Waldwachstumskunde
Systemanalyse

Mixed-species forests. Their structure, growth, and yield compared with monocultures

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

Vortrag anläßlich des Weihenstephaner Kolloquiums zur Angewandten Ökologie und Planung,
22. 01. 2018, Dept. Ökologie und Ökosystemmanagement, Emil-Ramann- Str. 6, 85354 Freising

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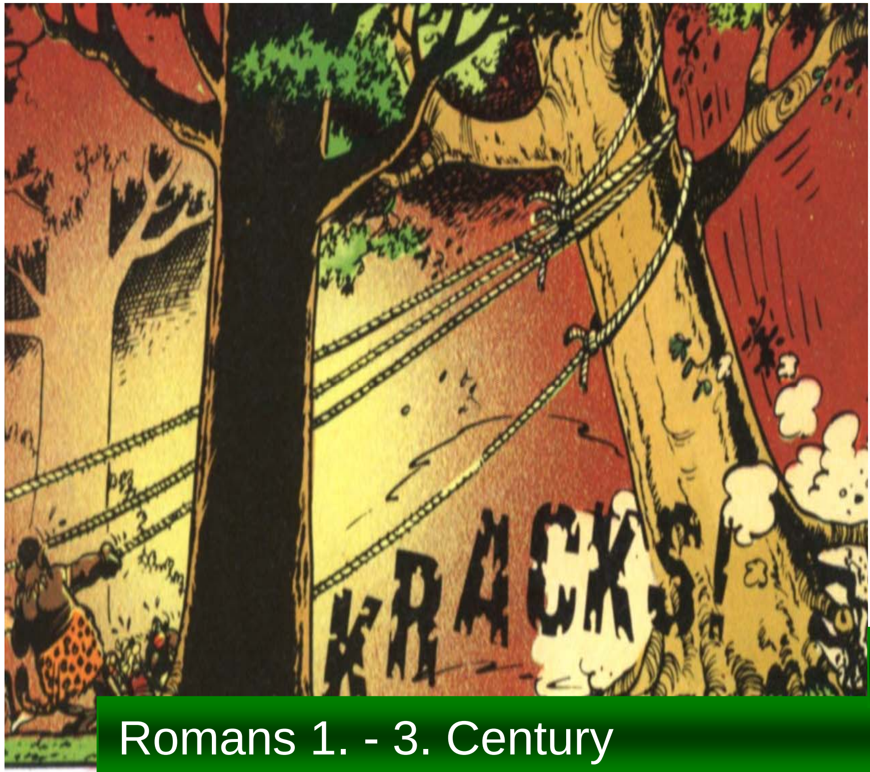
Mixed European beech forest in Central European lowlands

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

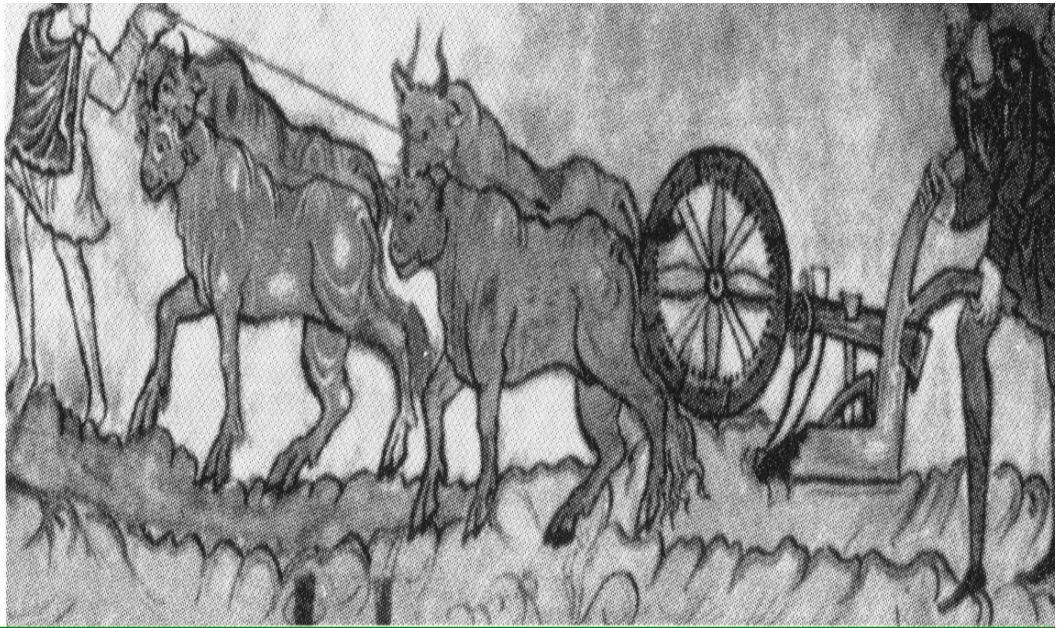
Criteria for sustainable forest ecosystem management. Objective hierarchy for the management of municipal forest Traunstein

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



Romans 1. - 3. Century



Clearings in medieval times 12. – 13. Century

Industrialisation 18. – 19. Century

World War I. und II. 20. Century

humanmade Norway spruce monocultures in the lowlands


Neerdar, Sauerland, 1959


Norway spruce stands damaged by bark beetle
Rachel und Lusen, Bavarian Forest, 2010


Storm damage by Gudrun
>75 million m³ Småland,
Schweden, 2005

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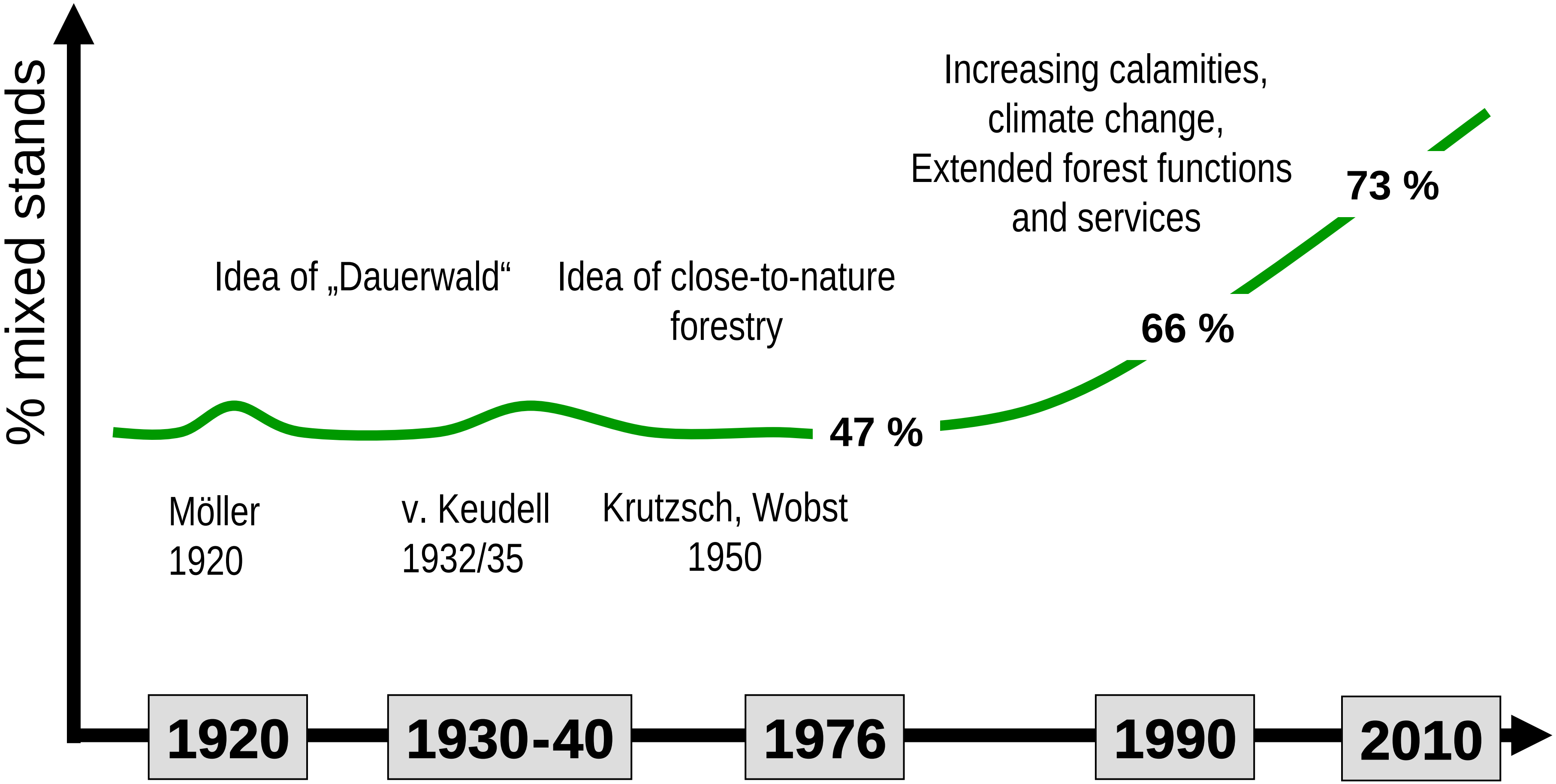
Back to complex mixed-species forests.
From the idea to realization in Bavaria



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

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1 Tree species mixing and stand productivity

2 Effect of mixing on population structure, size distribution

3 Effect on allometry at the tree and organ level

4 Main causes of mixing effects, modification with site conditions

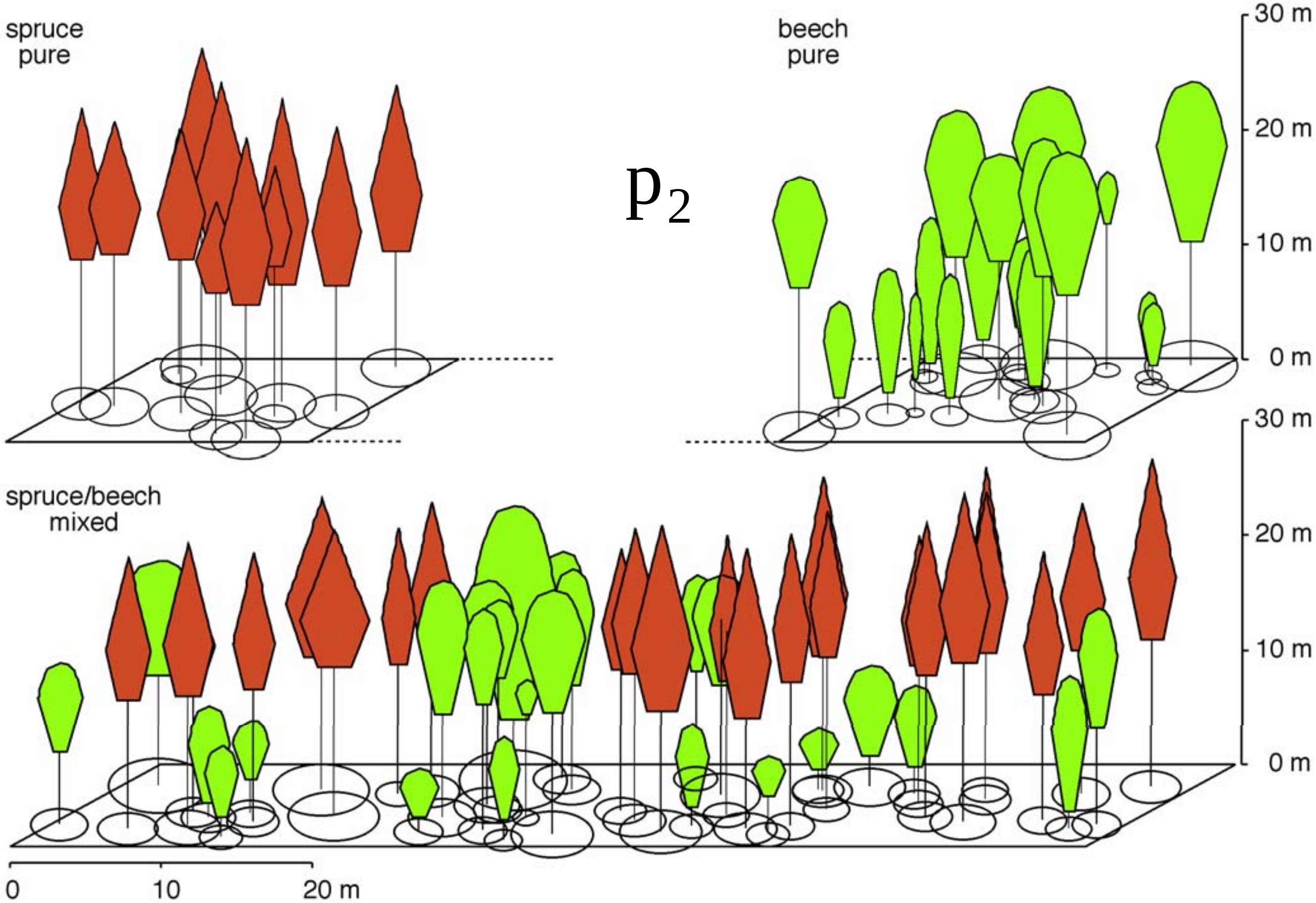
5 From analysis to design of mixed species stands

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

p_1

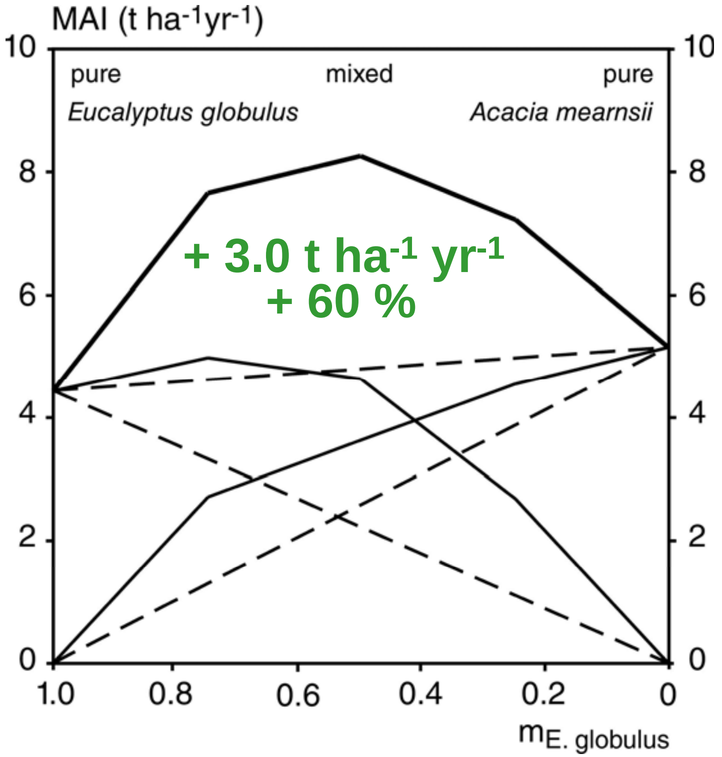
p_2

$p_{1,2}$
m_1
m_2



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

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



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

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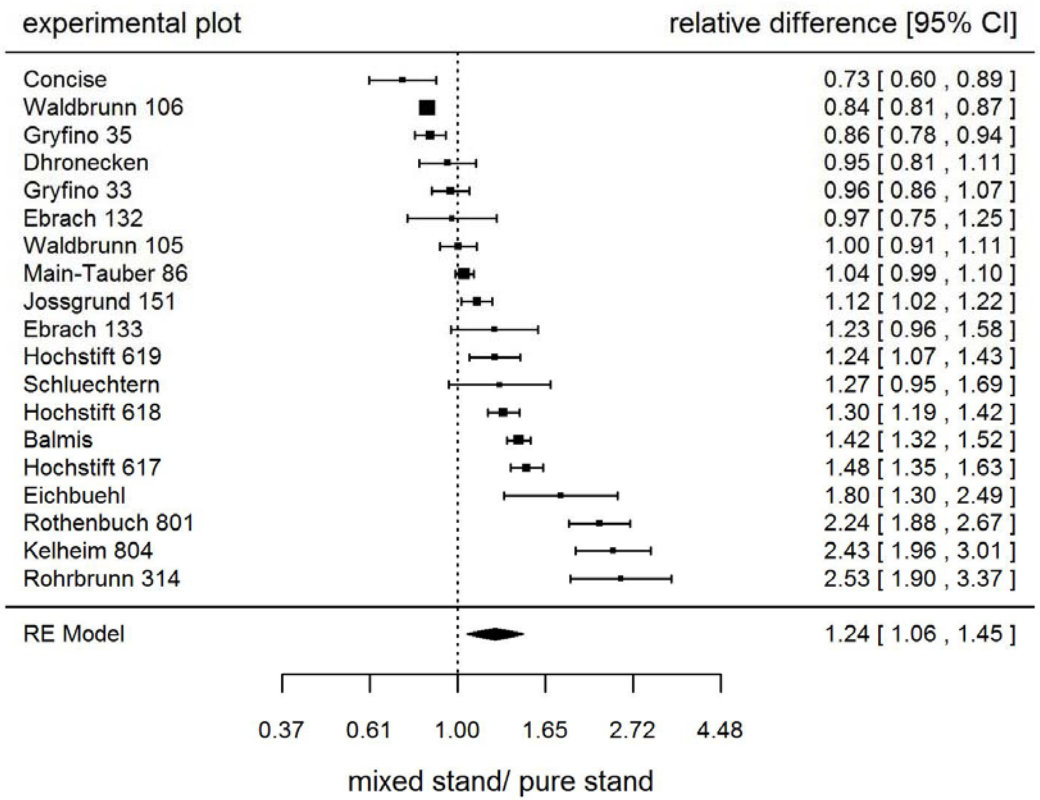
Meta-analysis on overyielding of mixed stands of sessile oak and European beech versus pure stands in Europe based on long-term experiments

oak-beech



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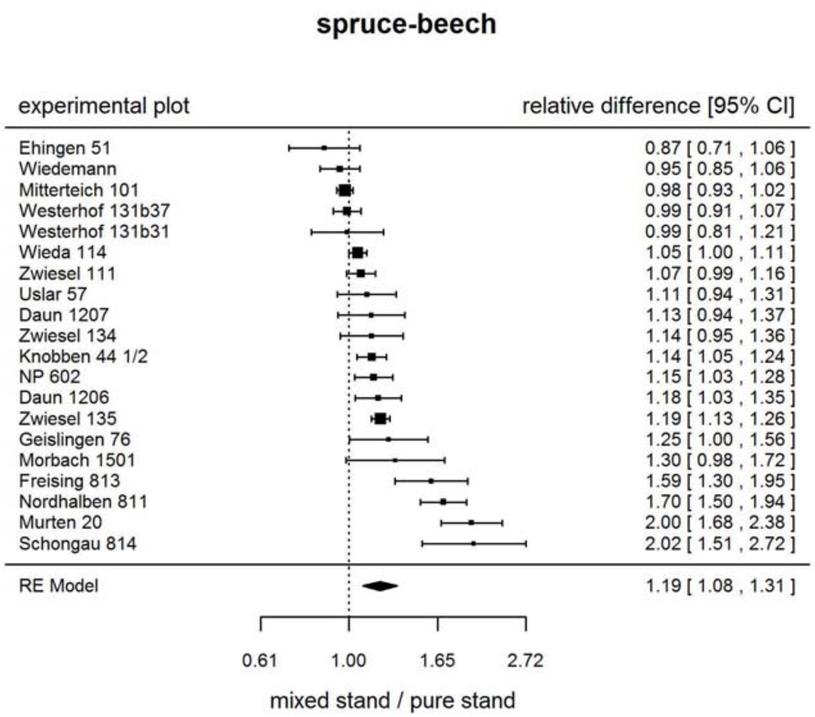
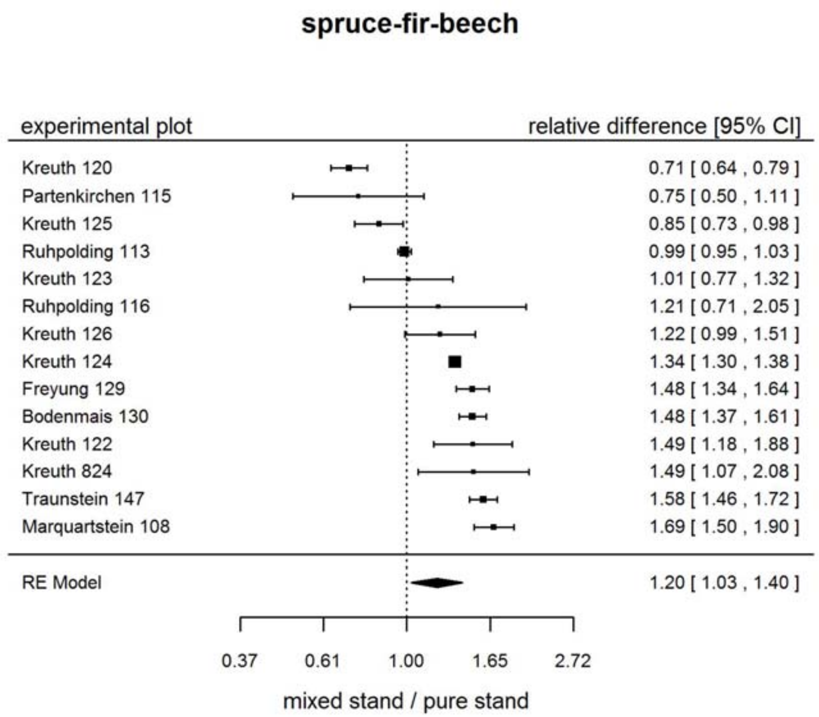
Meta-analysis on overyielding of mixed stands of Norway spruce, European beech, silver fir in Europe based on long-term experiments





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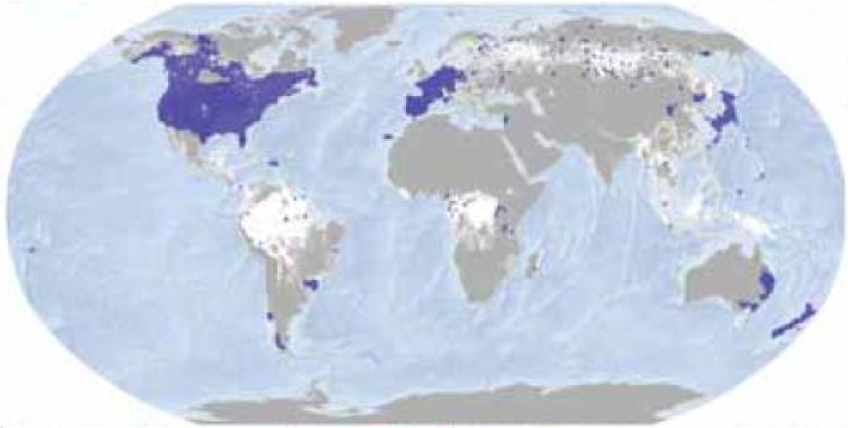
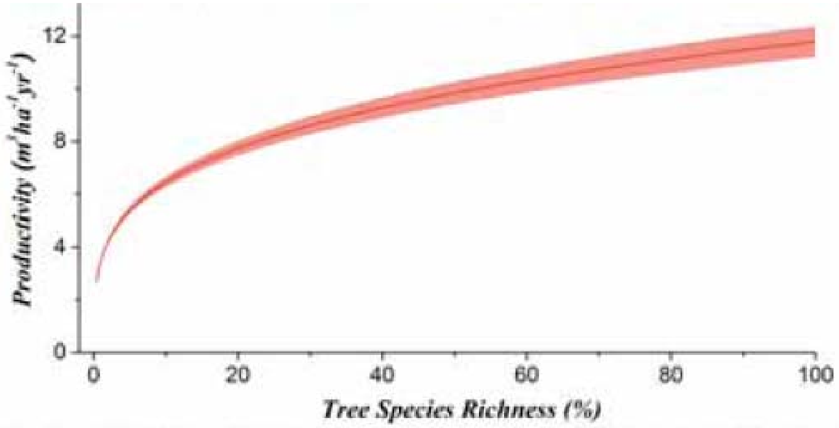
Mixing effects on productivity of forests worldwide and in Central Europe





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 (± SE) in %	21 (± 3)	30 (± 9)	20 (± 3)	11 (± 8)	21 (± 11)	25 (± 6)	13 (± 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

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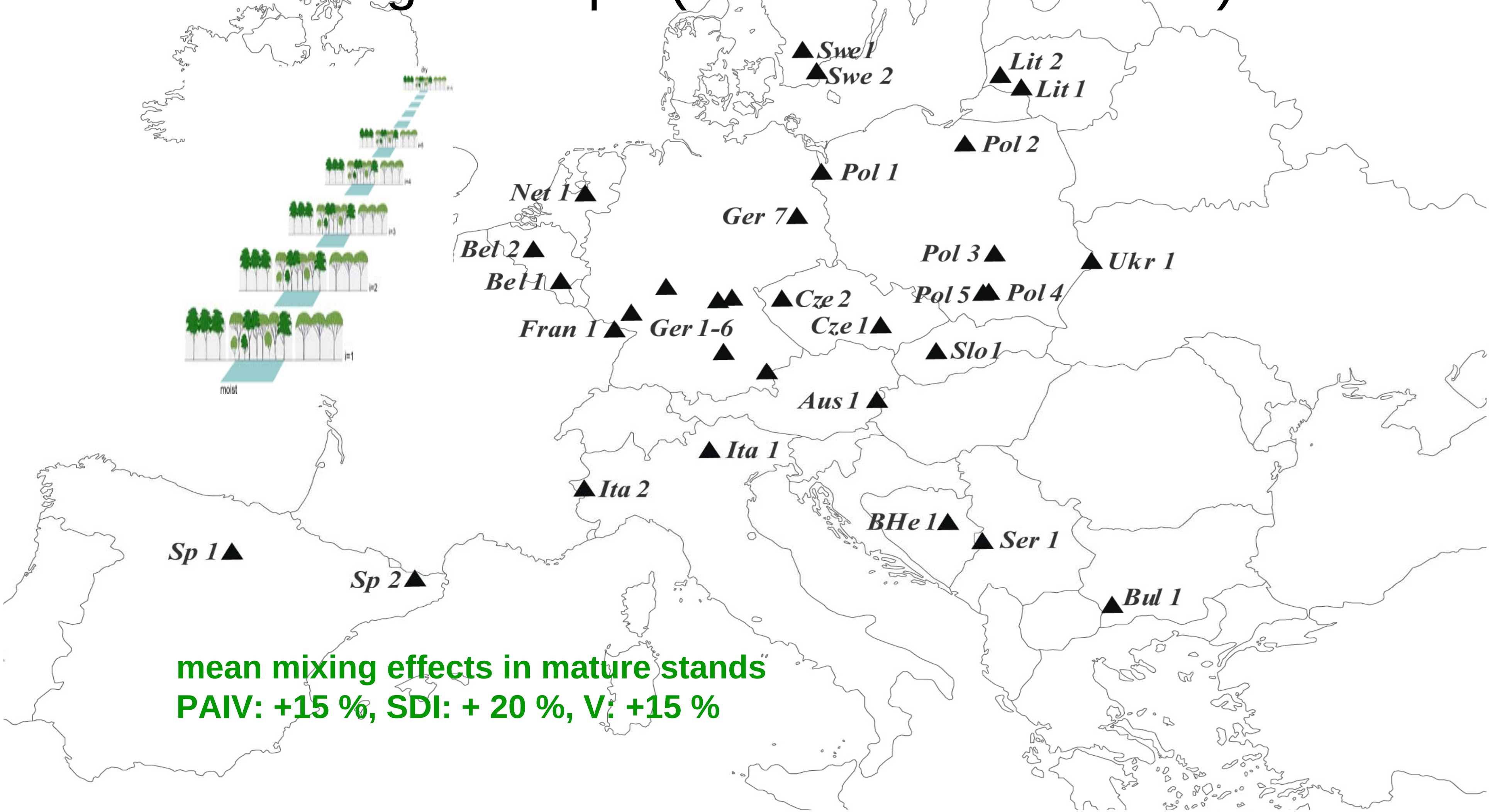
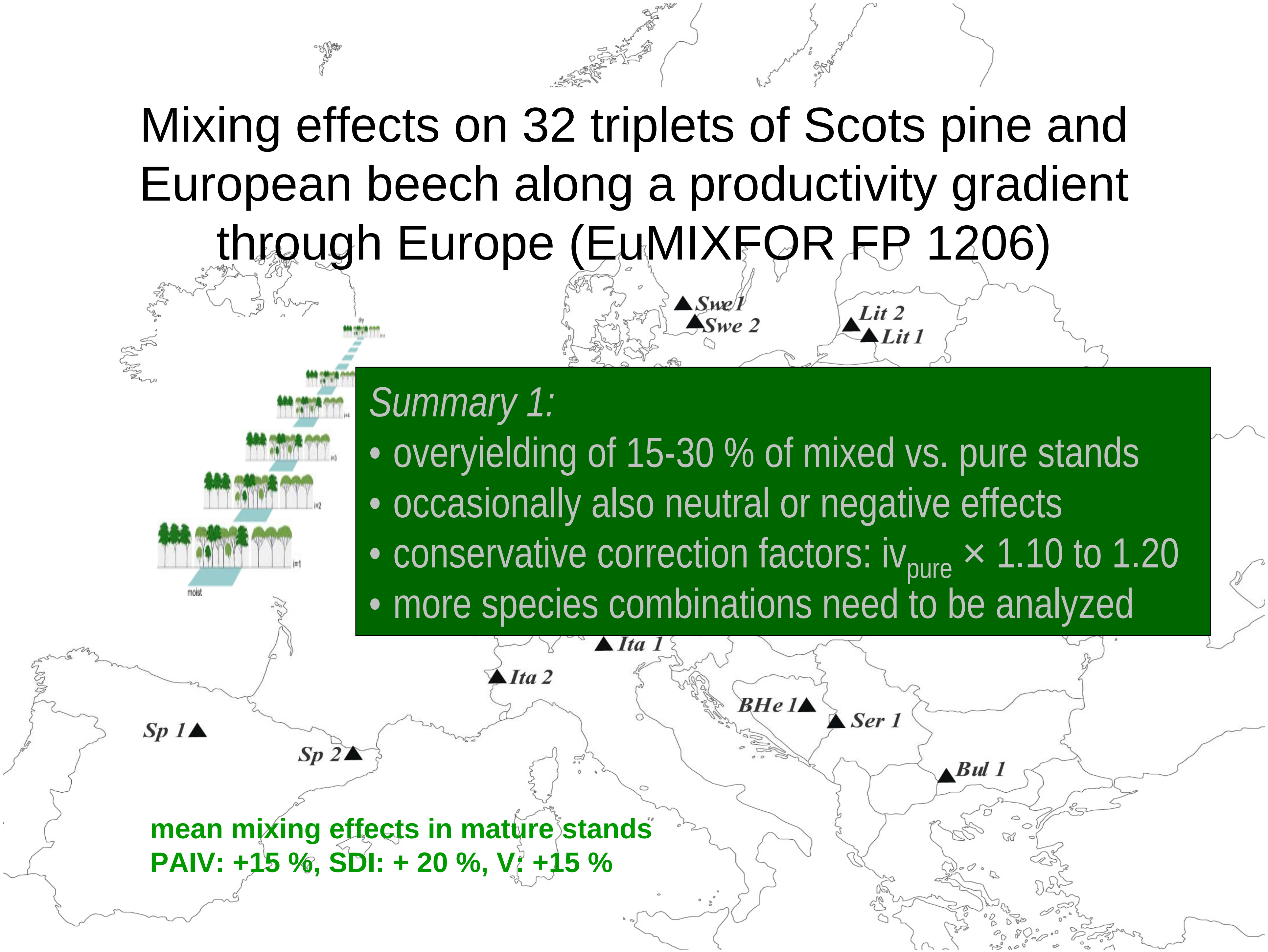
Mixing effects on 32 triplets of Scots pine and European beech along a productivity gradient through Europe (EuMIXFOR FP 1206)



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

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

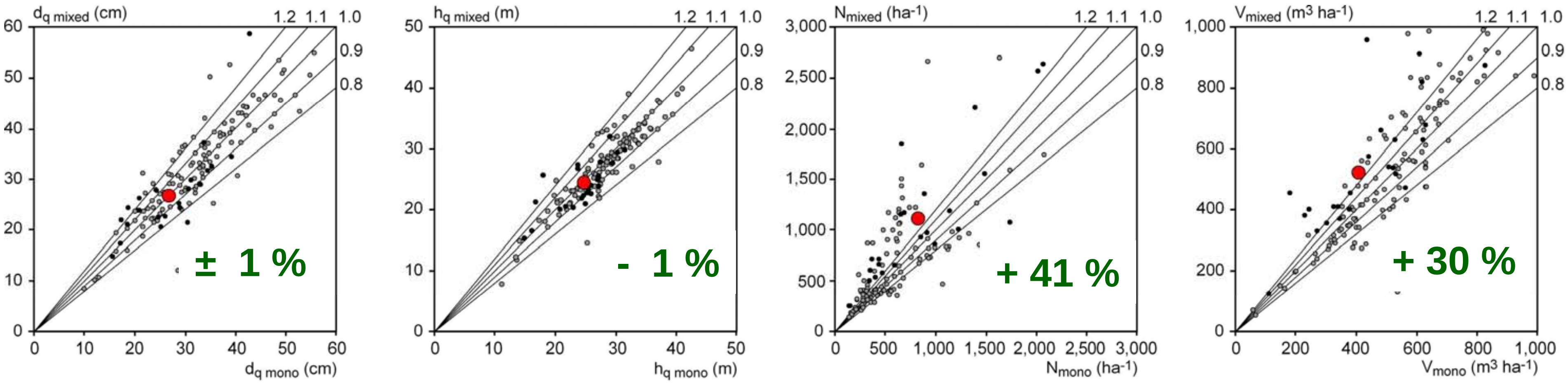


Summary 1:

- 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

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

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



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

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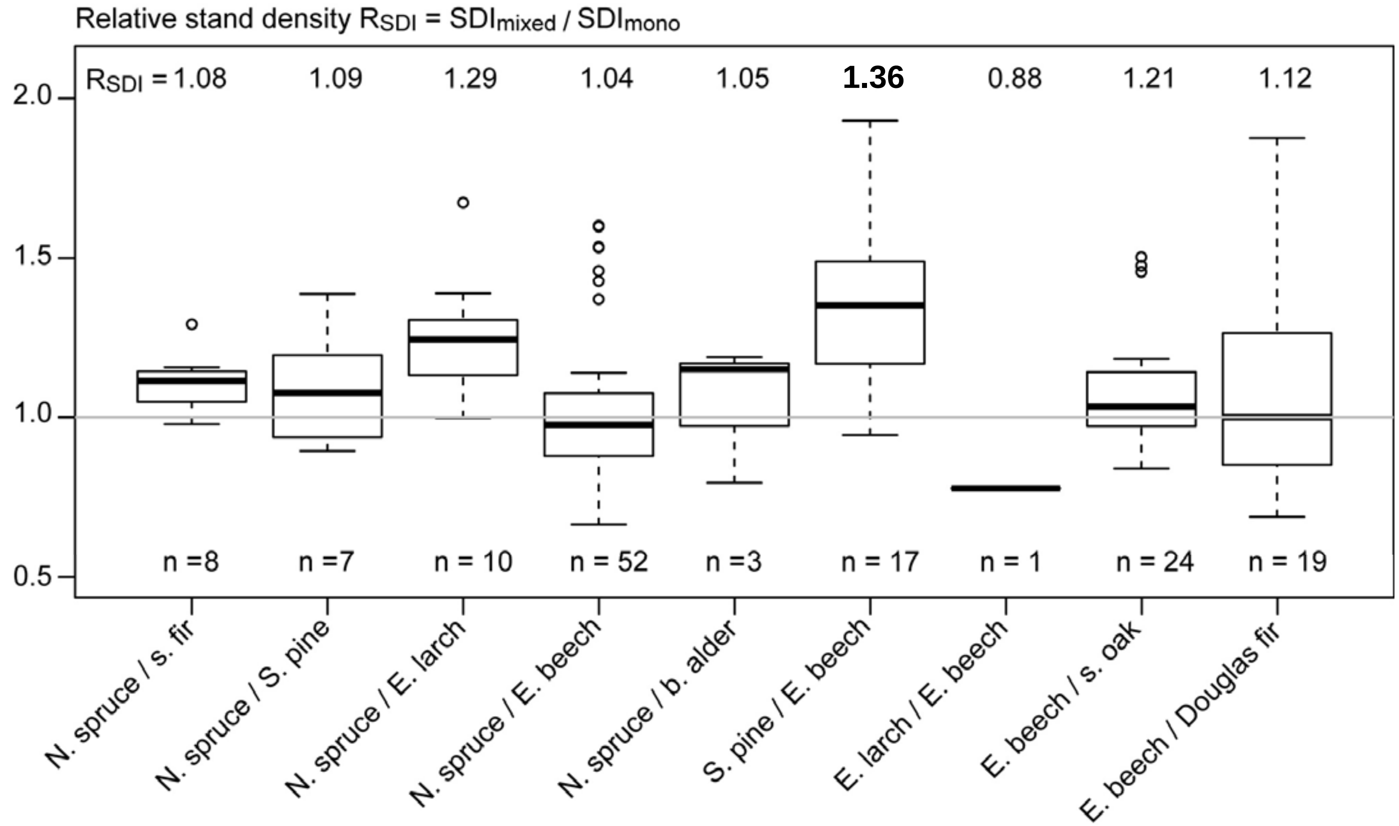
Stand density (SDI) of mixed-species stands versus monocultures on long-term experiments in Central Europe



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

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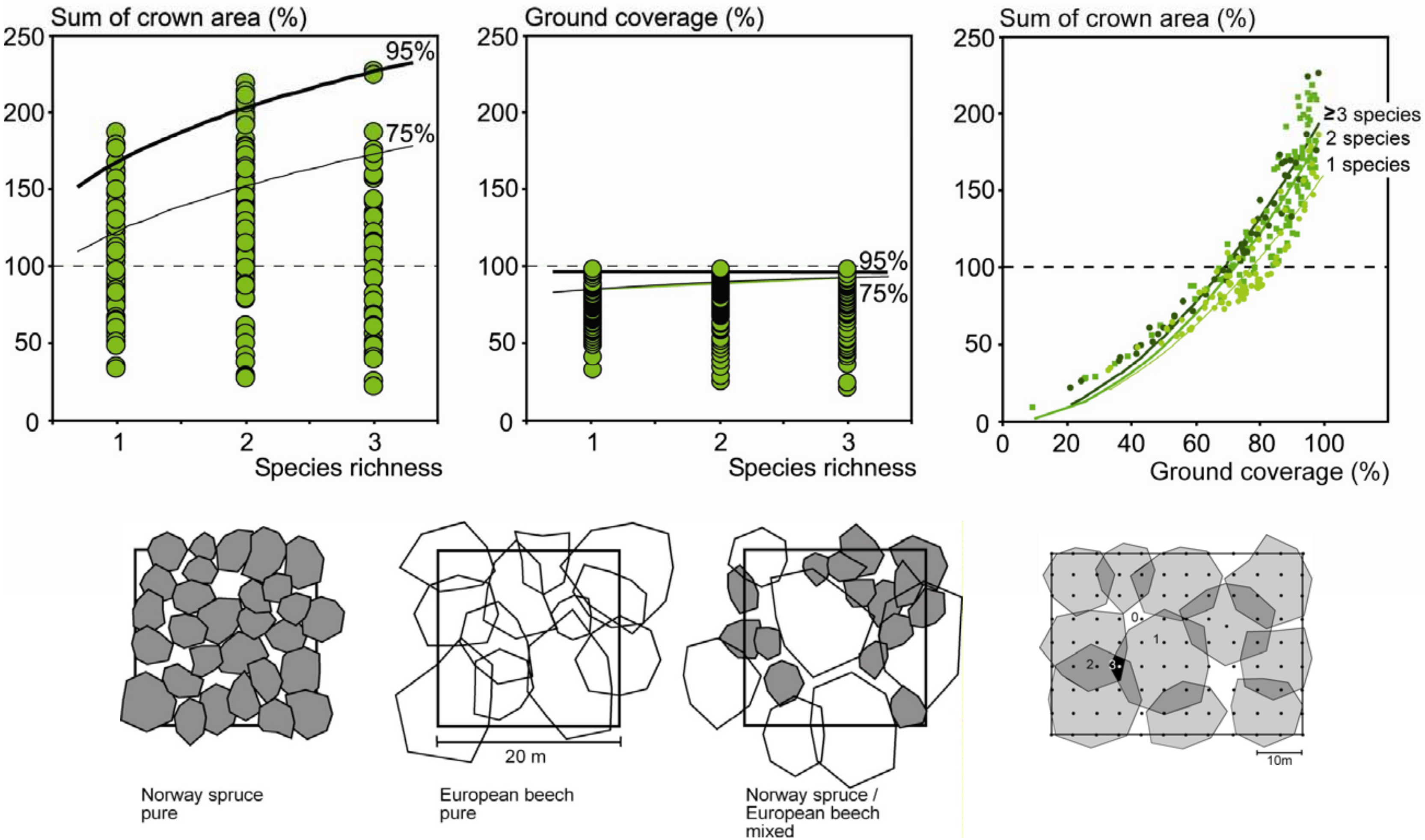
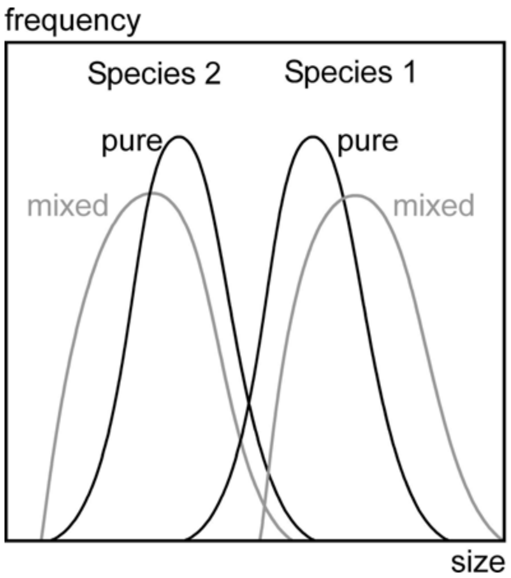
Denser canopy space filling in mixed stands: higher sum of crown area and multiple ground coverage

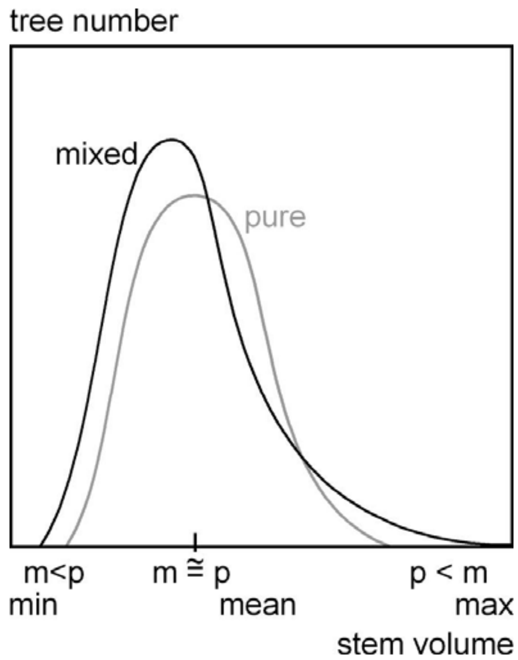


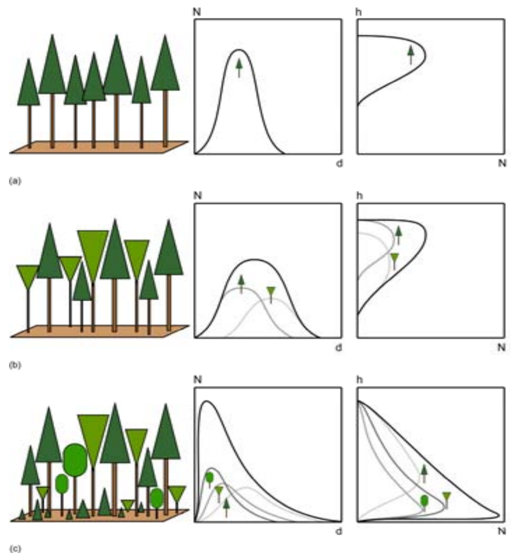
Pretzsch, H. (2014) Canopy space filling and tree crown morphology in mixed-species stands compared with monocultures. Forest Ecology and Management, 327: 251-264.

TUM

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.

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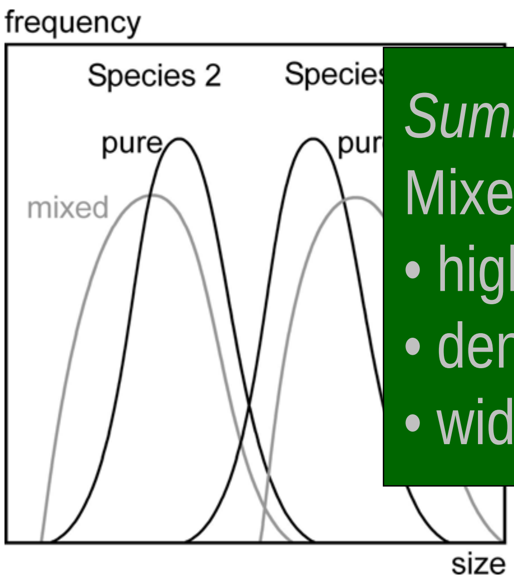

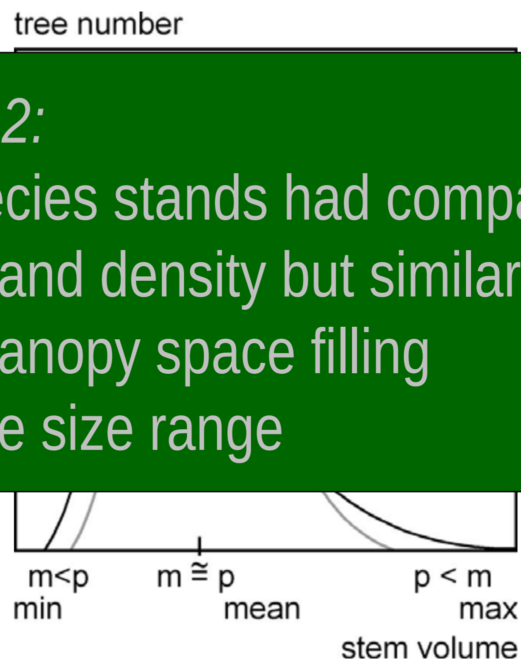

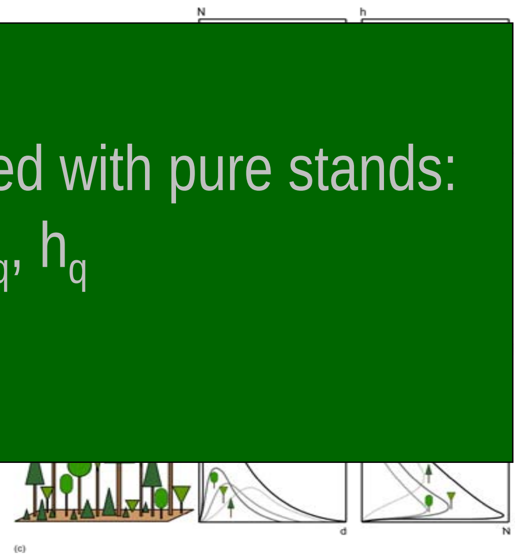

Summary 2:

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.

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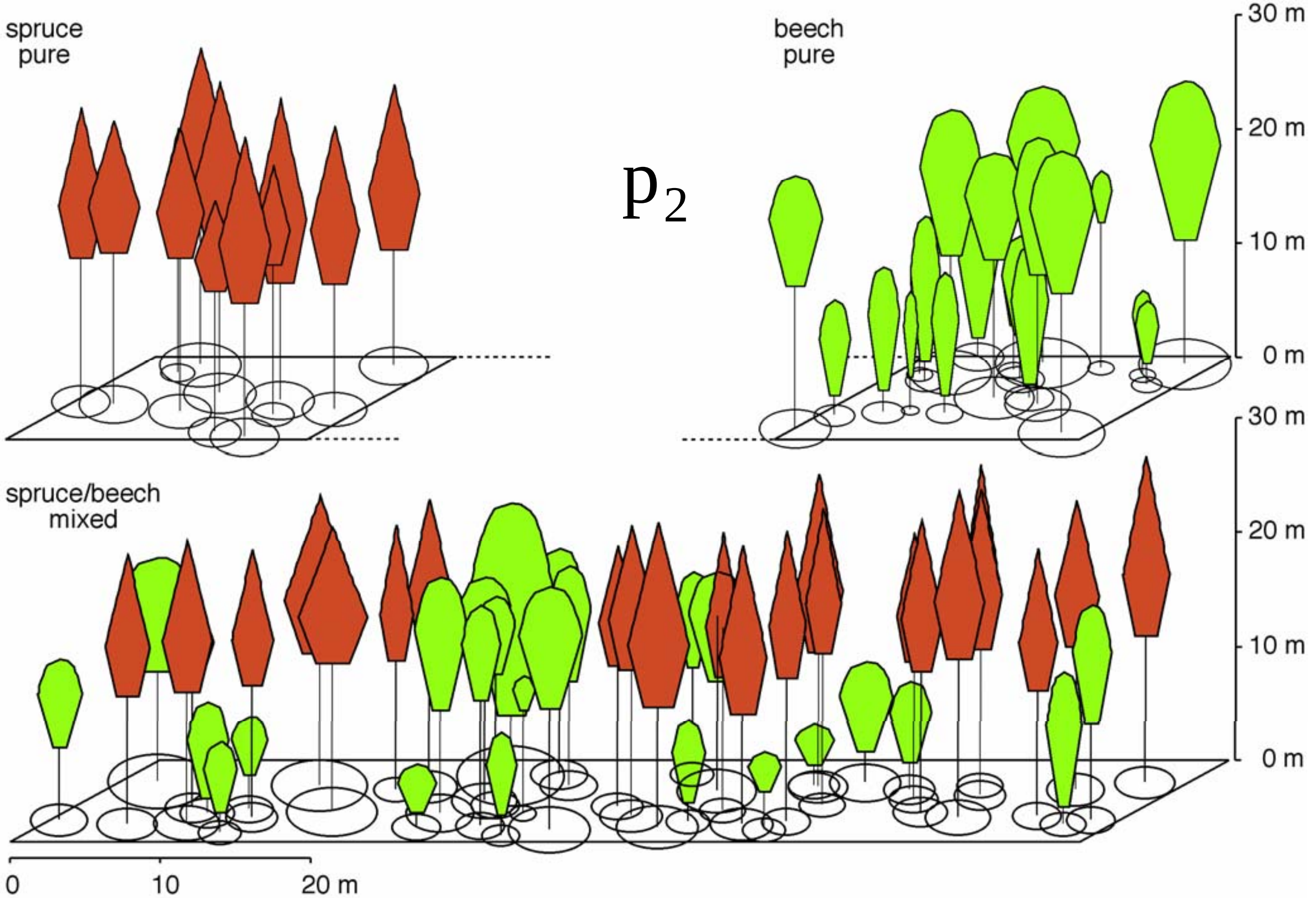
Experimental setup for scrutiny of mixing effects
Zwiesel 111/3,4,5 Bavarian Forest

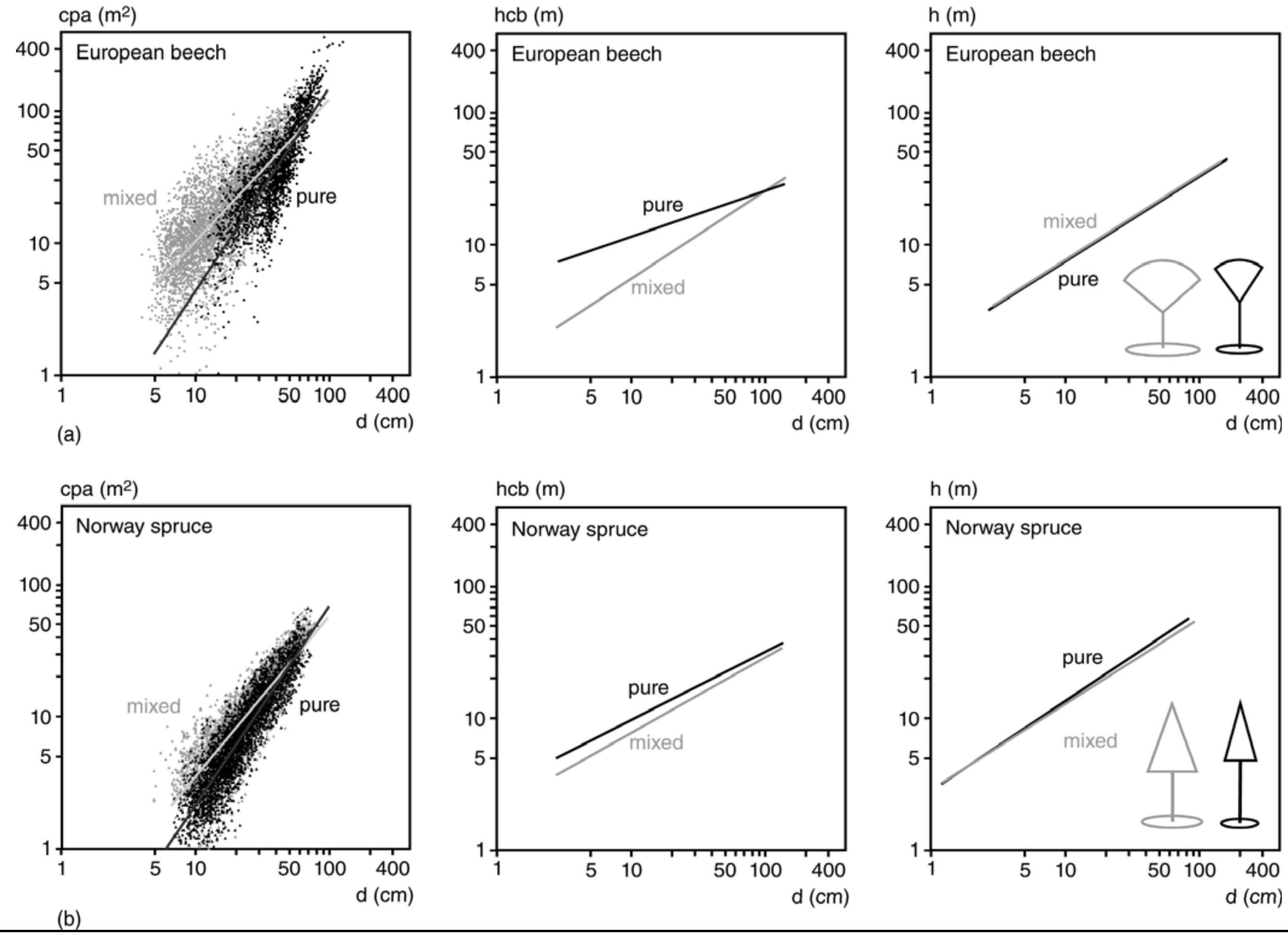
p_1 p_2

$p_{1,2}$
m_1
m_2



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

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.

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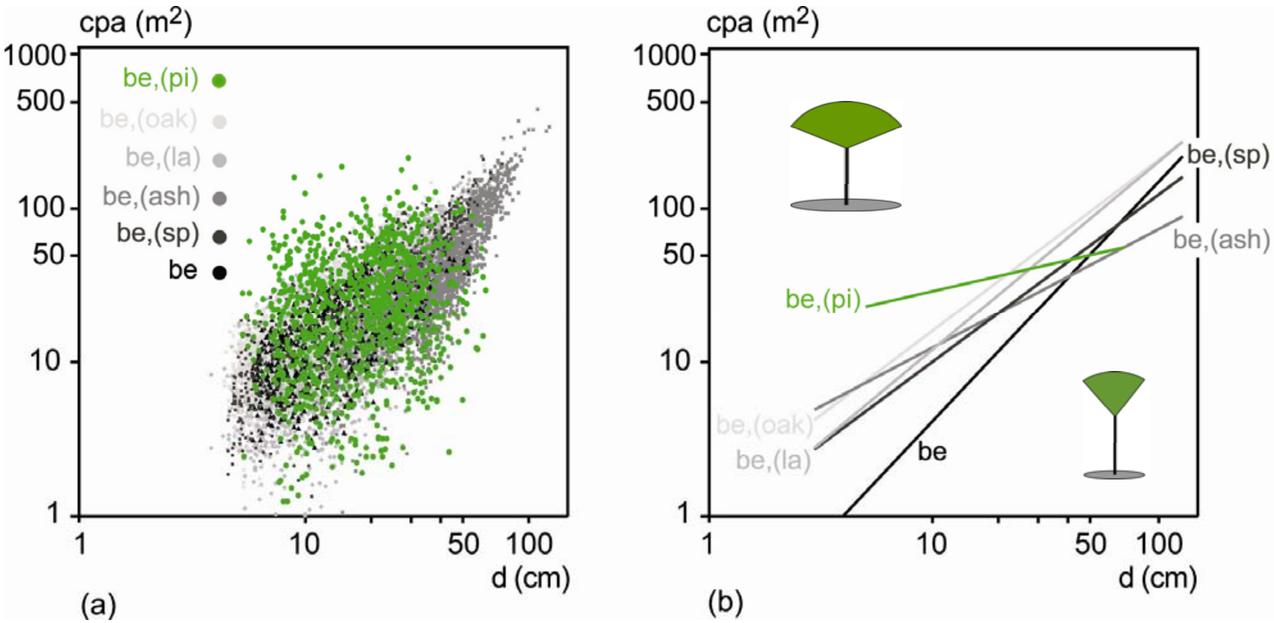
Allometry between crown projection area and stem diameter of European when growing in mono-specific versus mixed stands



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.

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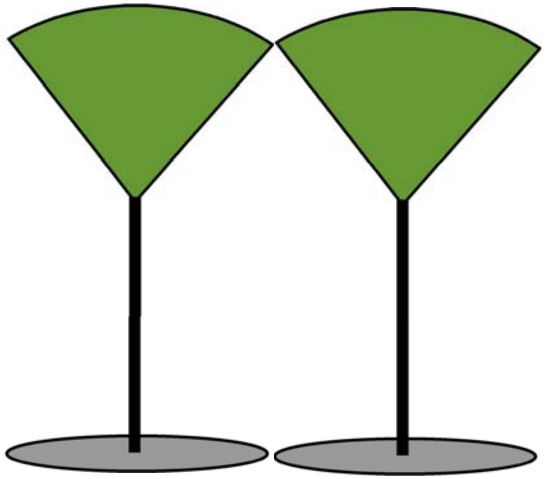
Morphological differences in intra- vs. inter-specific environment despite of equal biomass

beech/beech



branch number
19 vs. 36

branch length
4.8 m vs. 4.3 m

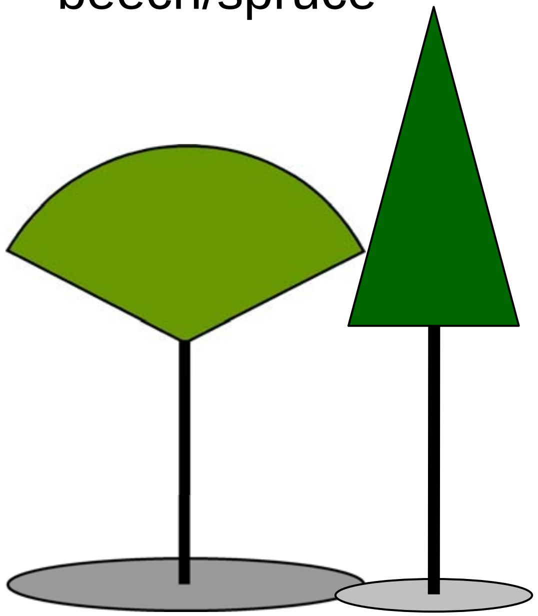
branch angle
139° vs. 128°

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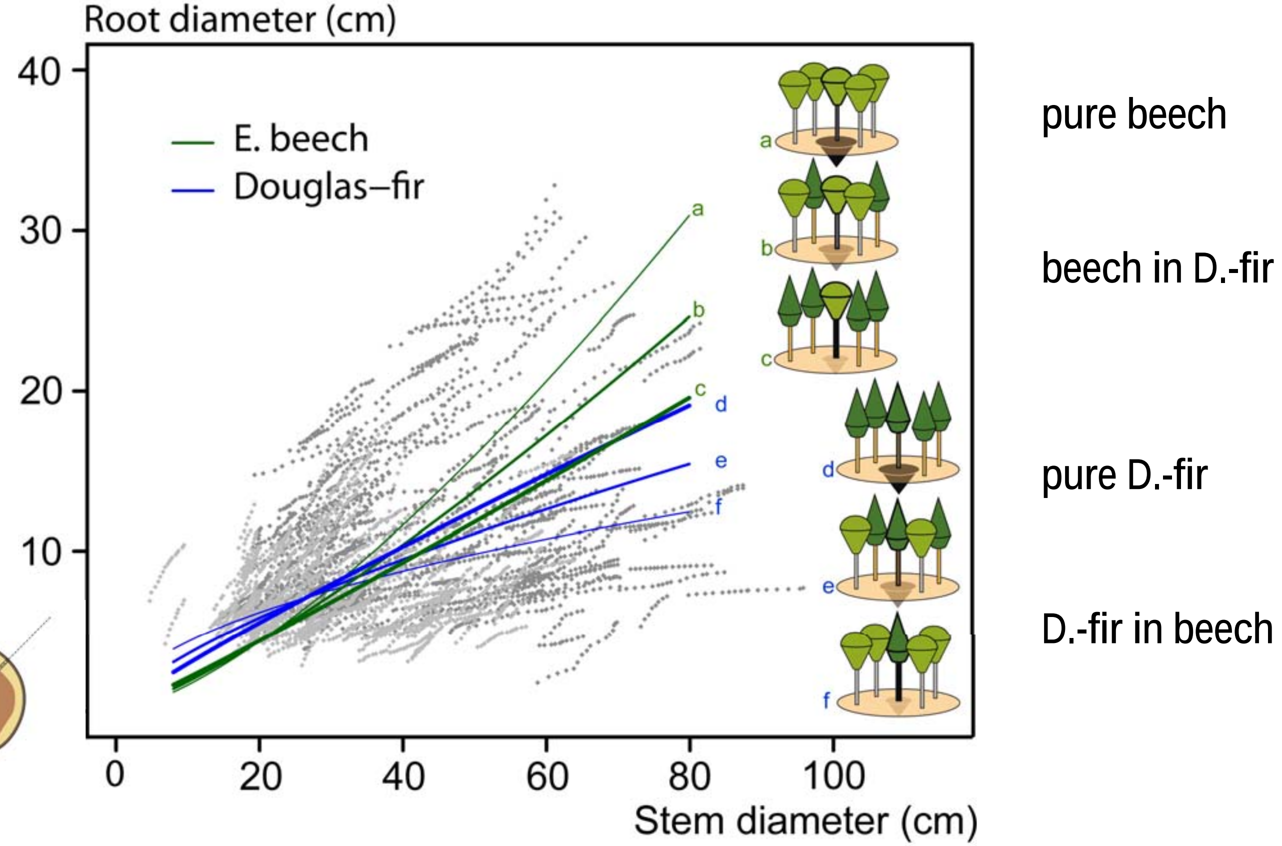
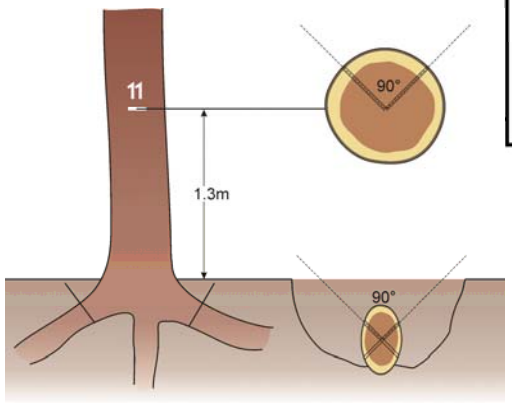
Enhancement of shoot in relation to coarse root growth in mixed compare with mono-specific stands of European beech and Douglas-fir





Thurm et al. (2017)

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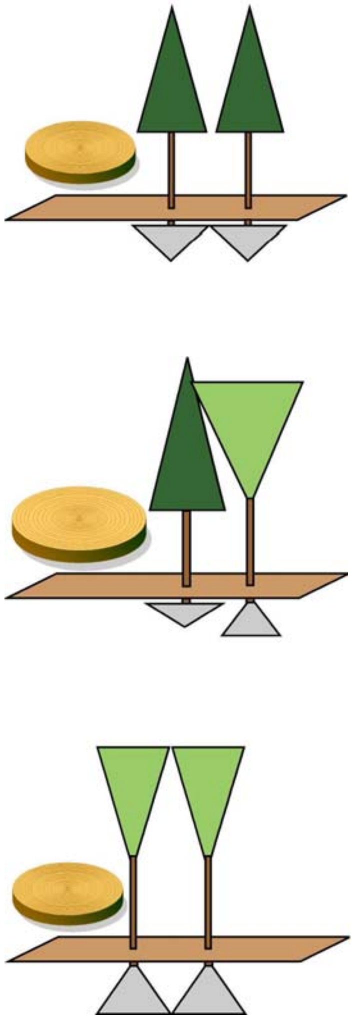
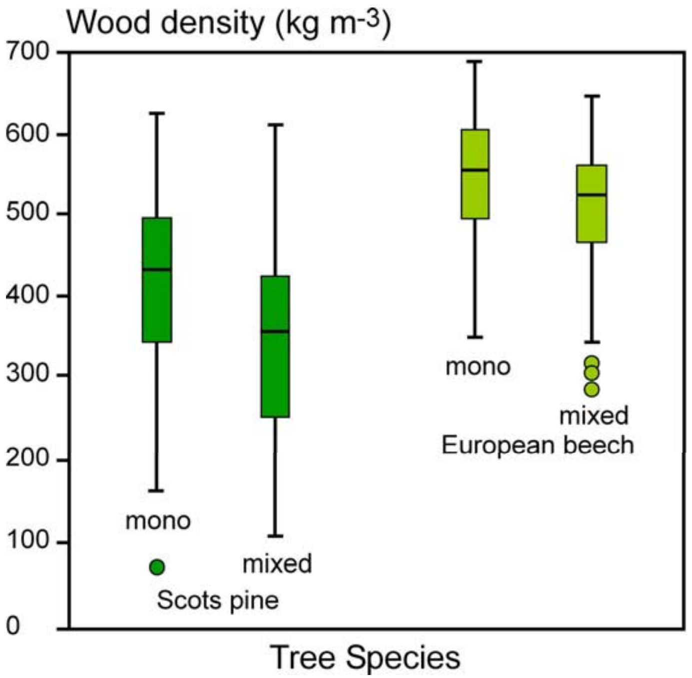
Wood density in mixed-species stands of S. pine and E. beech compared with monocultures





Zeller et al. 2017, Pretzsch and Rais 2016

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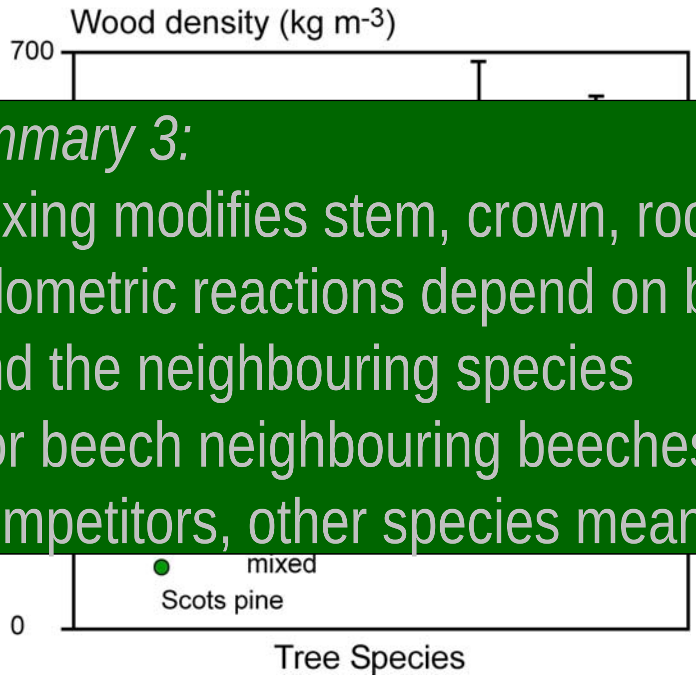
Wood density in mixed-species stands of S. pine and E. beech compared with monocultures



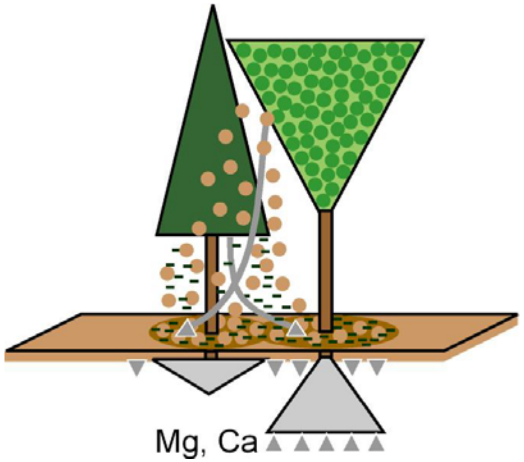
Summary 3:

- 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

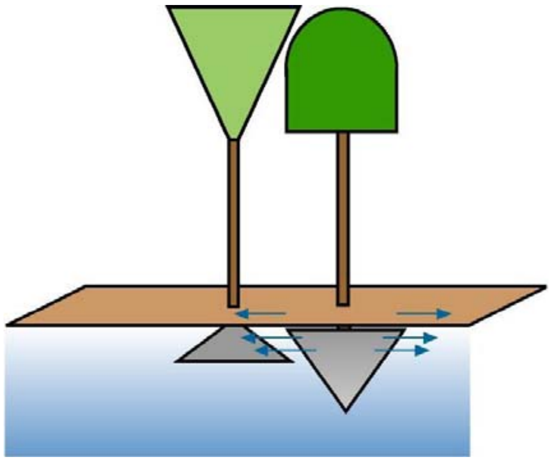
Facilitation by better mineral nutrients and water exploitation

nutrients
upward transport



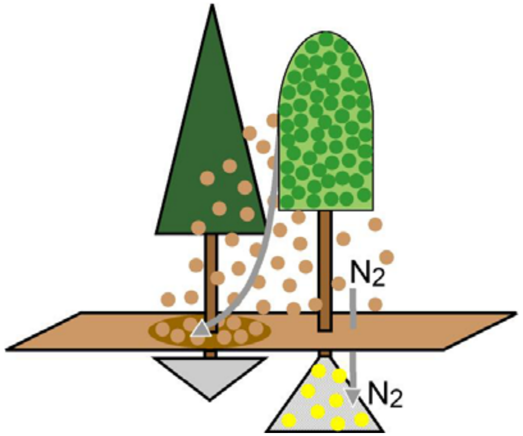
e.g. Rothe, Binkley (2001)

hydraulic
redistribution



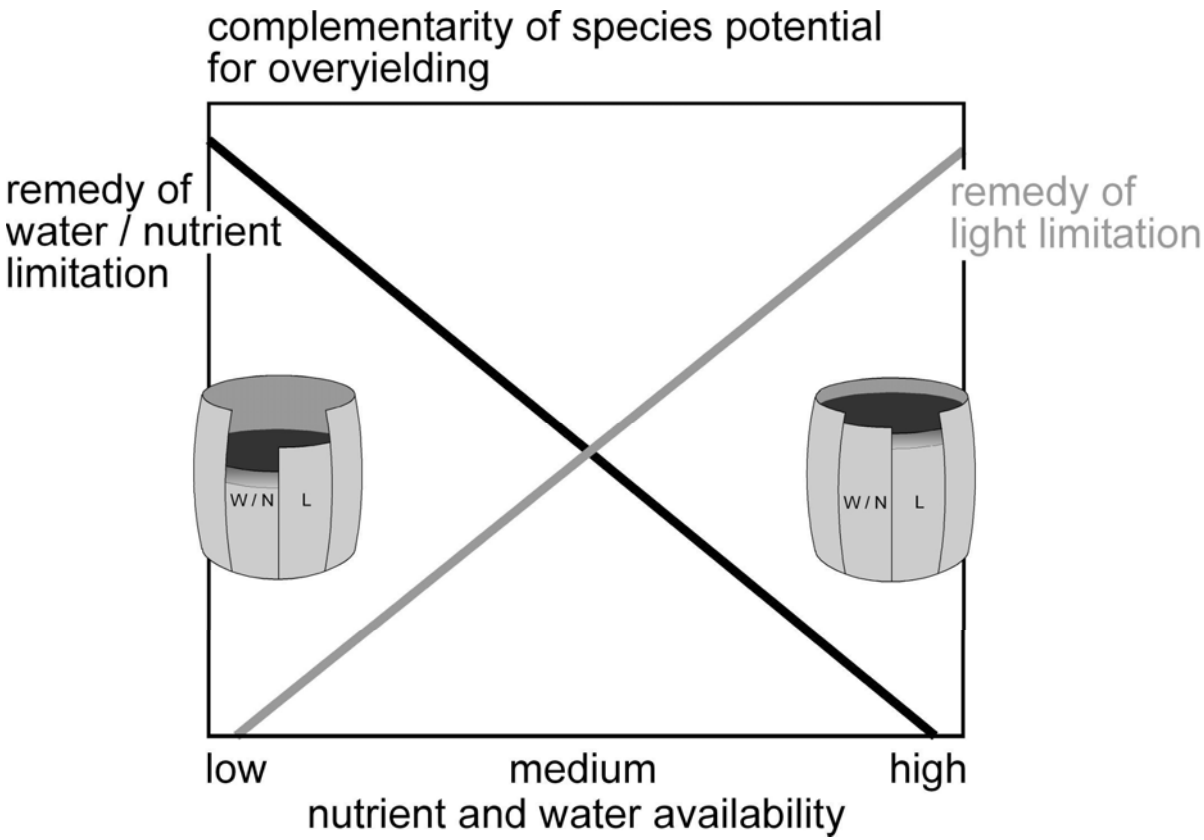
e.g. Prieto et al. 2012

atmospheric
N_2 fixation



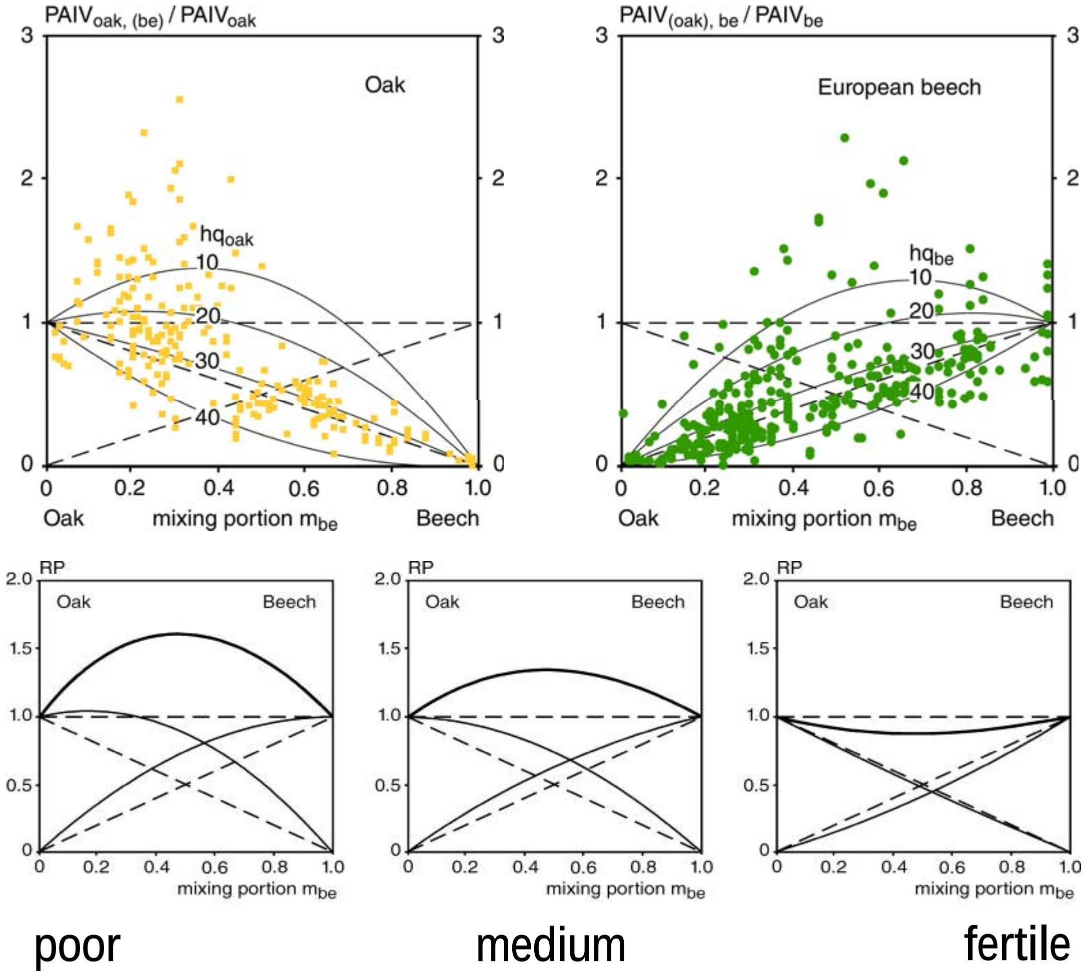
e..g. Forrester et al. 2007, 2007

Conceptual model for the dependency of overyielding on site conditions



e. g. Forrester (2017), Pretzsch (2017)

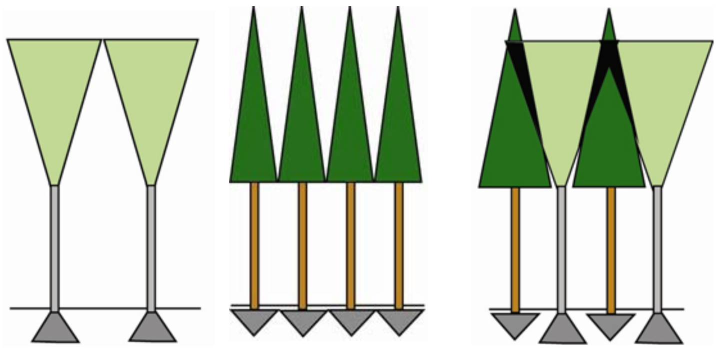
Transect study: Overyielding increases with water and nutrient scarcity



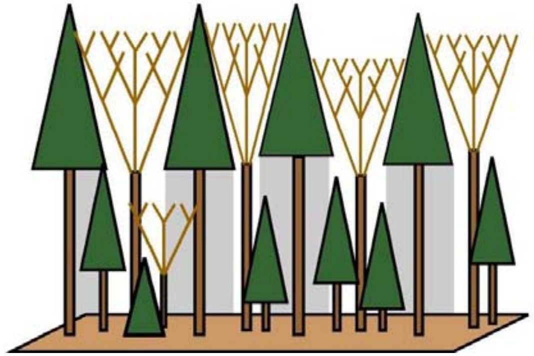
Pretzsch et al. (2013) Productivity of mixed versus pure stands of oak (*Quercus petraea* (Matt.) Liebl. and *Quercus robur* L.) and European beech (*Fagus sylvatica* L.) along an ecological gradient, EJFOR, 132 (2):263-280

Complementarity in light use causes competition reduction

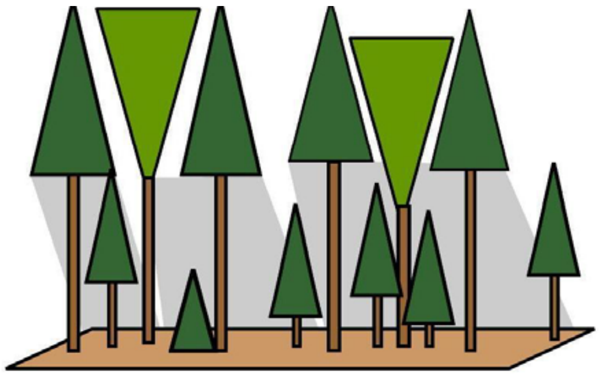
Morphological complementarity



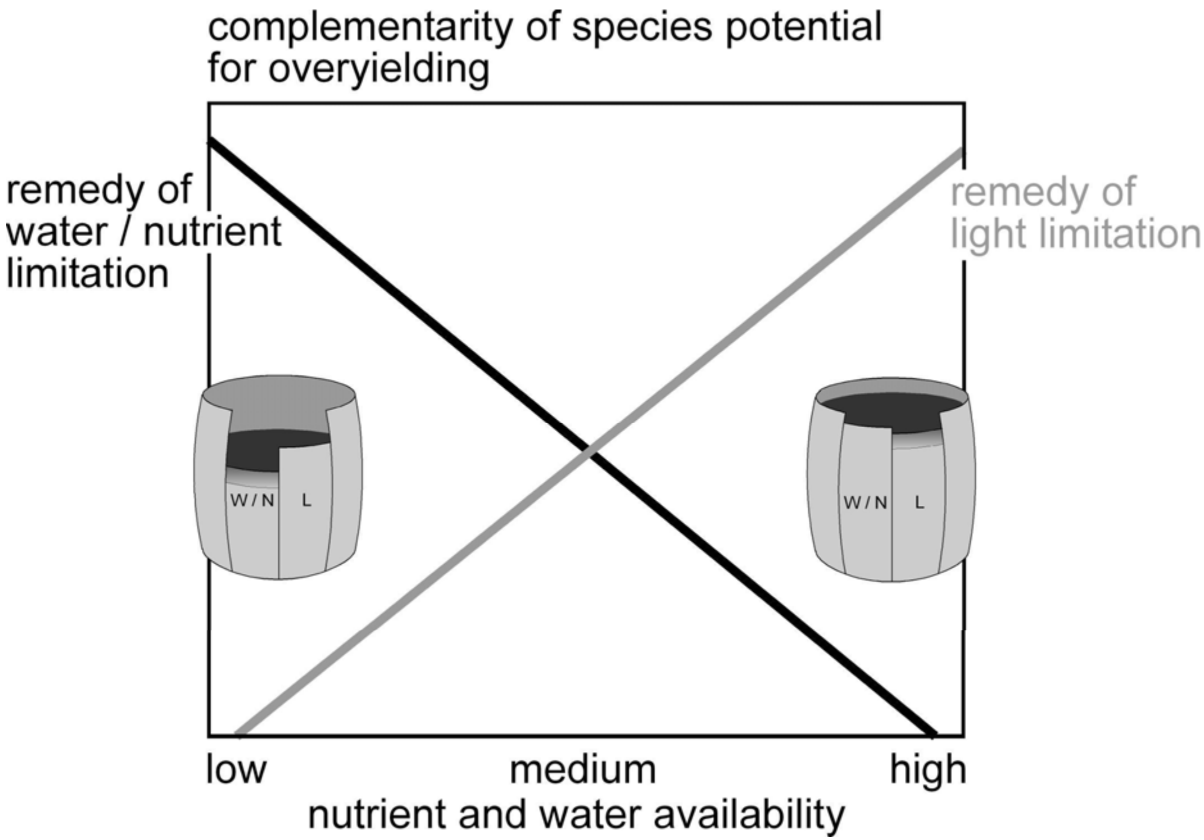
Temporal complementarity



Physiological complementarity



Conceptual model for the dependency of overyielding on site conditions



e. g. Forrester (2017), Pretzsch (2017)

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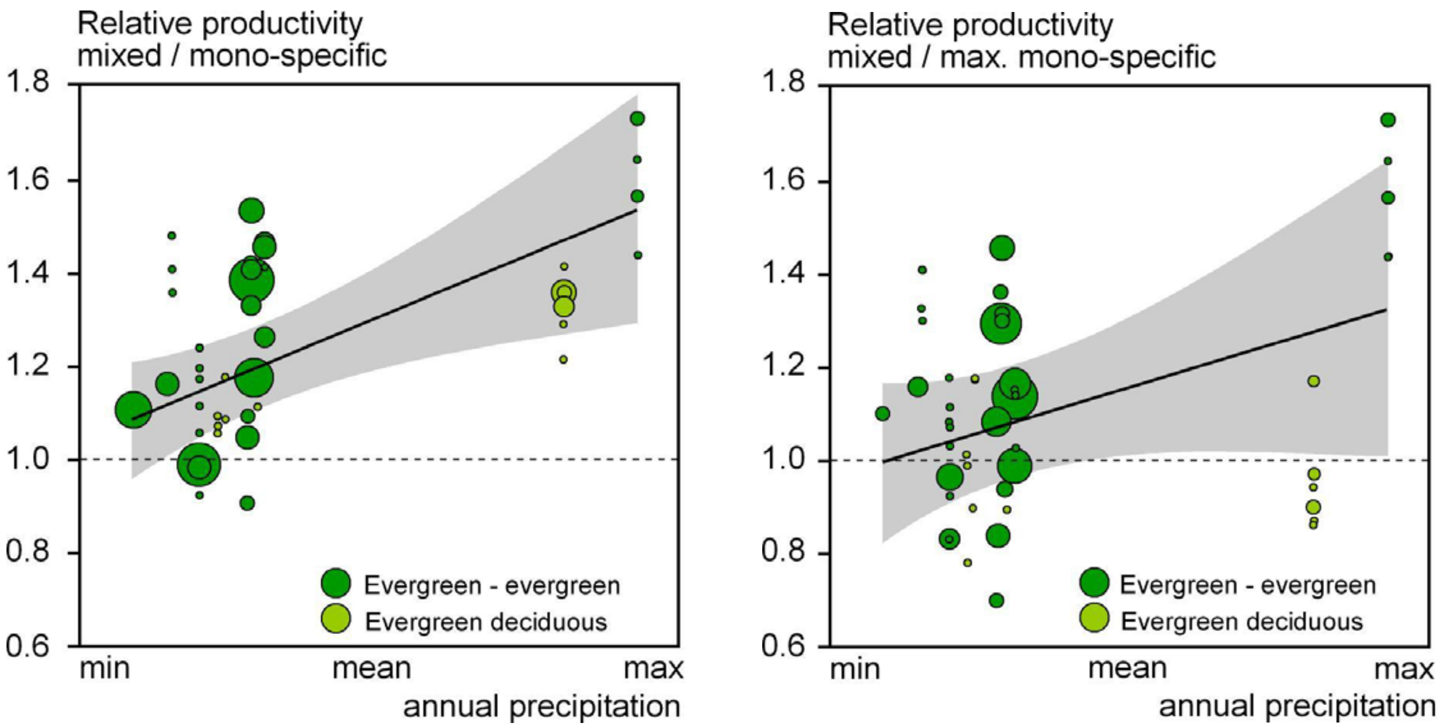
Increasing overyielding (15 %) and transgressive overvielding with water availability



no significant transgressive underyielding

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

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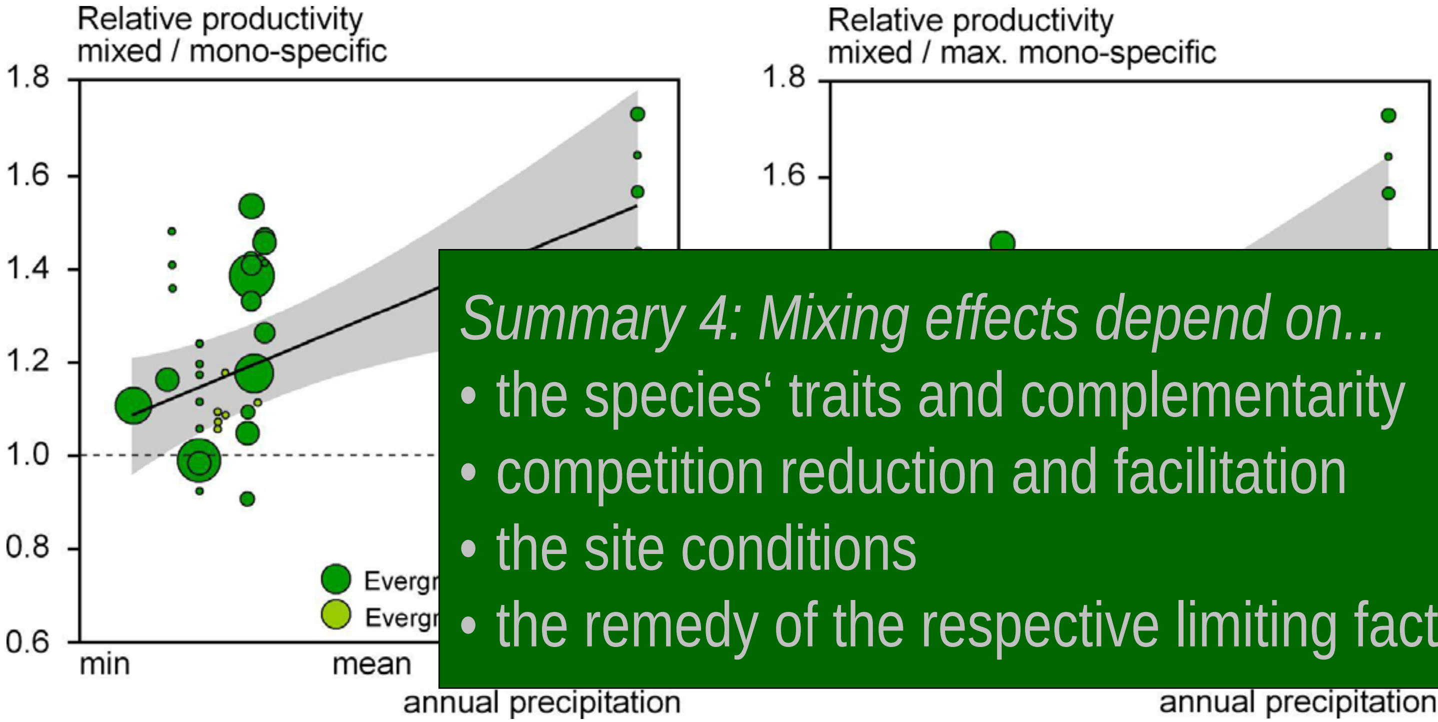
Increasing overyielding (15 %) and transgressive overvielding with water availability



Summary 4: Mixing effects depend on...

- the species‘ traits and complementarity
- competition reduction and facilitation
- the site conditions
- the remedy of the respective limiting factor

no significant transgressive underyielding

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

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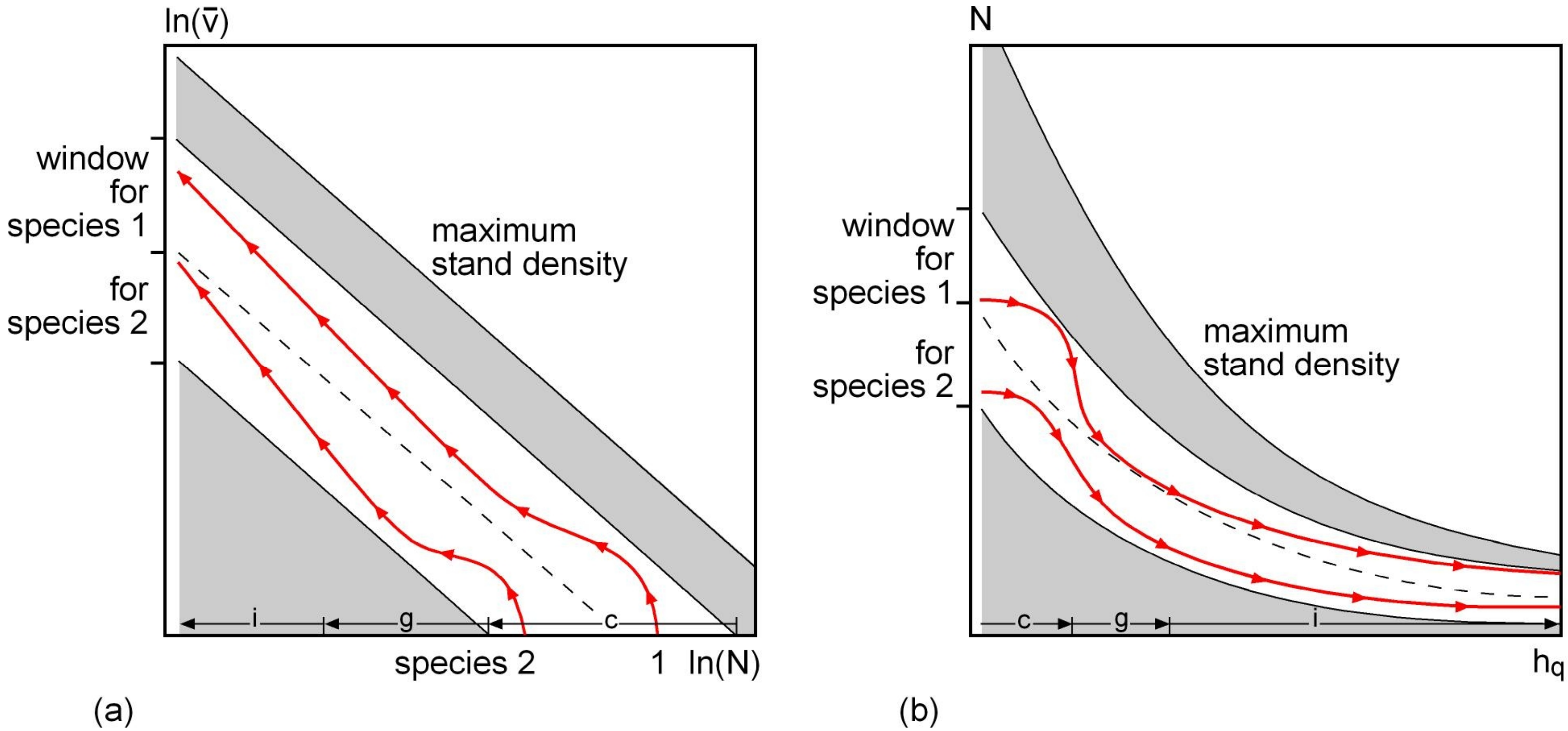
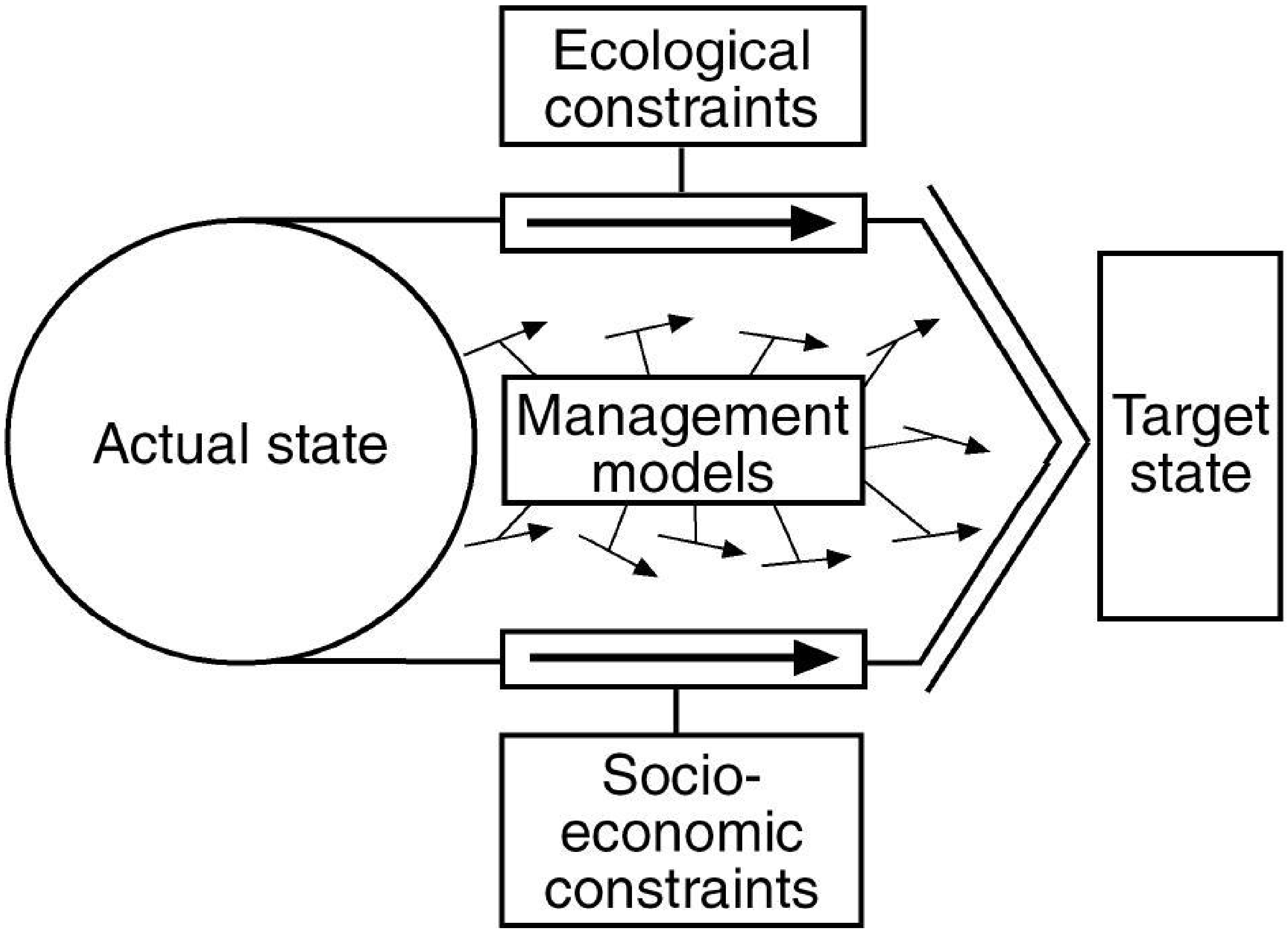
Guidelines for silvicultural regulation of mixed-species stand can bring the mixing idea onto the ground



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

Model application for deriving silvicultural guidelines



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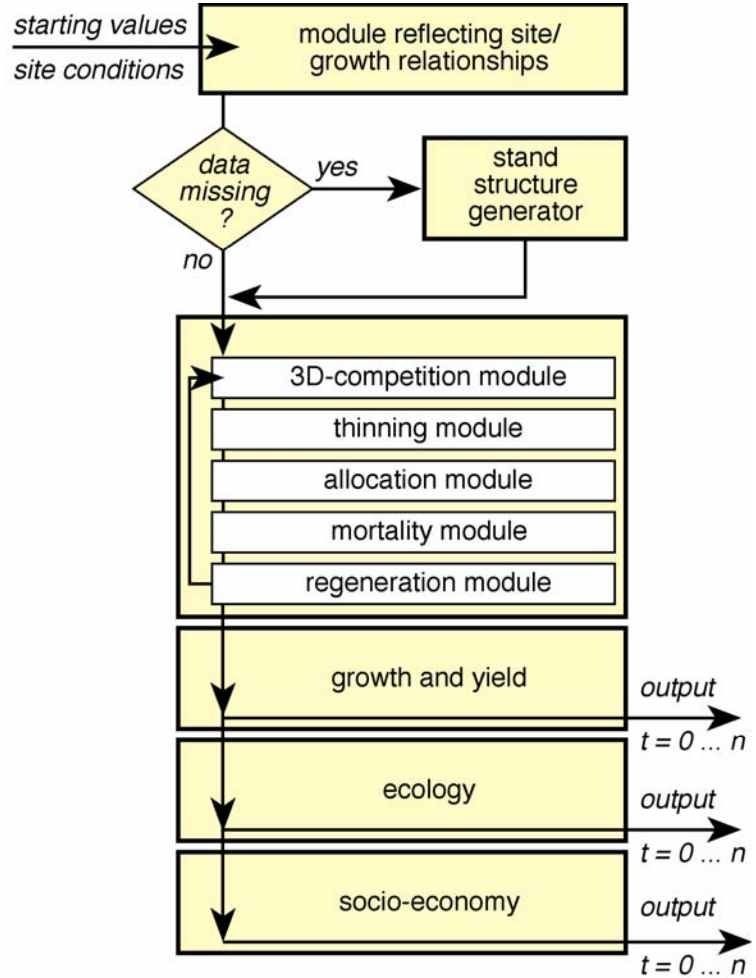
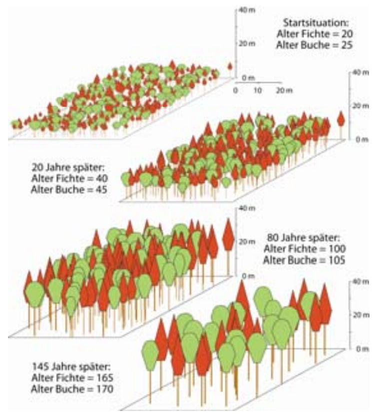
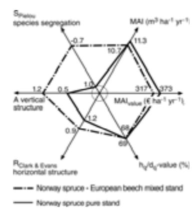
SILVA 3.0 as example of a spatially explicit individual tree model for pure and mixed stands







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

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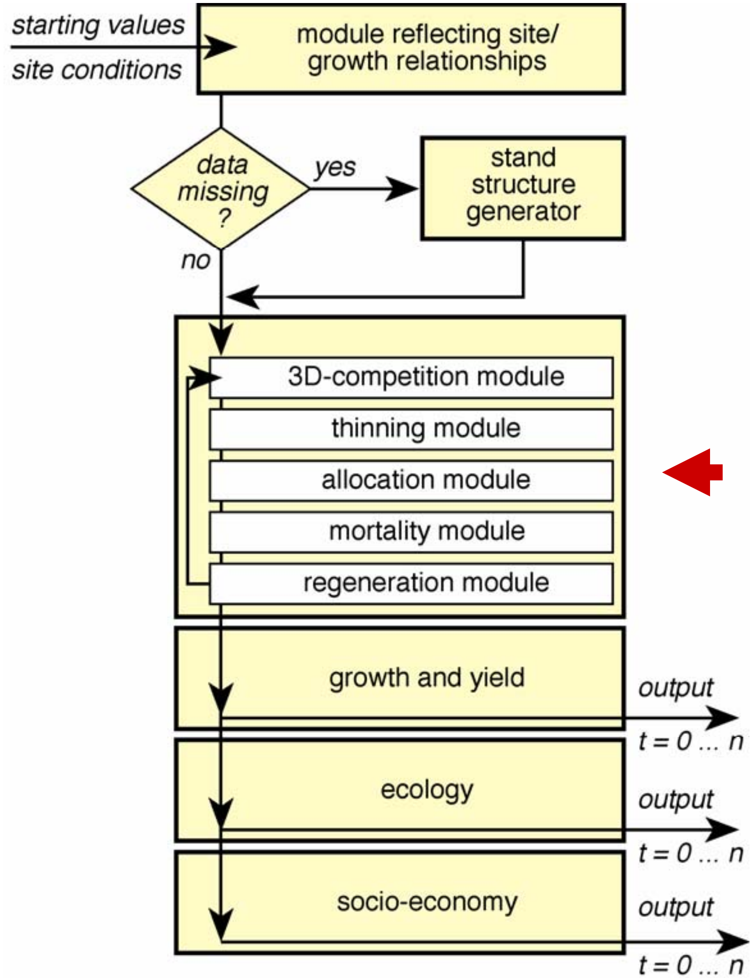
SILVA 3.0 as example of a spatially explicit individual tree model for pure and mixed stands



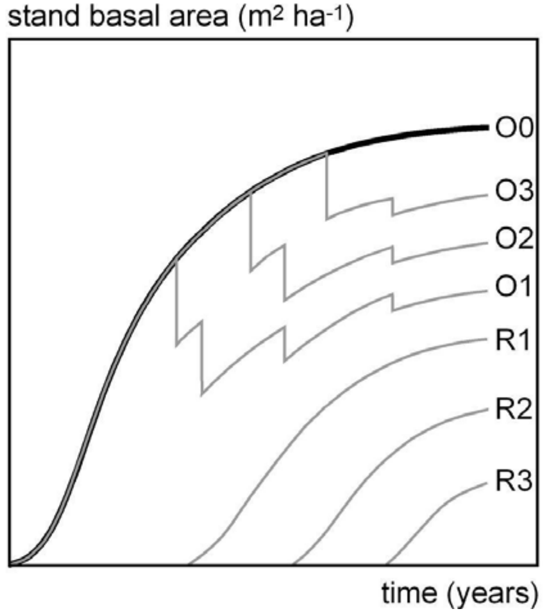
Integration of mixing effects on growth, structure, mortality

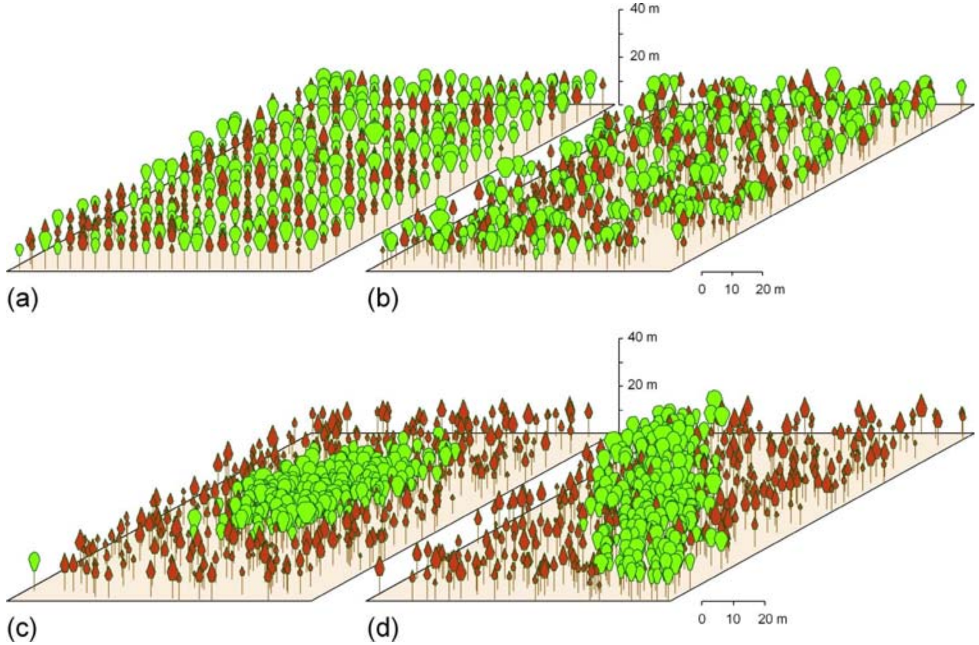
Extension of the algorithms for silvicultural regulation

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

Waldwachstumskunde
Systemanalyse

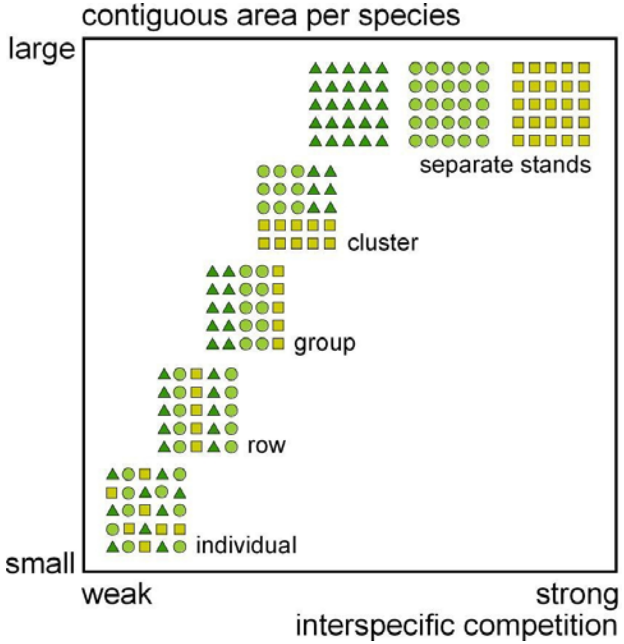
Rules and algorithms for initiating the regeneration depending on the density of the overstorey

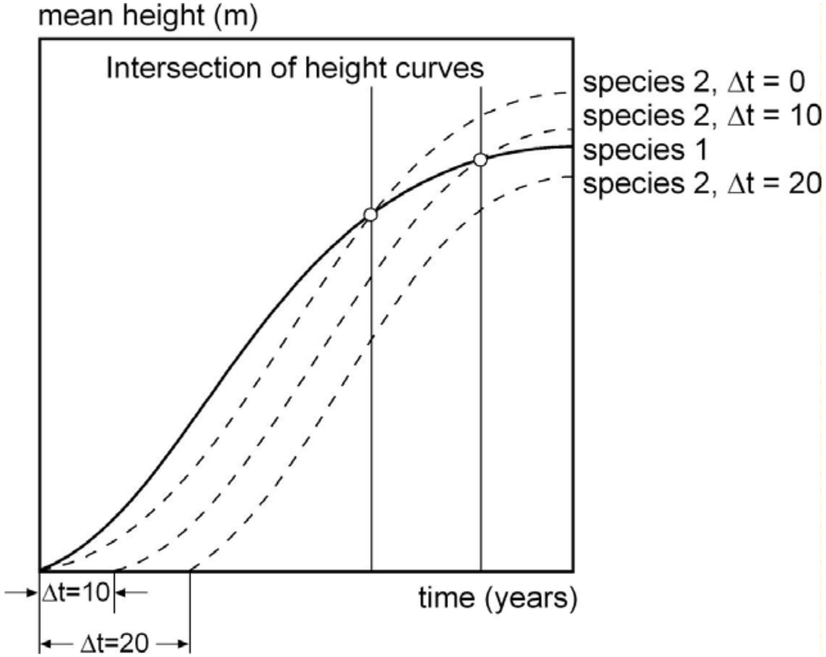




Pretzsch H, Forrester D, Bauhus J (2017) Mixed-species forests. Ecology and Management, Springer, Berlin, 653 p

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

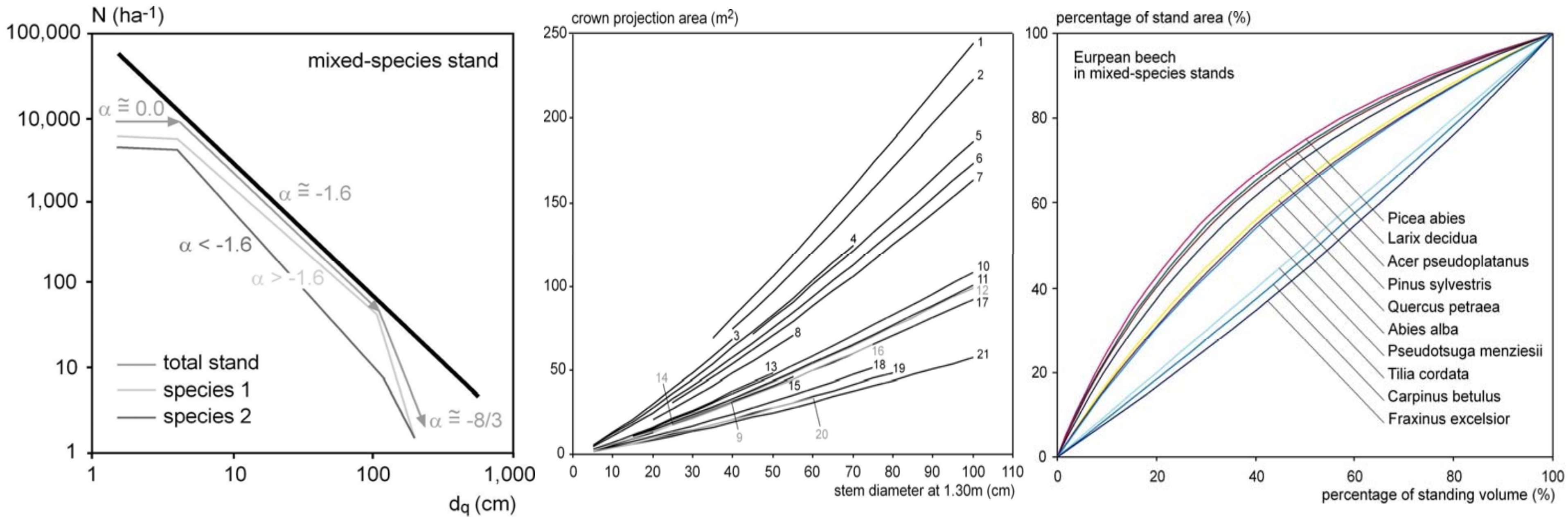




Pretzsch H, Forrester D, Bauhus J (2017) Mixed-species forests. Ecology and Management, Springer, Berlin, 653 p

Waldwachstumskunde
Systemanalyse

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

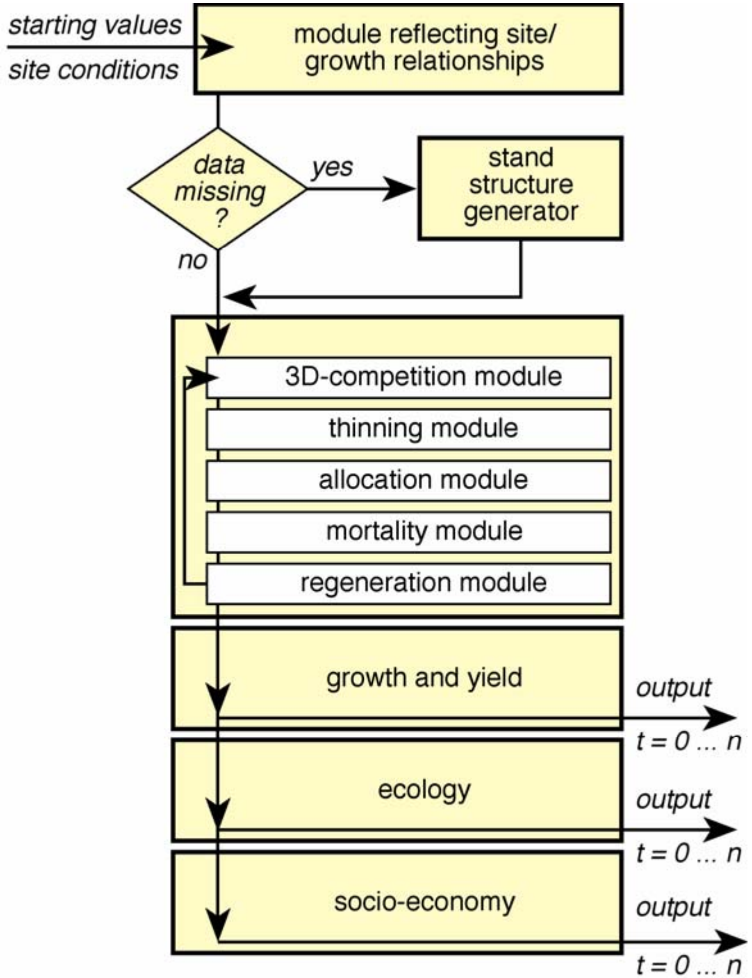


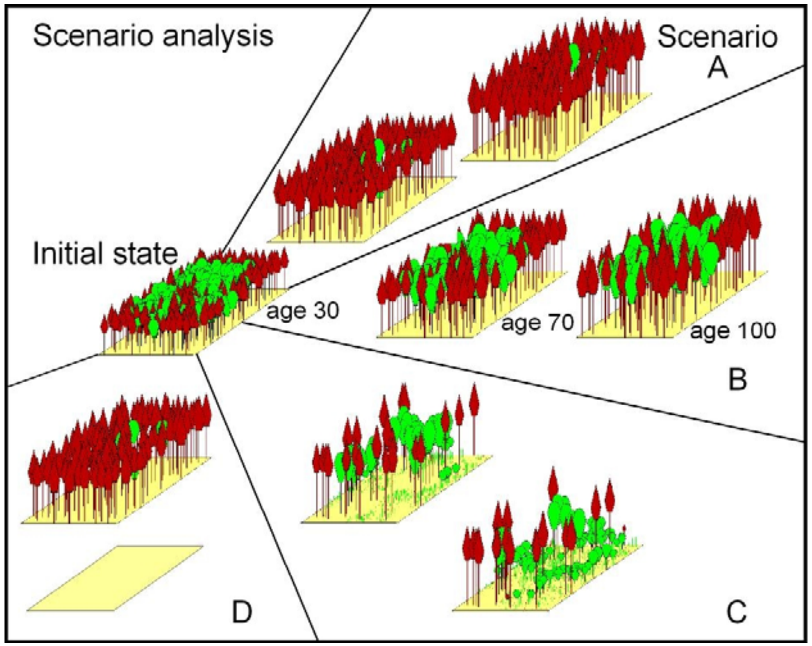
1) *Quercus nigra* L., 2) *Platanus x hispanica* Münchh., 3) *Carpinus betulus* L., 4) *Tilia cordata* Mill., 5) *Khaya senegalensis* (Desr.) A.Juss., 6) *Fagus sylvatica* L., 7) *Aesculus hippocastanum* L., 8) *Robinia pseudoacacia* L., 9) *Alnus glutinosa* [L.] Gaertn., 10) *Araucaria cunninghamii* 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.

TUM

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

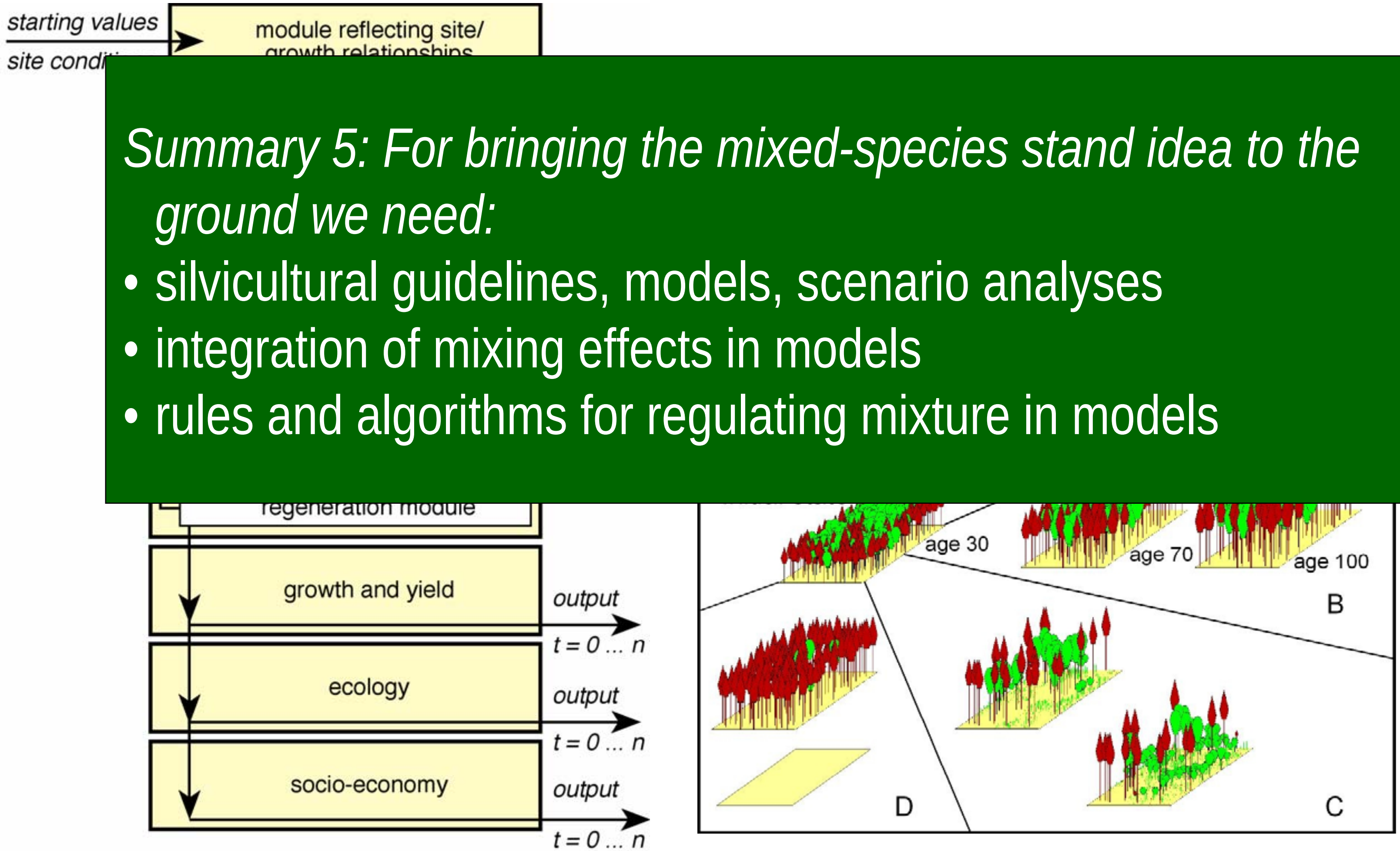




Pretzsch, H., Biber, P. und Dursky, J., 2002: The single tree based stand simulator SILVA. Construction, application and evaluation, Forest Ecology and Management, 162: 3-21

Waldwachstumskunde
Systemanalyse

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



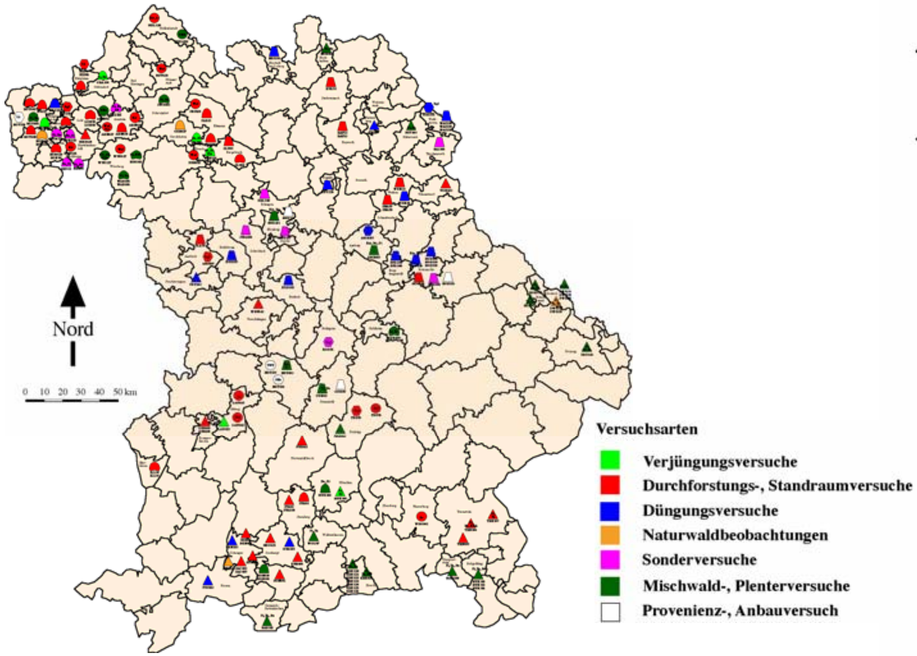
Summary 5: For bringing the mixed-species stand idea to the ground we need:

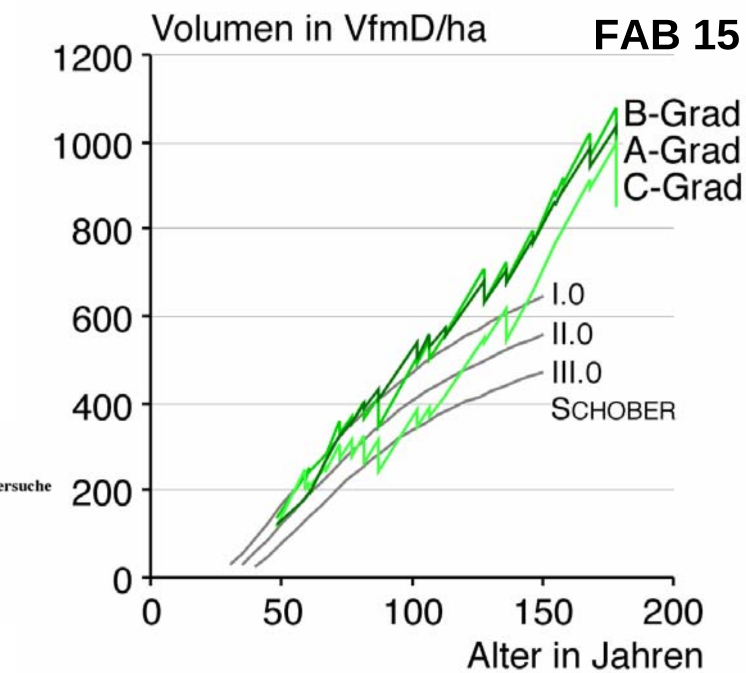
- silvicultural guidelines, models, scenario analyses
- integration of mixing effects in models
- rules and algorithms for regulating mixture in models

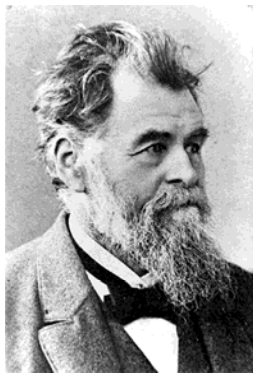
Pretzsch, H., Biber, P. und Dursky, J., 2002: The single tree based stand simulator SILVA. Construction, application and evaluation, Forest Ecology and Management, 162: 3-21

Waldwachstumskunde
Systemanalyse

Long-living organisms need long-term research







A. v. Ganghofer
⋆1827 †1900

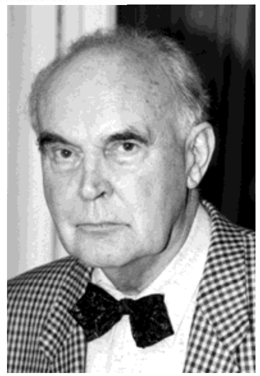
F. v. Baur
1878-1897

R. Weber
1897-1905

V. Schüpfer
1905-1937

K. Vanselow
1937-1951

E. Assmann
1951-1972

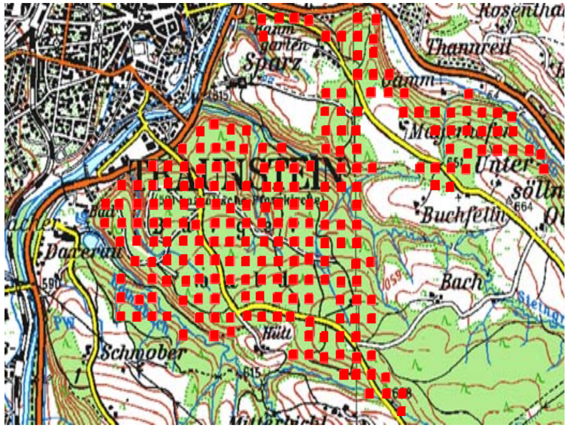


F. Franz
1972-1993

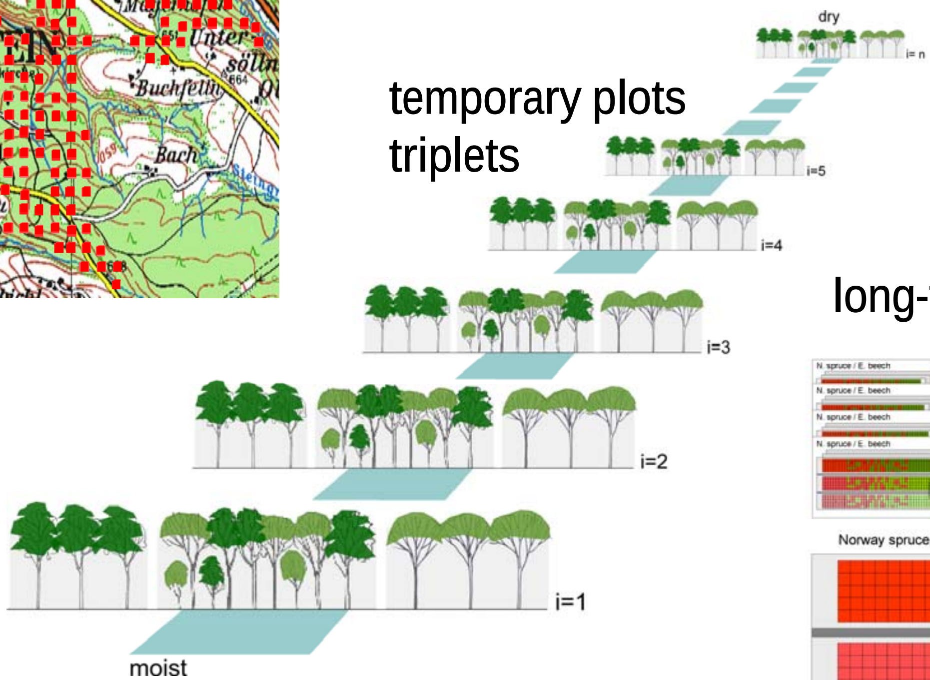
Waldwachstumskunde
Systemanalyse

Data base: From forest inventories to temporary plots and long-term experiments

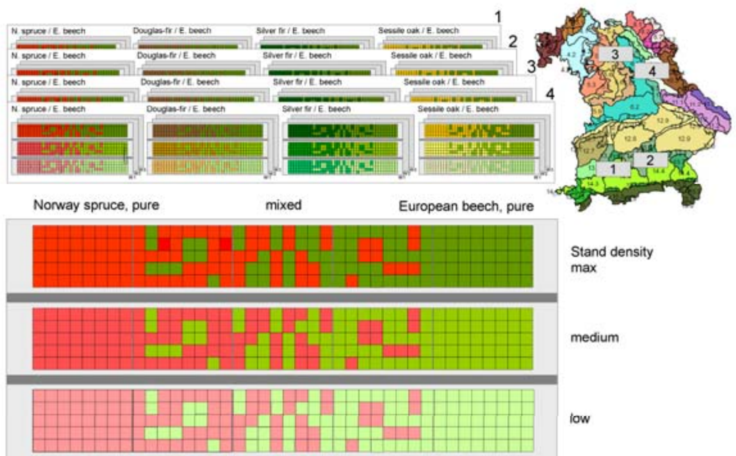
forest inventories



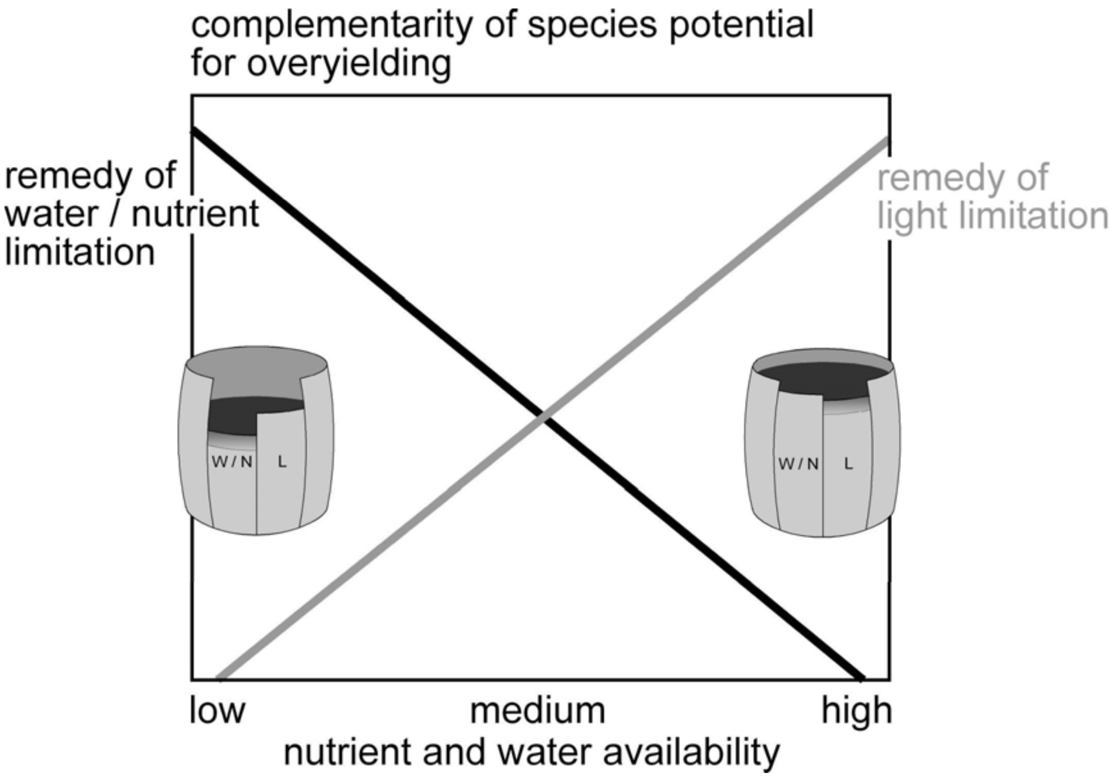
temporary plots
triplets



long-term experiments



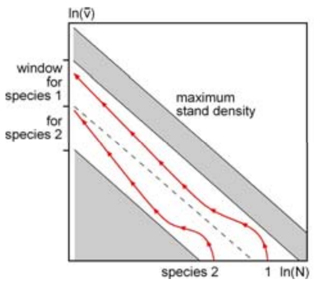
Theory....Conceptual model for the dependency of overyielding on site conditions

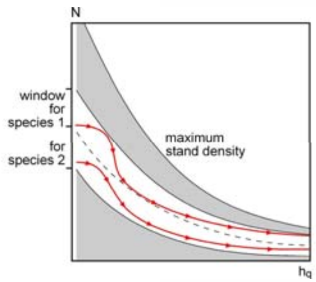


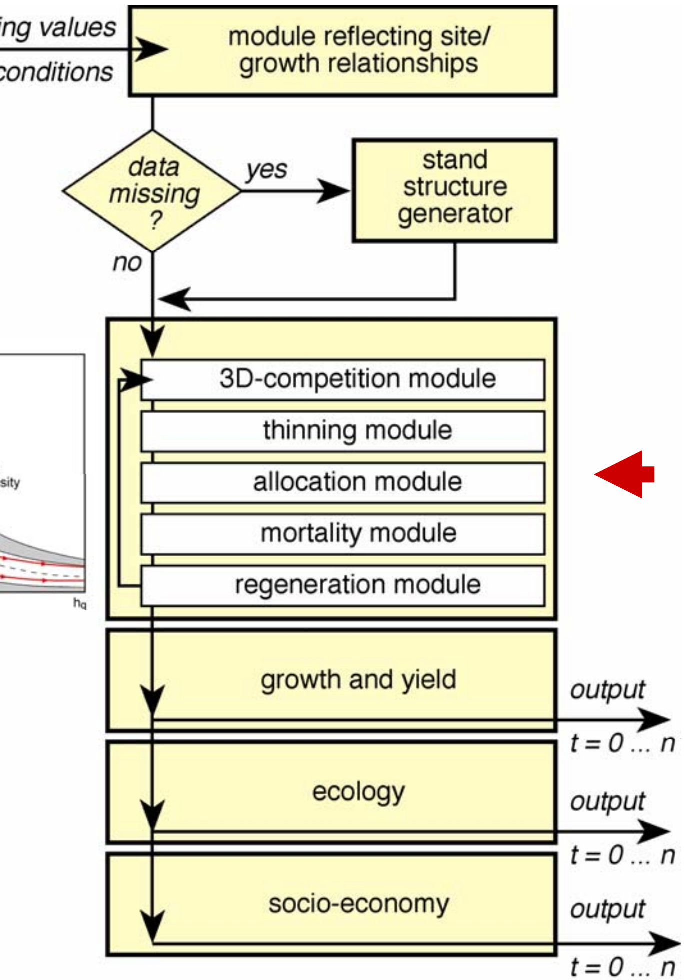
Forrester 2017, Pretzsch 2017

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

Criteria for sustainable forest ecosystem management. Objective hierarchy for the management of municipal forest 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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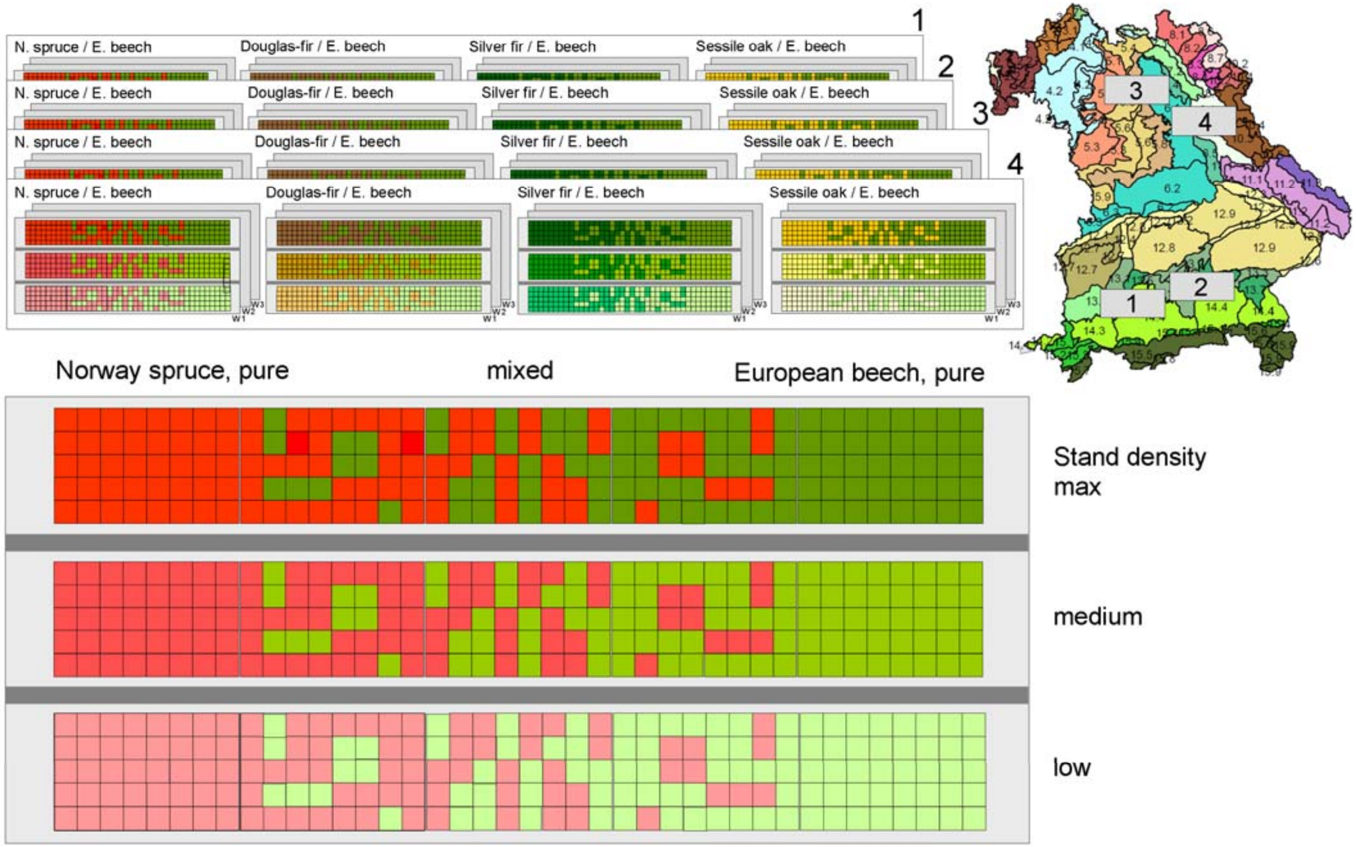
DFG
EU
MStELF, MStU, BaySF
Thanks for provinding data to
partner institutions in Sweden, Denmark,
England, Poland, France, Germany
Austria, Switzerland, Italy, Spain, and others
http://waldwachstum.wzw.tum.de/index.php?id=presentations

Waldwachstumskunde
Systemanalyse

Long-term experiments for data acquisition, model parameterization, teaching and training



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