Waldwachstumskunde
Systemanalyse

Mixed-species forests. Tracing mixing effects from the stand to the organ level

Hans Pretzsch
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http://waldwachstum.wzw.tum.de/index.php?id=presentations


Norway spruce monocultures in the lowlands

Mixed-species stands of European beech and Douglas-fir

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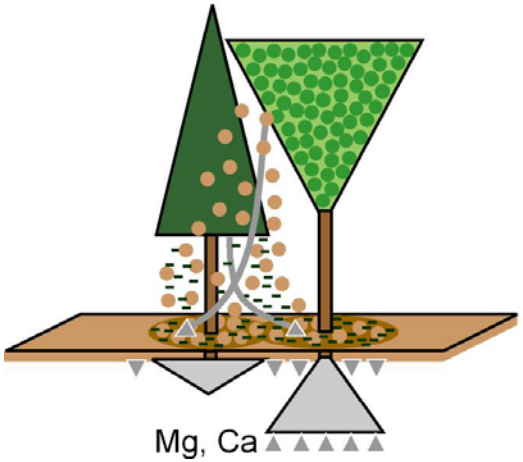
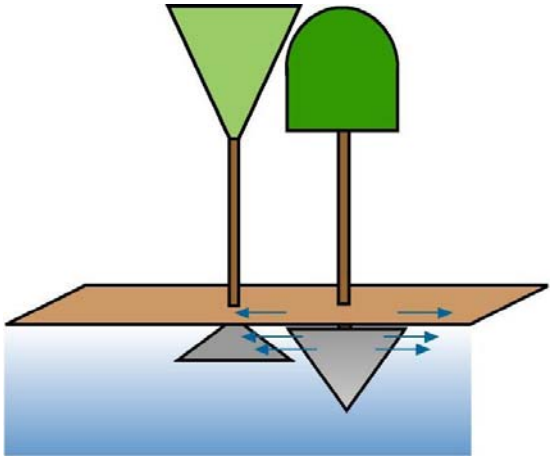
Facilitation by better mineral nutrients and water exploitation

nutrients
upward transport



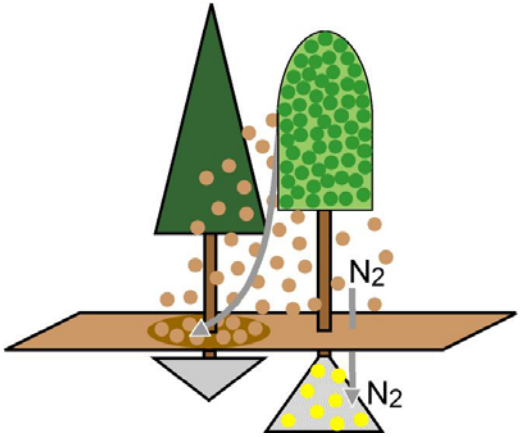
e.g. Rothe, Binkley (2001)

hydraulic
redistribution



e.g. Prieto et al. 2012

atmospheric
N_2 fixation



e..g. Forrester et al. 2007, 2007

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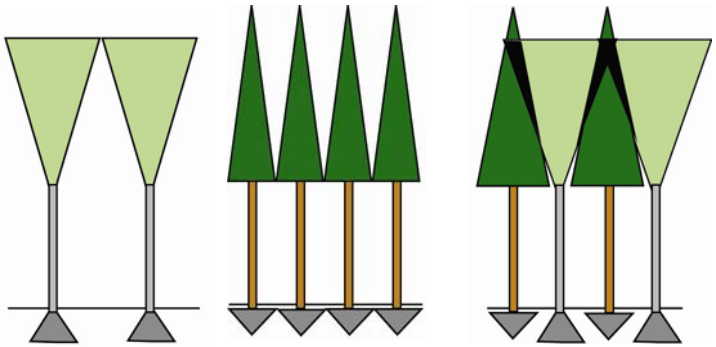
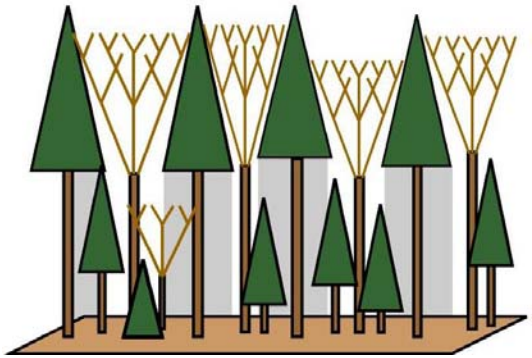
Complementarity in space filling and light use

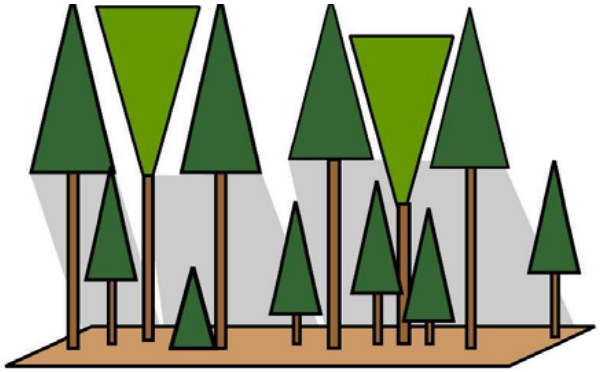
Morphological complementarity



Temporal asynchronity



Physiological complementarity



Ammer Ch(2018) Diversity and forest productivity in a changing climate, New Phytologist
Pretzsch, H, Forrster, D, Bauhus, J (2017) Mixed-species Forests, Springer, Berlin, 653 p

Criteria for sustainable forest ecosystem management. Objective hierarchy for the municipal forest of Traunstein

Criteria for sustainable forest management	Indicators	Weight (%)
Forest resources	timber resources, area of forest, extension of area	20
Health and vitality	stability, fitness, elasticity	17
Productive functions	growth, yield, net return	12
Biological diversity	habitat quality, richness flora/fauna, conservation	10
Protective functions	soil, water, climate, noise, protection	10
Socio-economic functions	employment, recreation, esthetics, proximity to nature	31

according to MCPFE, 2000

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1 Tree species mixing and stand productivity
2 Effect of mixing on population structure and size distribution
3 Effect on allometry at the tree and the organ level

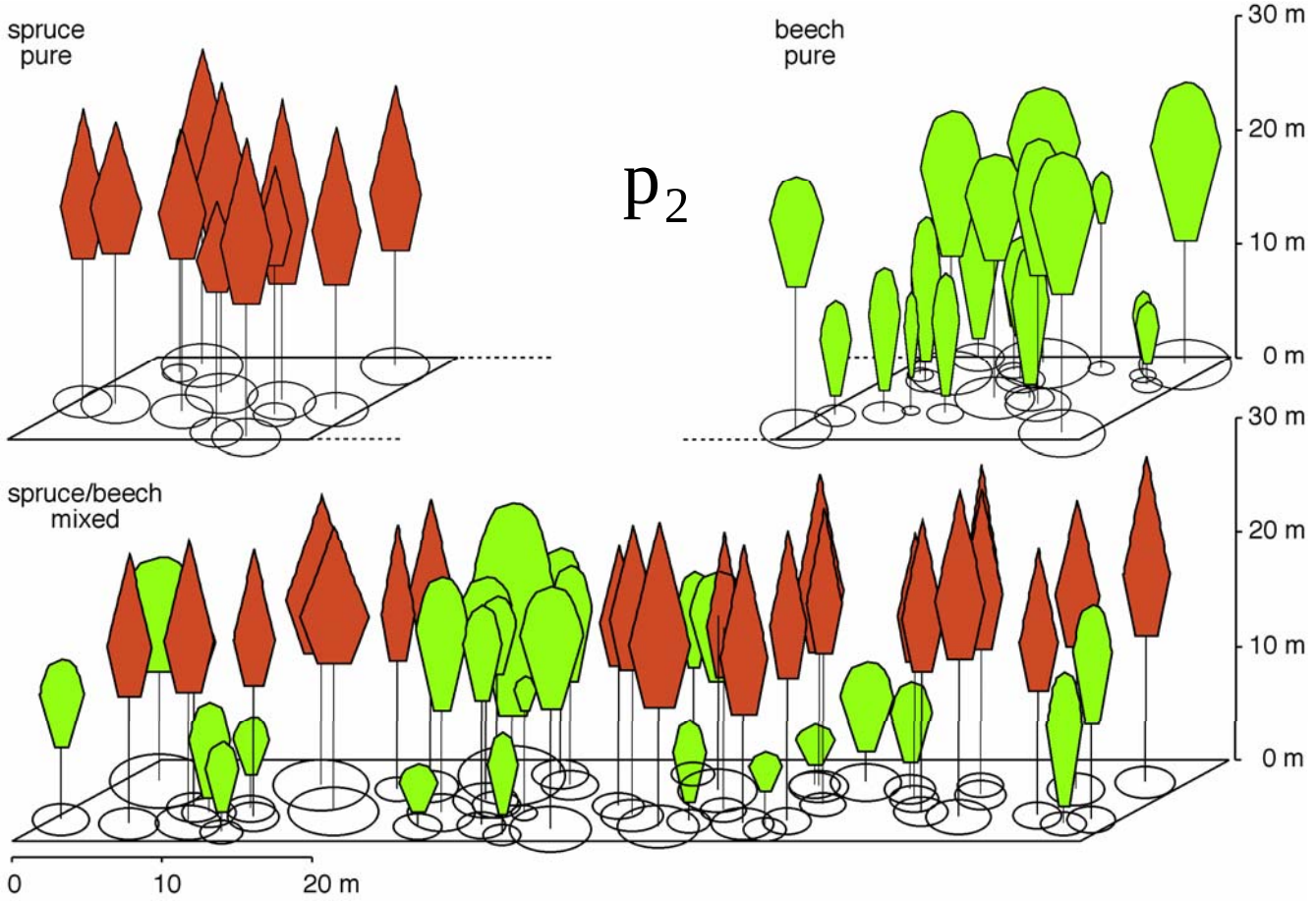
Perspectives

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

p_1

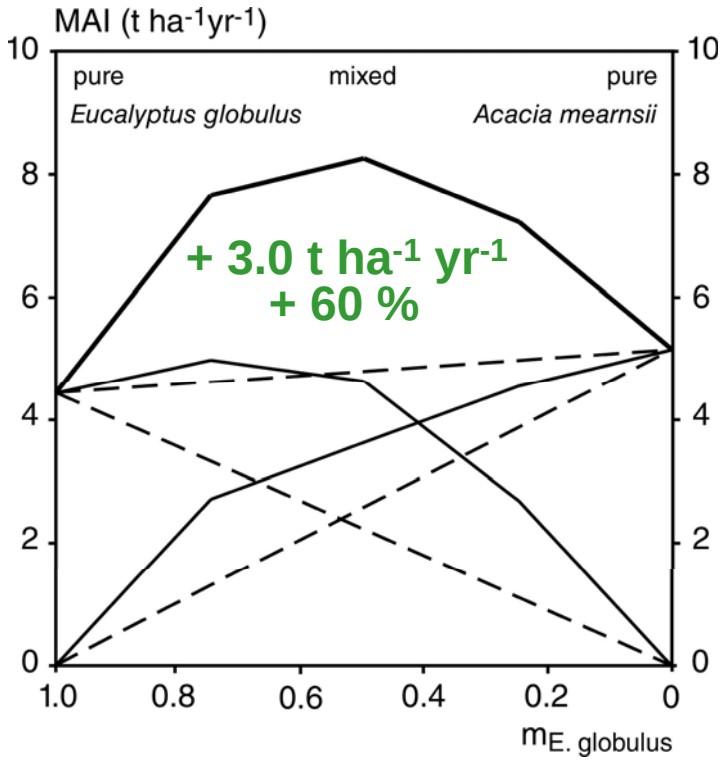
p_2

$p_{1,2}$
m_1
m_2



$p_{1,2}$ compared with $p_1 \times m_1 + p_2 \times m_2$

Visualization of the overyielding in mixed vs. pure stands of *Eucalyptus globulus* Labill and *Acacia mearnsii* De Wild. by a cross diagram



Forrester et al. (2006), Pretzsch and Forrester (2017)

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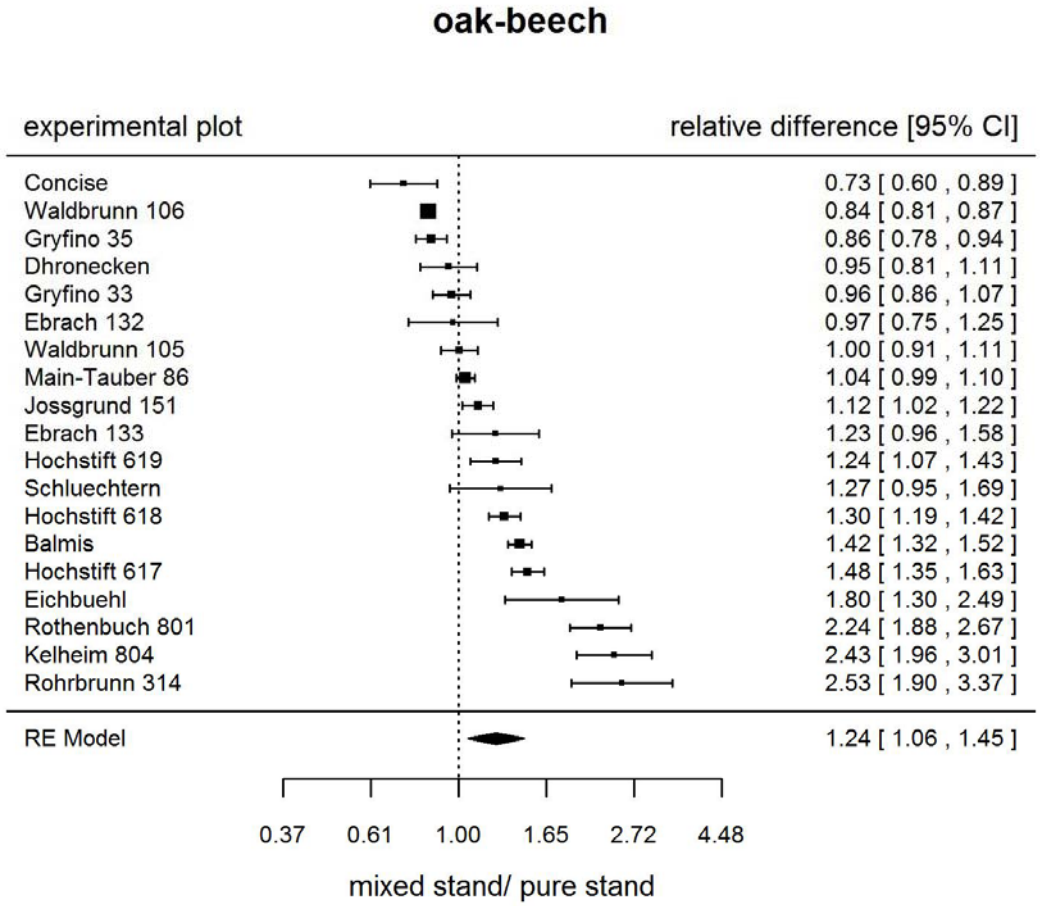
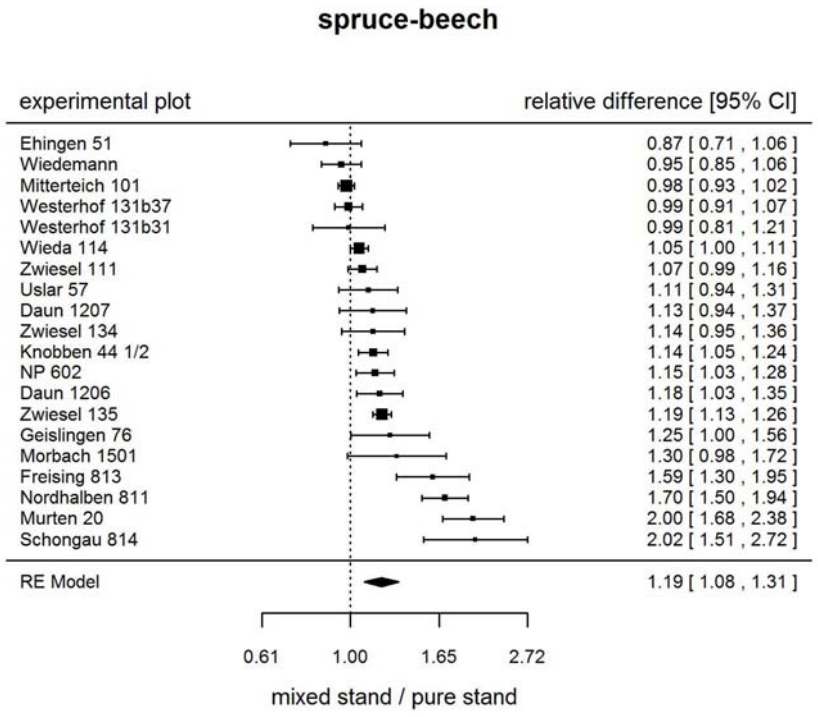
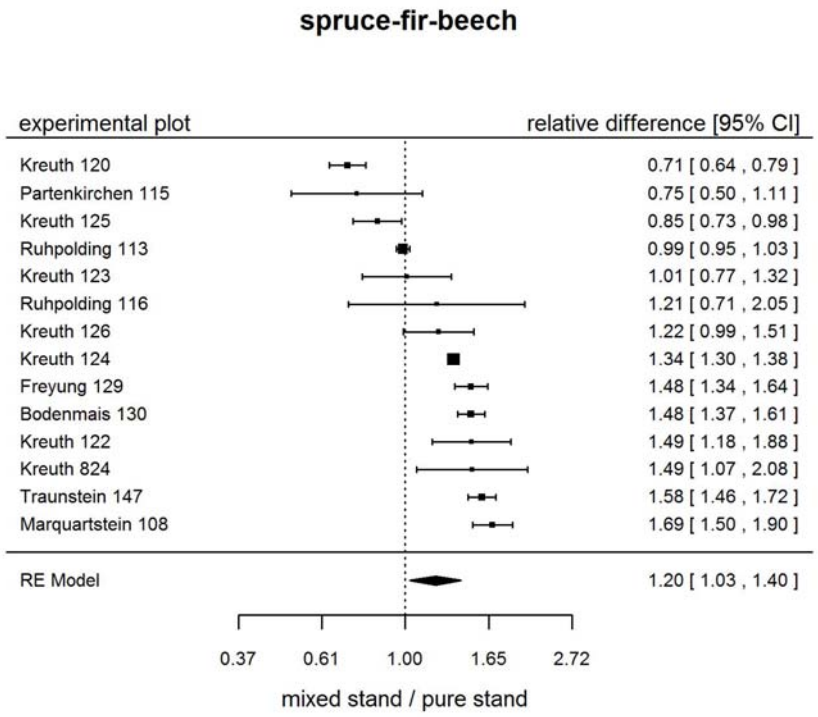
Meta-analysis on overyielding of mixed stands of sessile oak and European beech versus pure stands in Europe based on long-term experiments



Waldwachstumskunde
Systemanalyse

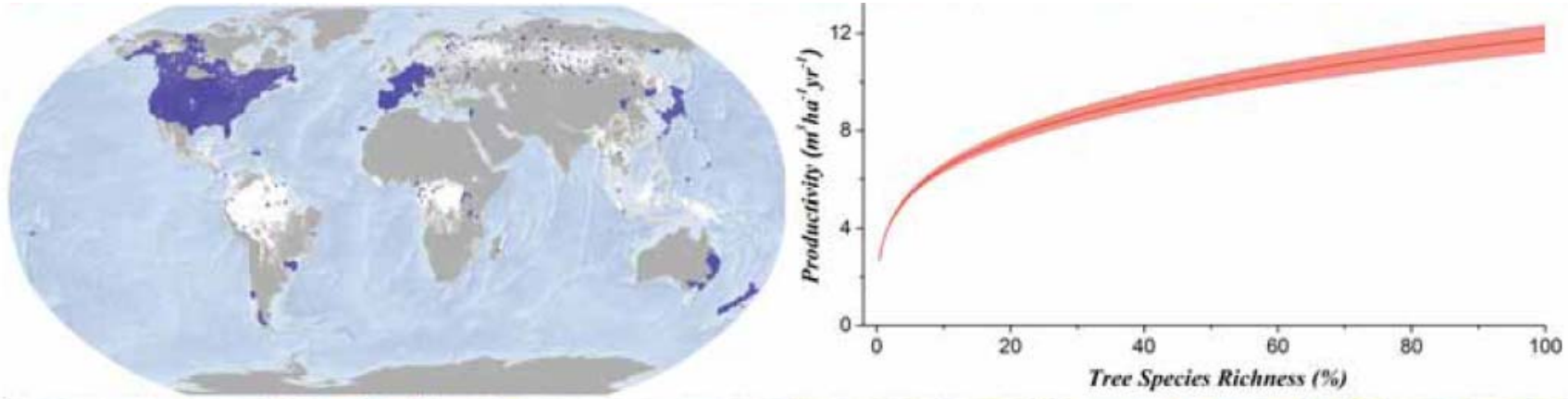
Meta-analysis on overyielding of mixed stands of Norway spruce, European beech, silver fir in Europe based on long-term experiments





Waldwachstumskunde
Systemanalyse

Mixing effects on productivity of forests worldwide and in Central Europe



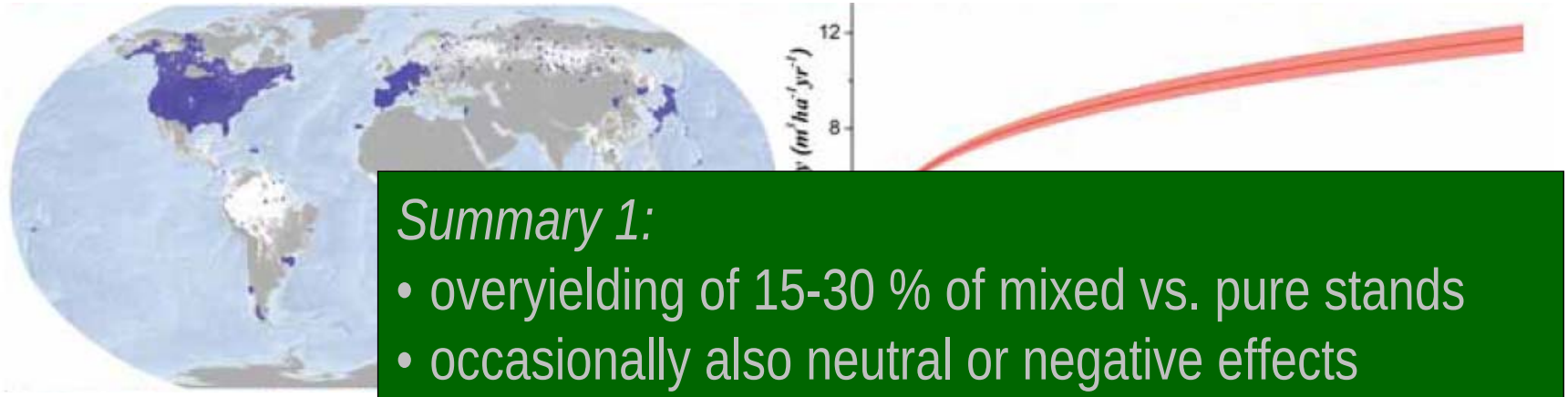
Liang, J. et al. (2016) Positive Biodiversity-Productivity Relationship Predominant in Global Forests, Science, 354 (6309), aaf8957

Species combination	N. sp/ E. be	S. pi/ E. be	s. oak/ E. be	E. be/ D-fir	S. pi/ N. sp	E. la/ N. sp	N. sp/ s. fir	mean
overyielding	21	30	20	11	21	25	13	
(± SE) in %	(± 3)	(± 9)	(± 3)	(± 8)	(± 11)	(± 6)	(± 6)	
corr. factor	1.10	1.20	1.10	1.10	1.20	1.20	1.10	1.10

Pretzsch (2016) Ertragstafel-Korrekturfaktoren für Umwelt- und Mischunsgeffekte, AFZ Der Wald, 14/2016: 47-50

Waldwachstumskunde
Systemanalyse

Mixing effects on productivity of forests worldwide and in Central Europe



Liang, J. et al. (2016) Posi
Global Forests, Science, 3

Summary 1:

- overyielding of 15-30 % of mixed vs. pure stands
- occasionally also neutral or negative effects
- conservative correction factors: iv_{pure} × 1.10 to 1.20
- more species combinations need to be analyzed

Species combination	N. sp/ E. be	S. pi/ E. be	s. oak/ E. be	E. be/ D-fir	S. pi/ N. sp	E. la/ N. sp	N. sp/ s. fir	mean
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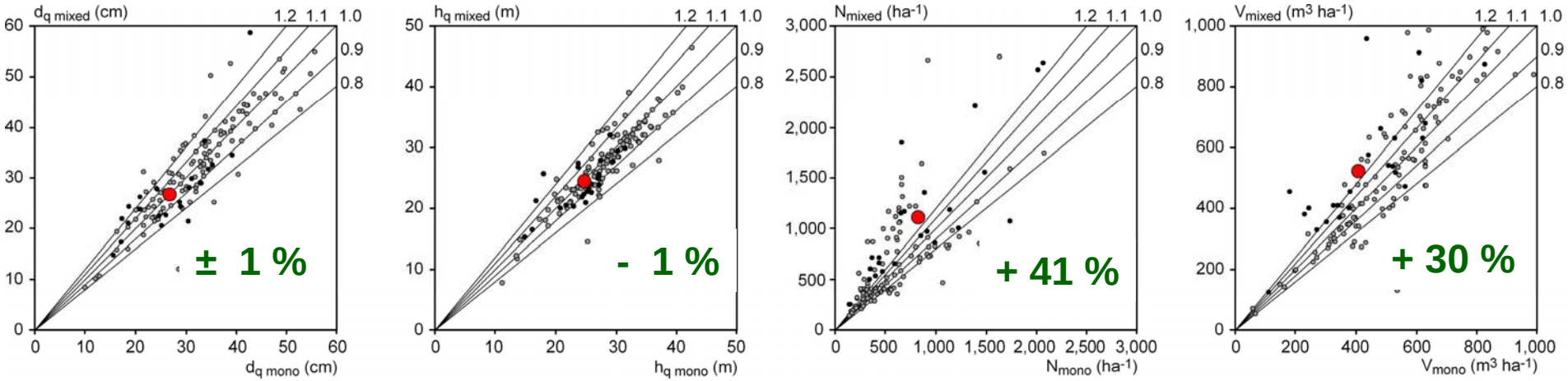
Pretzsch (2016) Ertragstafel-Korrekturfaktoren für Umwelt- und Mischunsgeffekte, AFZ Der Wald, 14/2016: 47-50

Waldwachstumskunde
Systemanalyse

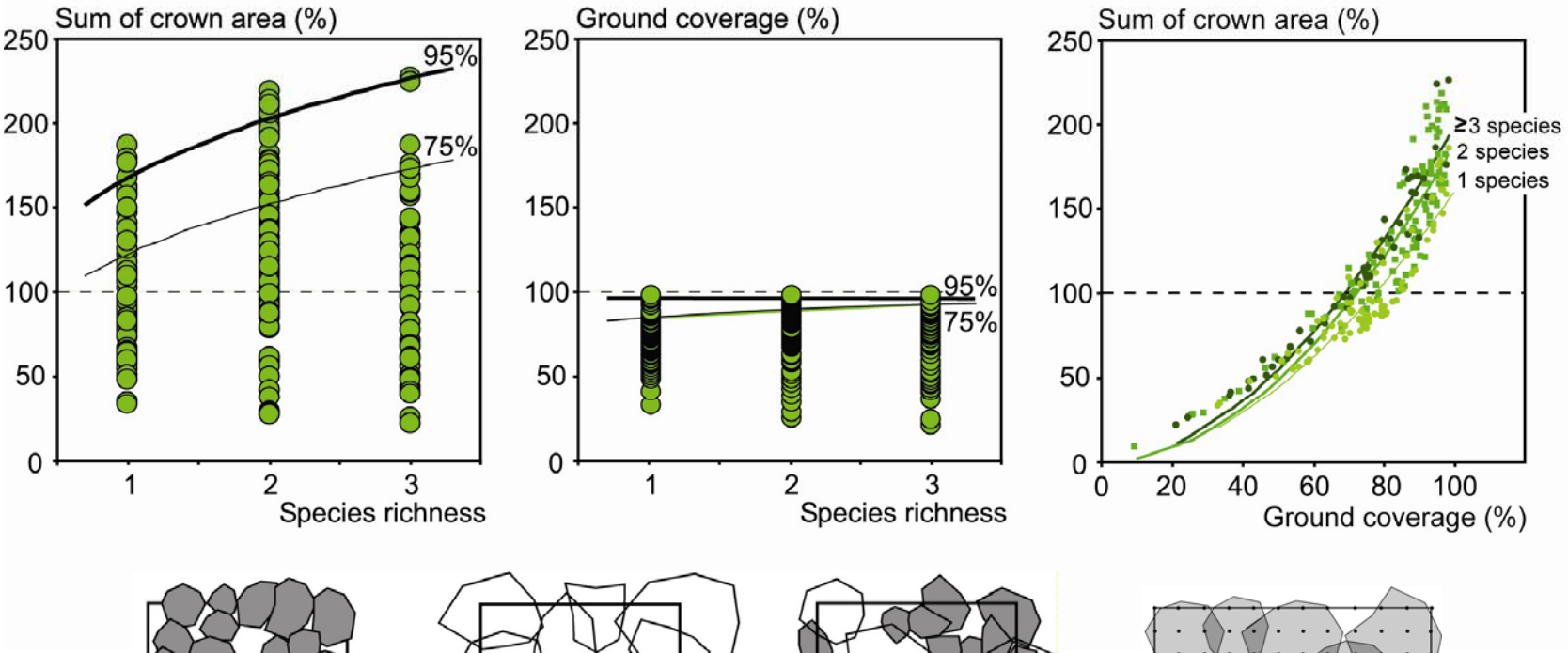
Mixing increases tree number and standing volume rather than mean tree diameter or height



Pretzsch, Forrester, Bauhus (2017) Mixed-speceis forests, Springer

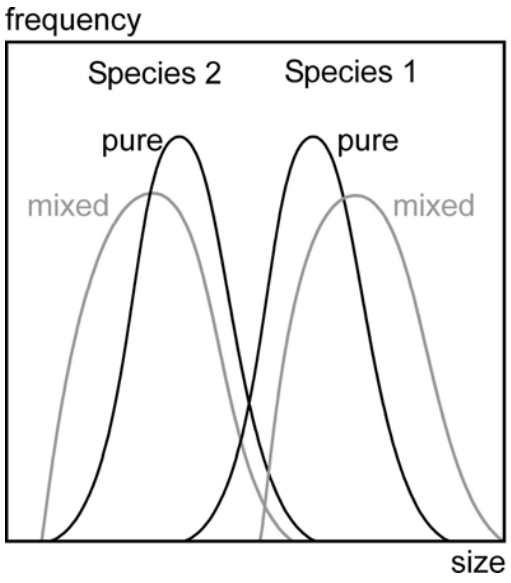
Waldwachstumskunde
Systemanalyse

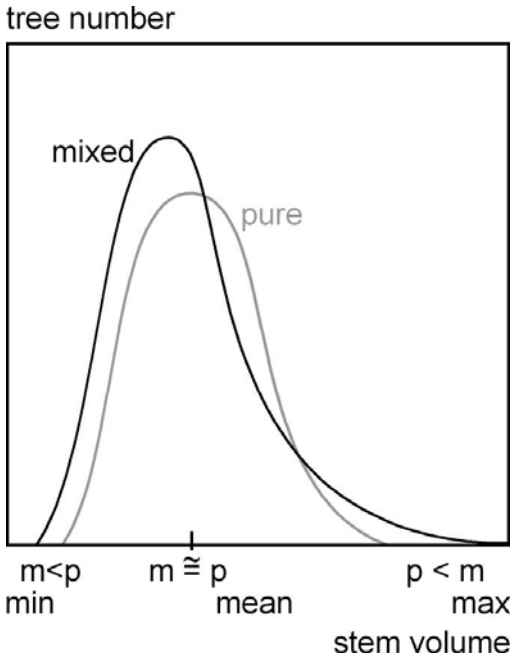
Denser canopy space filling in mixed stands: higher sum of crown area and multiple ground coverage

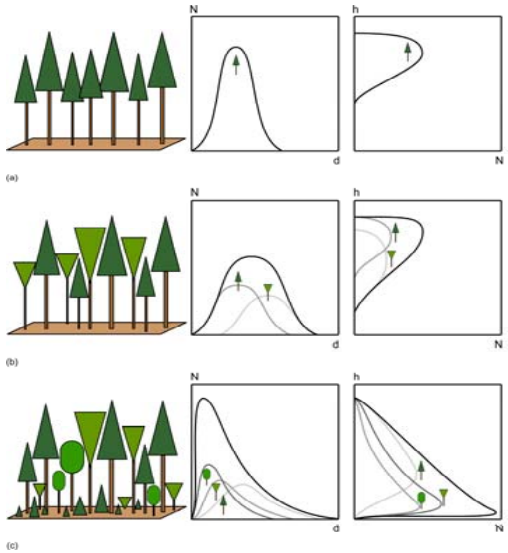


Pretzsch, H. (2014) Canopy space filling and tree crown morphology in mixed-species stands compared with monocultures. Forest Ecology and Management, 327: 251-264.

More trees, wider size range, stronger right-skewness in mixed stands; often species 1 ahead, species 2 behind the monoculture



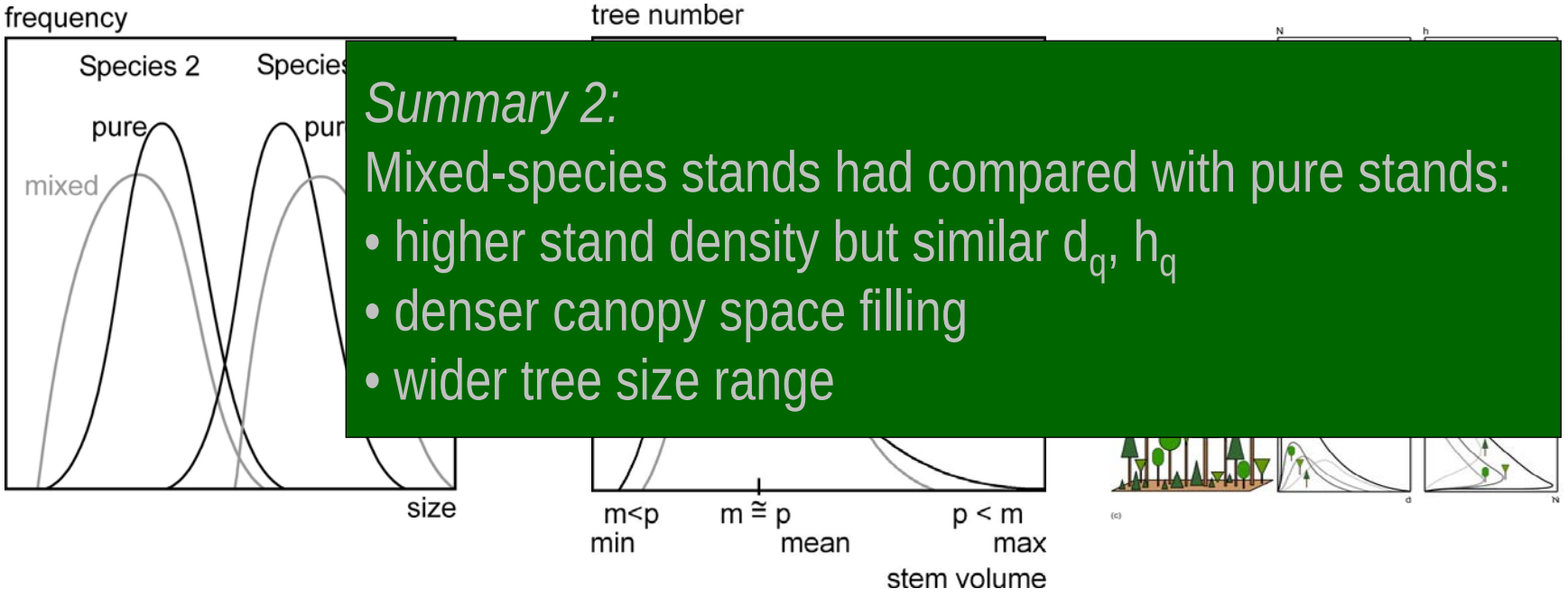




Pretzsch, H., Schütze, G. (2014) Size-structure dynamics of mixed versus pure forest stands, Forest Systems, 23(3):560-572.

Waldwachstumskunde
Systemanalyse

More trees, wider size range, stronger right-skewness in mixed stands; often species 1 ahead, species 2 behind the monoculture



Summary 2:

Mixed-species stands had compared with pure stands:

- higher stand density but similar d_q, h_q
- denser canopy space filling
- wider tree size range

Pretzsch, H., Schütze, G. (2014) Size-structure dynamics of mixed versus pure forest stands, Forest Systems, 23(3):560-572.

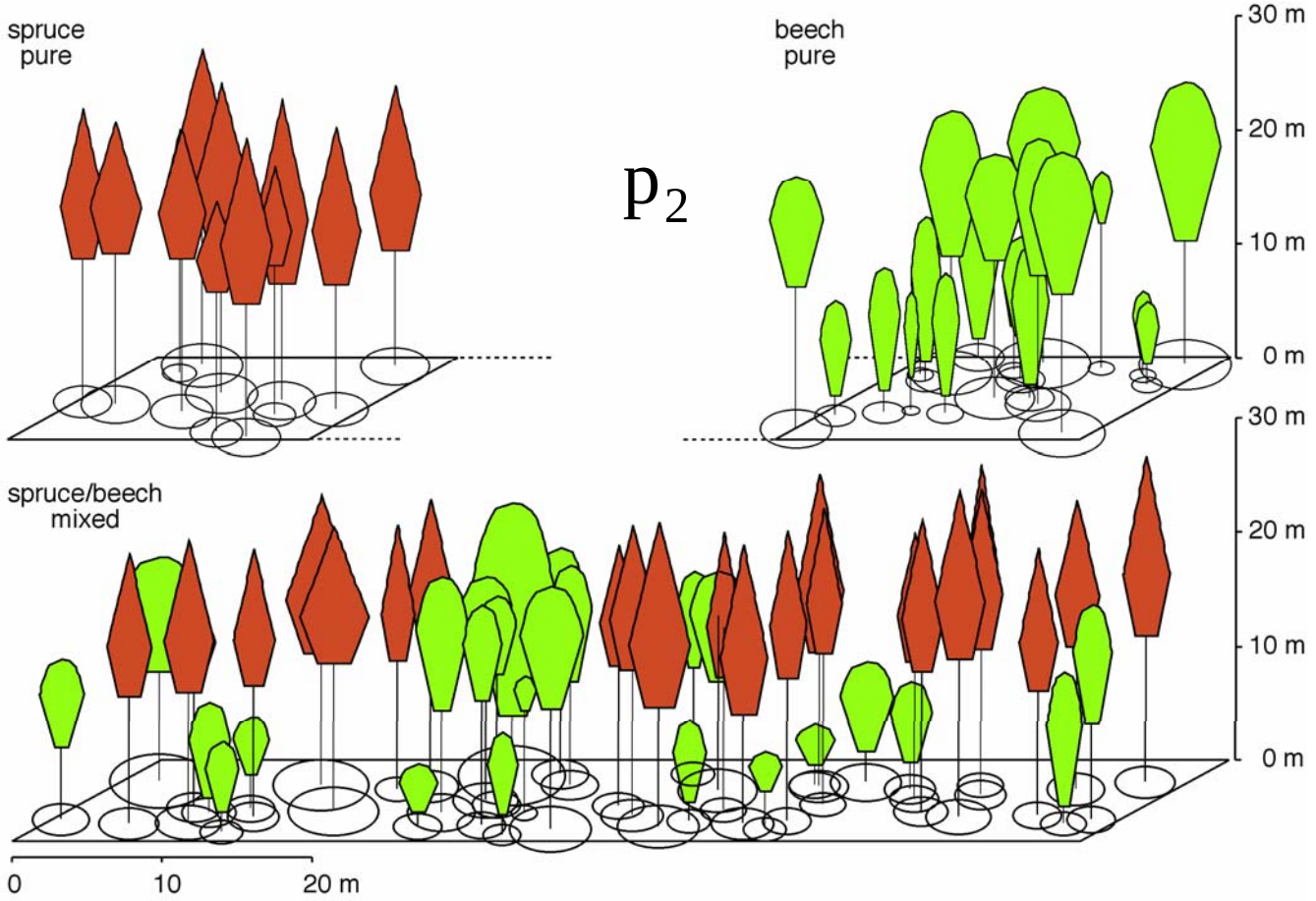
Waldwachstumskunde
Systemanalyse

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

p_1

p_2

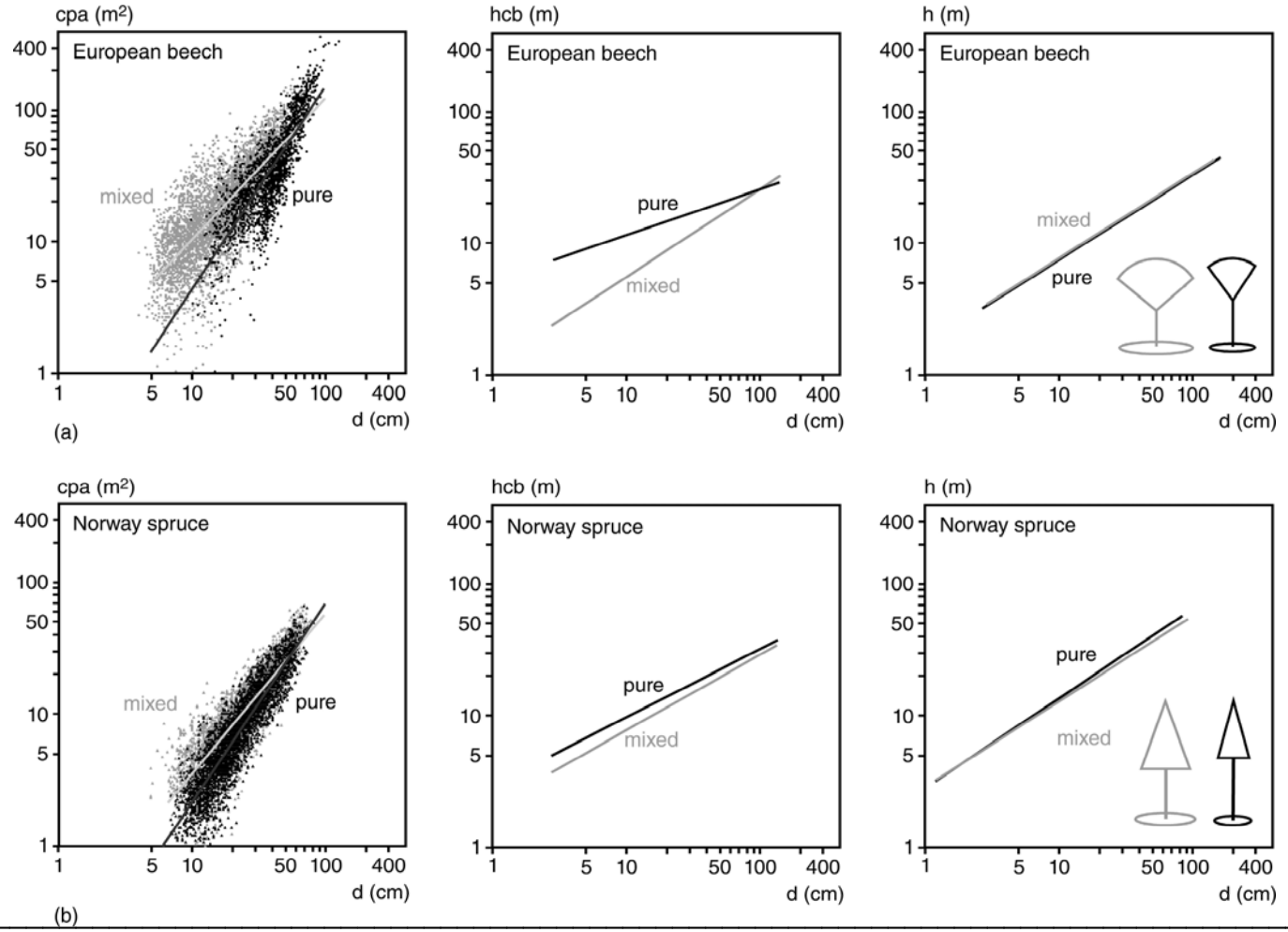
$p_{1,2}$
m_1
m_2



$p_{1,2}$ compared with $p_1 \times m_1 + p_2 \times m_2$

Waldwachstumskunde
Systemanalyse

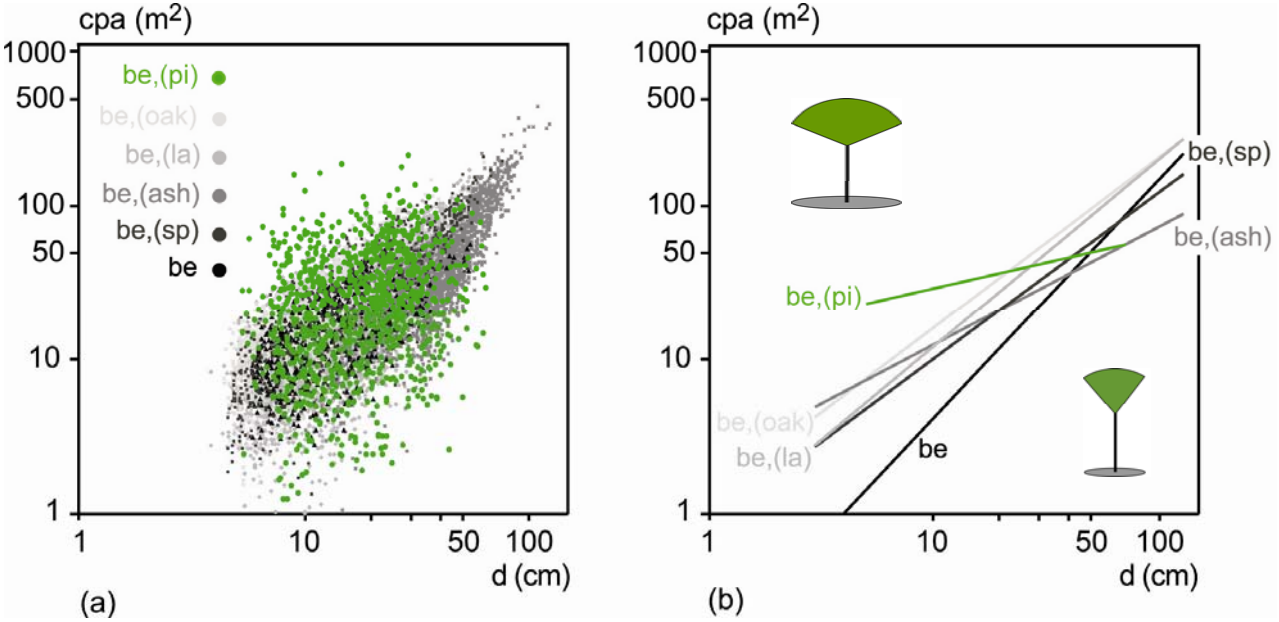
Effect of species mixing on the crown allometry of European beech and Norway spruce



Pretzsch, H. (2014) Canopy space filling and tree crown morphology in mixed-species stands compared with monocultures. Forest Ecology and Management, 327: 251-264.

Waldwachstumskunde
Systemanalyse

Allometry between crown projection area and stem diameter of European when growing in mono-specific versus mixed stands



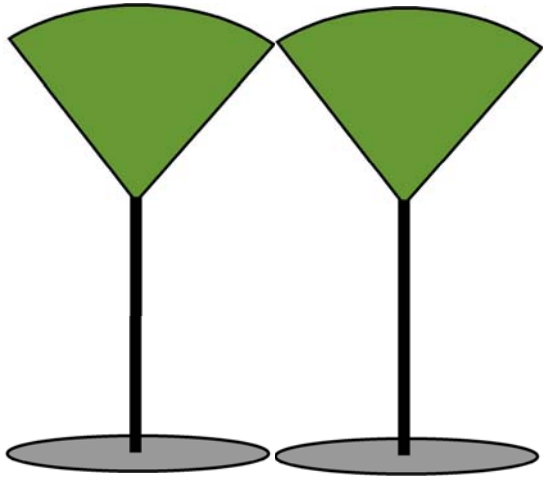
S. pine
s. oak
E. ash
E. larch
N. spruce

Pretzsch, H. (2014) Canopy space filling and tree crown morphology in mixed-species stands compared with monocultures. Forest Ecology and Management, 327: 251-264.

Waldwachstumskunde
Systemanalyse

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

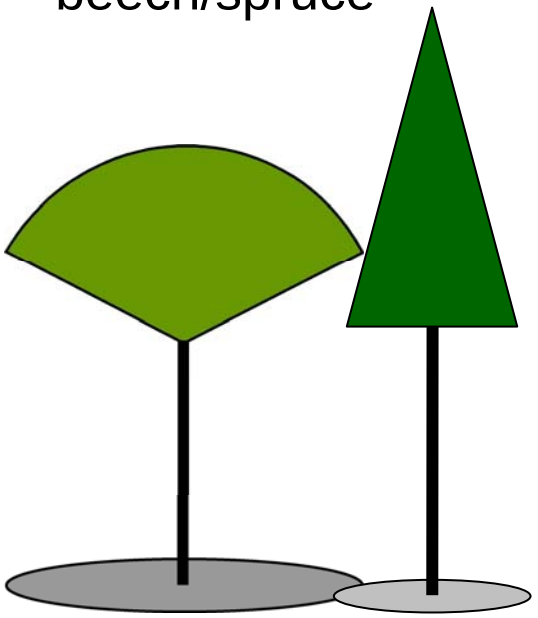
branch angle
139° vs. 128°

branch straightness
96 vs. 94

stem inclination
2° vs. 3.5°

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

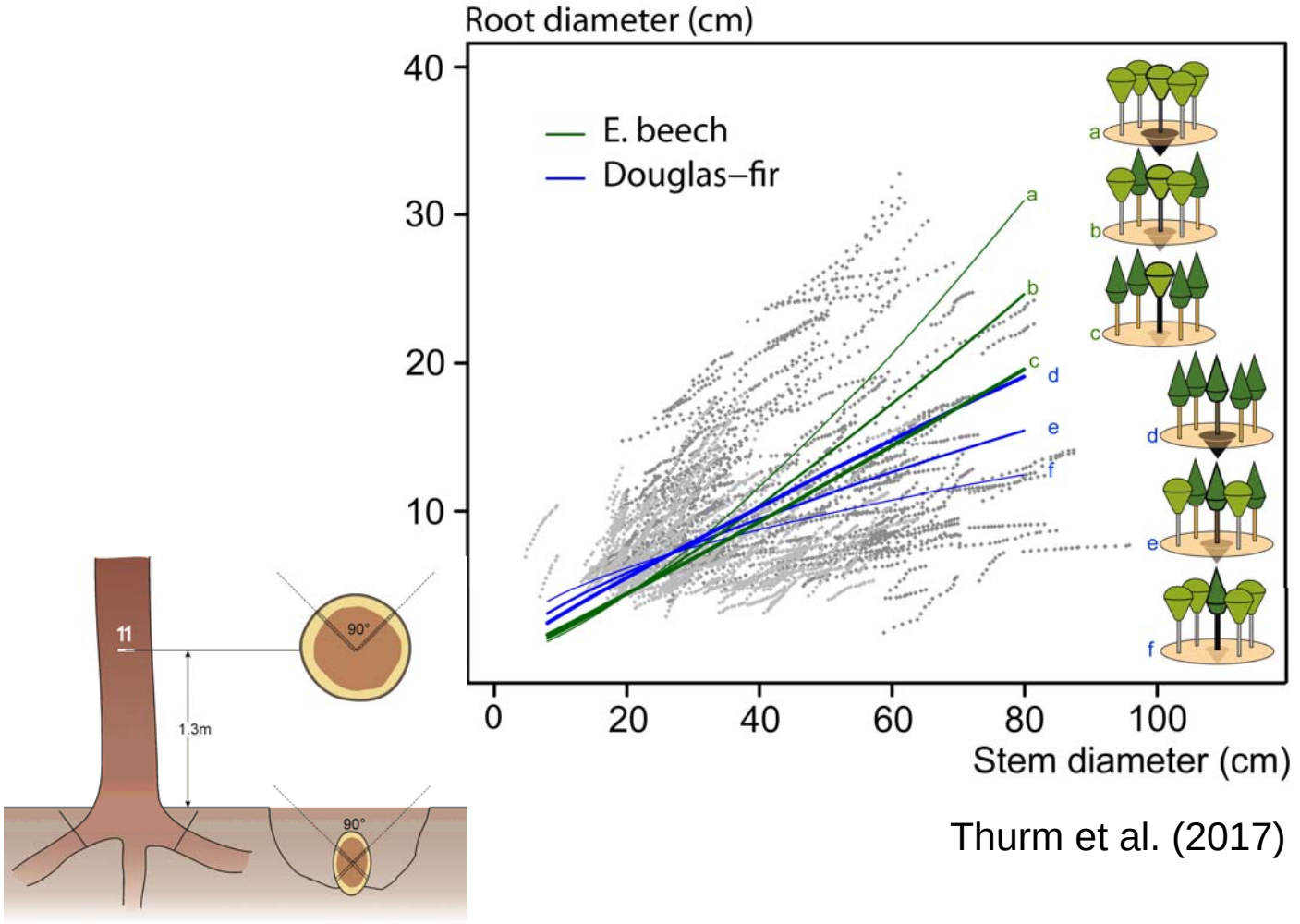
beech/spruce



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

Waldwachstumskunde
Systemanalyse

Enhancement of shoot in relation to coarse root growth in mixed compare with mono-specific stands of European beech and Douglas-fir



pure beech

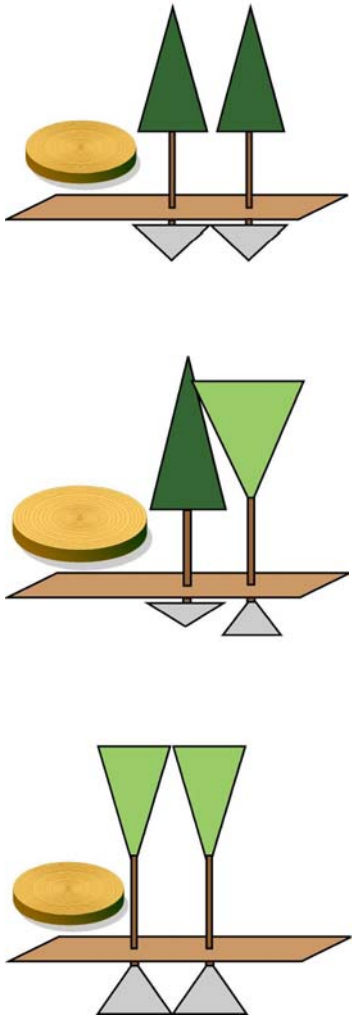
beech in D.-fir

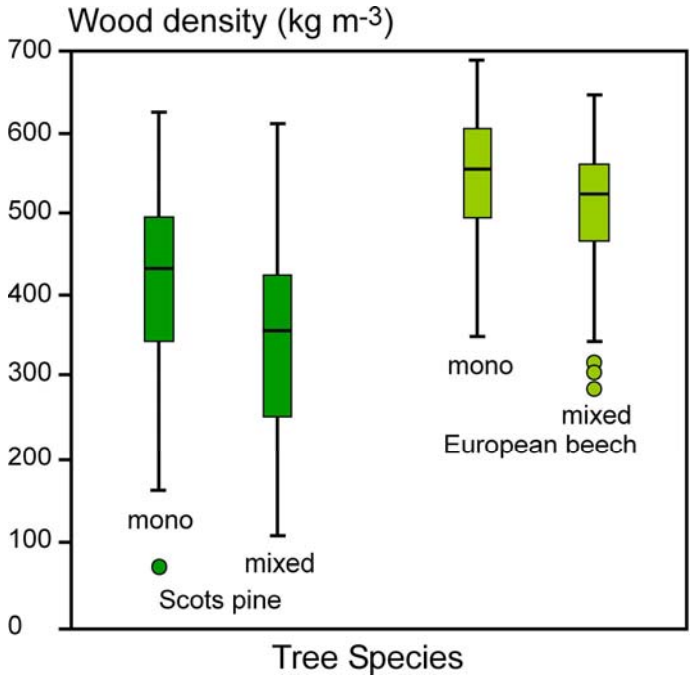
pure D.-fir

D.-fir in beech

Thurm et al. (2017)

Wood density in mixed-species stands of S. pine and E. beech compared with monocultures





Zeller et al. 2017, Pretzsch and Rais 2016

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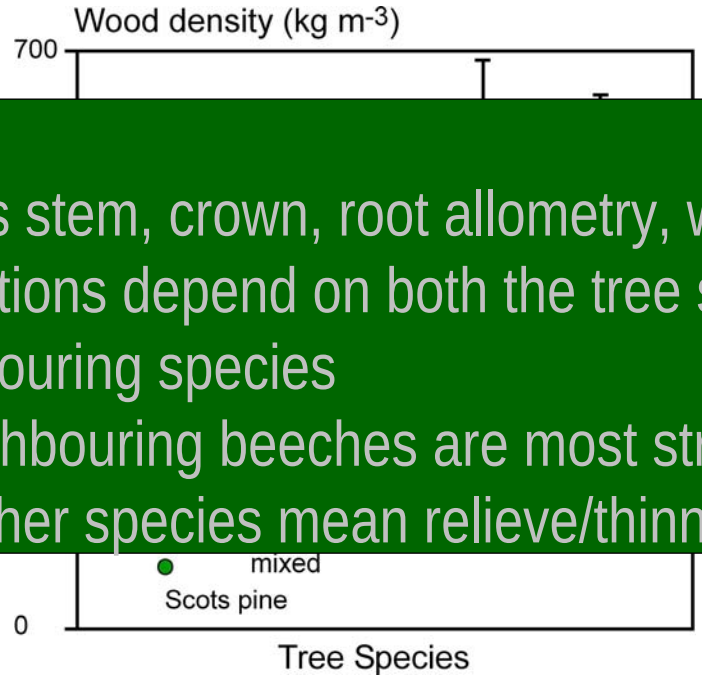
Systemanalyse

Wood density in mixed-species stands of S. pine and E. beech compared with monocultures



Summary 3:

- Mixing modifies stem, crown, root allometry, wood density
- Allometric reactions depend on both the tree species and the neighbouring species
- For beech neighbouring beeches are most strongest competitors, other species mean relieve/thinning

Zeller et al. 2017, Pretzsch and Rais 2016

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Systemanalyse

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2 Effect of mixing on population structure, size distribution
3 Effect on allometry at the tree and organ level

Perspectives

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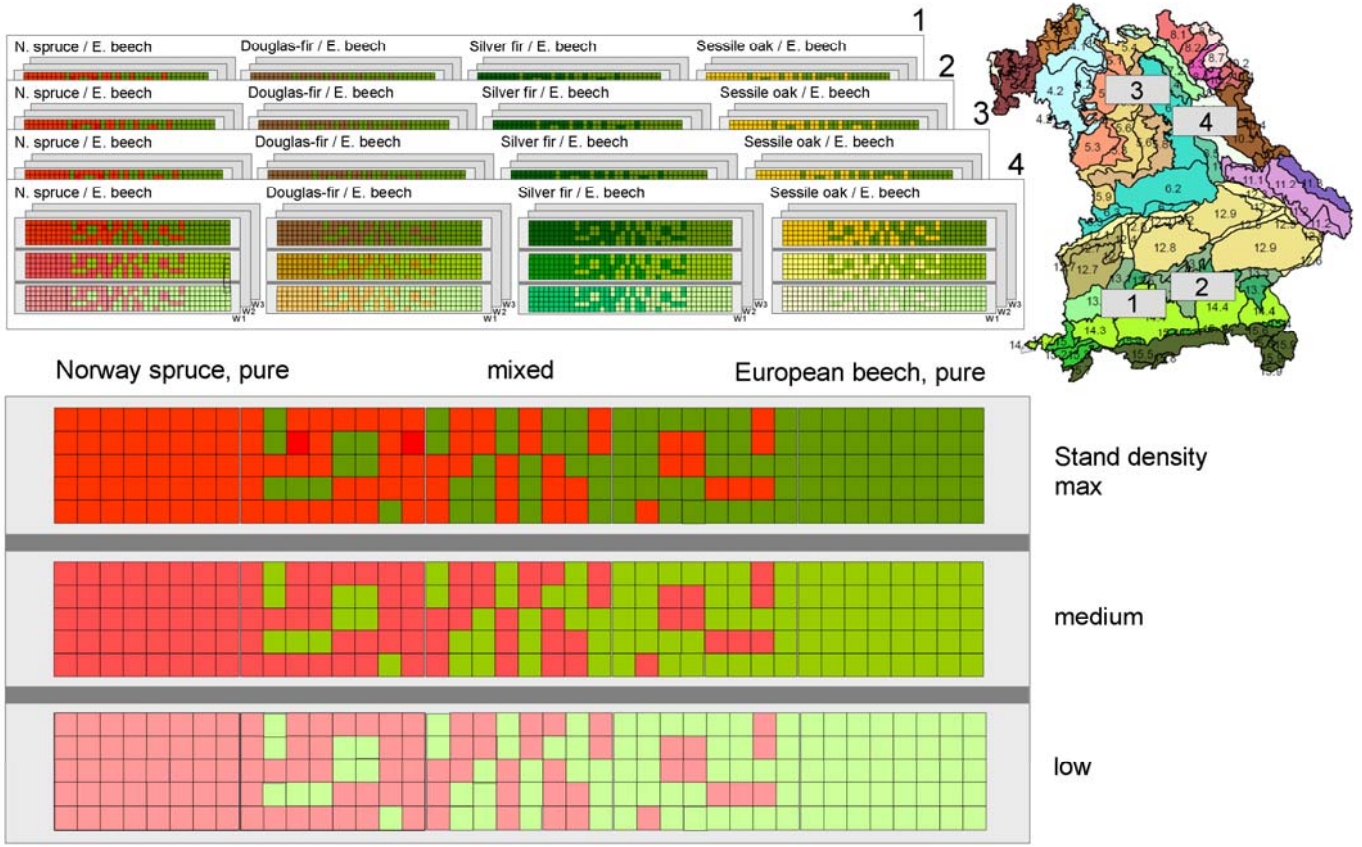
Long-term experiments in addition to inventory data for analyses, model parameterization, teaching, and training



Nagel et al. (2012), von Gadow (2017), Pretzsch et al. (2017)

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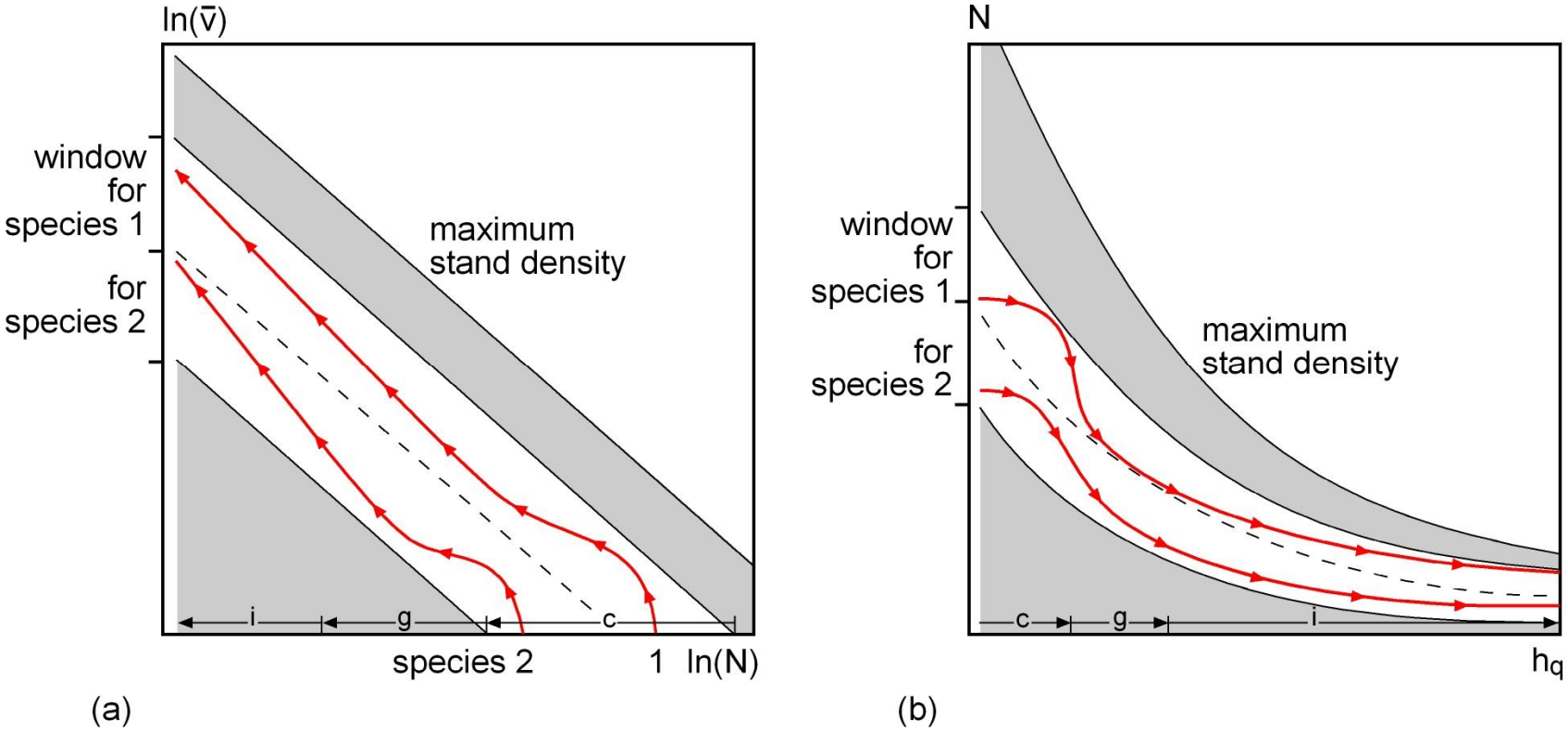
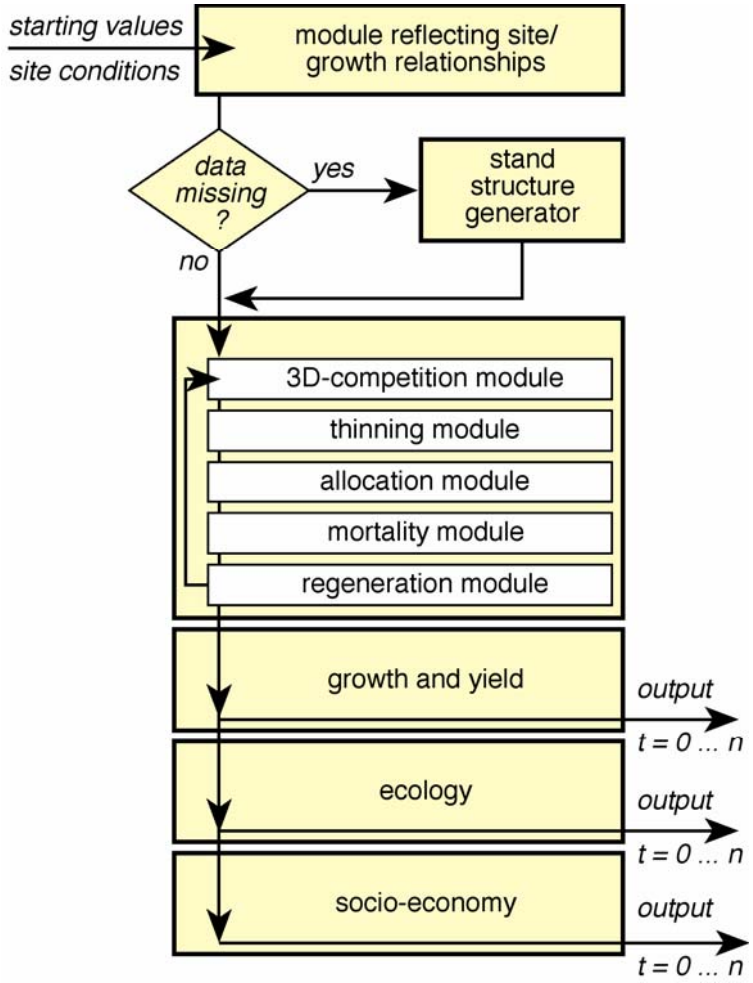
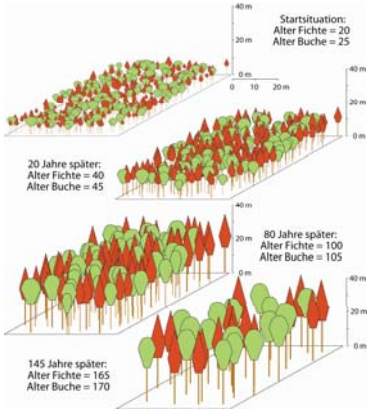
Guidelines for silvicultural regulation of mixed-species stand can bring the mixing idea onto the ground

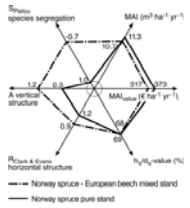


Pretzsch, H and Zenner E (2017) Toward managing mixed-species stands: from parametrization to prescription, Forest Ecosystems, DOI : 10.1186/s40663-017-0105-z

SILVA 3.0 as example of a spatially explicit individual tree model for pure and mixed stands







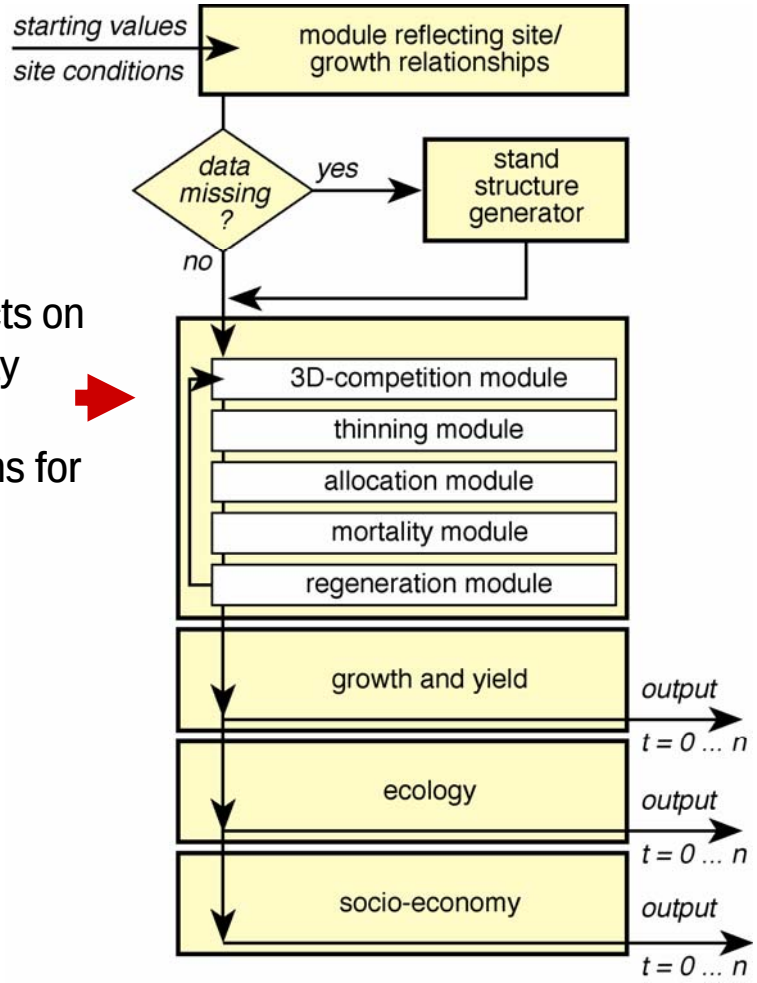
Pretzsch, H., Biber, P. und Dursky, J., 2002: The single tree based stand simulator SILVA. Construction, application and evaluation, Forest Ecology and Management, 162: 3-21

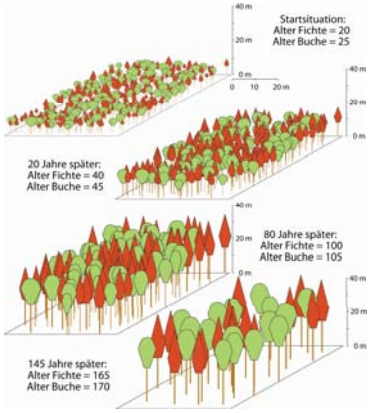
Waldwachstumskunde
Systemanalyse

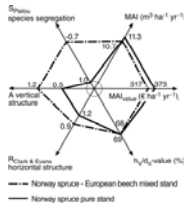
SILVA 3.0 as example of a spatially explicit individual tree model for pure and mixed stands

Integration of mixing effects on growth, structure, mortality

Extension of the algorithms for silvicultural regulation







Pretzsch, H., Biber, P. und Dursky, J., 2002: The single tree based stand simulator SILVA. Construction, application and evaluation, Forest Ecology and Management, 162: 3-21


From holistic to reductionistic: KROOF experiment TUM

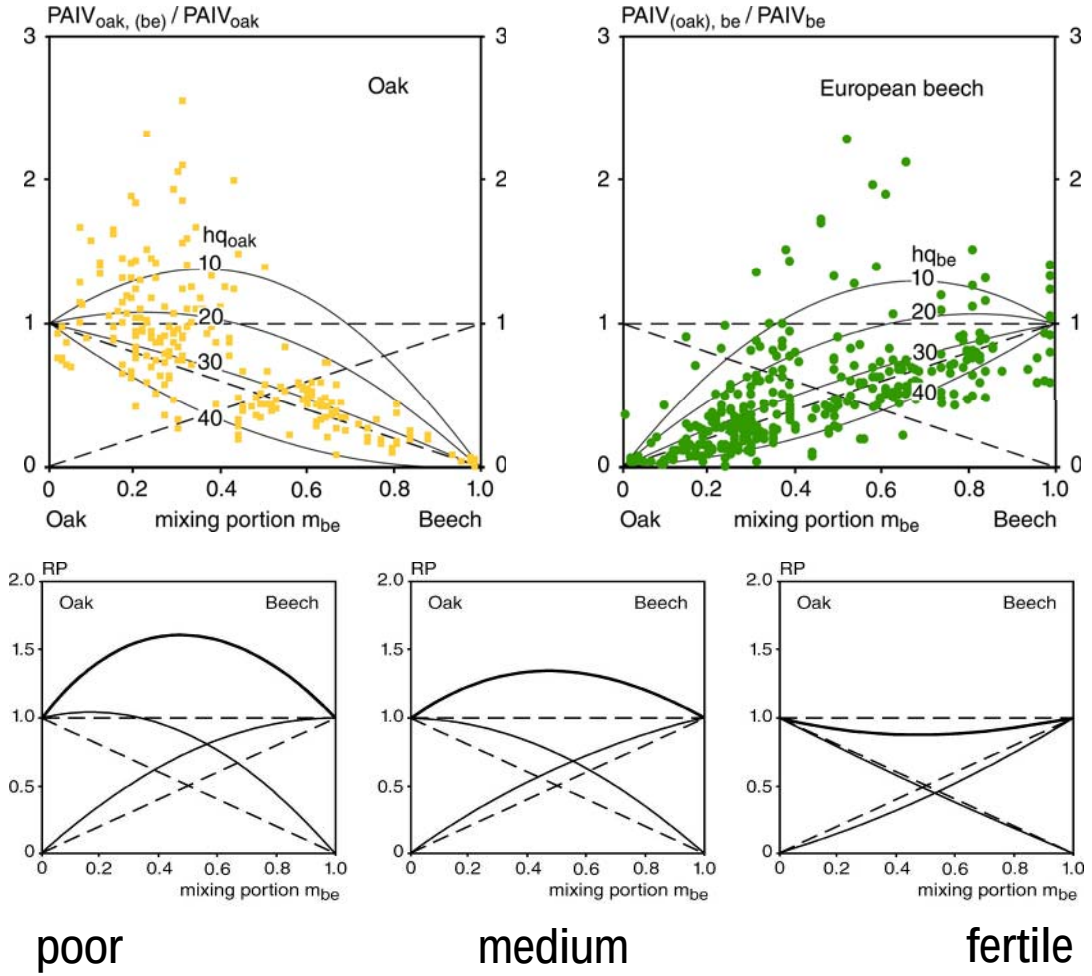
Thanks for funding by
DFG
EU
MStELF, MStU, BaySF

Thanks for provinding data to
partner institutions in Sweden, Denmark,
England, Poland, France, Germany
Austria, Switzerland, Italy, Spain, and others

http://waldwachstum.wzw.tum.de/index.php?id=presentations

Waldwachstumskunde
Systemanalyse

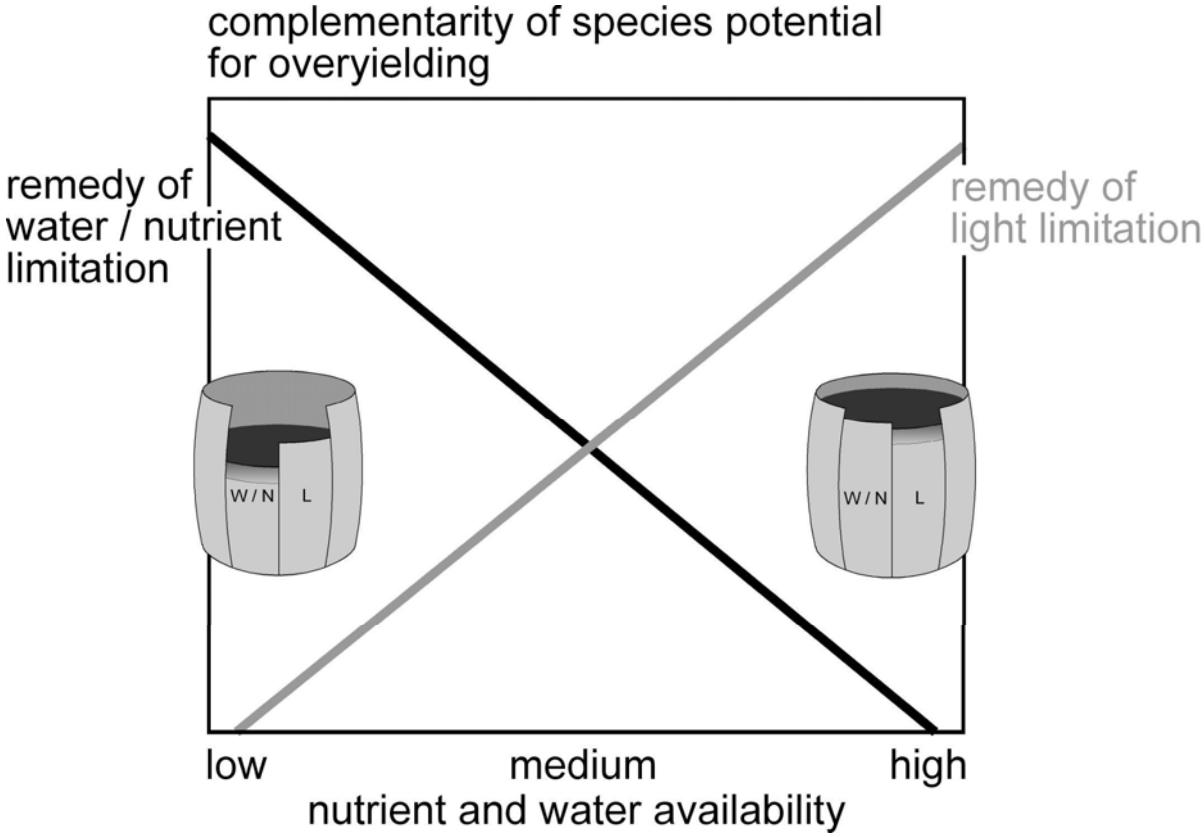
Transect study: Overyielding increases with water and nutrient scarcity



poor medium fertile

Pretzsch et al. (2013) Productivity of mixed versus pure stands of oak (*Quercus petraea* (Matt.) Liebl. and *Quercus robur* L.) and European beech (*Fagus sylvatica* L.) along an ecological gradient, EJFOR, 132 (2):263-280

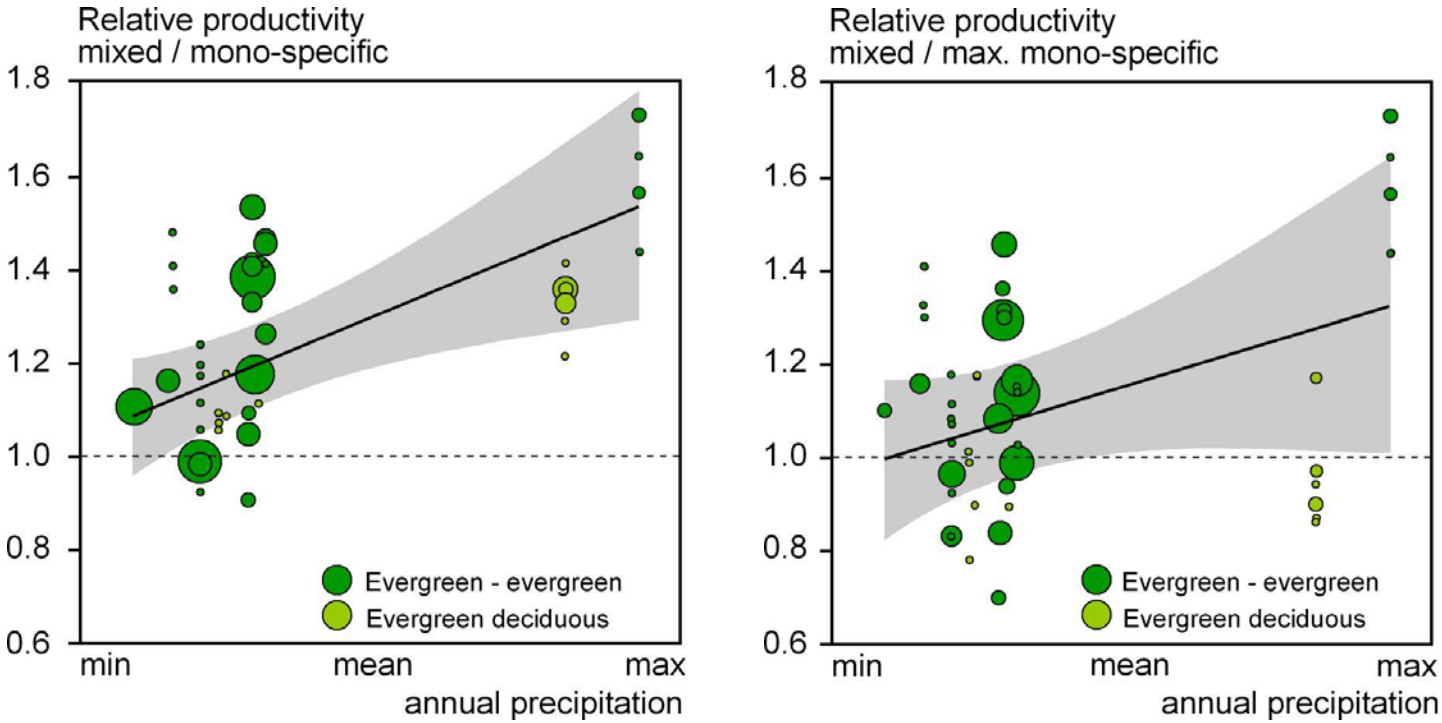
Conceptual model for the dependency of overyielding on site conditions



e. g. Forrester (2017), Pretzsch (2017), Jactel et al. (2018)

Waldwachstumskunde
Systemanalyse

Increasing overyielding (15 %) and transgressive overvielding with water availability



no significant transgressive underyielding

Jactel, H., Pretzsch, H et al. (2018) Positive diversity-productivity relationships in forests: climate matters, Biological Letters, 14(4)

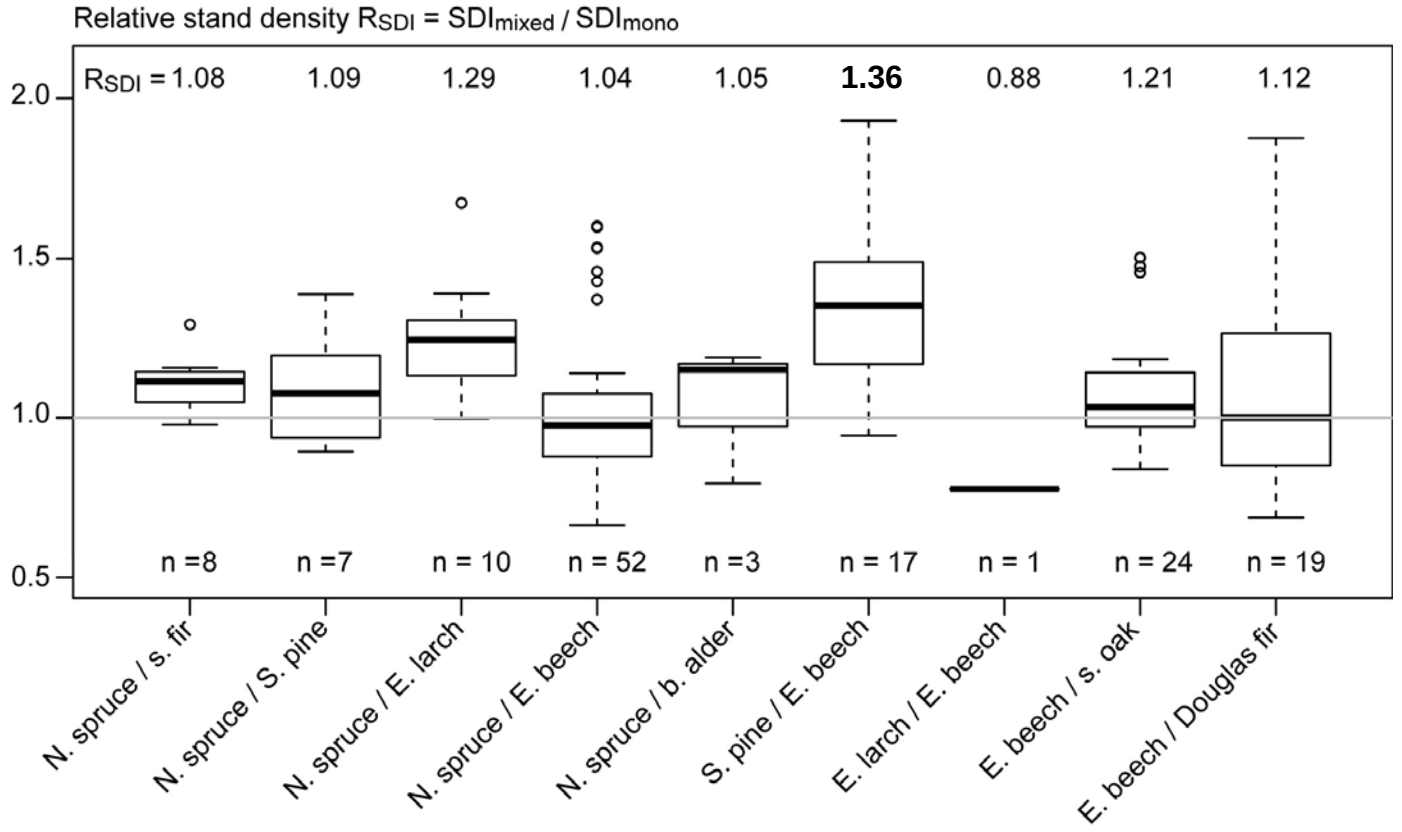
Mixing effects on 32 triplets of Scots pine and European beech along a productivity gradient through Europe (EuMIXFOR FP 1206)

Swe 1
Swe 2
Lit 2
Lit 1
Pol 2
Pol 1
Net 1
Ger 7
Bel 2
Bel 1
Pol 3
Ukr 1
Cze 2
Pol 5
Pol 4
Fran 1
Ger 1-6
Cze 1
Slo 1
Aus 1
Ita 1
Ita 2
BHe 1
Ser 1
Sp 1
Sp 2
Bul 1

mean mixing effects in mature stands
PAIV: +15 %, SDI: + 20 %, V: +15 %

Waldwachstumskunde
Systemanalyse

Stand density (SDI) of mixed-species stands versus monocultures on long-term experiments in Central Europe

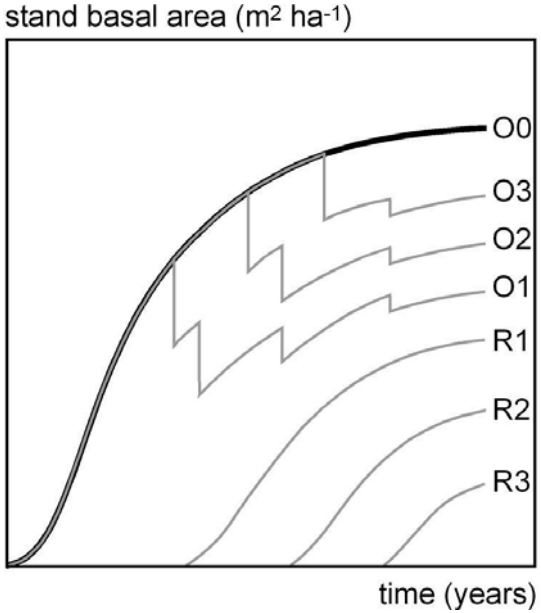


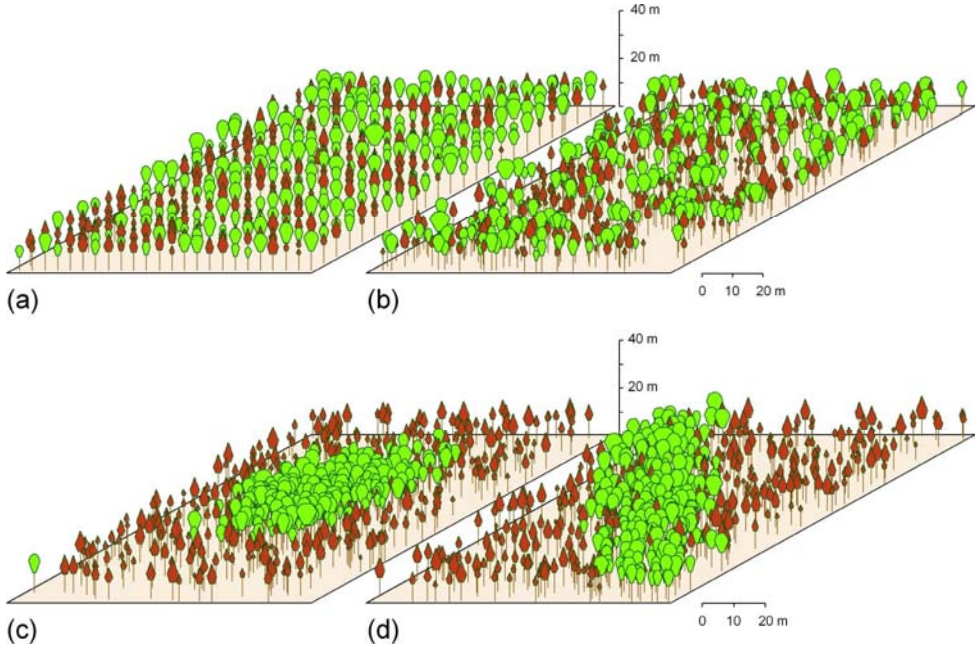
Pretzsch, H., Biber, P. (2016) Tree species mixing can increase maximum stand density.
Canadian Journal of Forest Research, DOI: 10.1139/cjfr-2015-0413

Mixed spruce-fir-beech mountain forest in montane and subalpine zones (600-1,400 m a.s.l.)

Waldwachstumskunde
Systemanalyse

Rules and algorithms for initiating the regeneration depending on the density of the overstorey

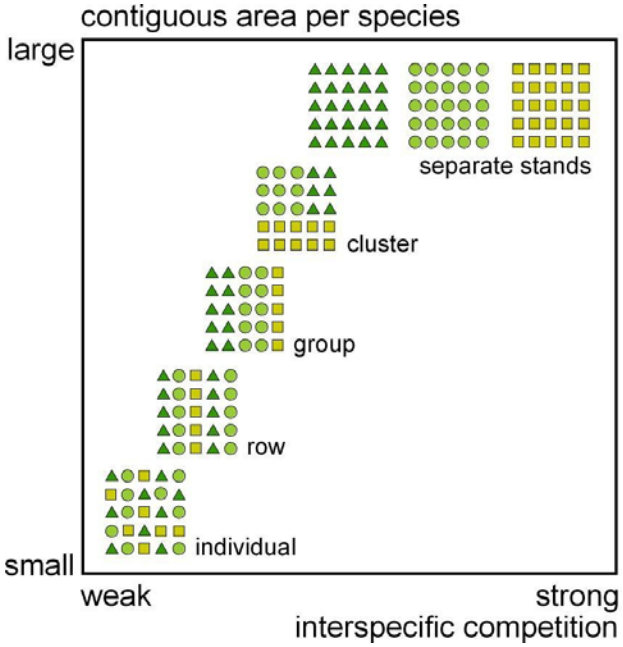


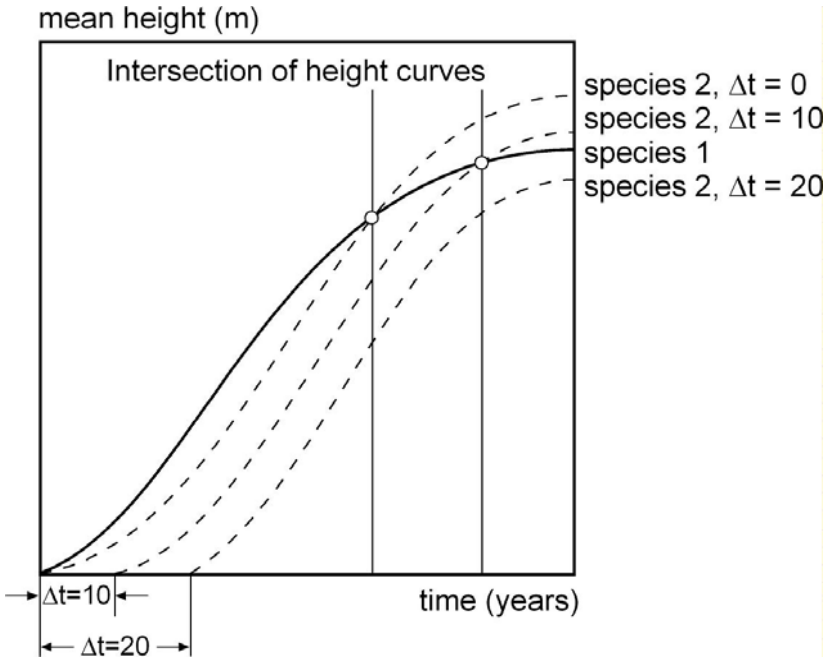


Pretzsch H, Forrester D, Bauhus J (2017) Mixed-species forests. Ecology and Management, Springer, Berlin, 653 p

Waldwachstumskunde
Systemanalyse

Rules and algorithms for regulation of competition by spatial or temporal separation

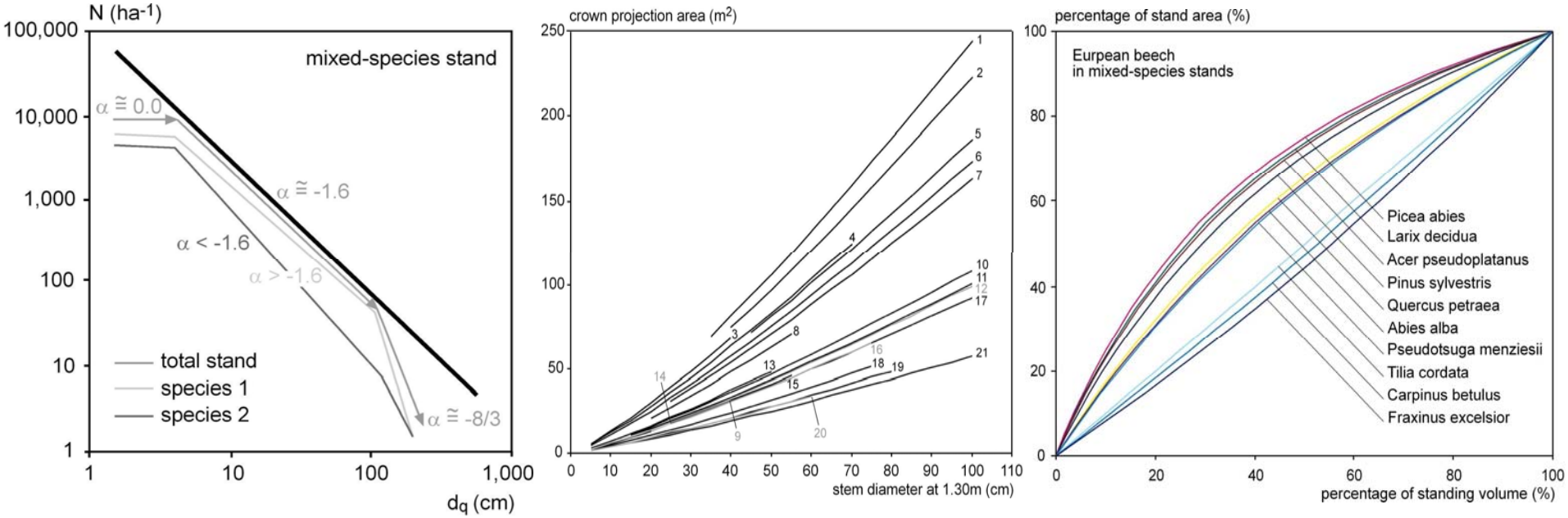




Pretzsch H, Forrester D, Bauhus J (2017) Mixed-species forests. Ecology and Management, Springer, Berlin, 653 p

Waldwachstumskunde
Systemanalyse

Rules and algorithms for regulation of stand density and species-specific mixing proportions



[1] *Quercus nigra* L., [2] *Platanus x hispanica* Münchh., [3] *Carpinus betulus* L., [4] *Tilia cordata* Mill.,
[5] *Khaya senegalensis* (Desr.) A.Juss., [6] *Fagus sylvatica* L., [7] *Aesculus hippocastanum* L.,
[8] *Robinia pseudoacacia* L., [9] *Alnus glutinosa* [L.] Gaertn., [10] *Araucaria cunninghamii* Aiton ex. D.Don,
[11] *Pseudotsuga menziesii* [Mirb.], [12] *Abies alba* Mill., [13] *Sorbus aucuparia* L., [14] *Betula pendula* Roth,
[15] *Acer pseudoplatanus* L., [16] *Abies sachalinensis* Mast., [17] *Quercus petraea* [Matt.] Liebl.,
[18] *Pinus sylvestris* L., [19] *Larix decidua* Mill., [20] *Fraxinus excelsior* L., [21] *Picea abies* [L.] Karst.

Pretzsch H, Zenner E K (2017) Toward managing mixed-species stands: from parametrization to prescription. Forest Ecosystems, 4(1), 19.

Waldwachstumskunde
Systemanalyse

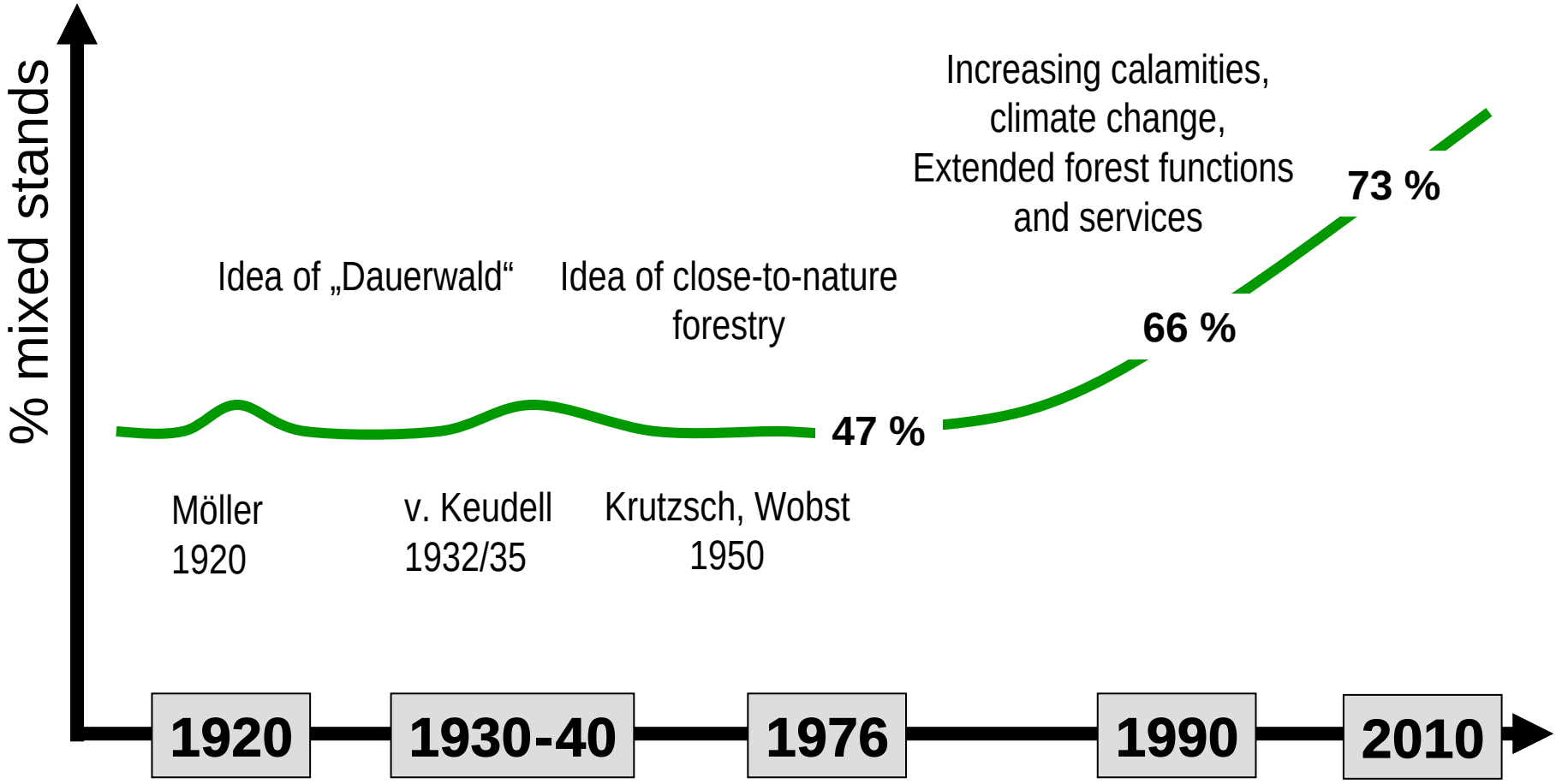
Criteria for sustainable forest ecosystem management. Objective hierarchy for the municipal forest of Traunstein

Criteria for sustainable forest management	Indicators	Weight (%)
Forest resources	timber resources, area of forest, extension of area	20
Health and vitality	stability, fitness, elasticity	17
Productive functions	growth, yield, net return	12
Biological diversity	habitat quality, richness flora/fauna, conservation	10
Protective functions	soil, water, climate, noise, protection	10
Socio-economic functions	employment, recreation, esthetics, proximity to nature	31

according to MCPFE, 2000

Waldwachstumskunde
Systemanalyse

Back to complex mixed-species forests. From the idea to realization in Bavaria



Mixing proportions (>10 % stand area) according to inventories GRI 1971, BWI I 1987, BWI 2 2002, BWI 3 2014 in Bavaria