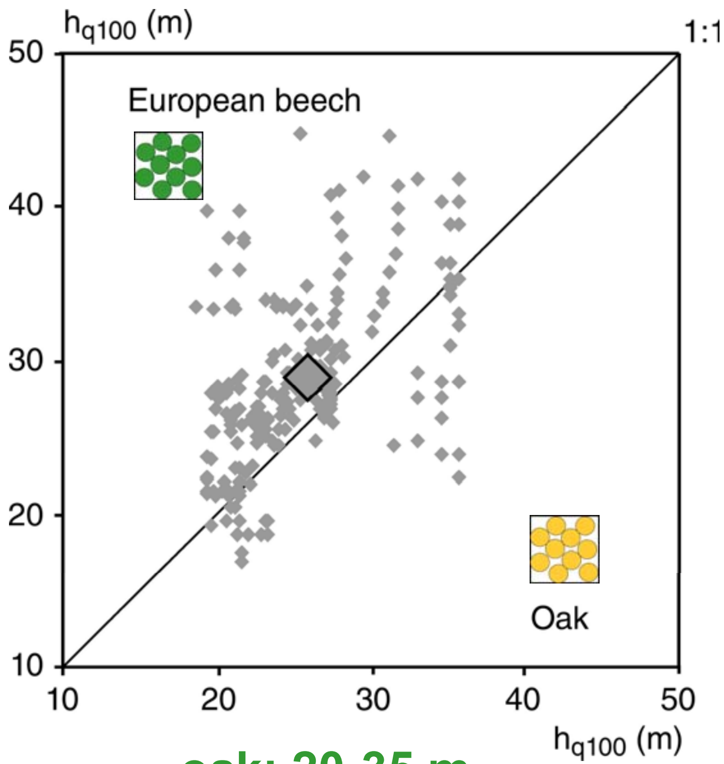
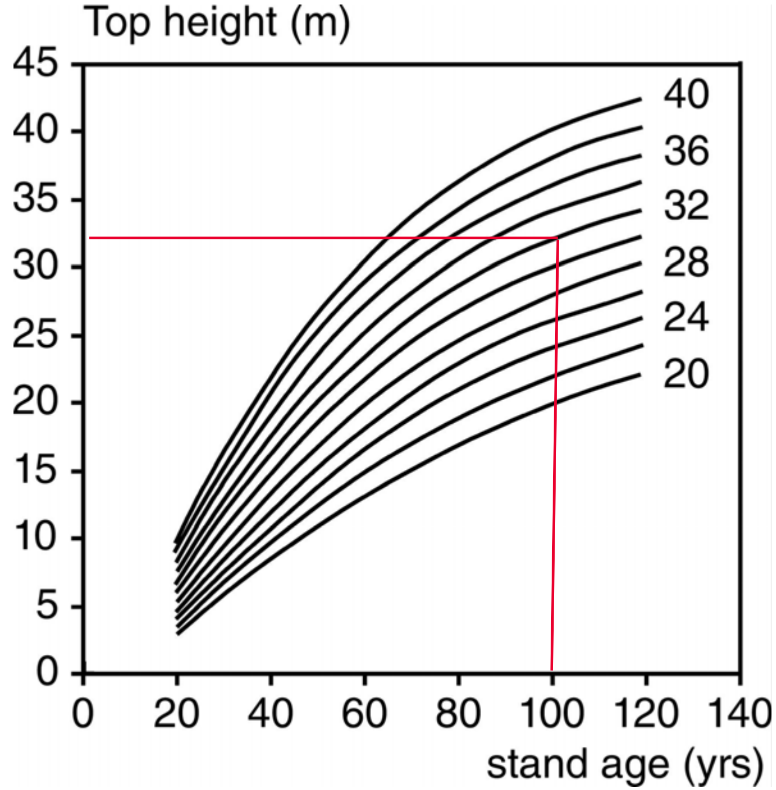
Growth and yield of mixed-species versus pure forest stands

3 Mean height of the pure oak and beech stands at age 100 as indicator for site quality

be: 18-45 m



oak: 20-35 m



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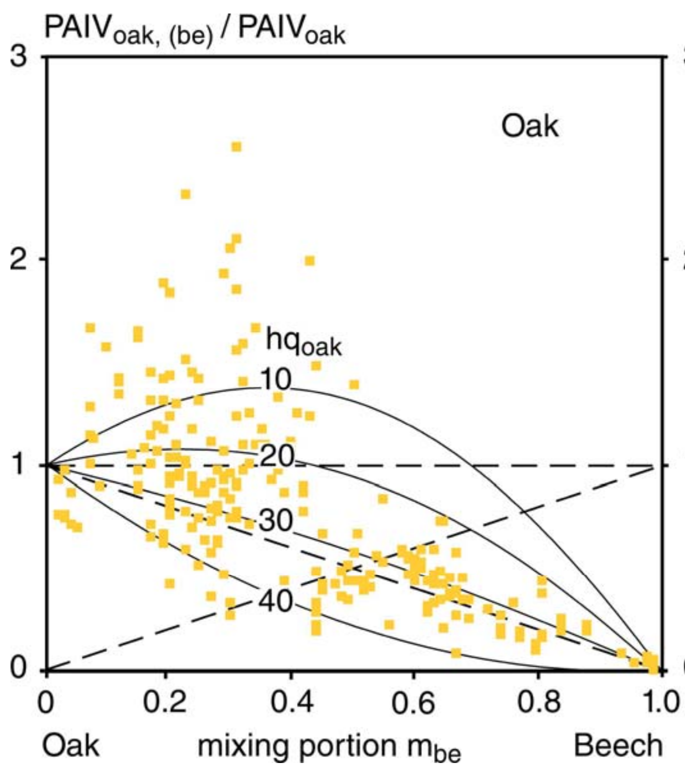
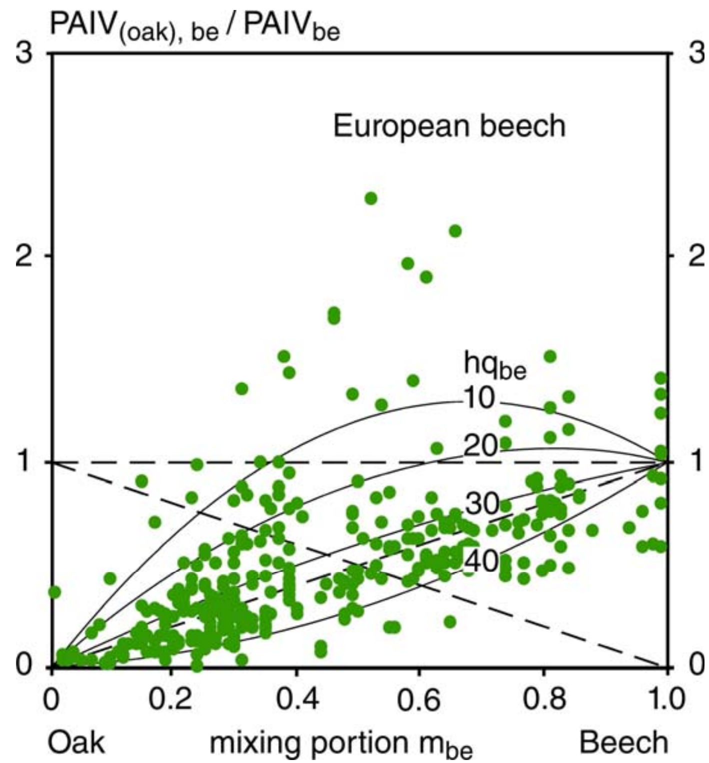
3 Site index (hq in m at age 100) as modifier of mixing reactions between oak and beeh



$RPP_{oak,(be)} = m_{oak} \times (1 + 4.685 \times m_{be} - 0.145 \times m_{be} \times hq_{oak})$
$n = 296$, $R^2 = 0.46$, $p<0.01$



$RPP_{(oak),be} = m_{be} \times (1 + 4.033 \times m_{oak} - 0.122 \times m_{oak} \times hq_{be})$
$n = 428$, $R^2 = 0.37$, $p<0.01$

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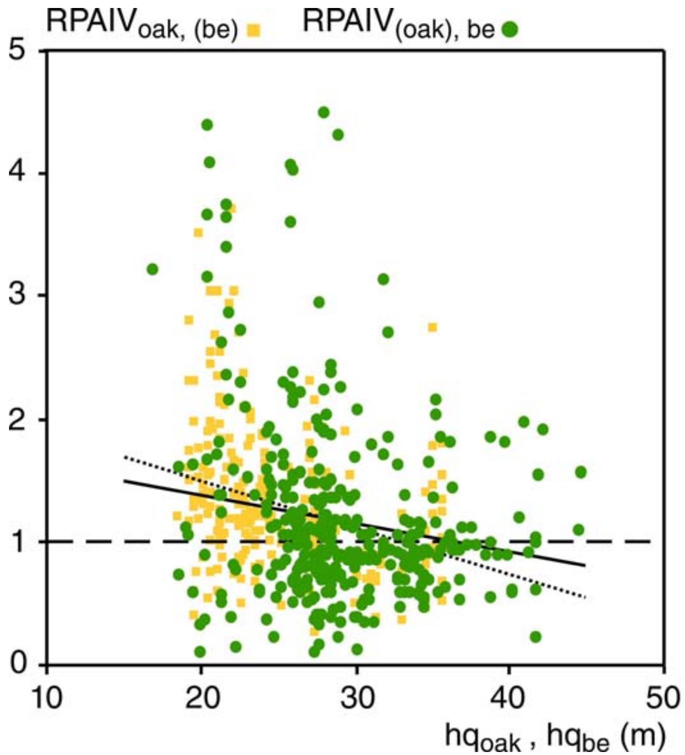
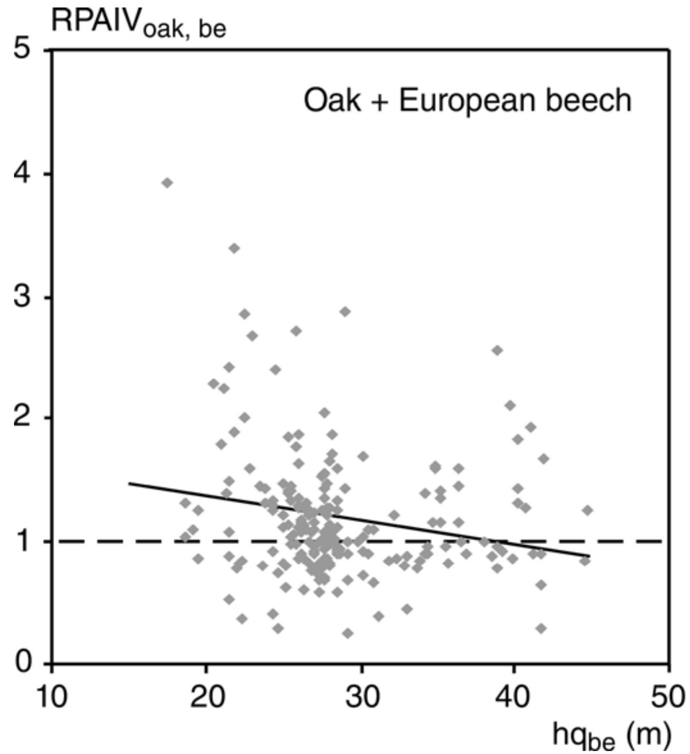
3 Site index (hq in m at age 100) as modifier of mixing reactions between oak and beech



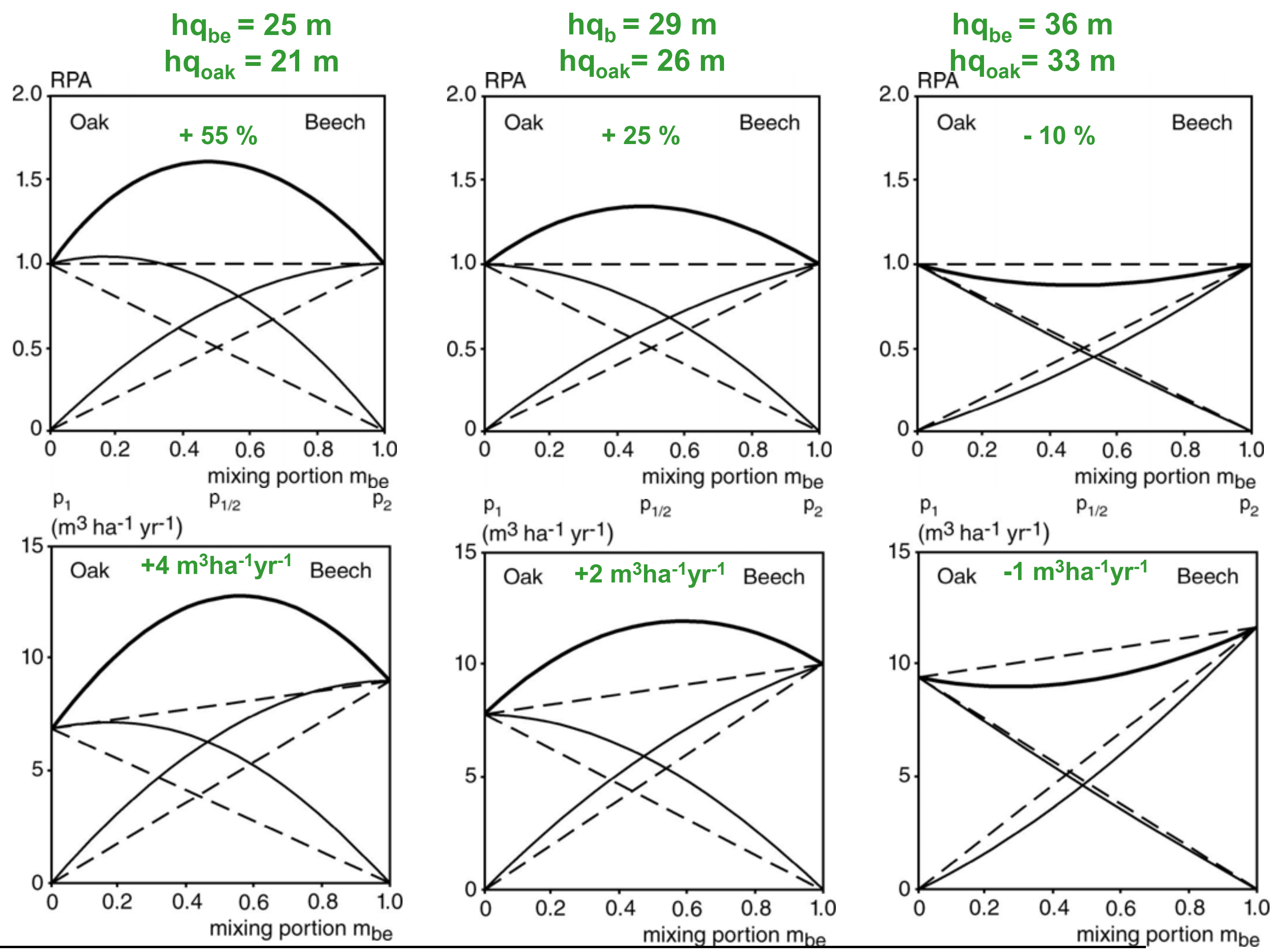
$RP_{oak,(be)} = 2.250 - 0.038 \times hq_{oak}$
n = 289, R^2=0.14, p<0.001,***

$RP_{(oak),be} = 1.841 - 0.023 \times hq_{be}$
n = 420, R^2=0.05, p<0.01, **



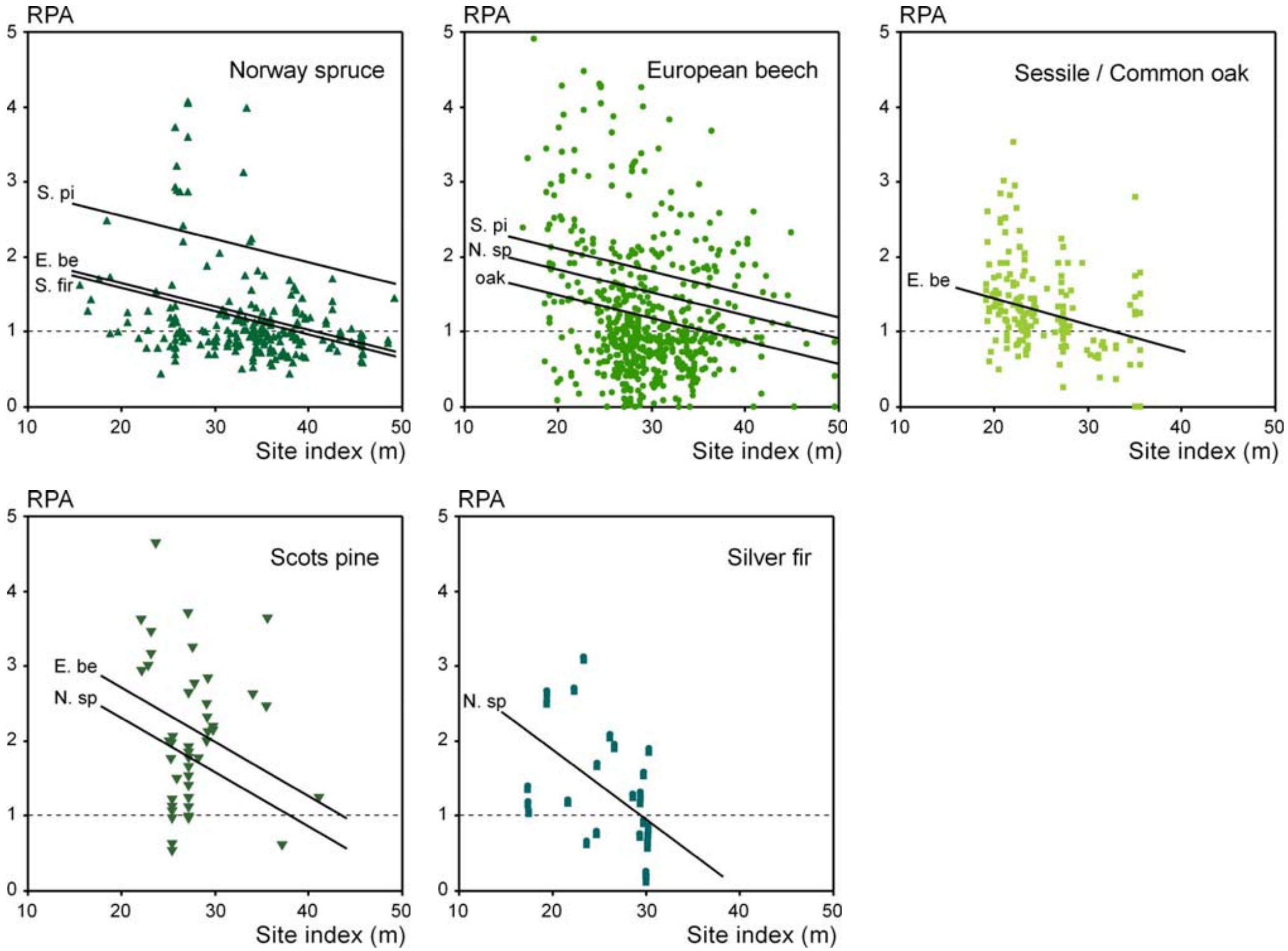
$RP_{oak,be} = 1.816 - 0.025 \times hq_{oak}$
n = 242, R^2=0.07
1.816 (± 0.165), p<0.001, ***
-0.025 (± 0.006), p<0.001, ***

3 Facilitation and competition in dependence on site conditions (hq) at age 50



Pretzsch et al. (2011) Productivity of pure versus mixed stands of oak (*Quercus petraea* (Matt.) Liebl. and *Quercus robur* L.) and European beech (*Fagus sylvatica* L.) along an ecological gradient, submitted

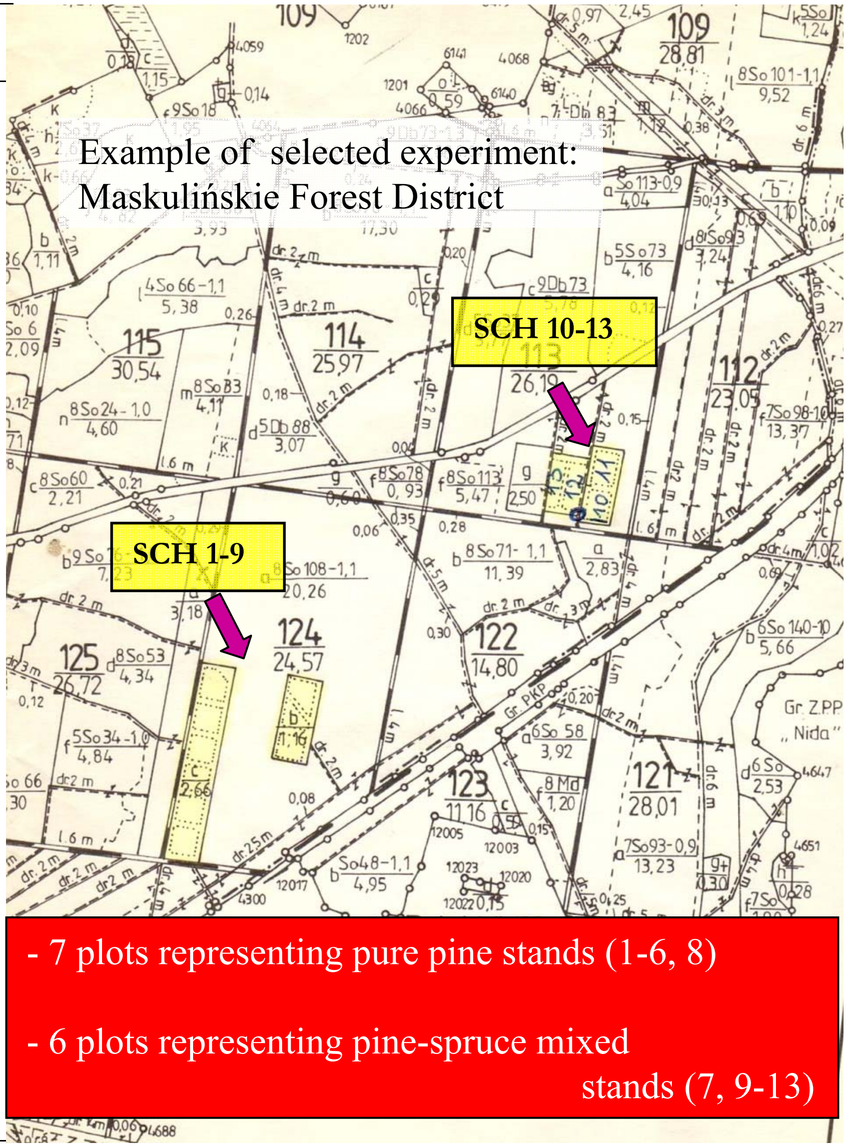
3 Spatial and temporal variation of mixing effects



Study sites

Overview on the observational plots included in the study

Characteristics	Pure pine min	max	Mixed pine-spruce min	max
Number of experiments (n)	3		3	
Number of plots (n)	8		6	
Number of observations (n)	125		91	
First survey (year)	1911	1932	1923	1928
Last survey (year)	2008	2010	2008	2010
Number of surveys (n)	14	16	15	16
Age at last survey (yr)	131	132	124	133
ho (m) last survey	29.7	36.0	33.1	36.3
N (ha^{-1}) la. surv.	165	324	123	324
SDI (ha^{-1}) la. surv.	396	755	548	807
Site index (m) la. surv.	28.3	32.1	28.3	32.1
dq (cm) la. surv.	39.1	47.0	38.8	45.3
PAI (m^{3}ha^{-1}yr^{-1}) l. surv.	2.4	7.0	4.0	12.5
V (m^3 ha^{-1}) la. surv.	332	714	452	721



- 7 plots representing pure pine stands (1-6, 8)

- 6 plots representing pine-spruce mixed stands (7, 9-13)


290
289
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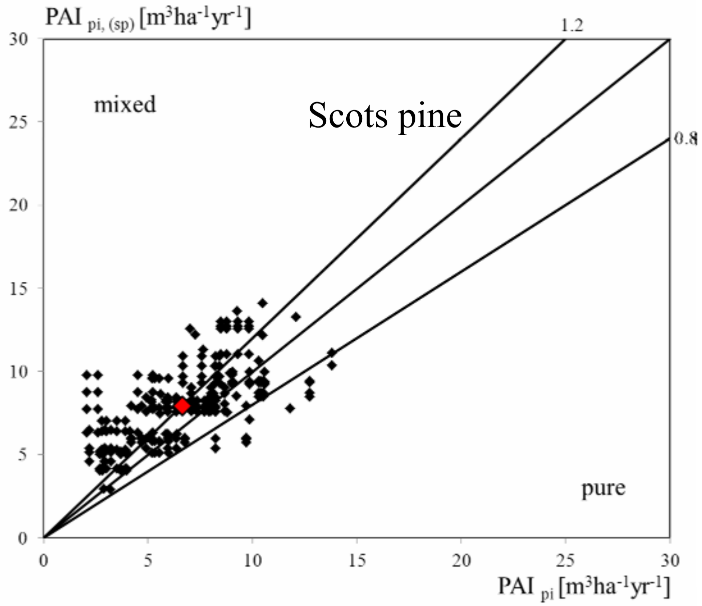
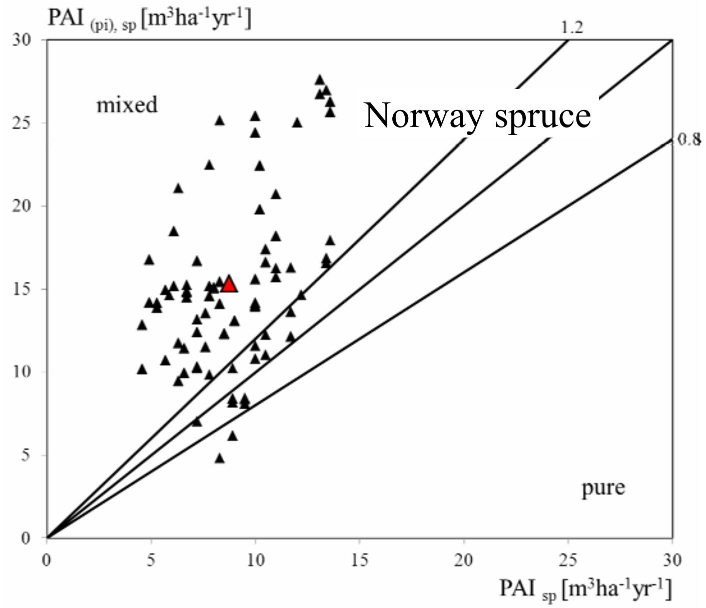
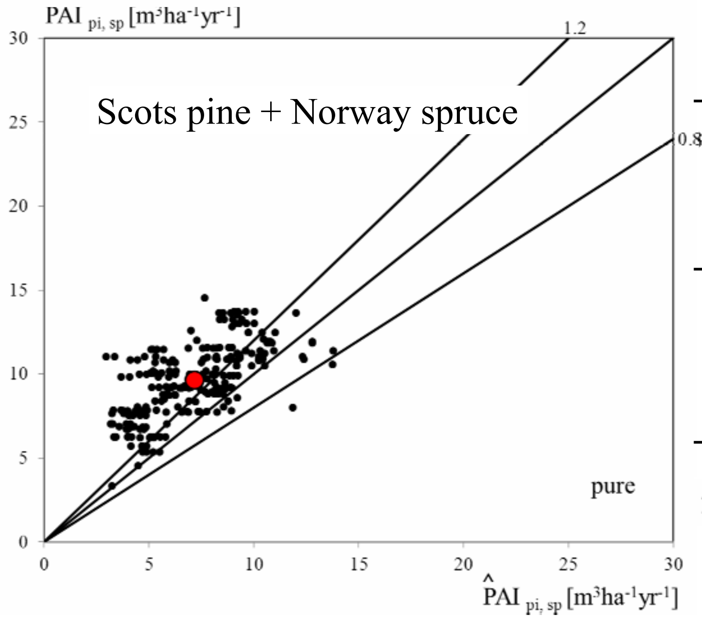
Data

Comparison of periodic mean annual increment (PAI)



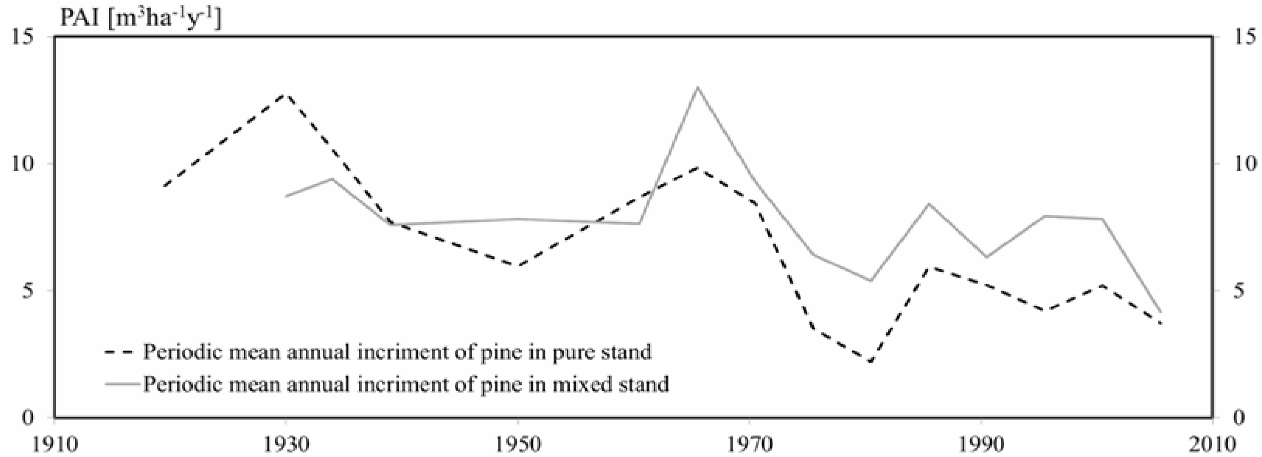


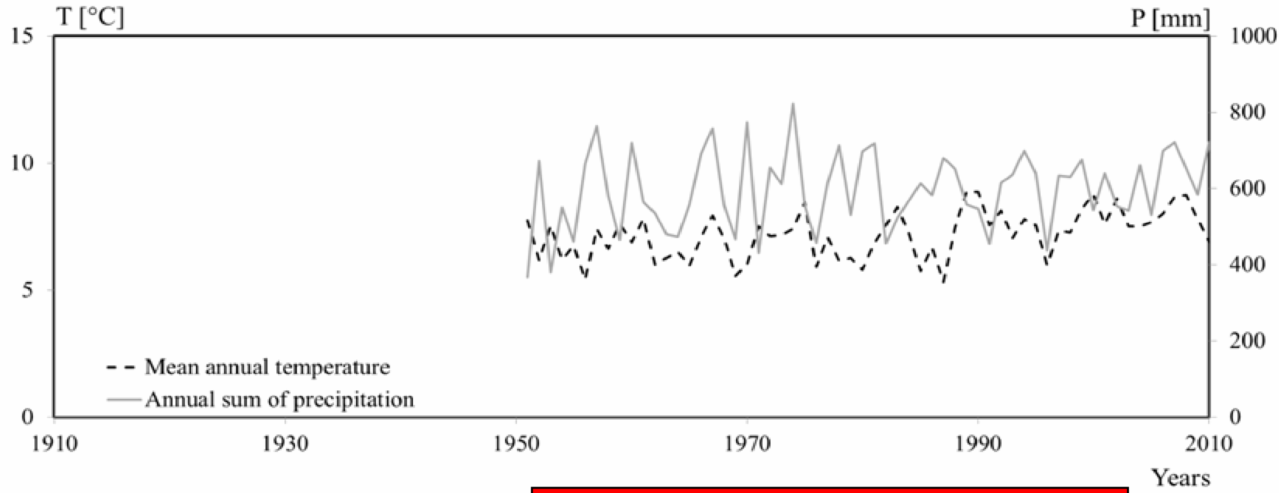


Species	PAI mixed mean ± SD ($m^3ha^{-1}yr^{-1}$)	PAI pure mean ± SD ($m^3ha^{-1}yr^{-1}$)	PAI ratio mean ± SD
Scots pine	7.9 ± 2.3	6.6 ± 2.7	1.34± 0.56
Norway spruce	15.3 ± 5.9	8.7 ± 2.5	1.83± 0.65
Pine and spruce	9.6 ± 2.3	7.2 ± 2.3	1.42± 0.41

$\overline{m}_{pi} = 0.75 \pm 0.09$

Methodology



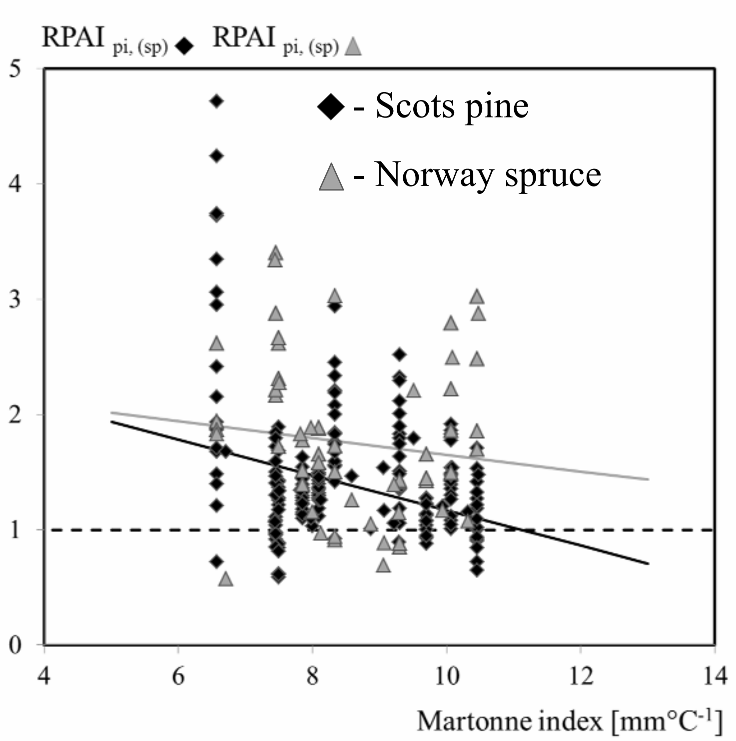


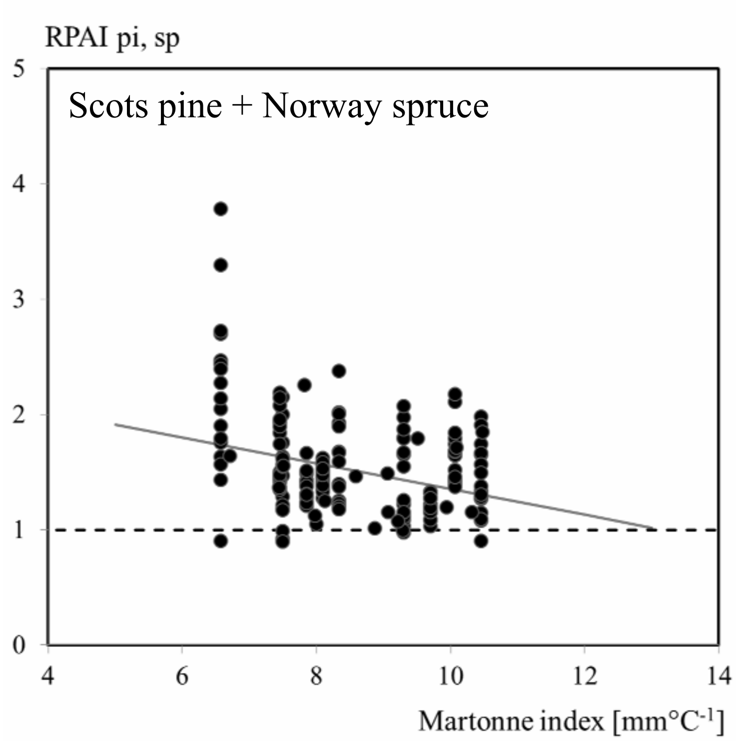
$$I_{ar} = \frac{P}{T+10}$$

P – Sum of precipitation (mm)
T – Mean temperature (°C)

Included months: June, July, August

Results





$$RPAI_{pi, (sp)} = 2.703 - 0.153^{***} \times I_{ar}$$

$$RPAI_{(pi), sp} = 2.375 - 0.072^{*} \times I_{ar}$$

$$RPAI_{pi, sp} = 2.470 - 0.112^{***} \times I_{ar}$$

n = 180, ***p < 0.001, *p < 0.05
I_{ar}- Martonne's Index of Aridity

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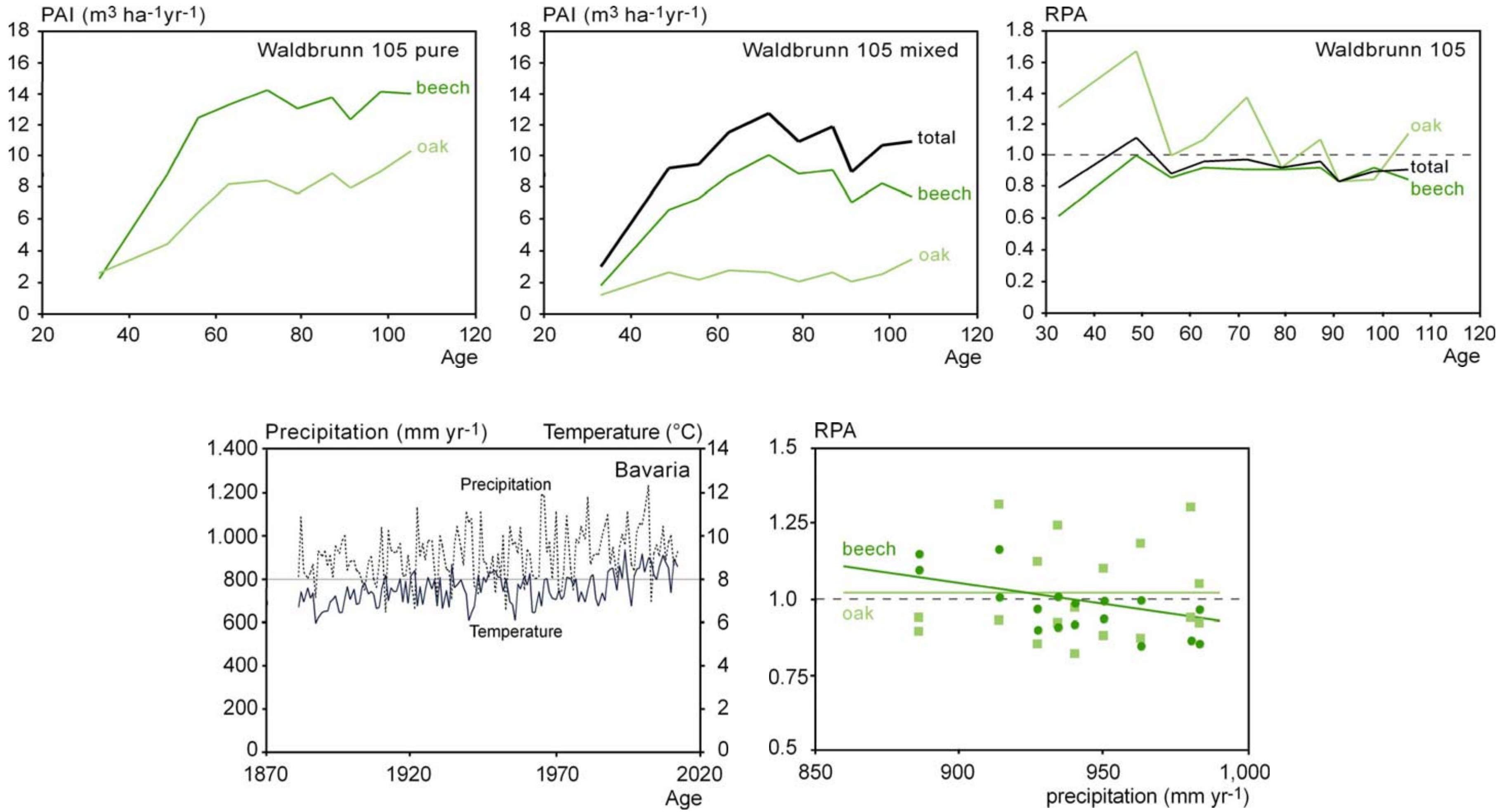
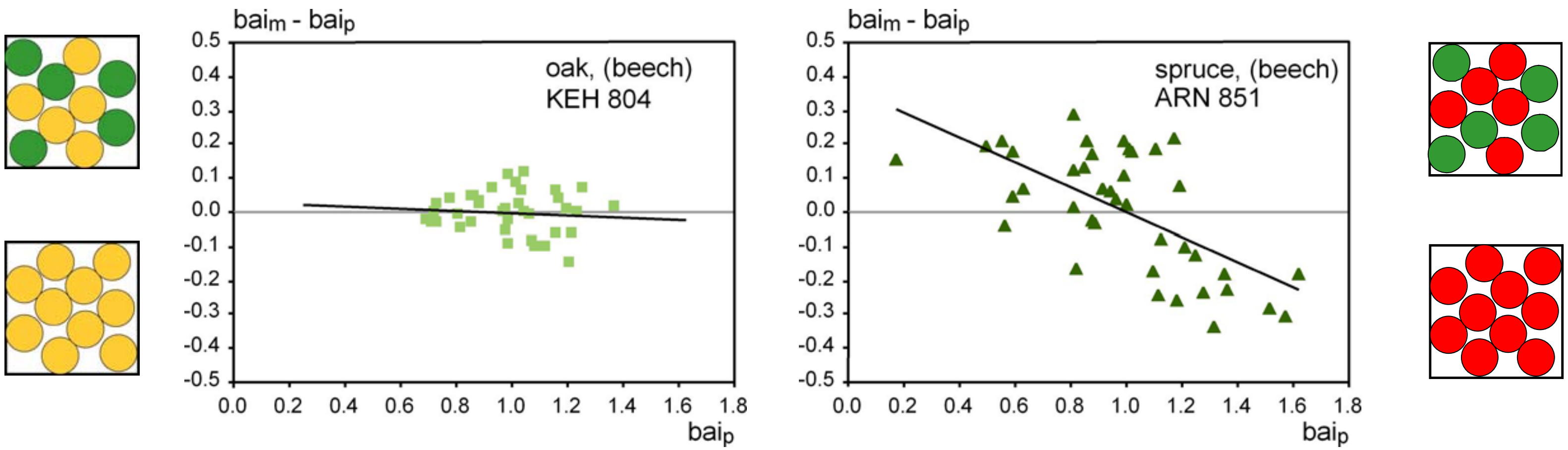
3 Temporal variation of mixing effects: Analyses on stand level



3 Temporal variation of mixing effects: Retrospective analyses based on increment cores



Río del, M., Schütze, G. & Pretzsch, H. (2013) Temporal variation of competition and facilitation in mixed species forests in Central Europe, Plant Biology, doi:10.1111/plb.12029

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Systemanalyse

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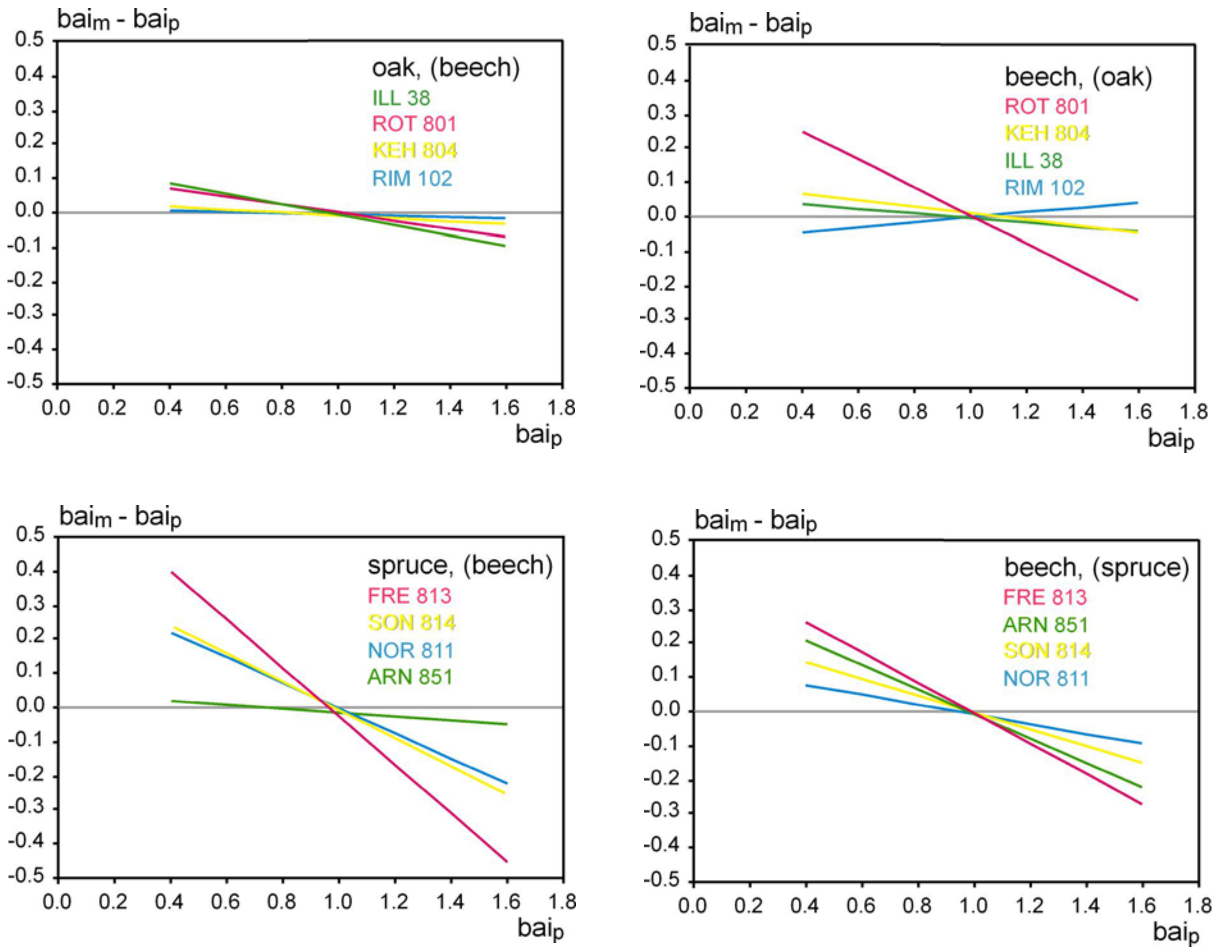

Río del, M., Schütze, G. & Pretzsch, H. (2013) Temporal variation of competition and facilitation in mixed species forests in Central Europe, Plant Biology, doi:10.1111/plb.12029

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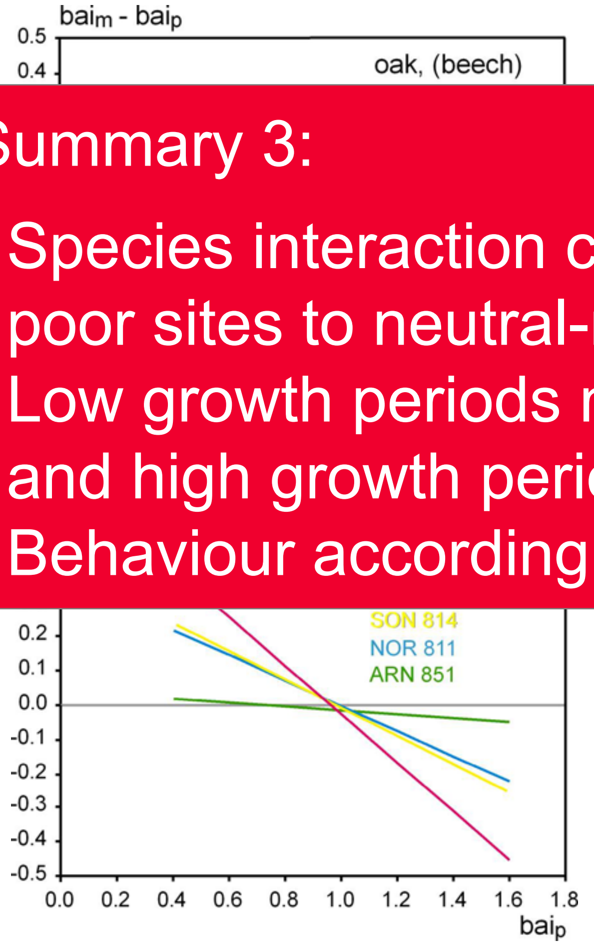
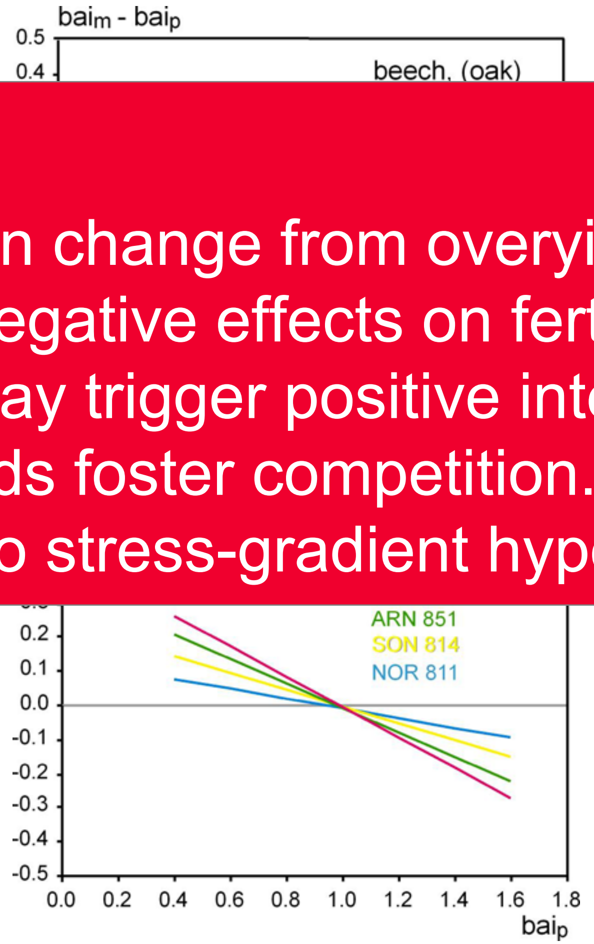




Summary 3:

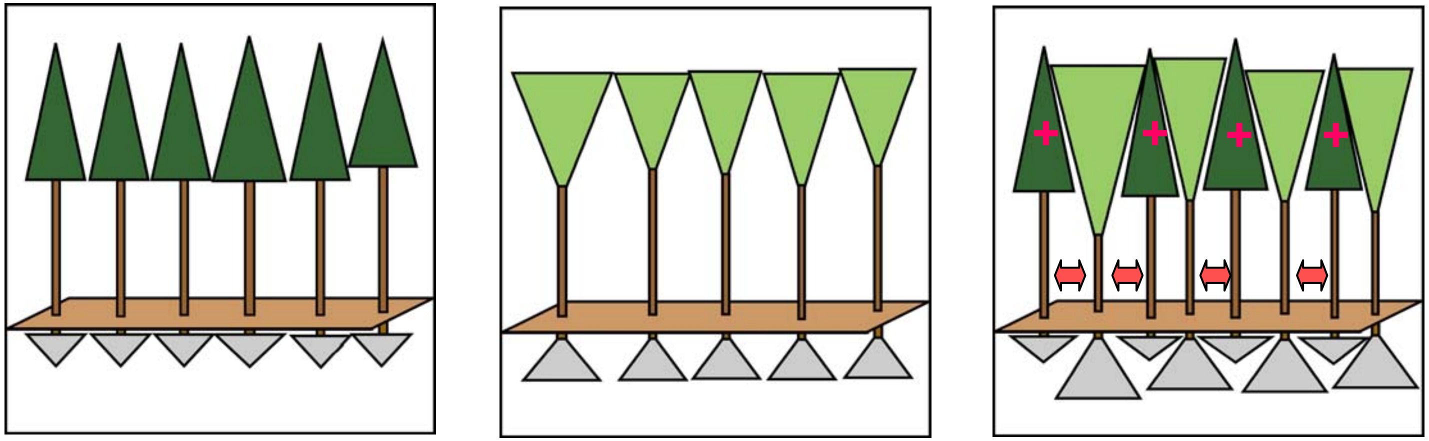
- Species interaction can change from overyielding on poor sites to neutral-negative effects on fertile sites.
- Low growth periods may trigger positive interactions and high growth periods foster competition.
- Behaviour according to stress-gradient hypothesis.

Río del, M., Schütze, G. & Pretzsch, H. (2013) Temporal variation of competition and facilitation in mixed species forests in Central Europe, Plant Biology, doi:10.1111/plb.12029

Growth and yield of mixed-species versus pure forest stands

Seminar held on June 6th, 2013 at the University of Palencia, Spain

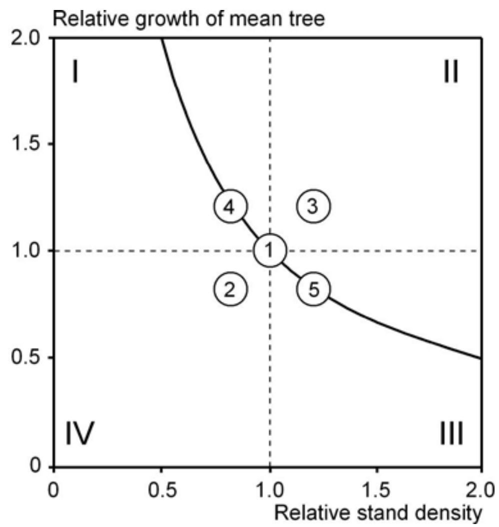
4 Analyzing the components of mixing effects: Change in stand density and/or growth of trees



+ Change in growth rate of mean tree → slower/faster growth → **indicates better nutrition of trees**.
Requires adaptation of thinning intensity (e.g., return intervals).

⇔ Change in stand density → higher/lower carrying capacity → **indicates long-term improvement of resource supply.**
Requires adaptation of stand density management (e.g., SDMD).

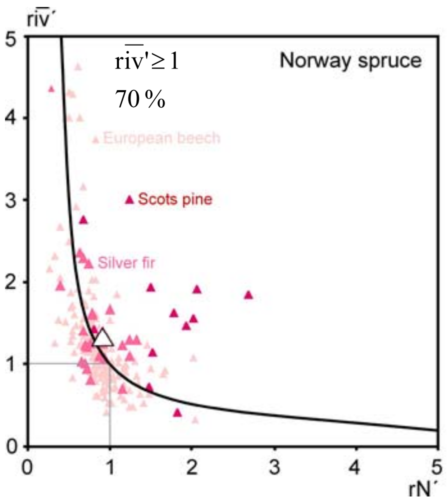
4 Effects on stand density rN or mean tree growth efficiency rp



$$P = \overline{p} \times N$$

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

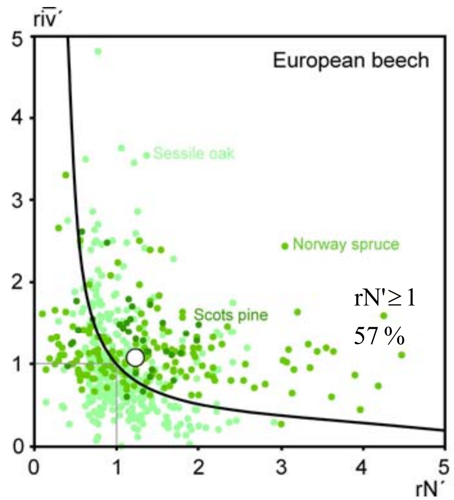
$$riv' = r\overline{iv}' \times rN'$$



Norway spruce

$rN' = 0.92$

$r\overline{iv}' = 1.32$

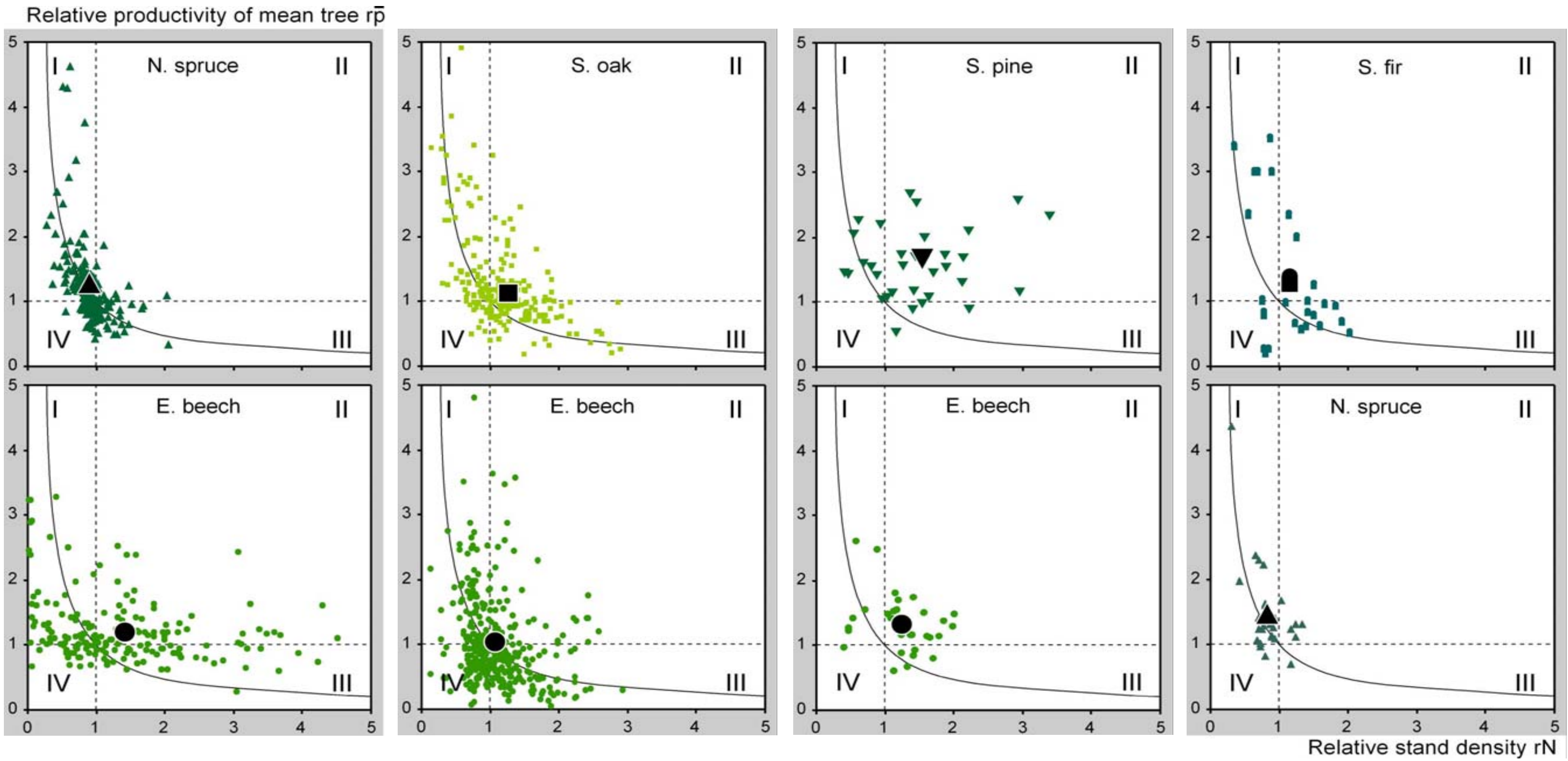


European beech

$rN' = 1.23$

$r\overline{iv}' = 1.09$

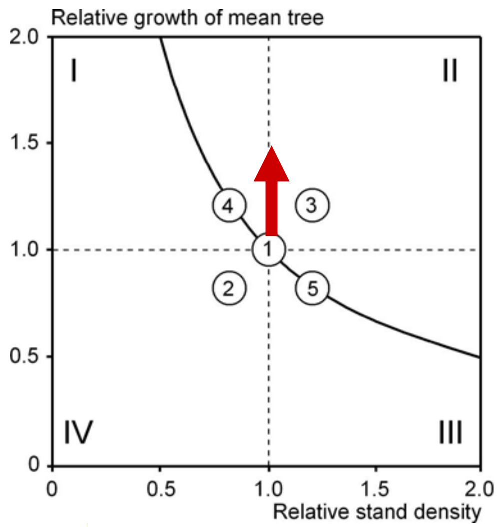
4 Effects on stand density or tree growth efficiency



Pretzsch et al. (2013) Mischung und Produktivität von Waldbeständen. Ergebnisse langfristiger ertragskundlicher Versuche, AFJZ, 184 Jg.

4 Effects on stand density or tree growth efficiency

	n	RN
N. spruce + E. beech	157	1.00 ±0.02
N. spruce	157	0.89 ±0.04
E. beech	157	1.27 ±0.05
E.beech+ S.oak	156	1.64 ±0. 08
S.oak	156	0.99 ±0. 04
E.beech	156	2.34 ±0. 14
S.fir+ N . spruce	15	1.15 ±0.10
S.fir	15	1.90 ±0.21
N. spruce	15	0.78 ±0.04
S. pine + N. spruce	12	1.54 ±0. 19
S. pine	12	0.99 ±0. 08
N. spruce	12	1.87 ±0. 22
S. pine + E. beech	33	1.44 ±0.13
S. pine	33	1.22 ±0.12
E. beech	33	1.68 ±0.18



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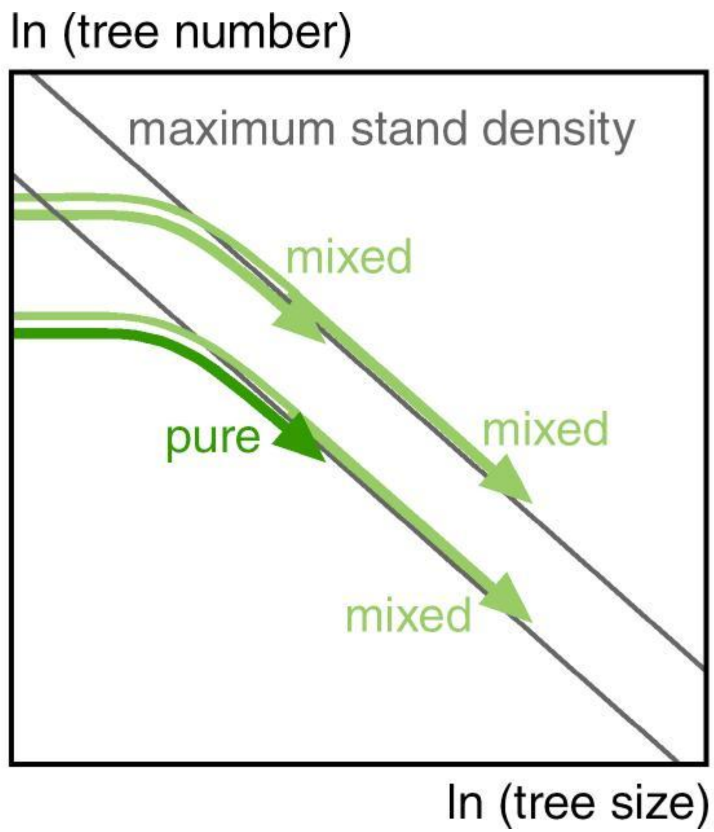
4 Effects on stand density and mean tree growth rate



Δ growth rate

Δ stand density

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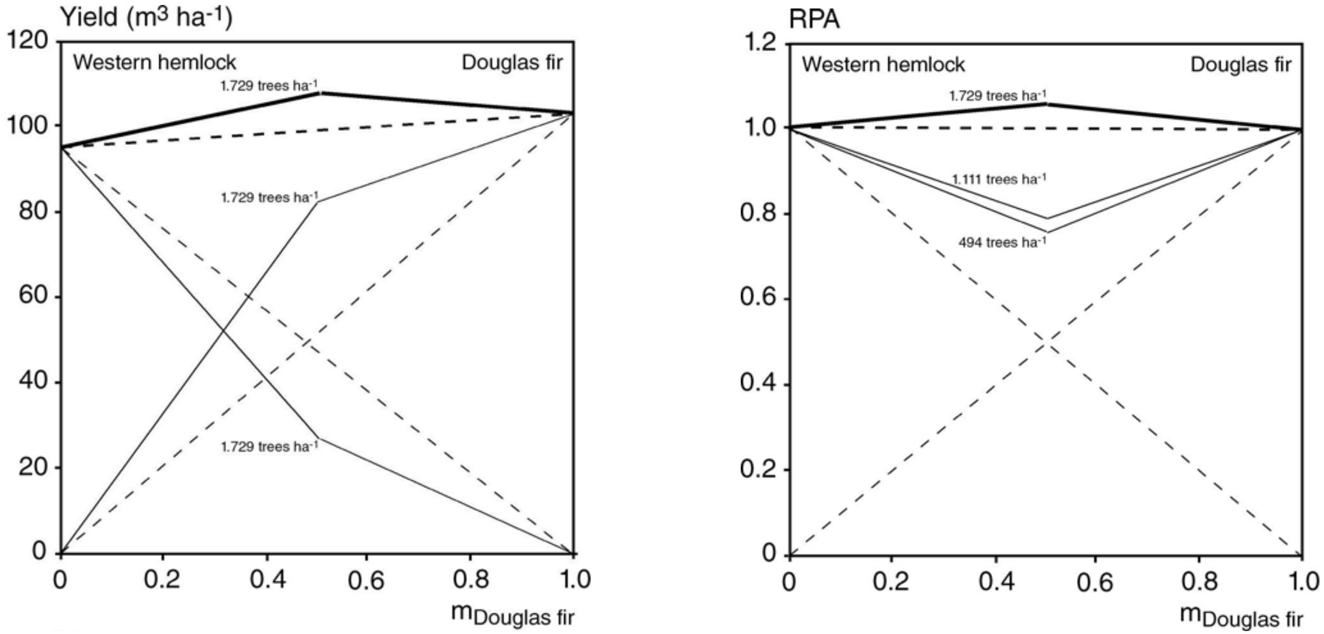
1 Experimental set-up, data, evaluation
Mixing effects may become obvious especially in fully stocked stands



Amorosos M. M. and Turnblom, E. C. (2006) Comparing productivity of pure and mixed Douglas-fir and western hemlock plantations in the Pacific Northwest, Can. J. For. Res. 36:1484-1496

1 Experimental set-up, data, evaluation
Mixing effects may become obvious especially in fully stocked stands

Summary 4:

- Species mixing can increase both growth rate of mean tree and stand density.
- Trees can grow quicker and denser in mixture.
- Species-mixing effects can only partly be „thinned away“

Amorosos M. M. and Turnblom, E. C. (2006) Comparing productivity of pure and mixed Douglas-fir and western hemlock plantations in the Pacific Northwest, Can. J. For. Res. 36:1484-1496

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TECHNISCHE UNIVERSITÄT MÜNCHEN

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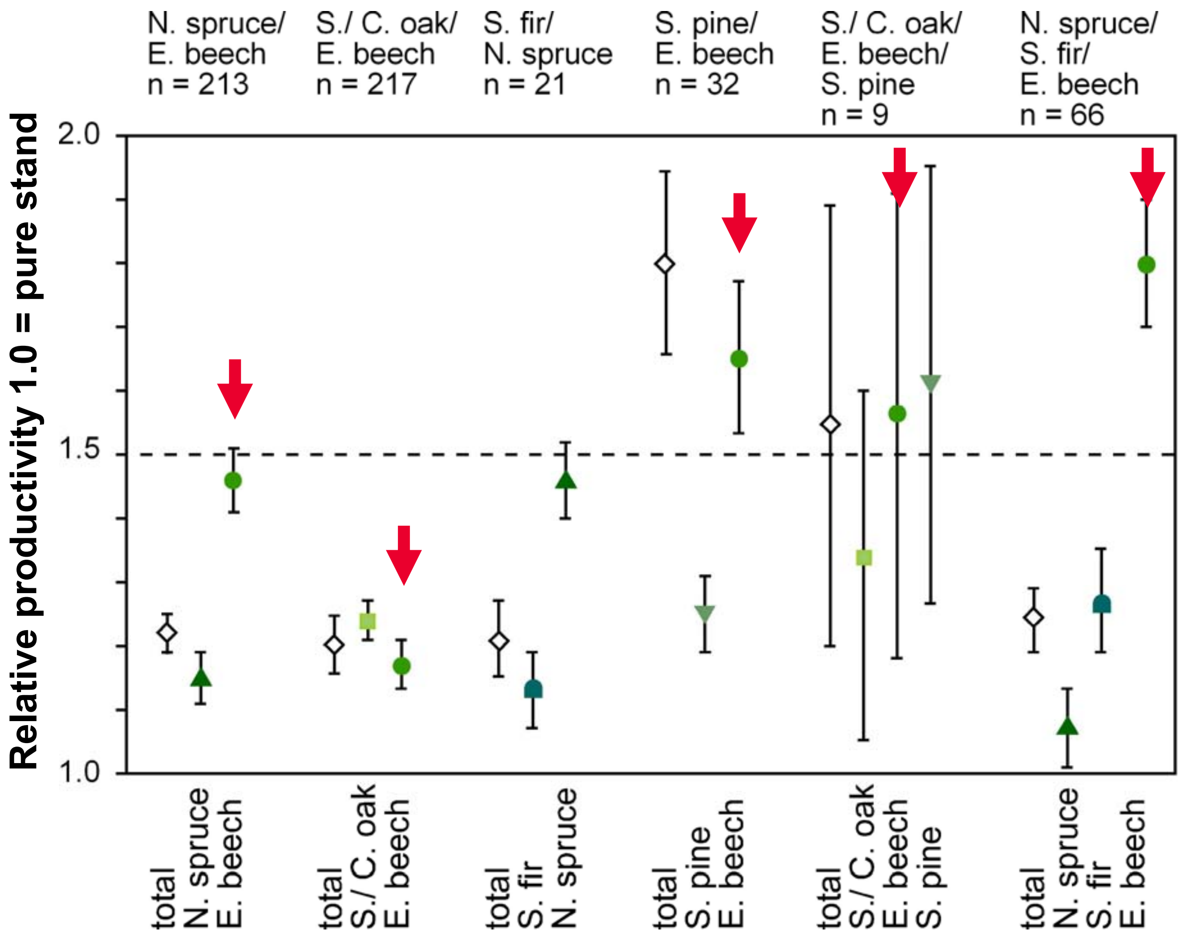
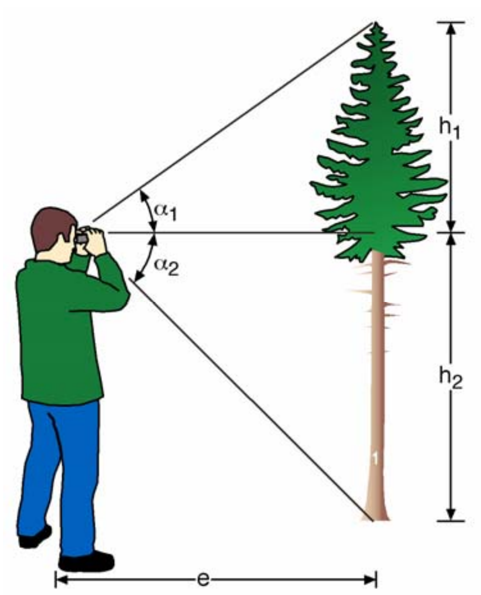
5 Tracing mixing effects from stand to tree level

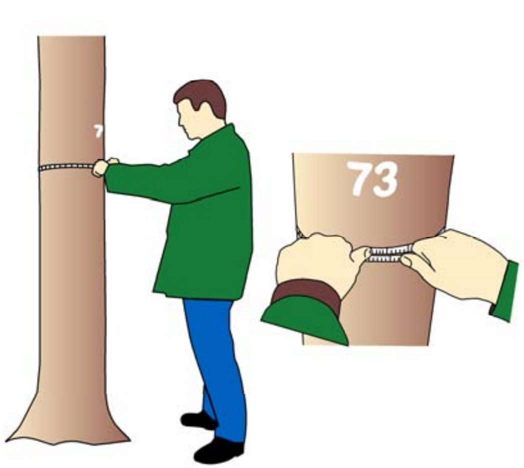
Summary and perspective

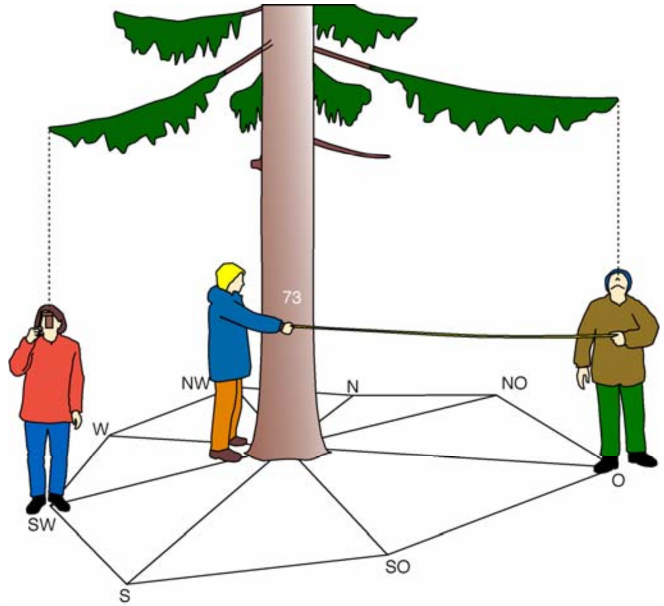
5 Notorious overyielding of beech in mixture



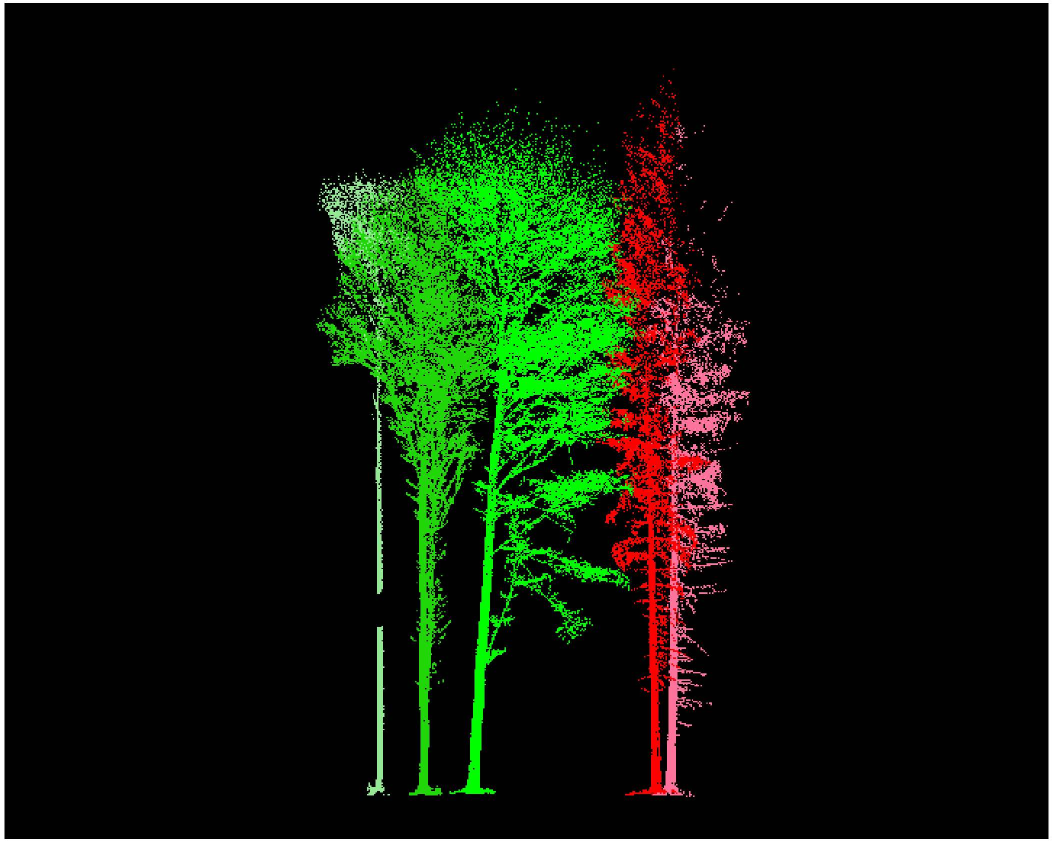
5 Classical measurement of tree and stand structure





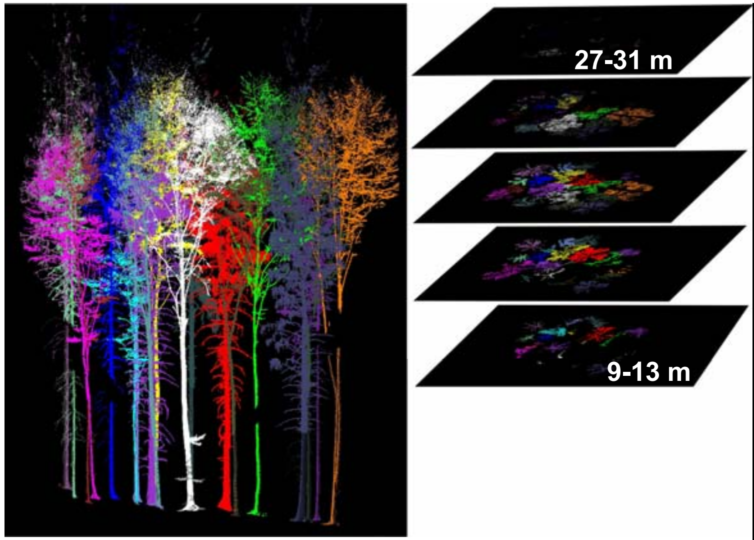


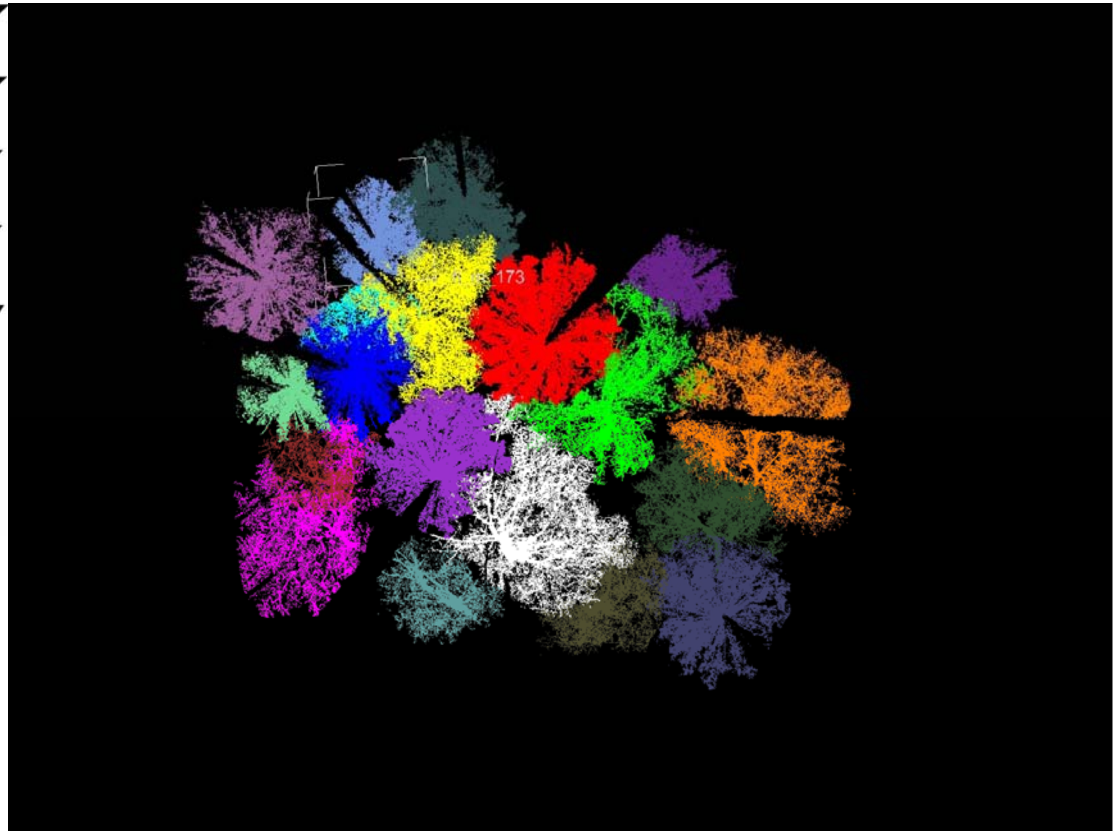
5 TLidar Riegl Z420i for measuring crown morphology and space occupation



measurement range: 2 – 1,000 m, accuracy (dist 50 m): <10 mm
minimum angle stepwidth: 0.004°, field of view: 80° × 360 °

5 TLidar provides voxel patterns and canopy space occupation by plants





- radiation profile and shading
- biomass allocation
- air corridors for birds and bats

Bayer, Seifert, Pretzsch (2012) Structural crown properties of Norway spruce and European beech in mixed versus pure stands revealed by terrestrial laser scanning, Trees, DOI: 10.1007/s00468-013-0854-4

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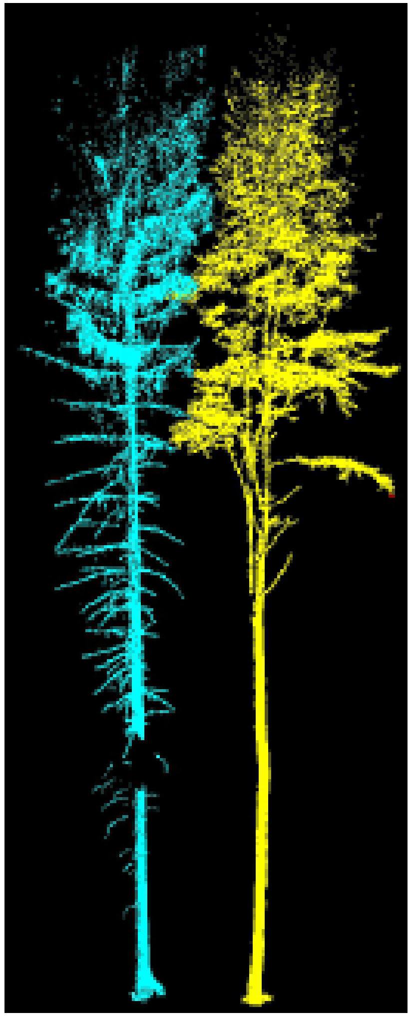
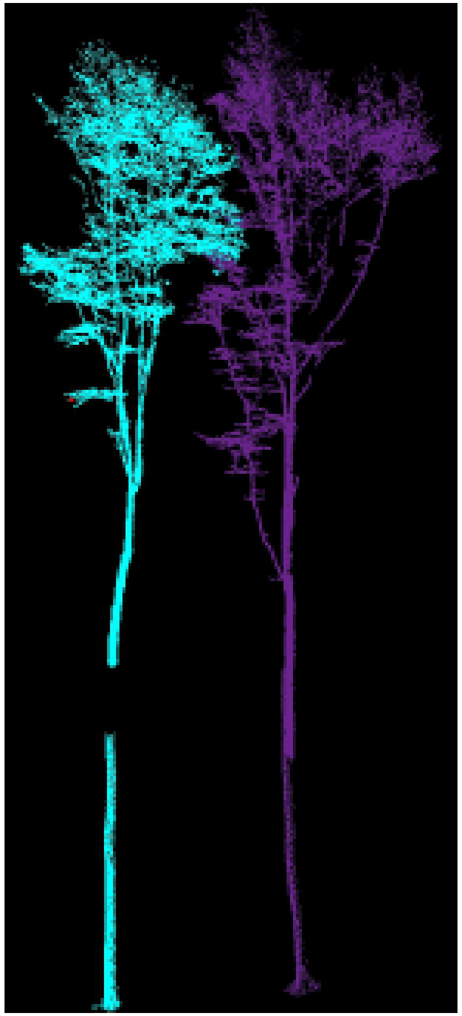
5 TLidar for measuring tree-tree interaction

spruce-beech



beech-beech



- crown penetration
- crown shyness
- mechanical abrasion
- canopy roughness and stability

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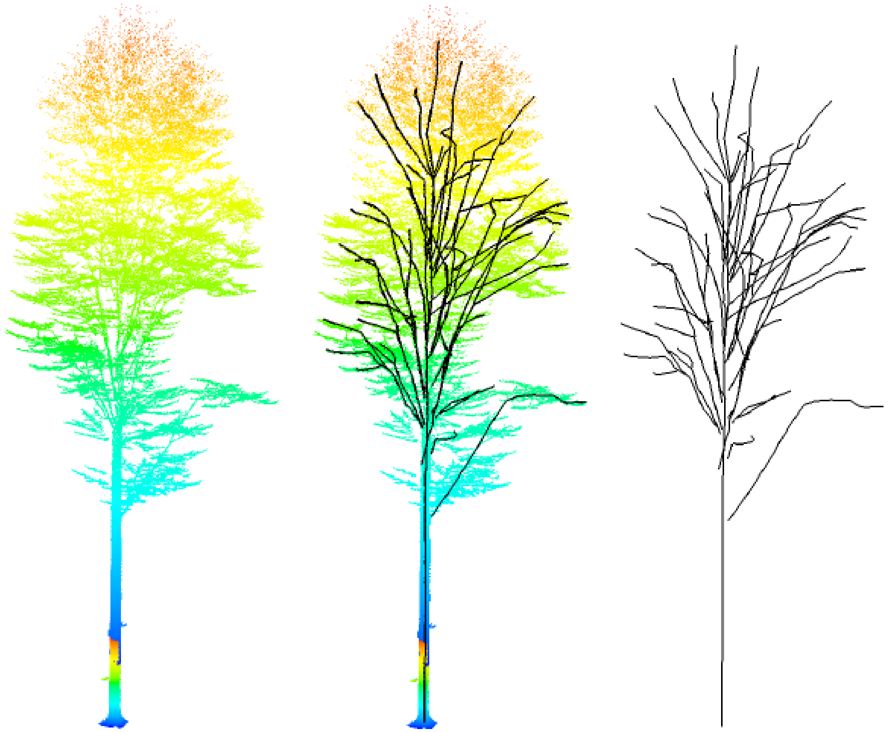
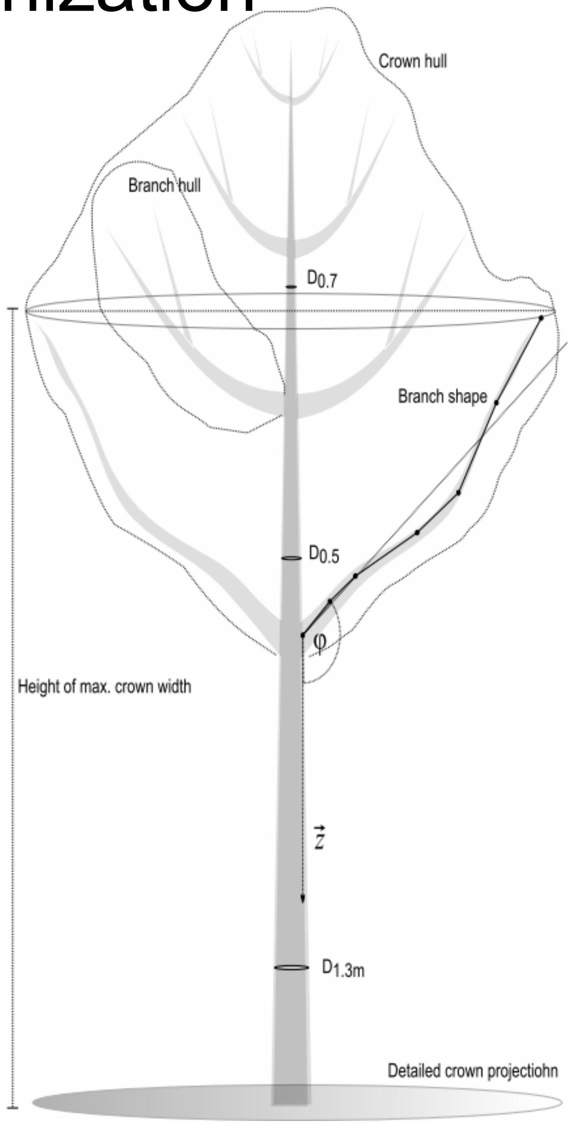
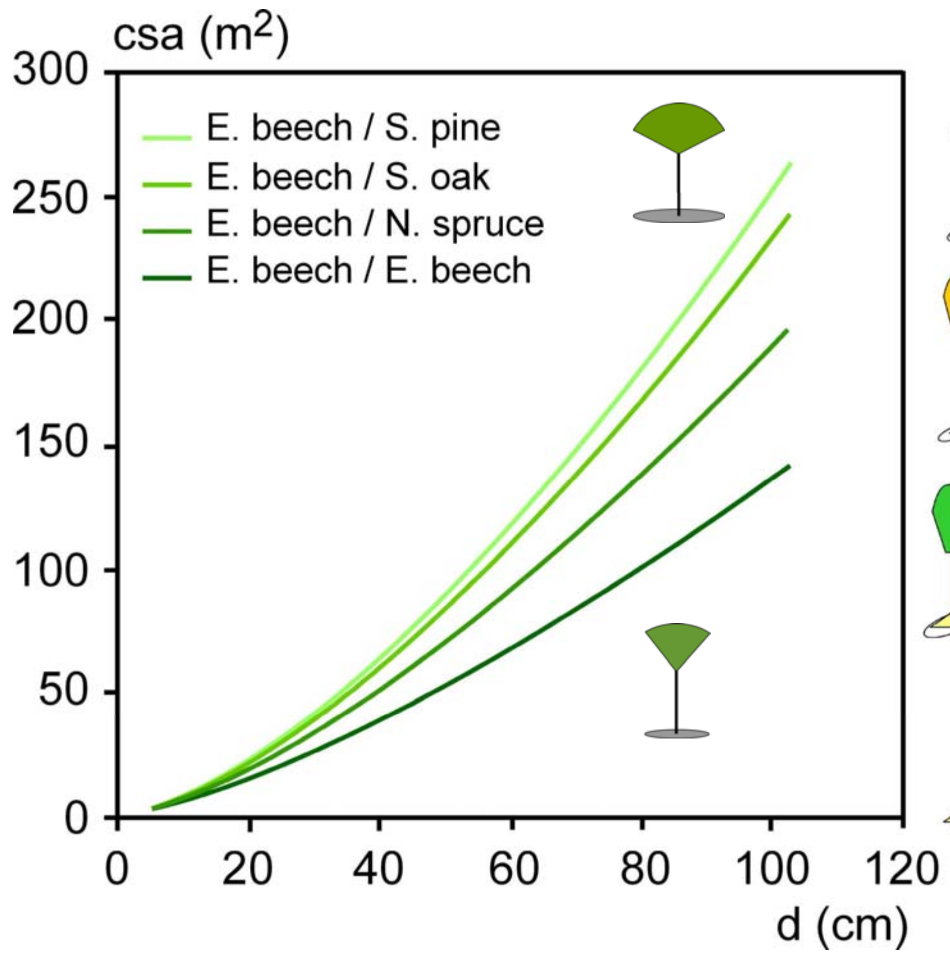
5 TLidar for measuring crown morphology after tree structure skeletonization

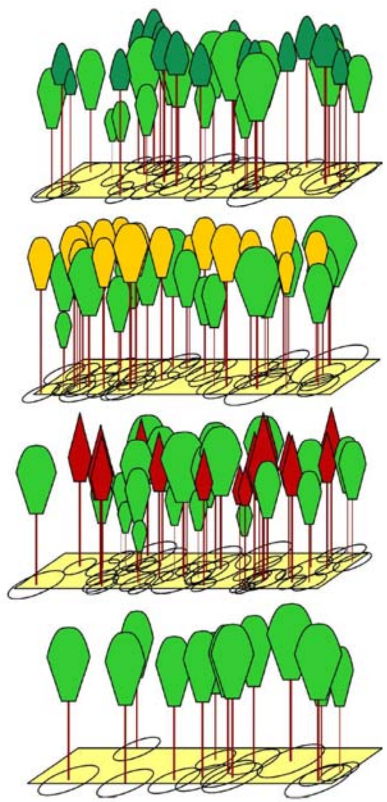


- convex hull of crown or branches
- stem diameter, height, inclination
- branch number, length, angle
- wood quality



5 Crown allometry of beech in mixed stands: csa= f(SDI, species, d), SDI const. = 463 N ha^{-1}





Data base:

88 experiments
147 plots
182 surveys
4,035 beeches:
1,977 be-be,
66 beech solitairs
1,020 be-oak
833 be-sp
139 be-pi

Dieler, J. and Pretzsch, H. (2013) Morphological plasticity of European beech (Fagus sylvatica L.) in pure and mixed-speceis stands, Forest Ecol. Manage. http://dx.doi.org/10.1016/j.foreco.2012.12.049

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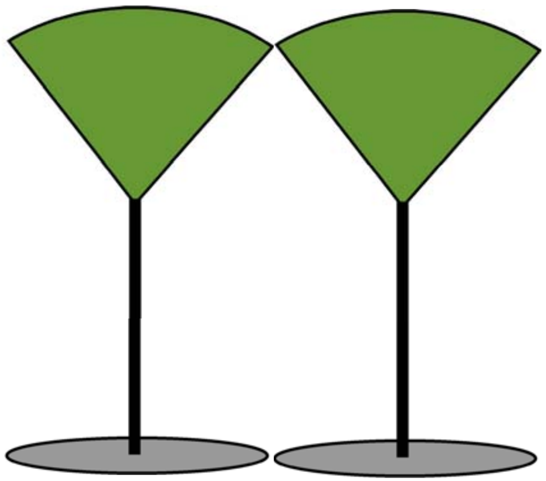
5 Morphological differences in intra- vs. inter-specific environment despite of equal biomass

beech/beech



branch number
19 vs. 36

branch length
4.8 m vs. 4.3 m

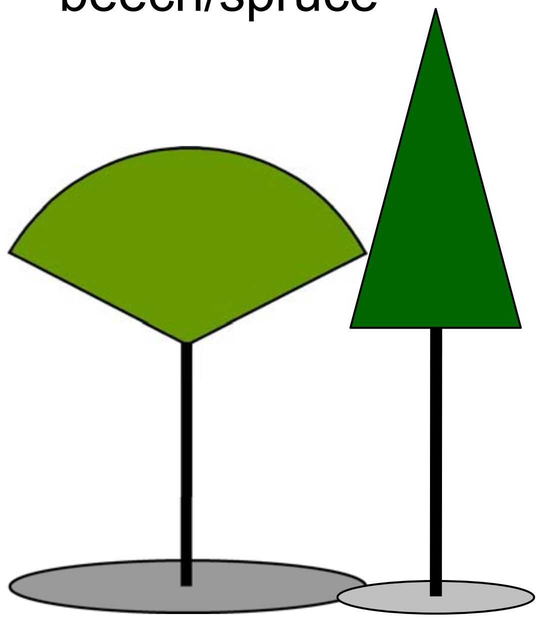
branch angle
139° vs. 128°

branch straightness
96 vs. 94

stem inclination
2° vs. 3.5°

crown volume
25 m^3 vs. 59 m^3

beech/spruce



Bayer, Seifert, Pretzsch (2012) Structural crown properties of Norway spruce and European beech in mixed versus pure stands revealed by terrestrial laser scanning, Trees, DOI: 10.1007/s00468-013-0854-4

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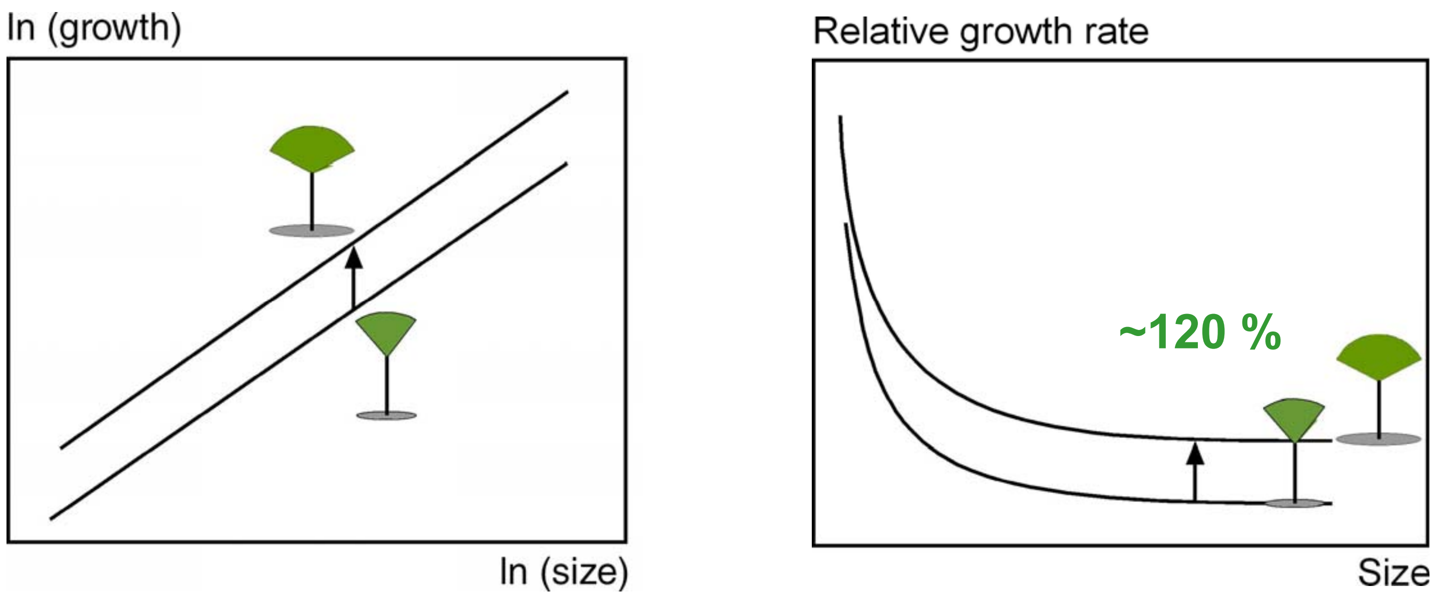
5 Overyielding of beech in mixture by wider crown expansion and surpression of neighbours during continuous stand development



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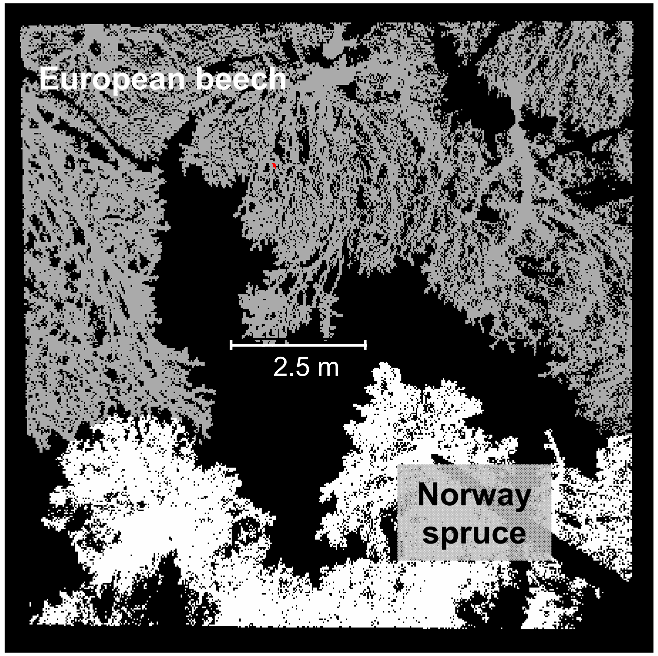
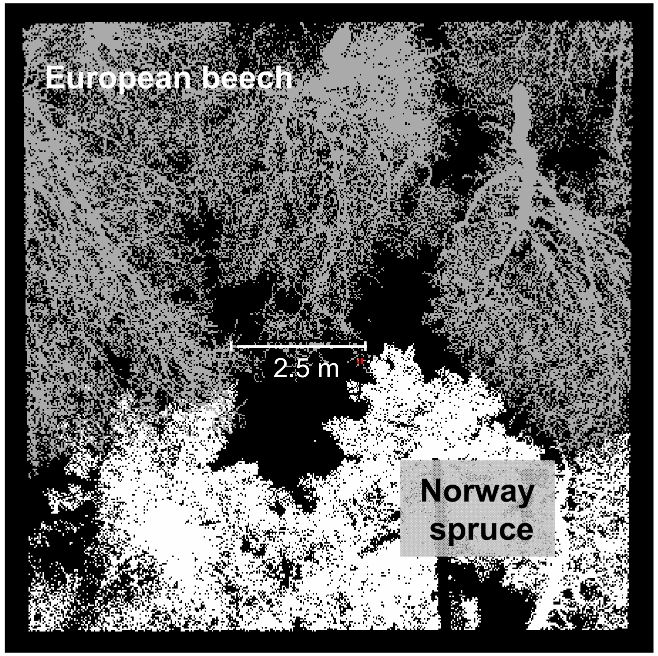
5 Gap filling by Norway spruce and European beech from 2006-2010 plasticity after disturbances





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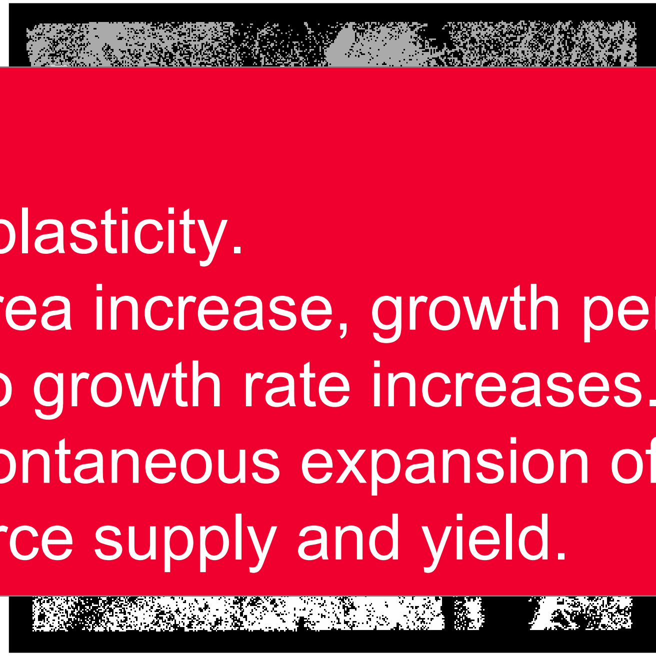
5 Gap filling by Norway spruce and European beech from 2006-2010



Summary 5:

- Mixing can trigger crown plasticity.
- In case of beech crown area increase, growth per crown area is constant, so growth rate increases.
- Continuous overlap or spontaneous expansion of crown can improve resource supply and yield.

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Summary and perspective

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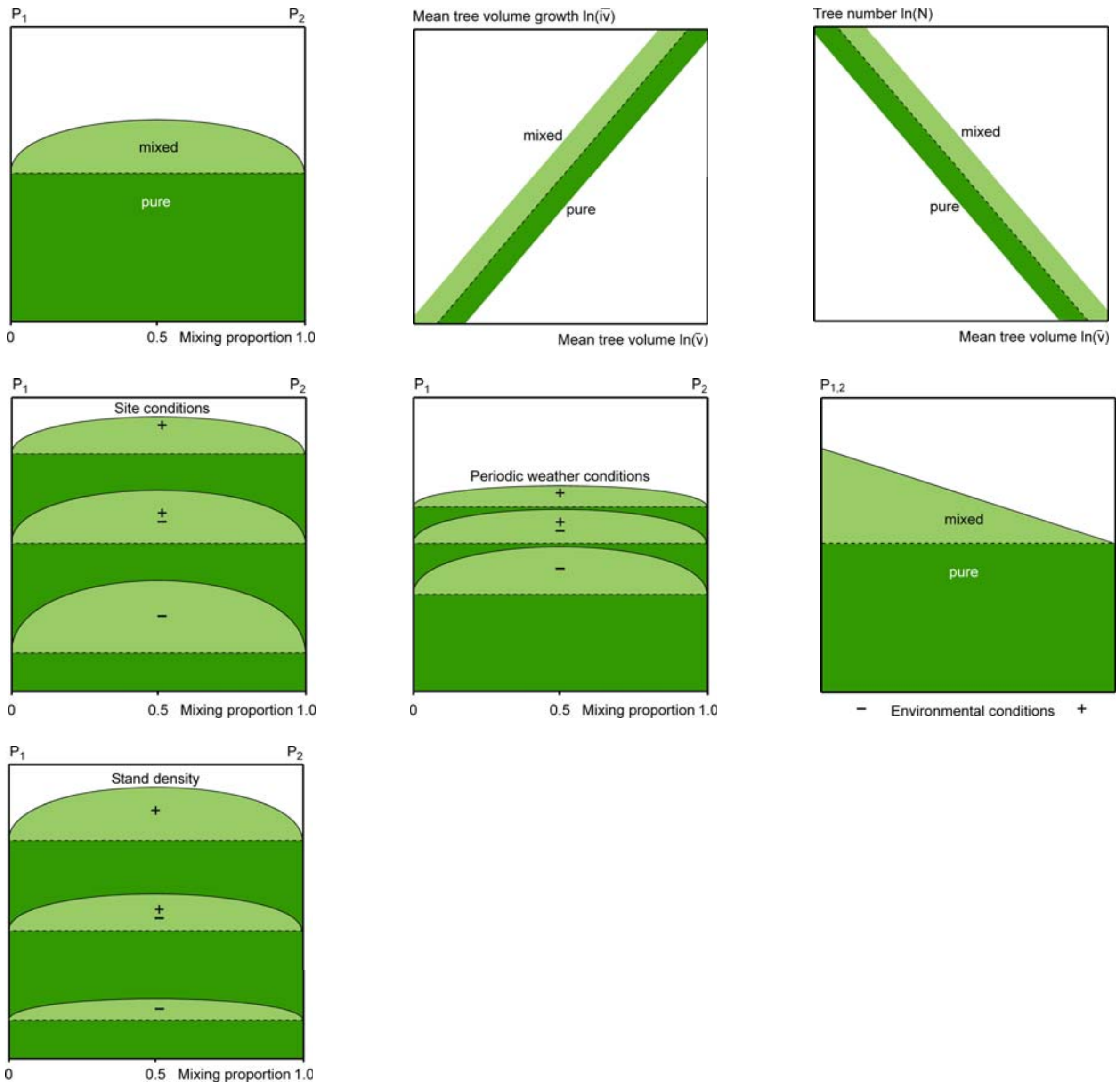
Synopsis and perspective



stand productivity modified by species mixing

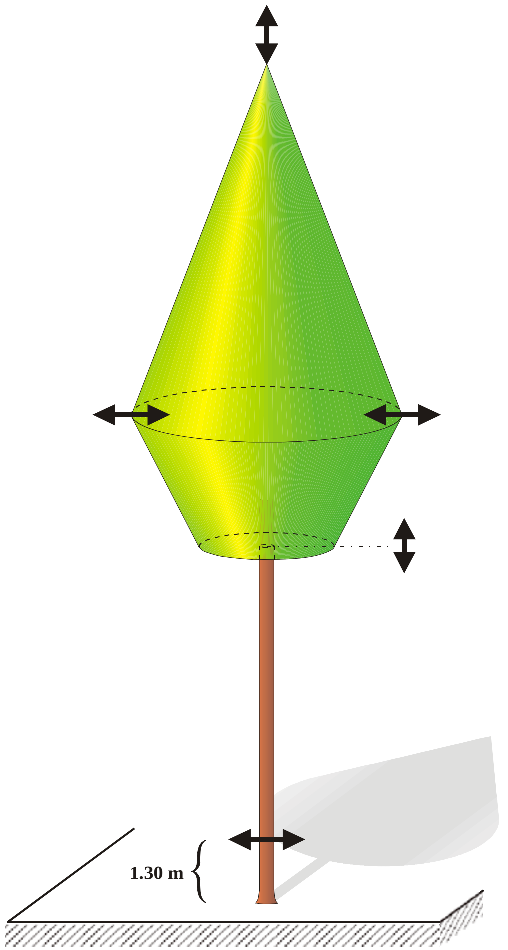
environmental conditions as modifier

stand density as modifier

Synopsis and perspective

- Analoguous evaluation of additional mixtures.
- Causes with respect to environmental conditions (experiments, transects).
- Causes in terms of structural traits of crown and root.
- Effect of density modification by spacing, thinning, and other disturbances.
- Integration of mixing effects into process-based models and individual tree hybrid models.

Functions for regulation of the individual tree growth in the SILVA 3.0 simulator



$$\frac{\Delta\,\text{height}}{\Delta\,t} = f_1(\text{height, crown, competition, site conditions})$$

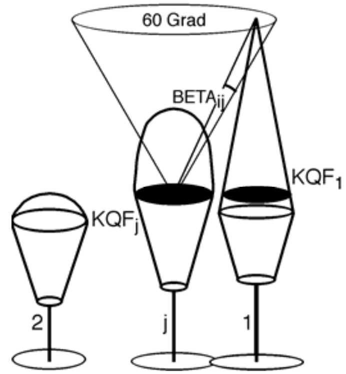
$$\text{crown-diameter} = f_2(\text{height, diameter})$$

$$\text{crownbase} = f_3(\text{height, diameter})$$

$$\frac{\Delta\,\text{diameter}}{\Delta t} = f_4(\text{diameter, crown, competition, site conditions})$$

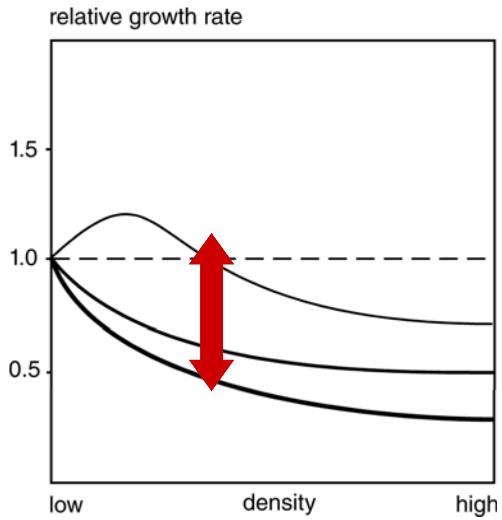
$$\text{mortality}_{\Delta t} = f_5\left(\begin{array}{c}\text{height, diameter, } \dfrac{\Delta\,\text{diameter}}{\Delta\,t}, \\ \text{competition, site conditions}\end{array}\right)$$

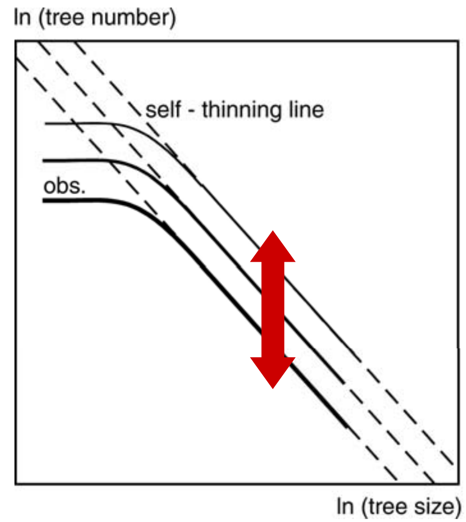
Quantification of competition

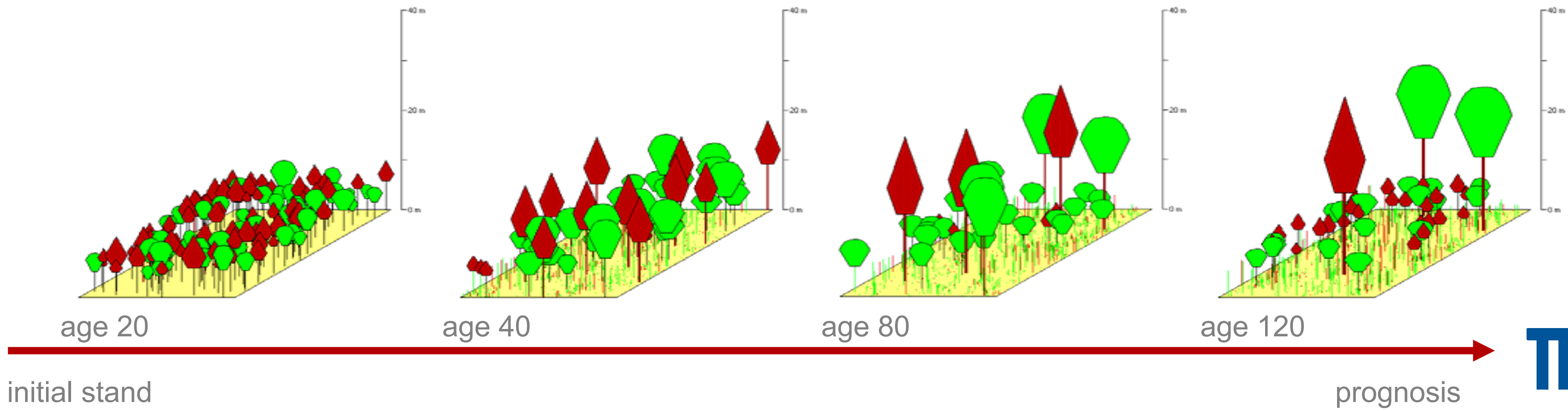


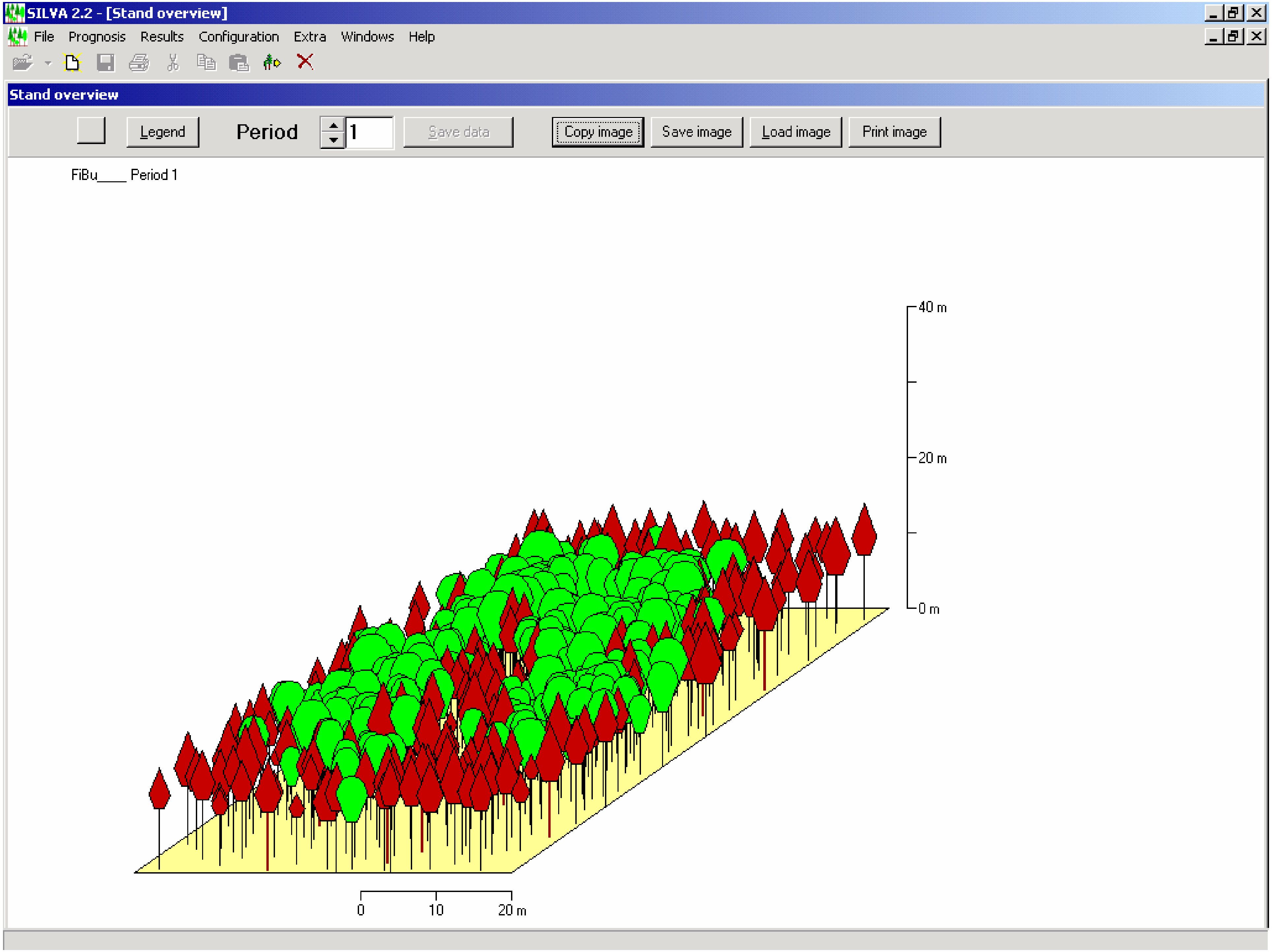
$$KKL_j = \sum_{\substack{i=1 \\ i \neq j}}^{n} BETA_{ij} \cdot \frac{KQF_i}{KQF_j} \cdot TM_i$$

Synopsis and perspective








SILVA 2.2 - [Stand overview]
File Prognosis Results Configuration Extra Windows Help
Stand overview
Legend
Period
1
Save data
Copy image
Save image
Load image
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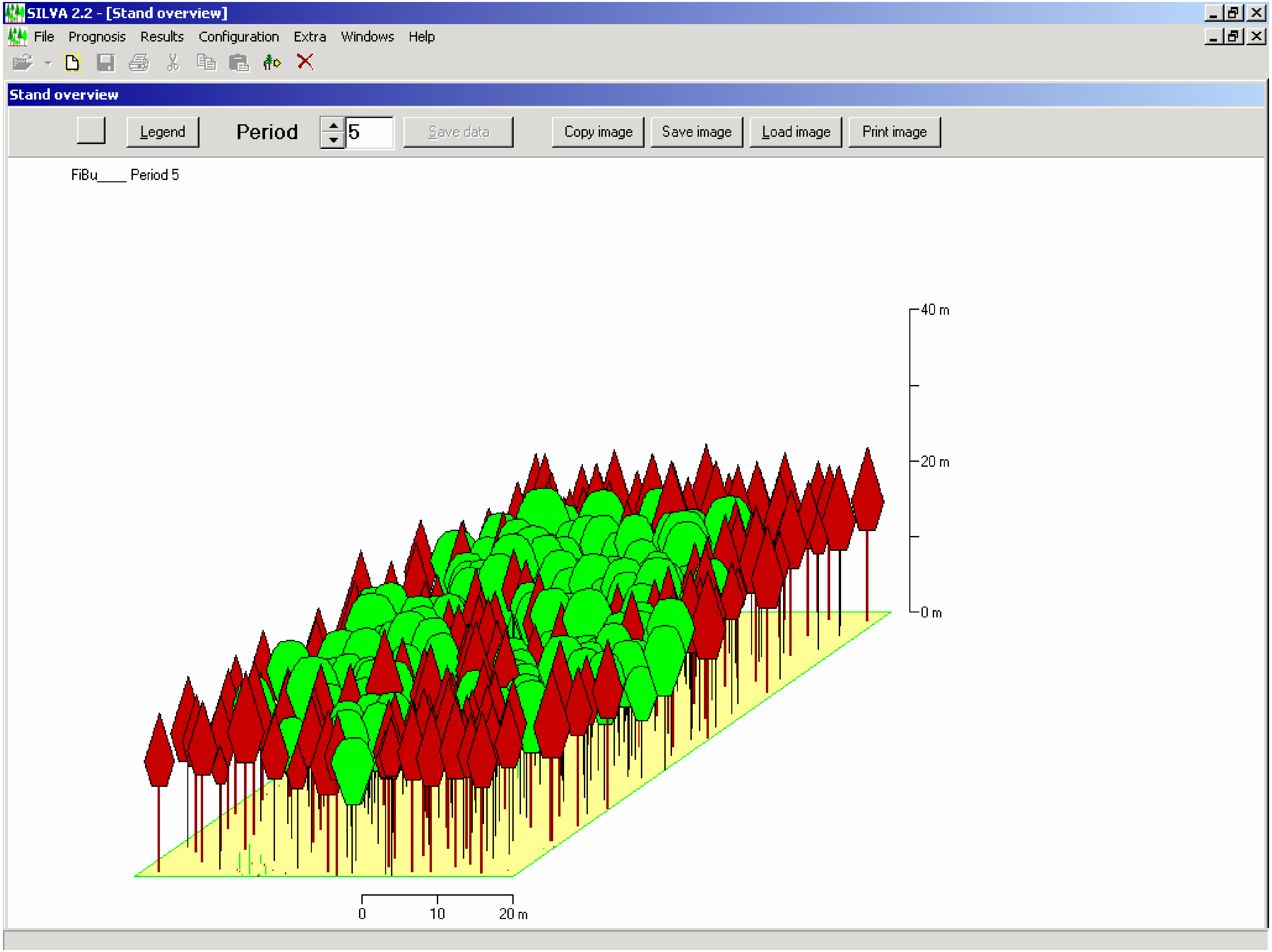
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Stand overview
Legend
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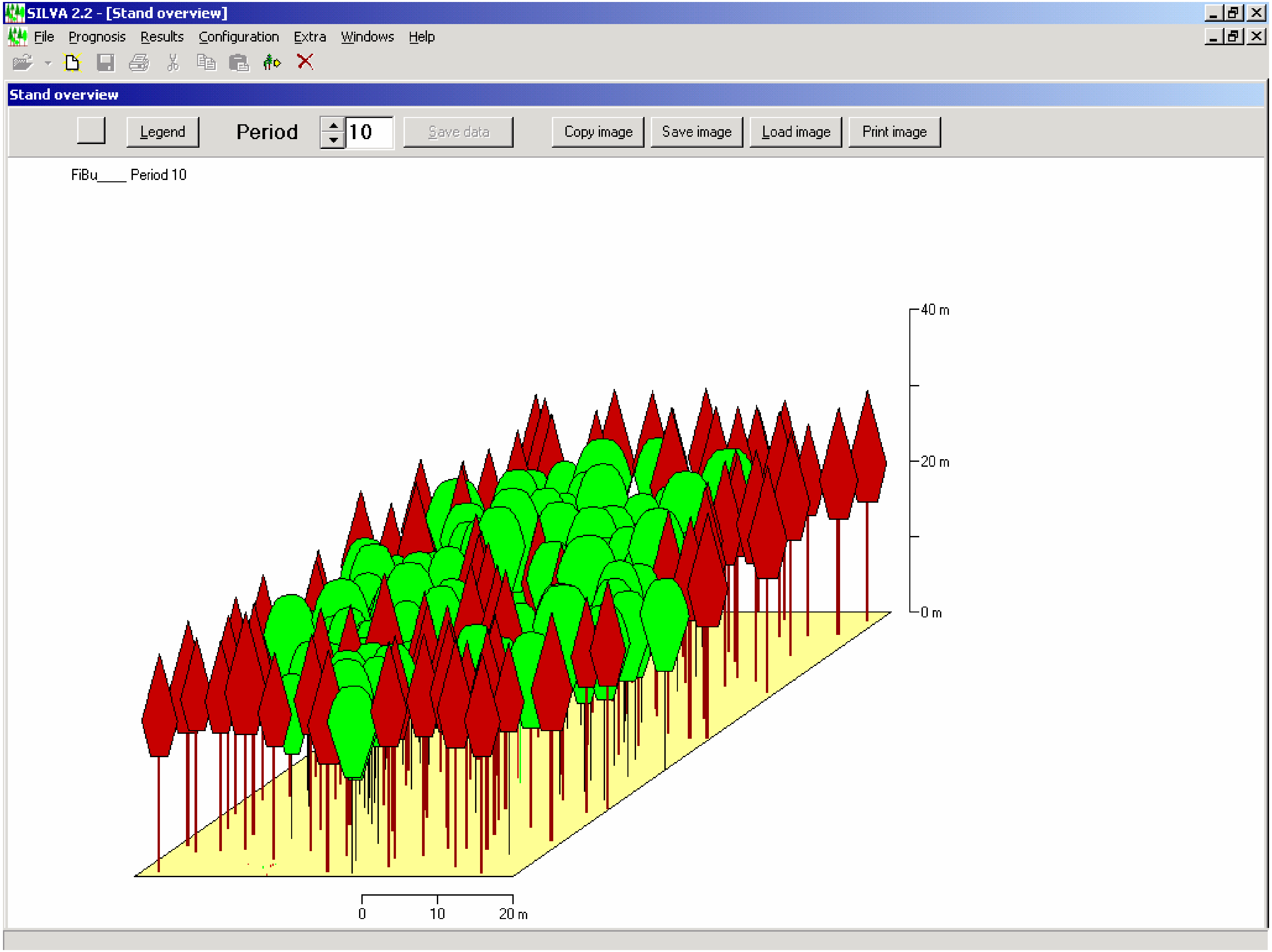
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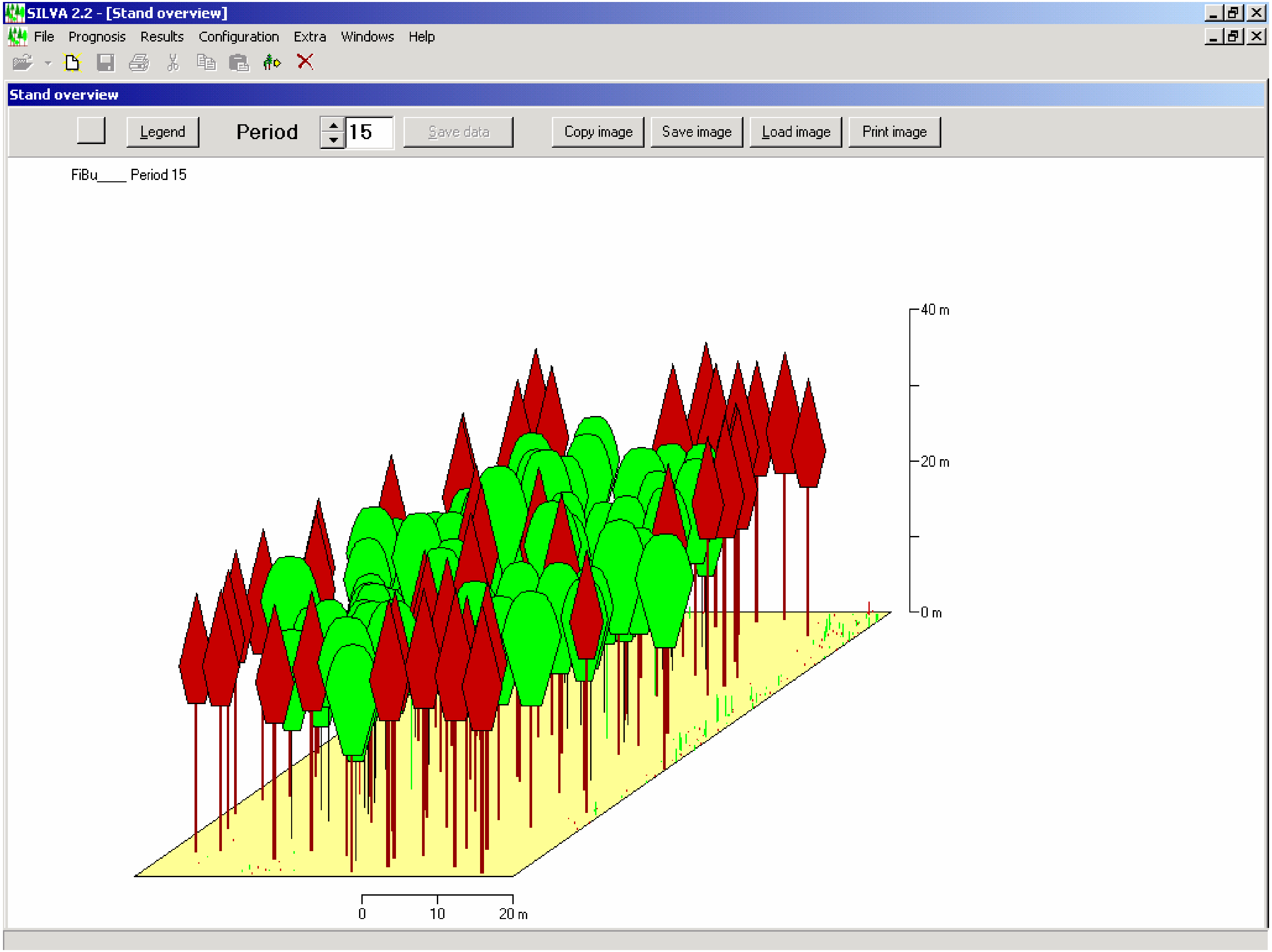
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Stand overview
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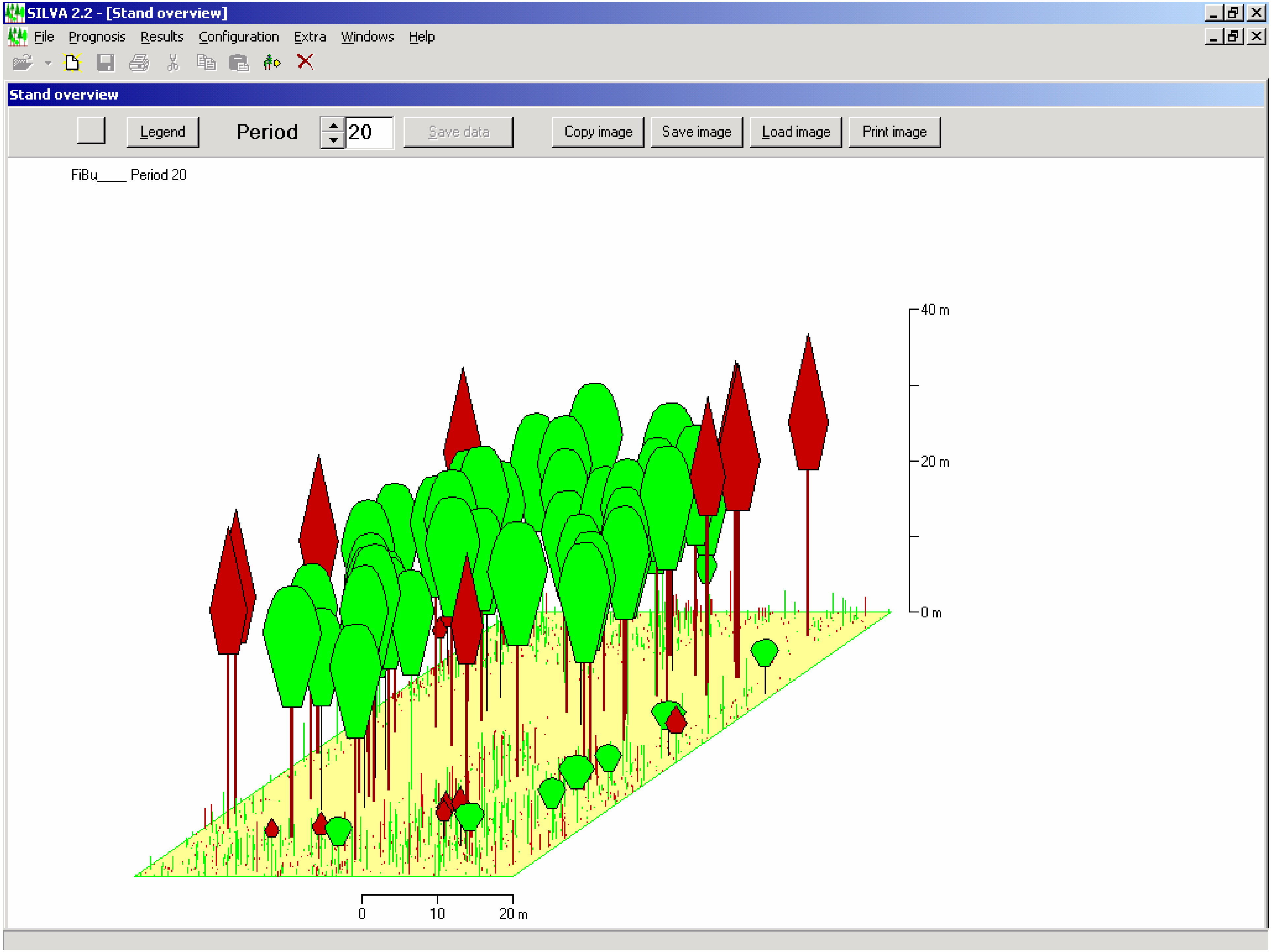

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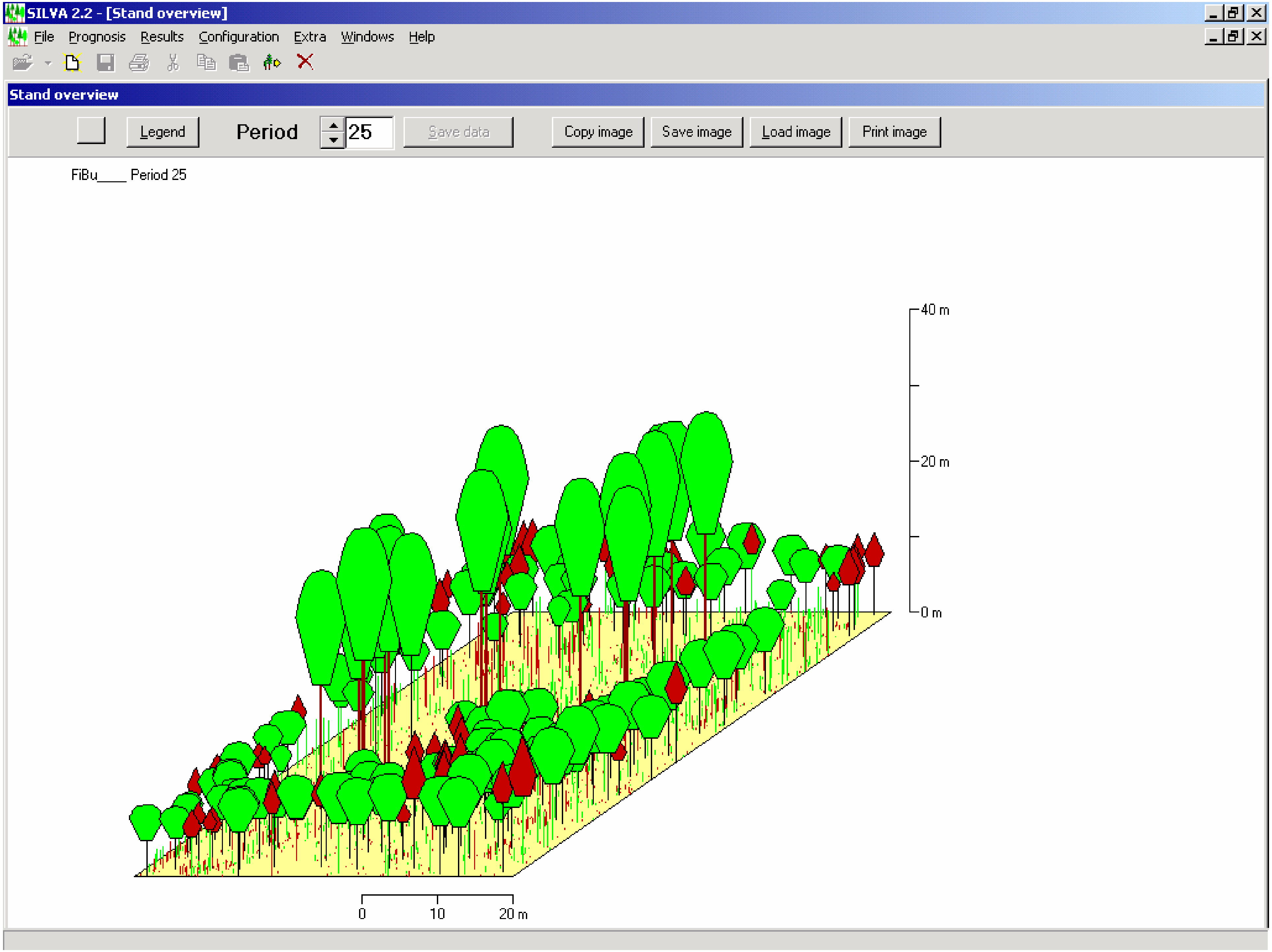
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20 m
0 m
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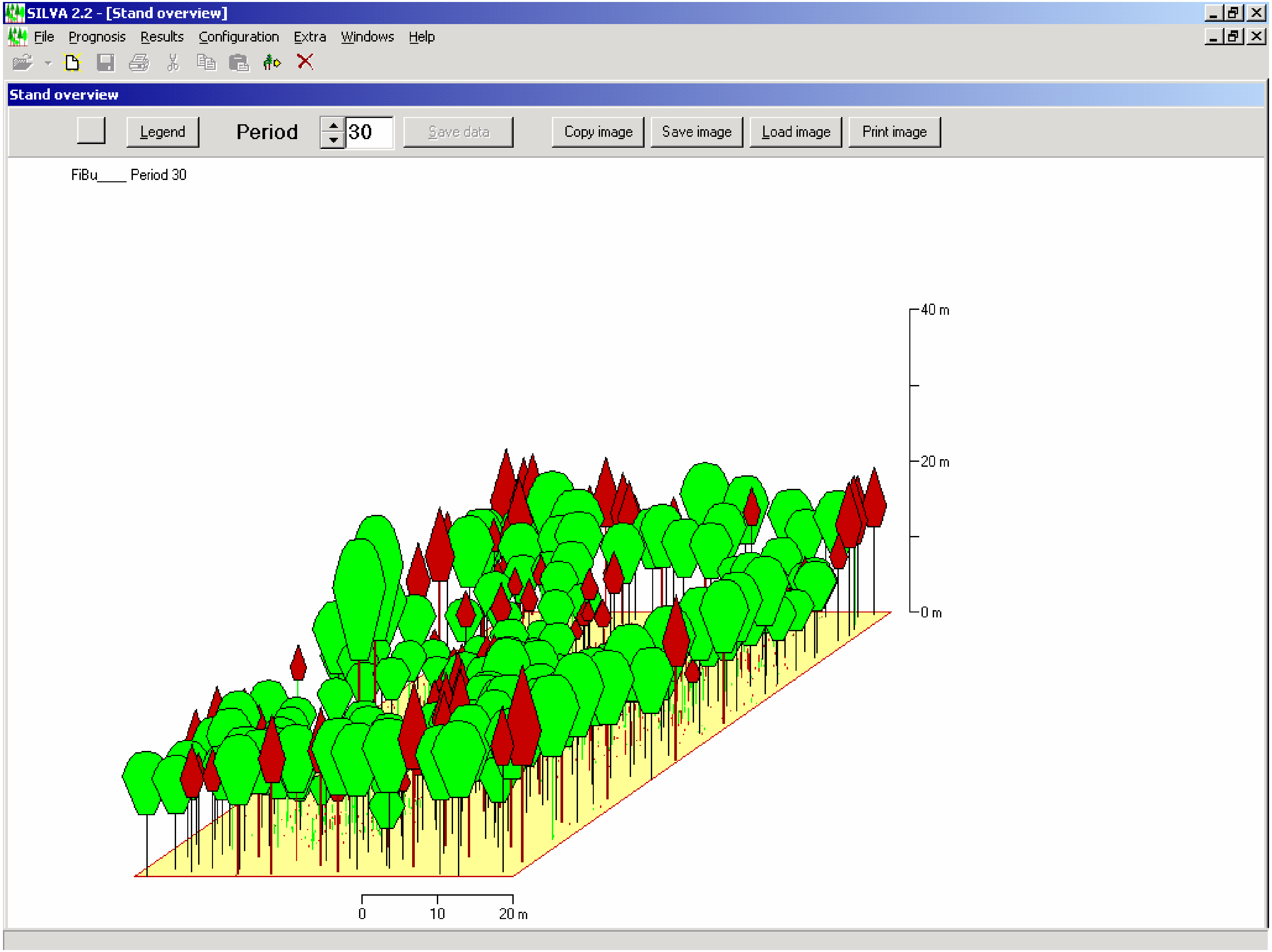
20 m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File Prognosis Results Configuration Extra Windows Help
Stand overview
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40 m
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0 m
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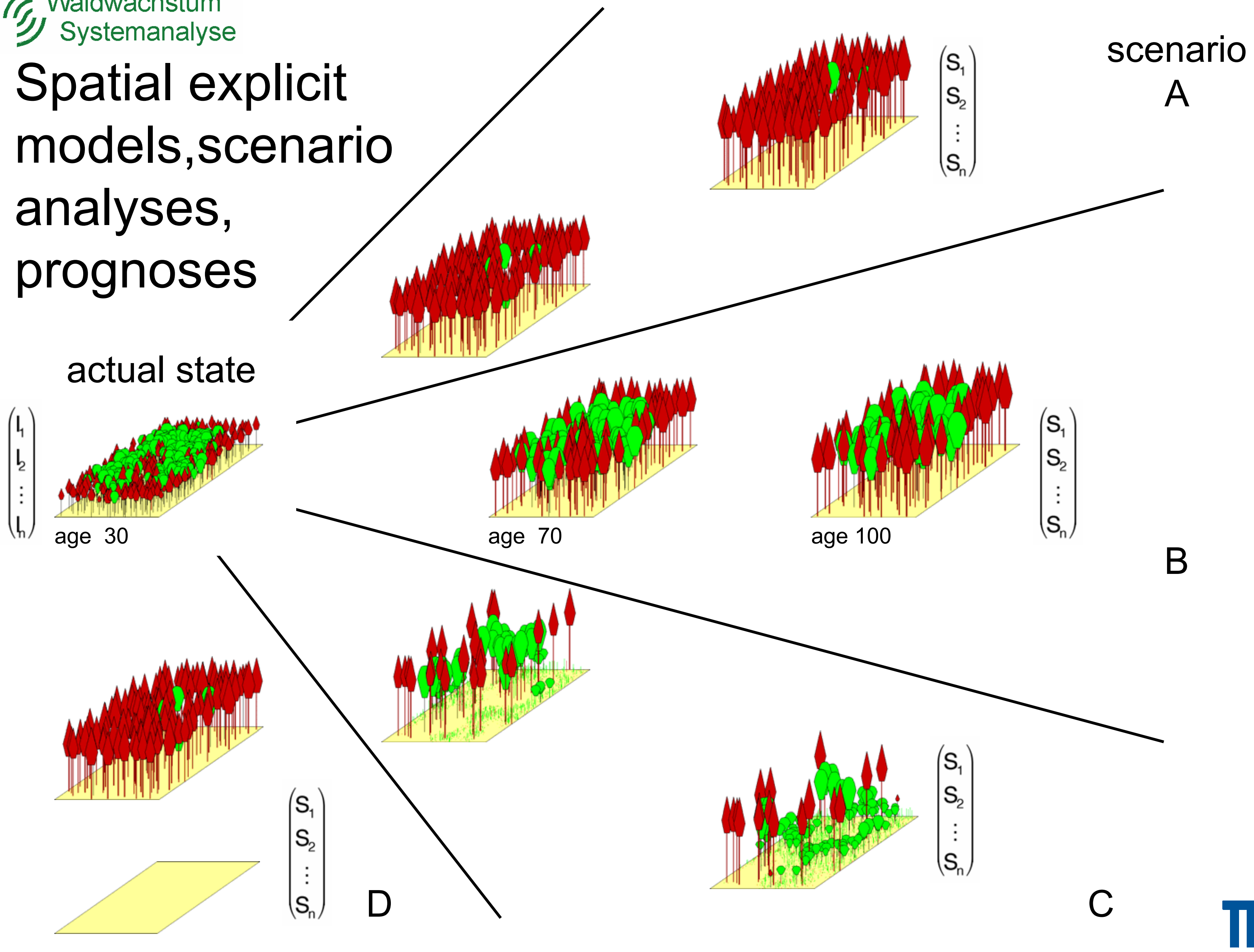
10
20 m

Waldwachstum Systemanalyse

Spatial explicit models,scenario analyses, prognoses



Criteria and indicators for sustainable forest management. Helsinki 1993, Lisbon 1998, Vienna 2003, Warsaw 2007

Criteria for sustainable forest management	Indicators
Forest resources	timber resources, area of forest, extension of area
Health and vitality	stability, fitness, elasticity
Productive functions	growth, yield, net return
Biological diversity	habitat quality, richness flora/fauna, conservation
Protective functions	soil, water, climate, noise, protection
Socio-economic functions	employment, recreation, esthetics, proximity to nature

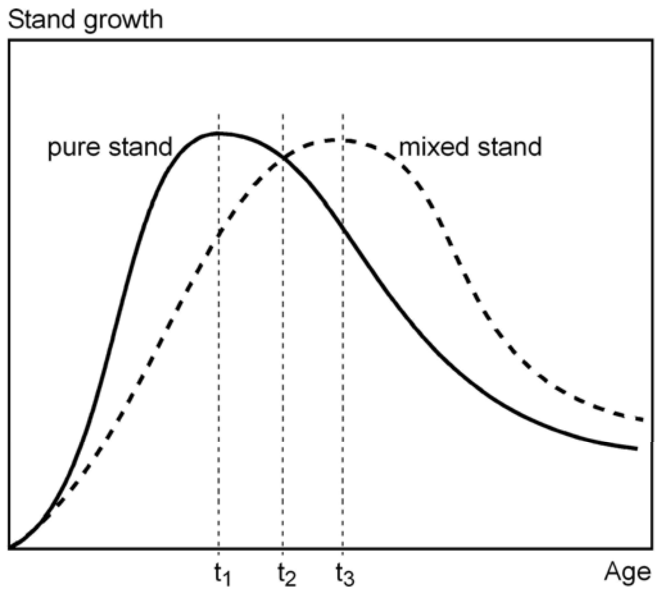
Thanks to:

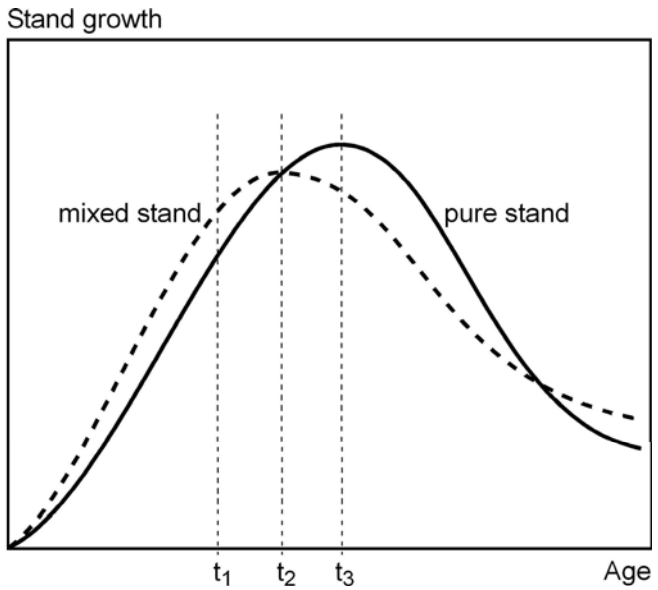
Hermann Spellmann/NW-FVA Göttingen
Hans-Peter Ehrhart/FAWF Trippstadt
Ulrich Kohnle/FVA Freiburg
Andreas Zingg/WSL Birmensdorf, Zürich
Kamil Bielak, Michal Zasada, Warsawa
Arkadiusz Bruchwald/Univ. Warsawa
Axel Martin Jensen, Kopenhagen
for contributing valuable datasets
from long-term experimental plots
in pure and mixed stands to this study.

German Science Foundation for funding SFB 607 'Growth and Defence in Plants‘, SFB/TRR 38 'Chicken creek catchment project‘, PR 292/10-1 'Interaction between beech and spruce‘.

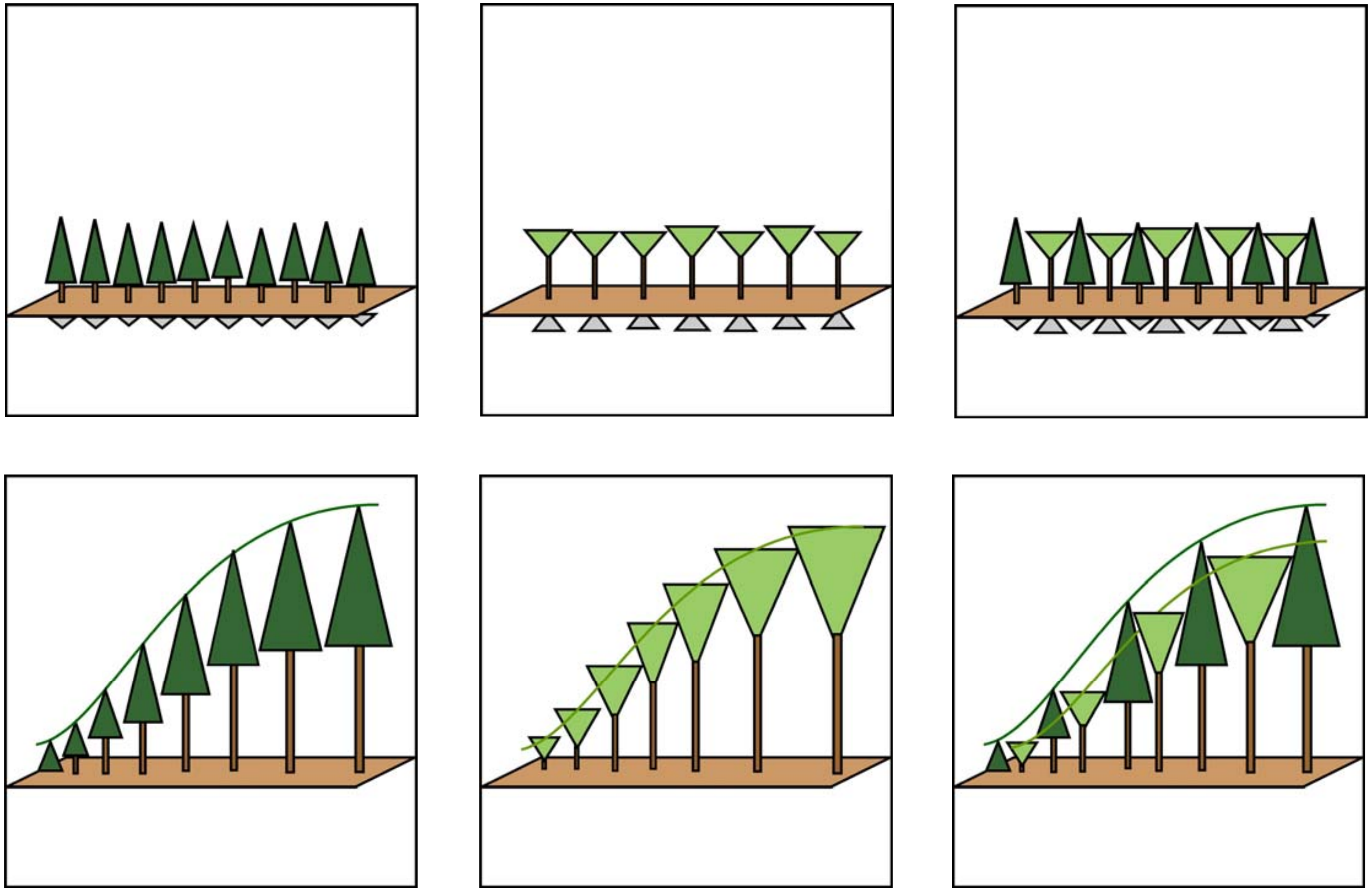
Waldwachstum
Systemanalyse

Supplement 1: Growth curve in mixed vs. pure stands in schematic representation: slowing down (left) and acceleration (right)





Supplement 1: Diminishing validity of the pure reference plots for a causal analysis of mixing effects



Supplement 1: Interspecific effect on course of growth, site index, and size development

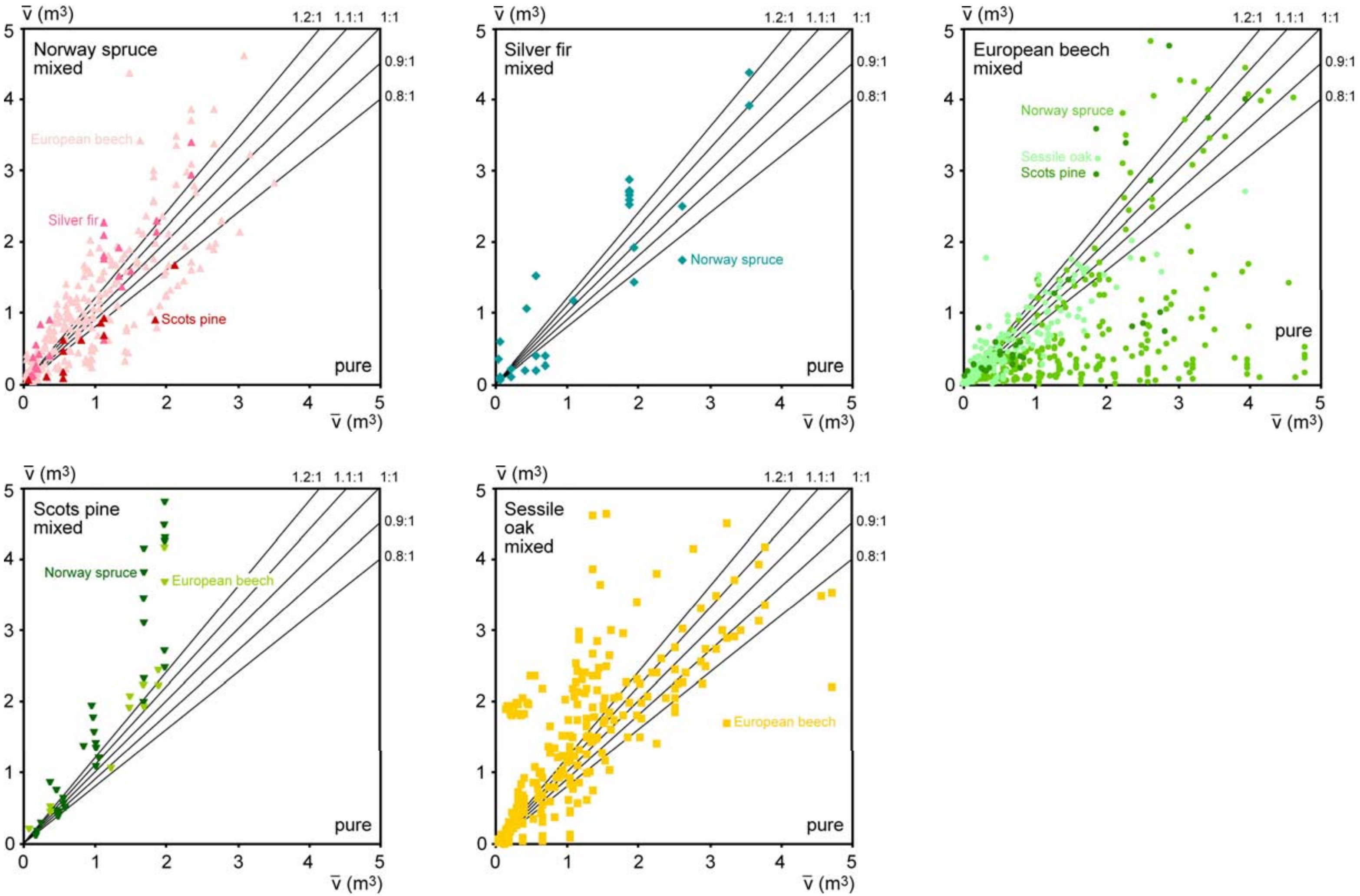
Mischbestand: Mischbestandstafel	Umtriebszeit (Jahre)	Ertragsklasse der einzelnen Holzarten mit ....Jahren	30	60	100	120 bzw. 140	dGZ des Mischbestandes (fm)	Reinbestand: Ertragstafel	Umtriebszeit (Jahre)	Ständige Ertragsklasse	dGZ des Reinbestandes (fm)
a.											
Eiche/Buche 1939	140	Eiche	I	I	I	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

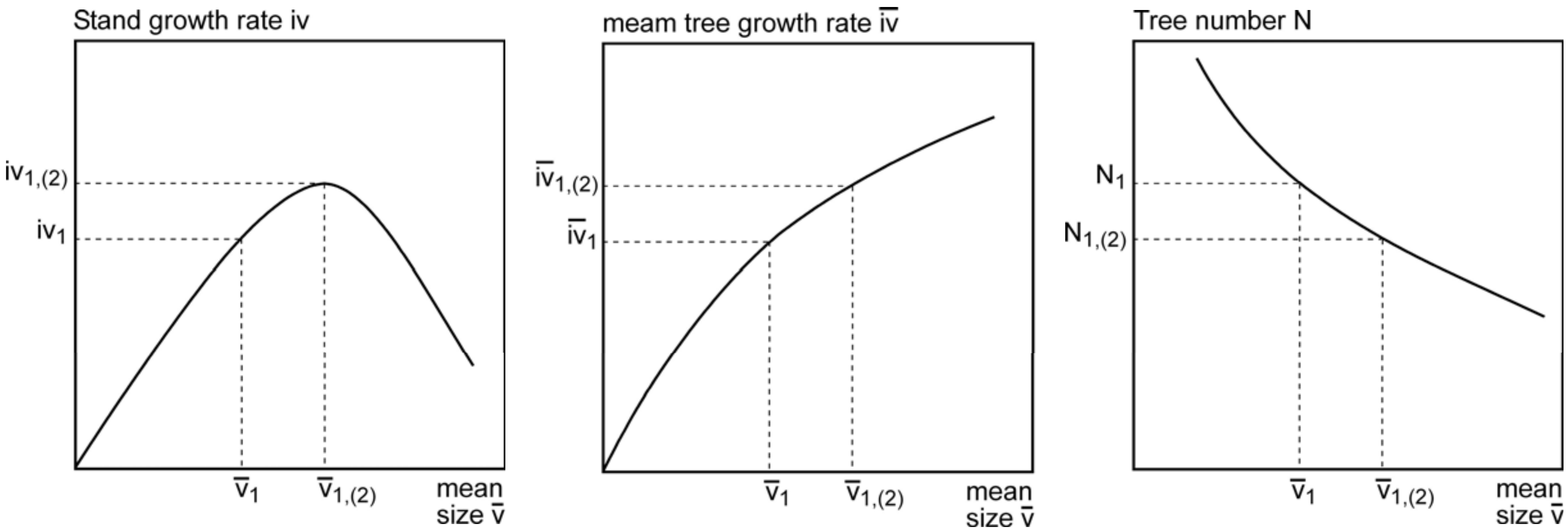
Wiedemann, E. (1951, p 132) Ertragskundliche und waldbauliche Grundlagen der Forstwirtschaft. Frankfurt, J. D. Sauerländer's Verlag

Waldwachstum
Systemanalyse

Supplement 1: Mean tree volume in mixed versus pure stand

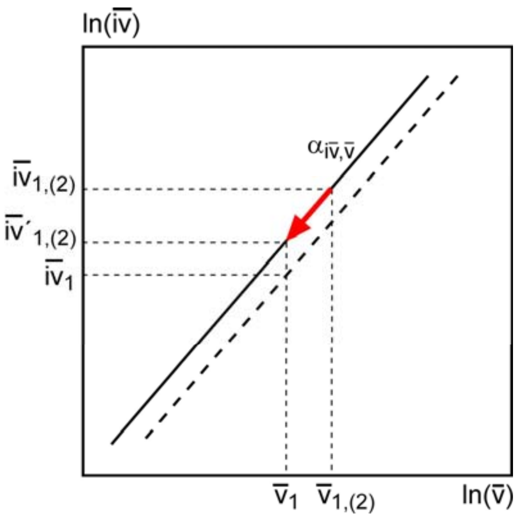


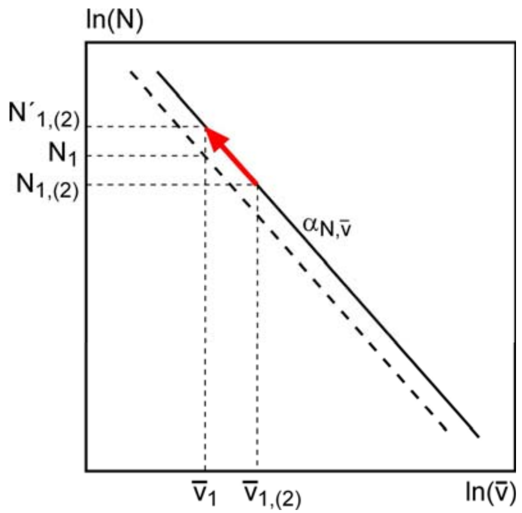
Supplement 1: Development of stand growth, tree growth and tree number in dependence on mean tree size:The problem of included allometric drift



Waldwachstum Systemanalyse

Supplement 1: 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

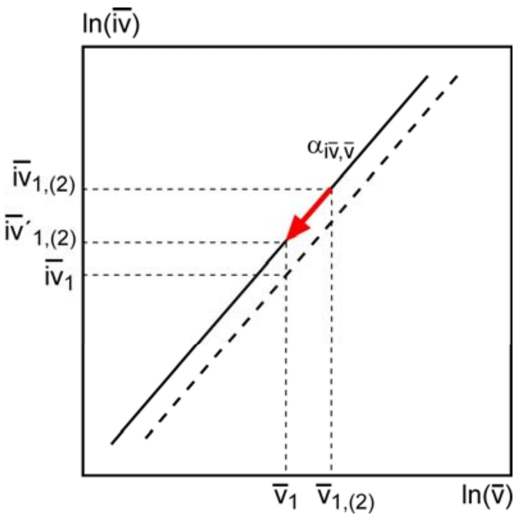
Scots pine

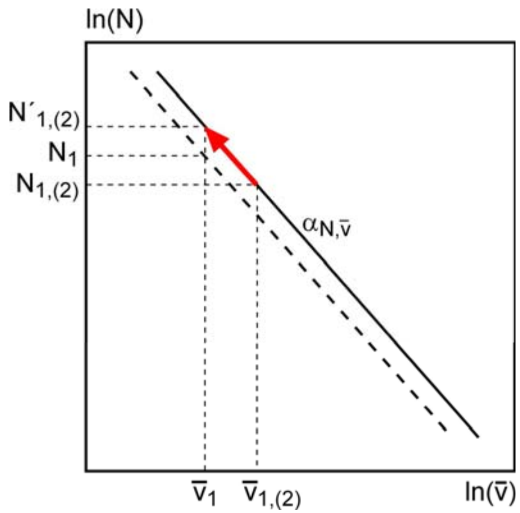
European beech

Sessile/Common oak

Waldwachstum Systemanalyse

Supplement 1: Elimination od allometric drift for comparing mixed vs. pure stand attributes





unadjusted:

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

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

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

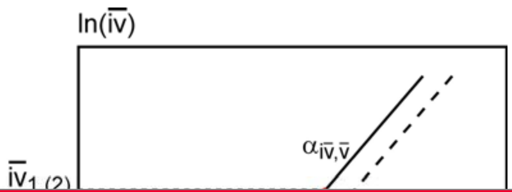
adjusted:

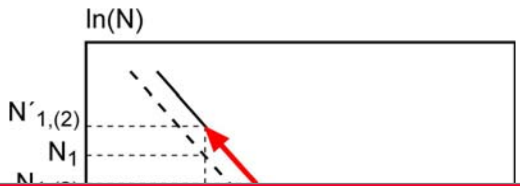
$$r\overline{iv}'_{1,(2)} = \frac{\overline{iv}'_{1,(2)}}{\overline{iv}_1} \qquad \overline{iv}'_{1,(2)} = \overline{iv}^{obs}_{1,(2)} \times \left(\frac{\overline{v}_1}{\overline{v}_{1,(2)}}\right)^{\alpha_2}$$

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

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

Supplement 1: Elimination od allometric drift for comparing mixed vs. pure stand attributes





Summary Supplement 1:

- 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:

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

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

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