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TECHNISCHE UNIVERSITÄT MÜNCHEN

# Analyzing species mixing effects at the stand and tree level

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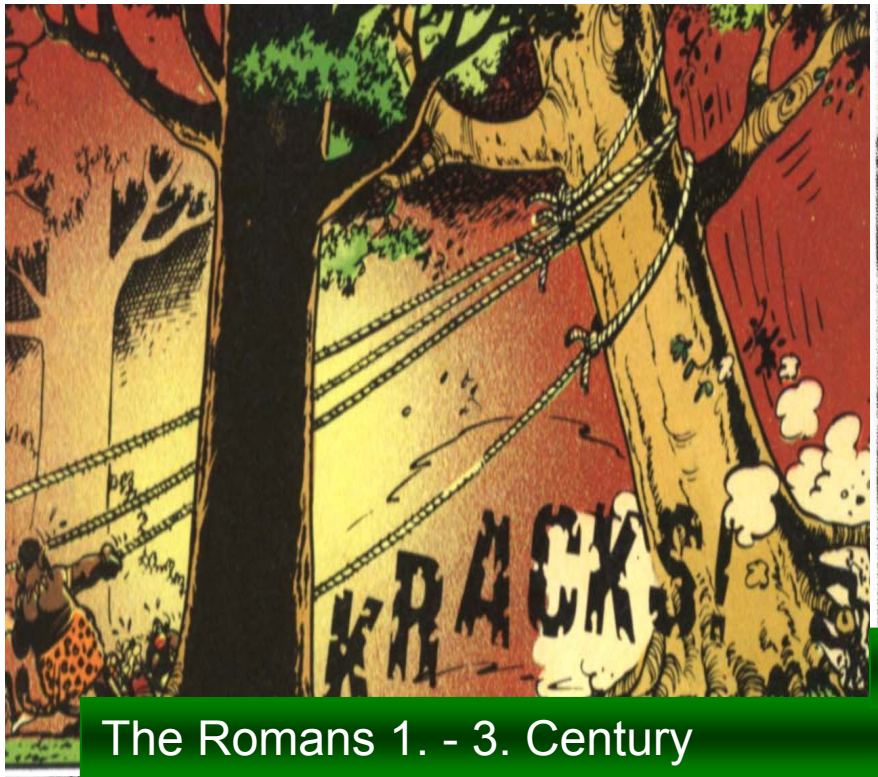
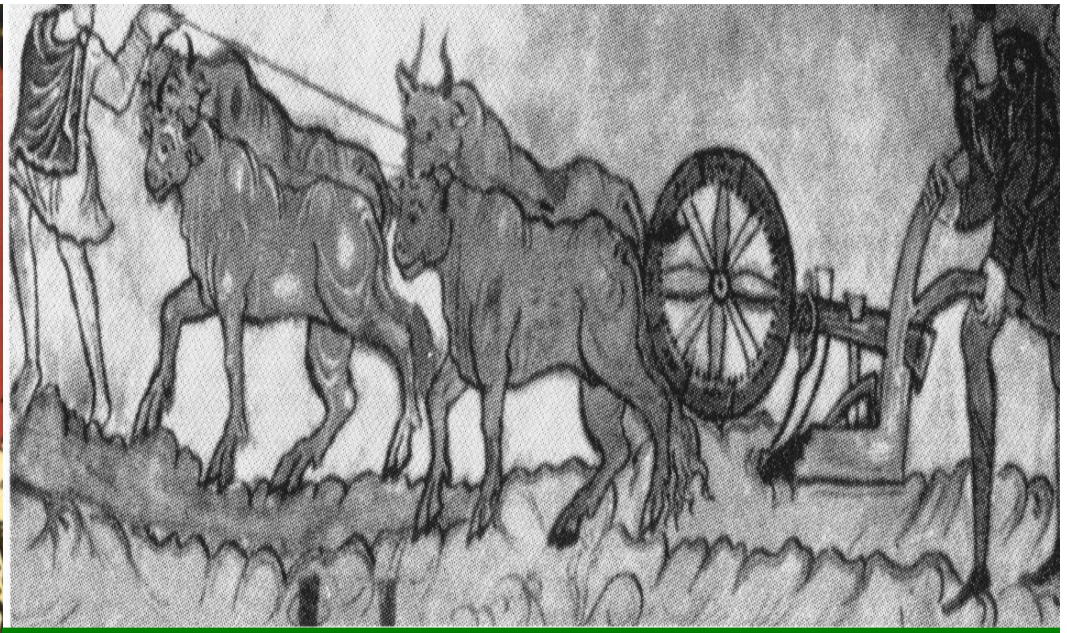
http://www.forestgrowth.wzw.tum.de/presentations.html

Lecture given at the conference “Ecology, silviculture, and management of spruce species in mixed forests”, IUFRO WG 1.01.08, August 11-13, 2015, University of Alberta, Edmonton, Canada

*Mixed European beech forest in Central European lowlands*




The Romans 1. - 3. Century



Clearings in medieval times 12. – 13. Century

Industrialisation 18. – 19. Century

World War I. und II. 20. Century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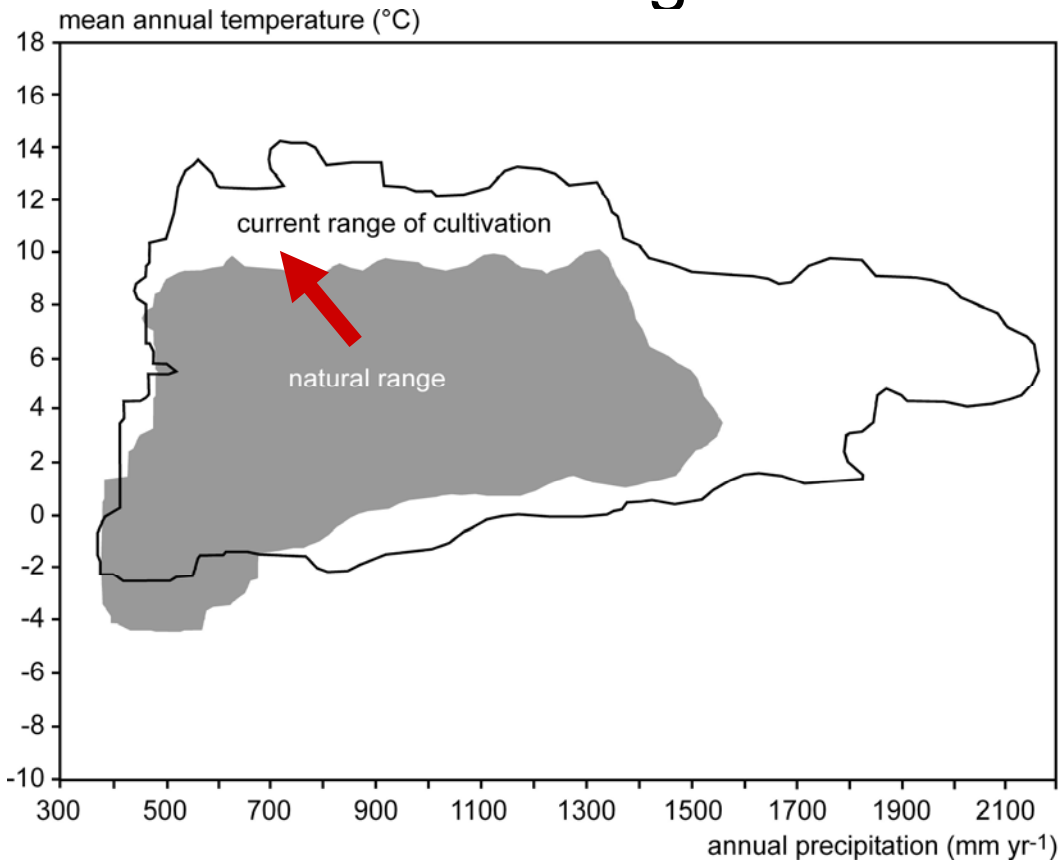
# Cultivation of Norway spruce far beyond its natural range




Kölling et al. (2009) Überlegungen zum Risiko des Fichtenanbaus in Deutschland vor dem Hintergrund des Klimawandels, Forstarciv 80: 42-54

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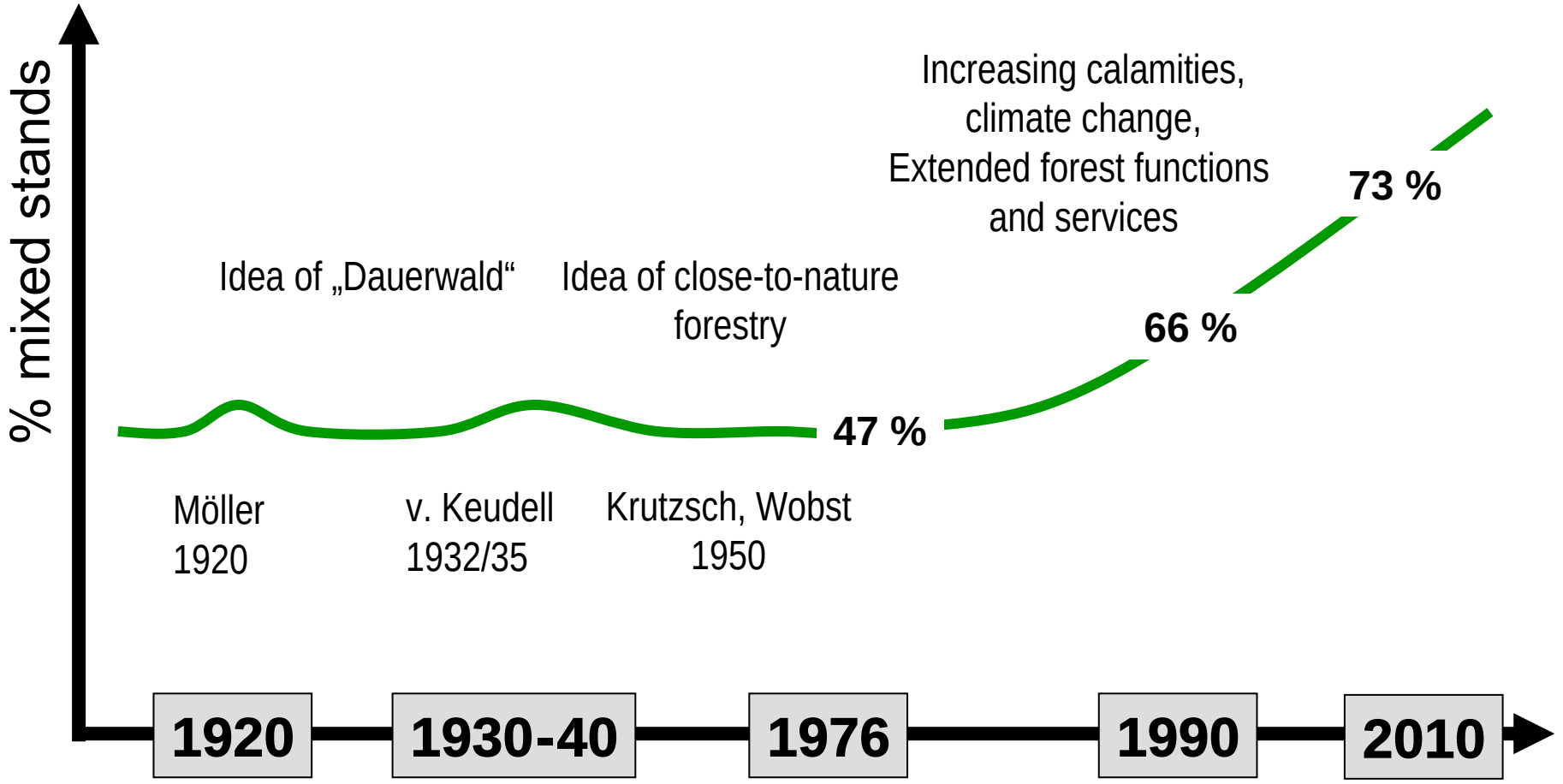
# Back to complex mixed-species forests. From the idea to realization in Bavaria




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

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

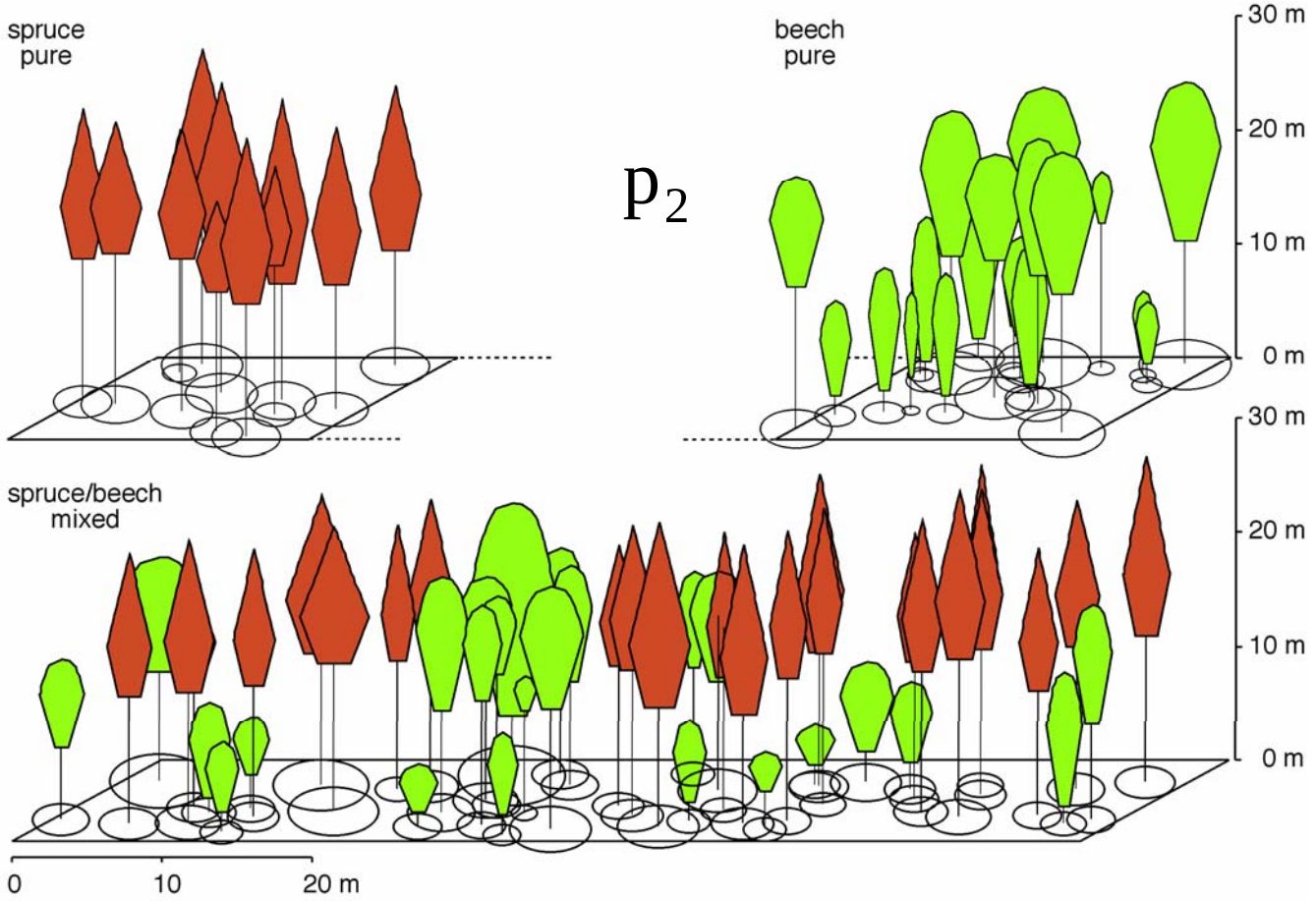
$p_1$

$p_2$

$p_{1,2}$

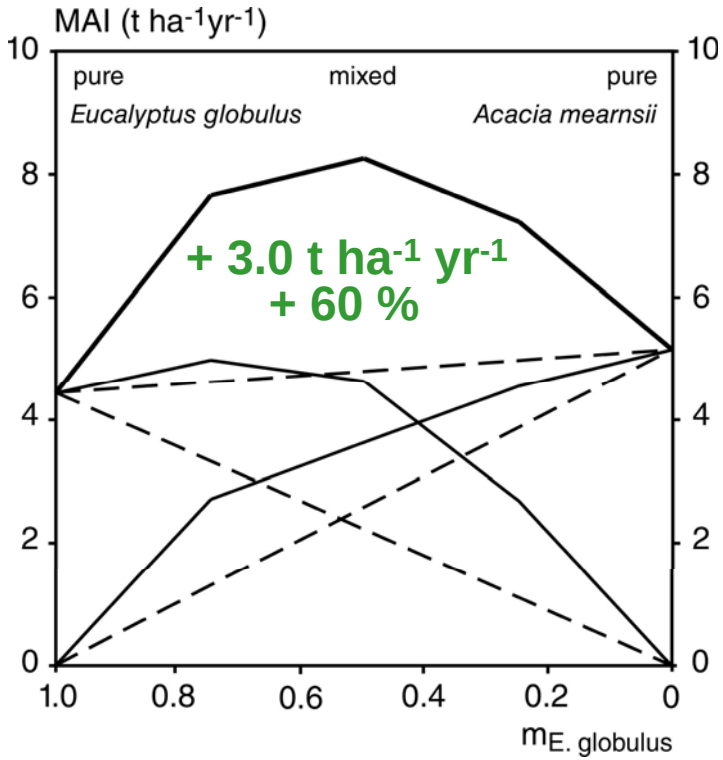
$m_1$

$m_2$



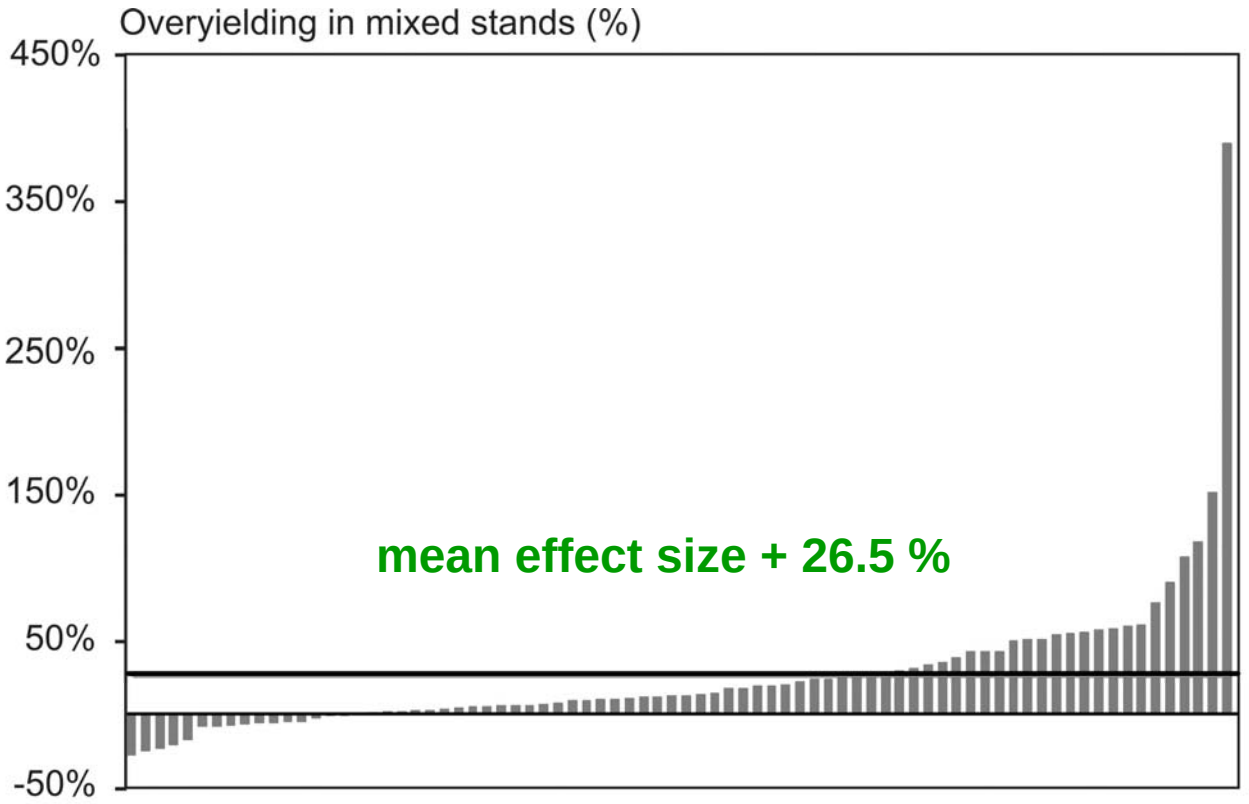

$$\hat{p}_{1,2} = p_1 \times m_1 + p_2 \times m_2 \qquad \text{rel. productivity} = p_{1,2}/\hat{p}_{1,2}$$

# Cross diagrams: 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
Harper, 1977, pp 255-267

# Meta-analysis on overyielding of mixed versus pure stands in boreal and temperate forests
# 29 publications, 78 case studies




Gritti, E. S. et al. 2015: Diversity-productivity relationships in Forests, a Meta-Analysis, in preparation

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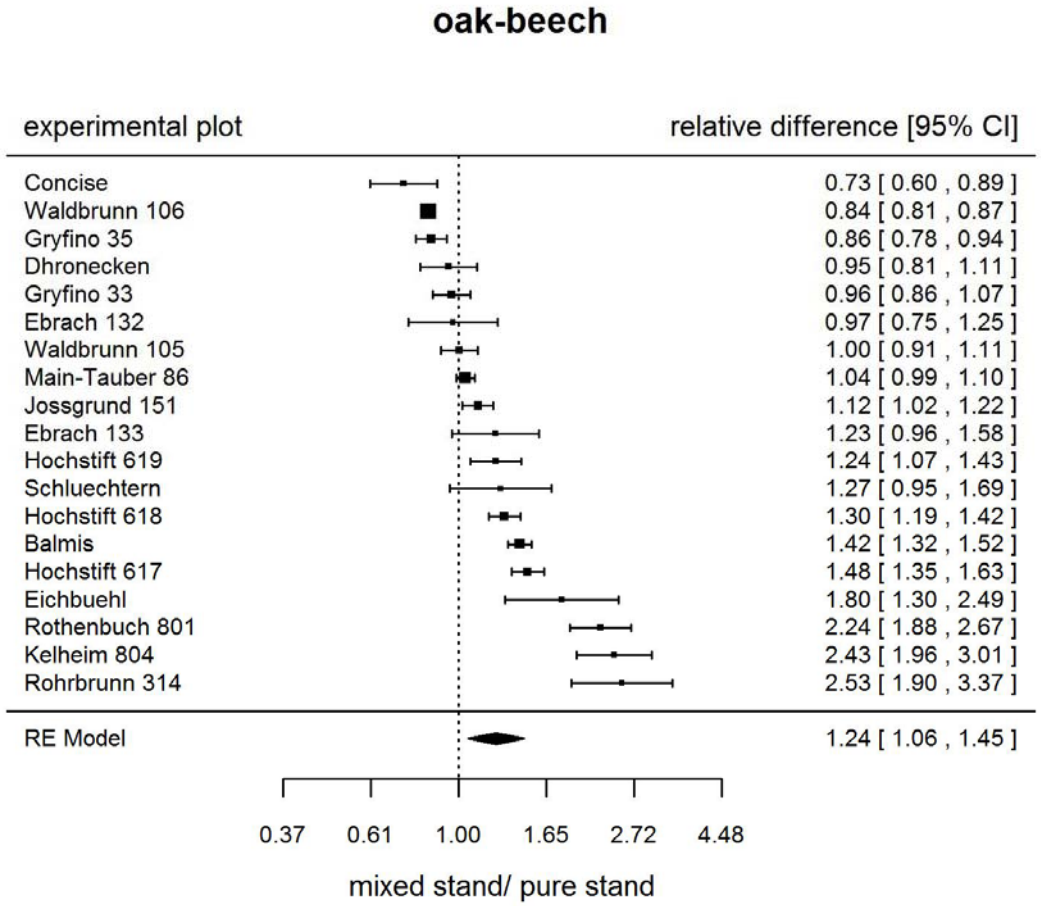
# Meta-analysis on overyielding of mixed stands of sessile oak and European beech versus pure stands in Europe based on long-term experiments



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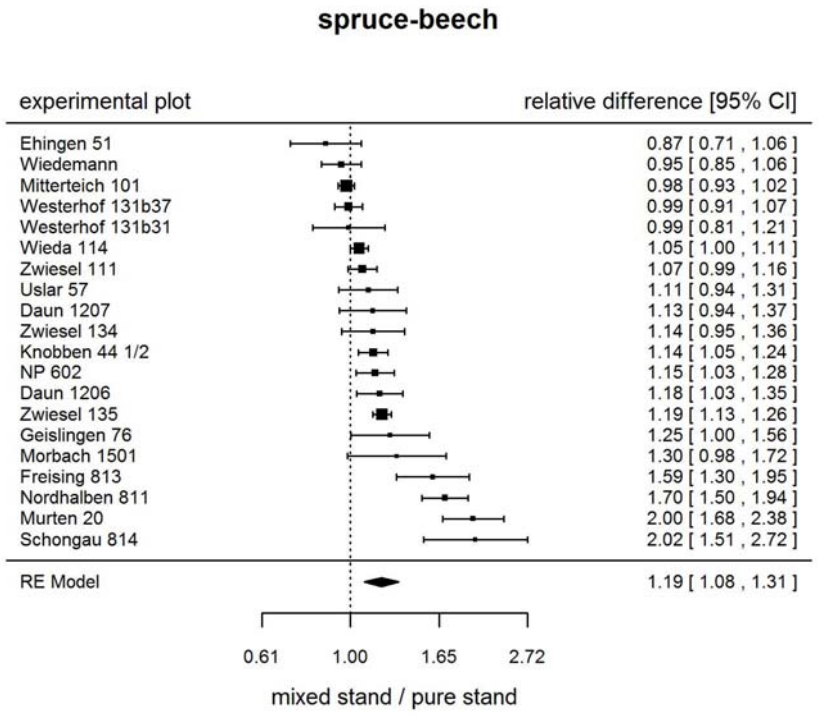
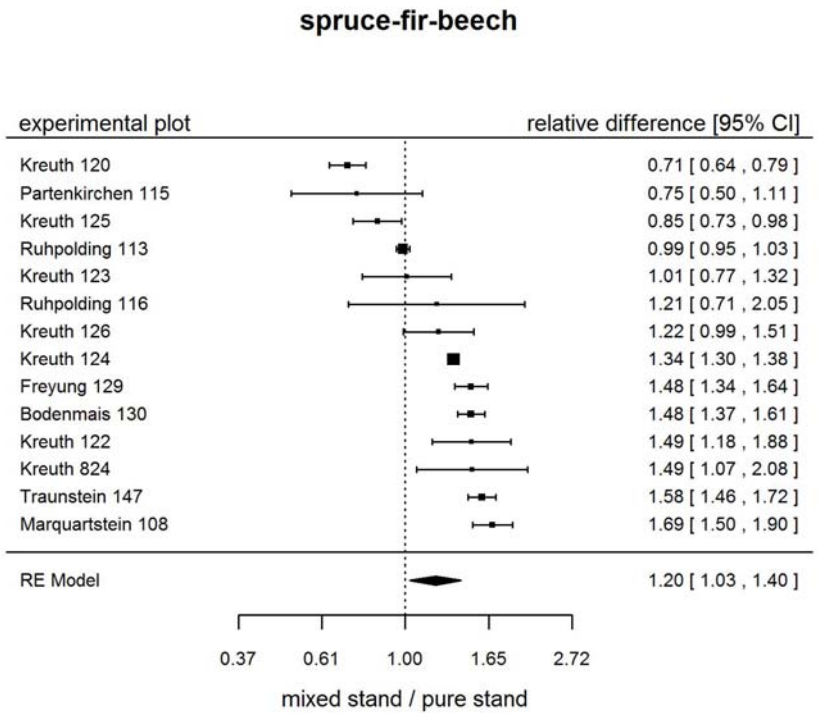
# Meta-analysis on overyielding of mixed stands of Norway spruce, European beech, silver fir in Europe based on long-term experiments



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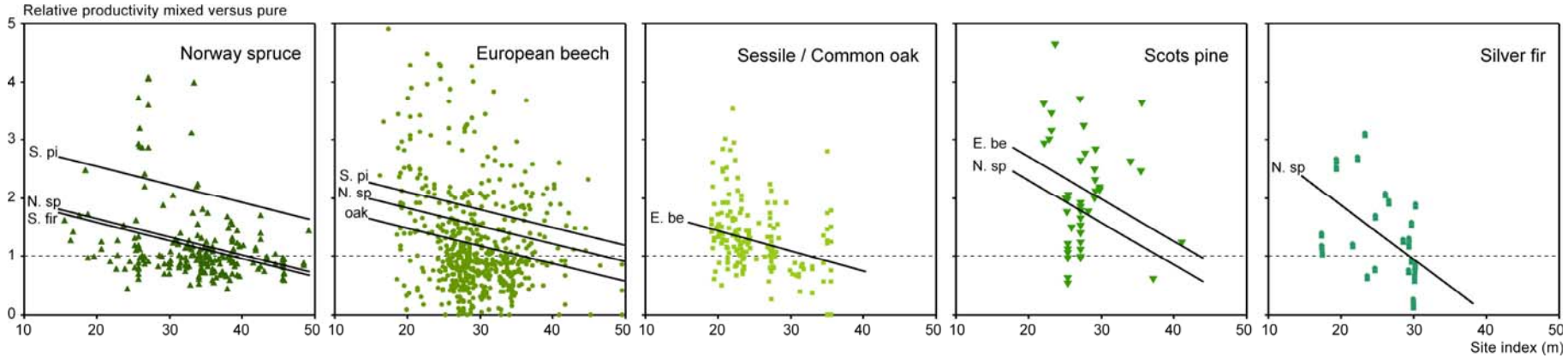
# Decrease of the overyielding of mixed versus pure stands with increase of the site index




| Target species $sp_1$<br>Admixed species<br>$sp_2$, $sp_3$, $sp_4$ | **N. spruce**<br>S. fir, E. be<br>S. pine | **E. beech**<br>S. oak, N. sp,<br>S. pine | **S. oak**<br>E. be | **S. pine**<br>N. sp, S.<br>pine | **S. fir**<br>N. sp |
|---|---|---|---|---|---|
| $rp'_{1,(2)}$ | | | | | |
| intercept | 1.54 | -0.03 | 1.84 | 4.45 | 3.30 |
| $m_2$ | 0.88 | 1.42 | -0.33 | -1.82 | 1.02 |
| $hq_1$ | - | 0.02 | 0.02 | - | - |
| $hq_1/hq_2$ | - | 1.01 | - | - | - |
| site index $sp_1$ | -0.03 | -0.31 | -0.03 | -0.07 | -0.10 |
| dummy $sp_3$ | 0.10 | 0.33 | - | 0.52 | - |
| dummy $sp_4$ | 1.19 | 0.60 | - | - | - |
| n total | 223 | 648 | 215 | 49 | 32 |
| whole model $R^2$ | 0.38 | 0.18 | 0.14 | 0.24 | 0.42 |

Pretzsch et al. 2013: Species mixing and productivity of forests, German Journal of Forest Research, 184 (7/8): 177-196

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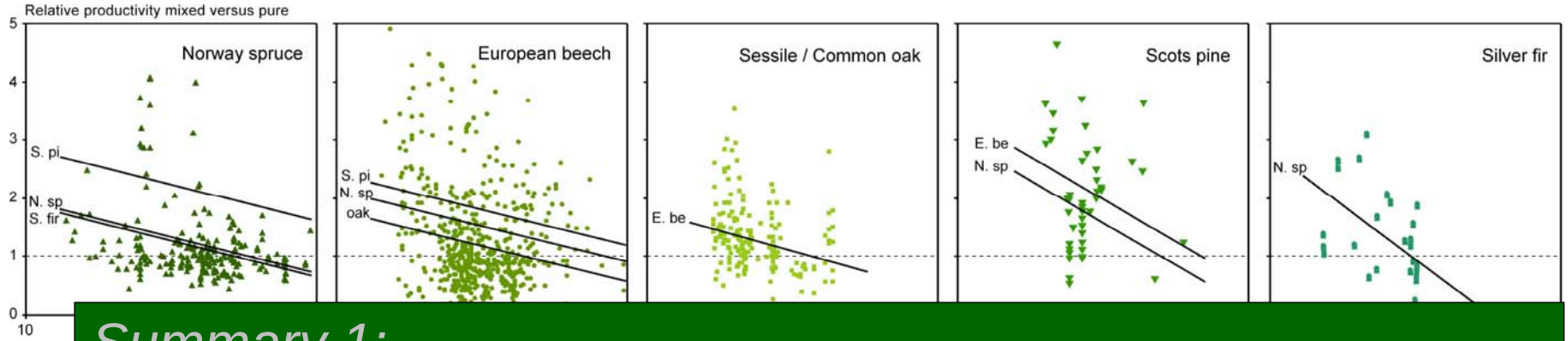


*Summary 1:*

- overyielding of 15-30 % in mixed vs. pure stands
- admixture of N-fixing species causes up to + 60 %
- gains can be higher on poor compared with fertile site
- Norway spruce shows a plus of 0-30 % in mixture (with pine, alder, beech, larch, fir) compared with monocultures

Pretzsch et al. 2013: Species mixing and productivity of forests, German Journal of Forest Research, 184 (7/8): 177-196

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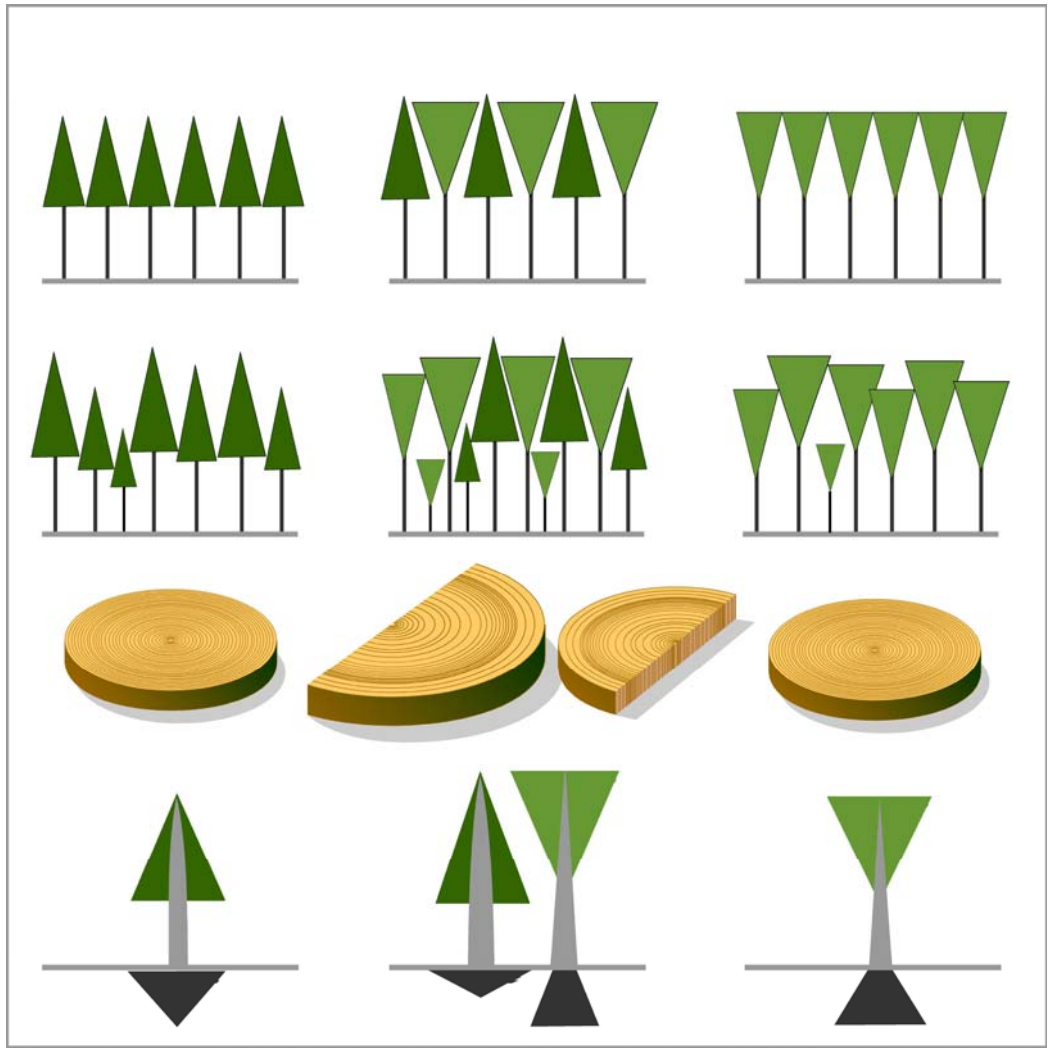
# Tracing tree species mixing effects from the stand to the tree level

Stand and mean tree level

Size-structure level

Tree and organ level



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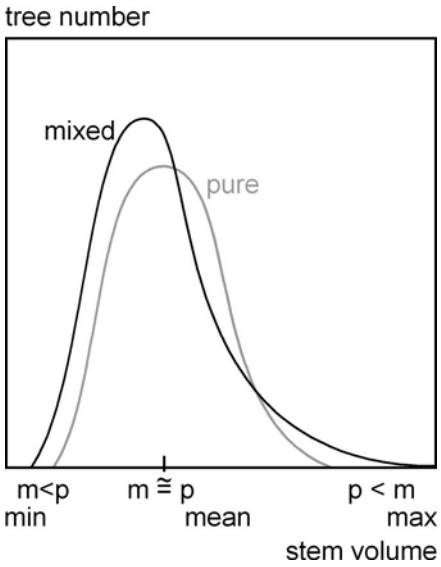
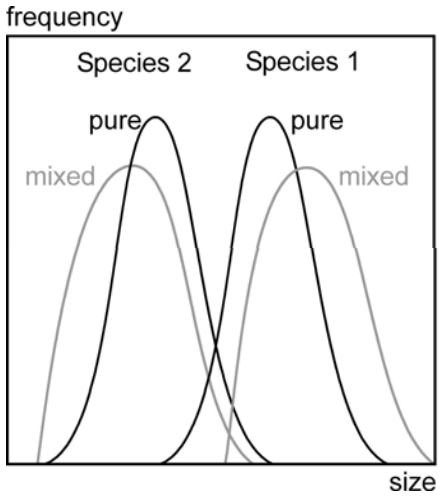
# More trees, wider size range, stronger right-skewness in mixed stands; often species 1 ahead, species 2 behind the pure stand




| Species | n | tree number ($ha^{-1}$) mean mixed | mean pure | tree number mixed/pure min | max | mean | SE |
|---|---|---|---|---|---|---|---|
| N.sp. / E.be | 22 | 571±72 | 655±68 | 0.39 | 1.68 | 0.98 | 0.07 |
| Sc.p. / E.be | 14 | 1093±268 | 1057±185 | 0.51 | 4.01 | 1.32 | 0.23 |
| D.-fir. / E.be | 36 | 1051±218 | 902±136 | 0.32 | 3,83 | 1.39** | 0.13 |
| N.sp. / Sc.p. | 12 | 1075±78 | 946±94 | 0.65 | 1.84 | 1.26* | 0.13 |
| total | 84 | 935±109 | 869±70 | 0.32 | 4.01 | 1.25 | 0.07 |

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

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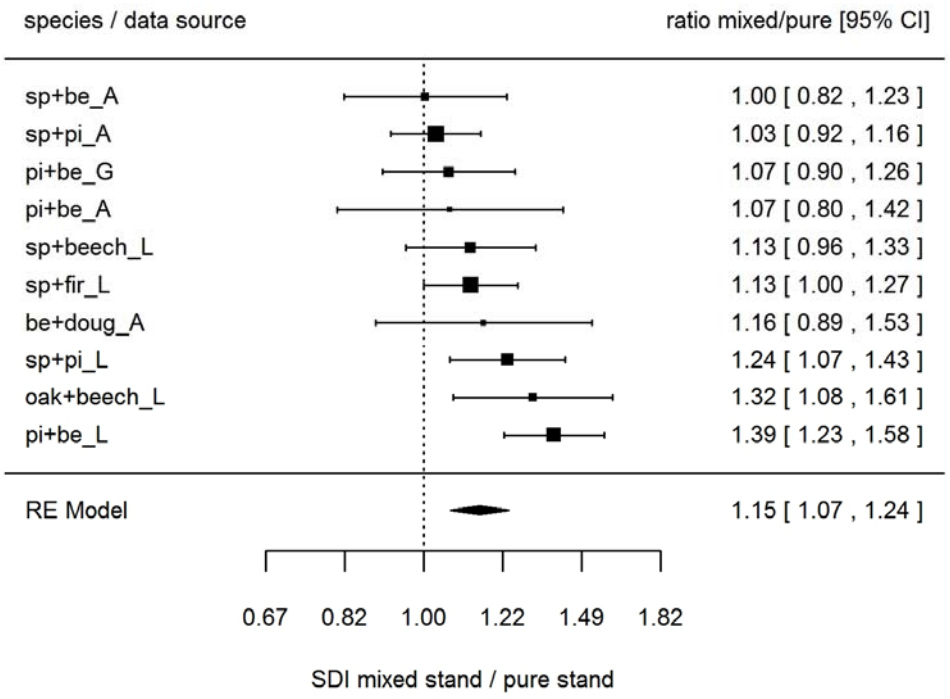
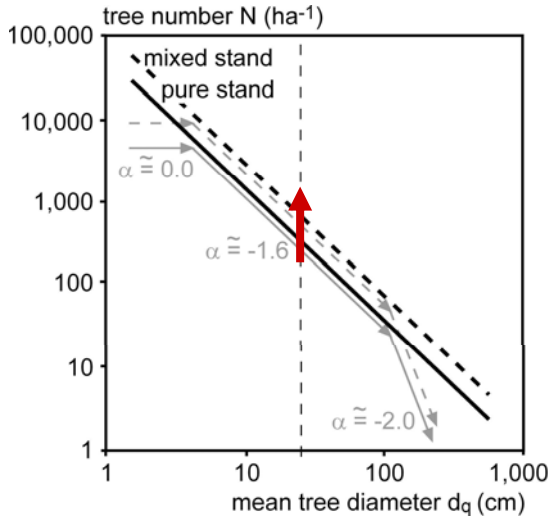
# Meta-analysis of stand density in fully stocked mixed versus pure stands (left) and effect on the self-thinning line (right)



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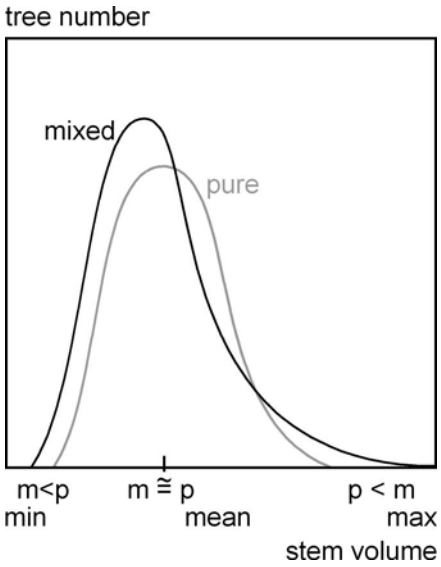


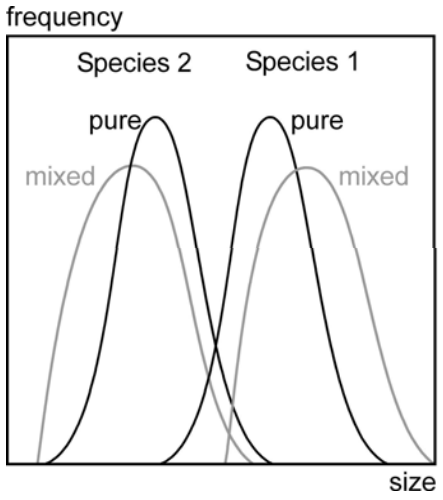


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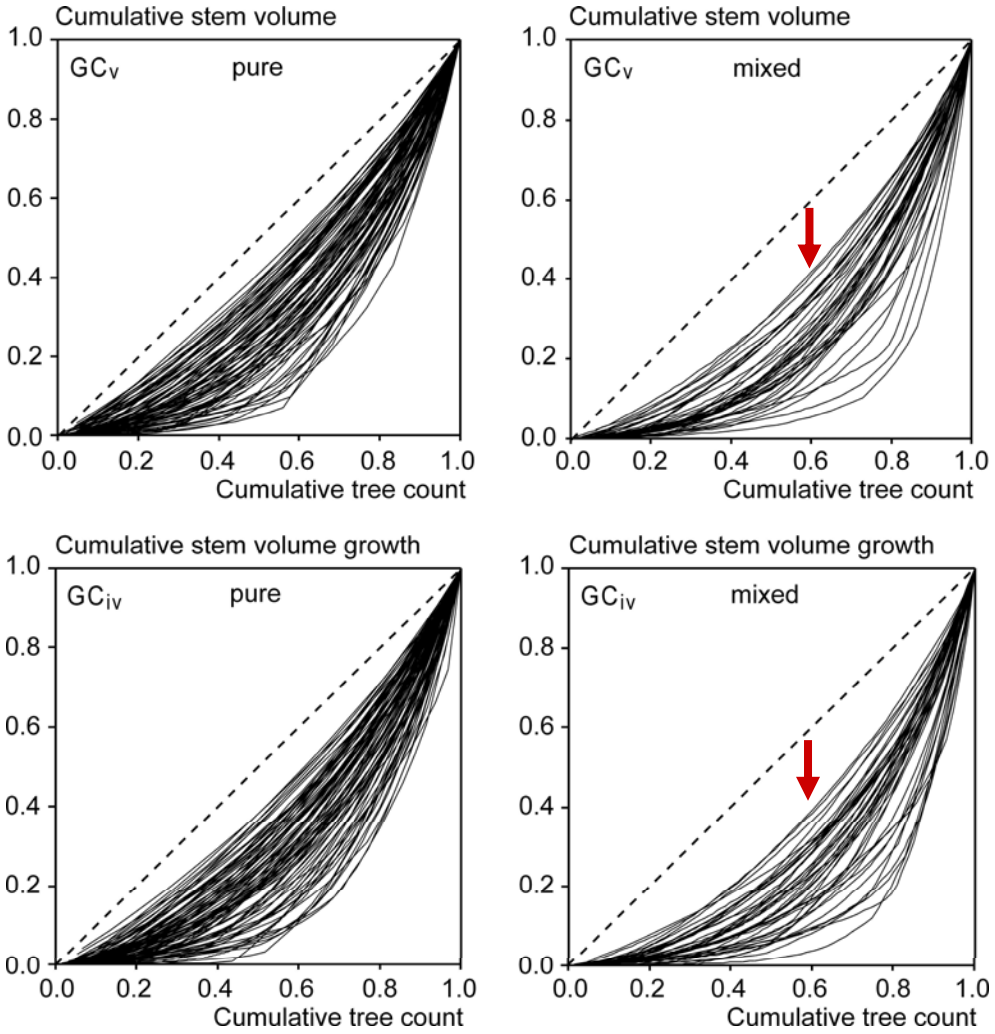
# Cumulative distribution of stem volume (above) and stem growth (below) over cumulative tree count (Lorenz-curve Gini-coefficient)



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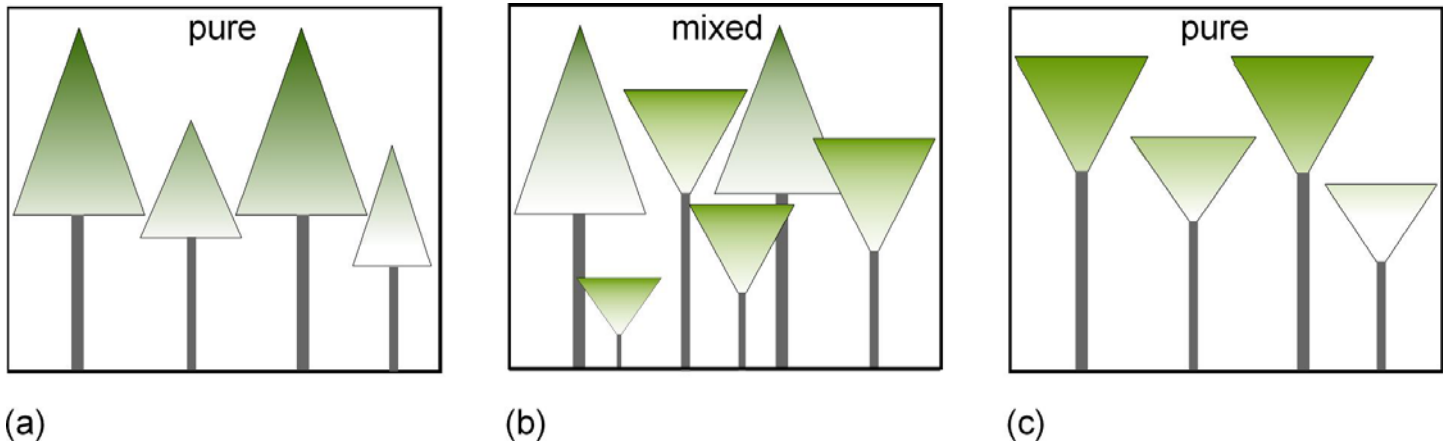
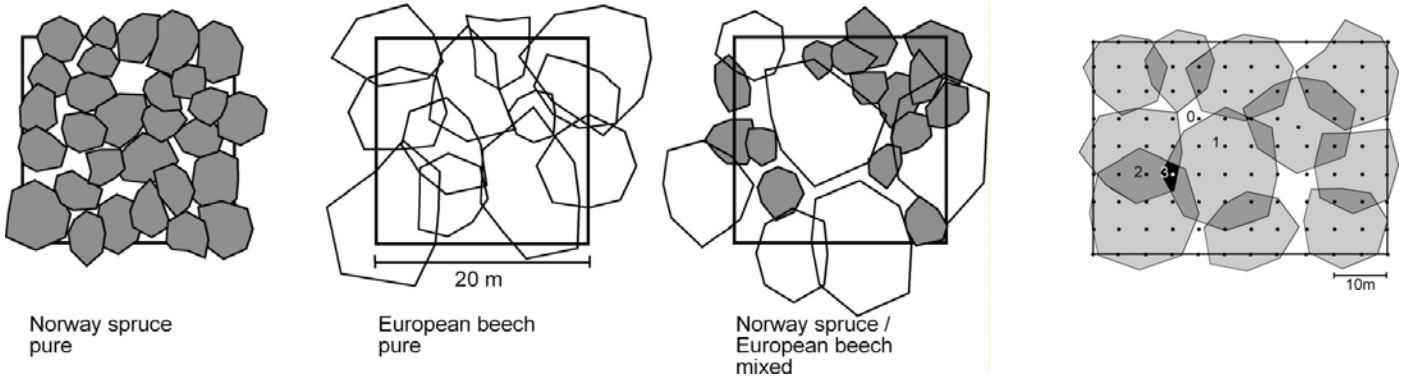
# Complementary in light ecology enables more smaller trees to survive and grow efficiently




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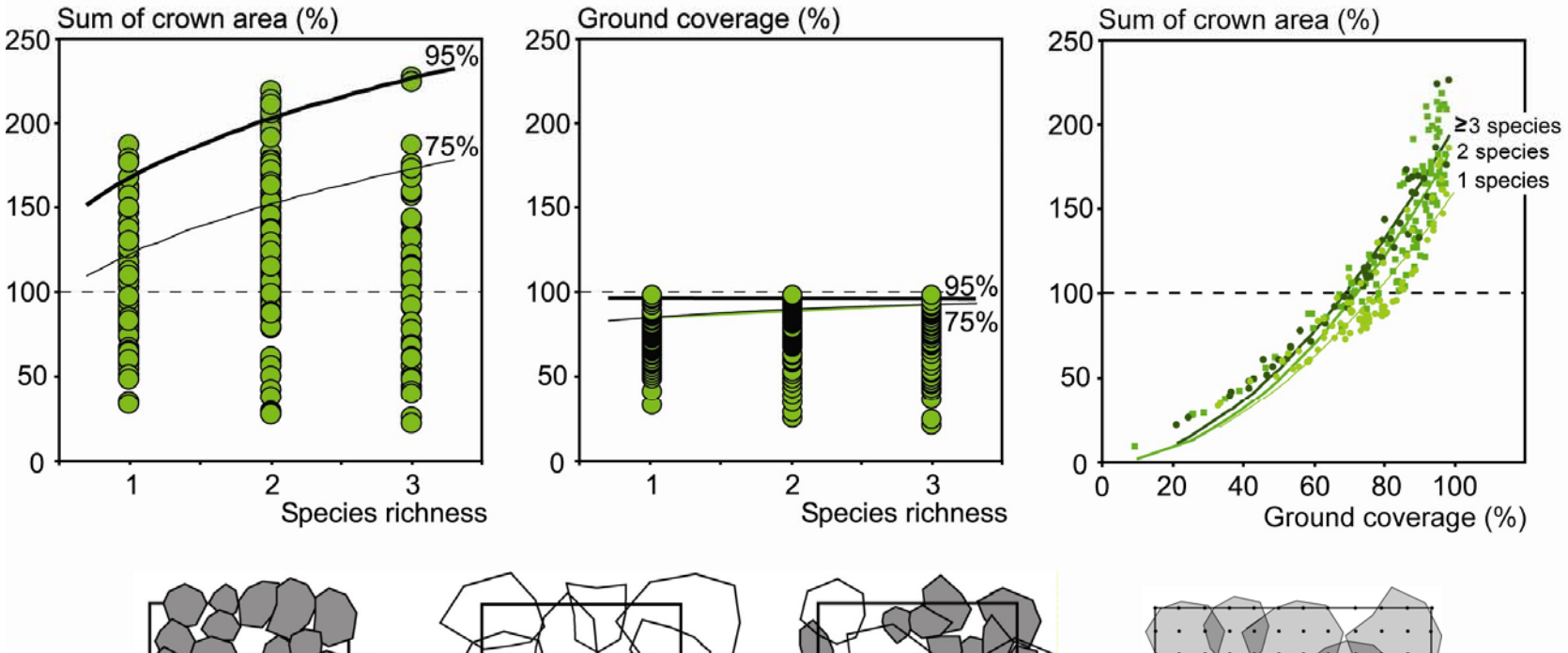
# Denser canopy space filling in mixed stands: higher sum of crown area and multiple ground coverage

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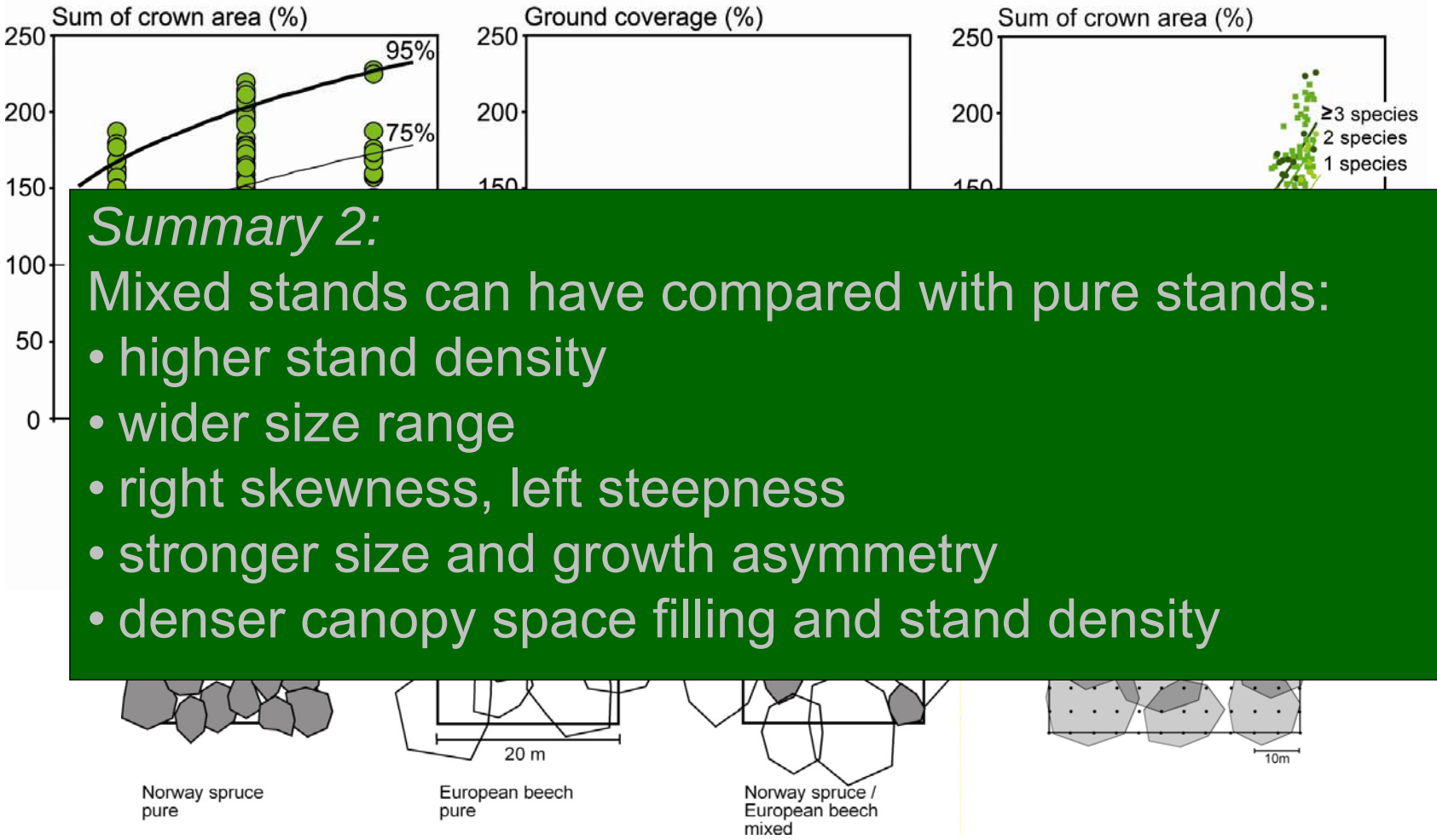


*Summary 2:*

Mixed stands can have compared with pure stands:

- higher stand density
- wider size range
- right skewness, left steepness
- stronger size and growth asymmetry
- denser canopy space filling and stand density

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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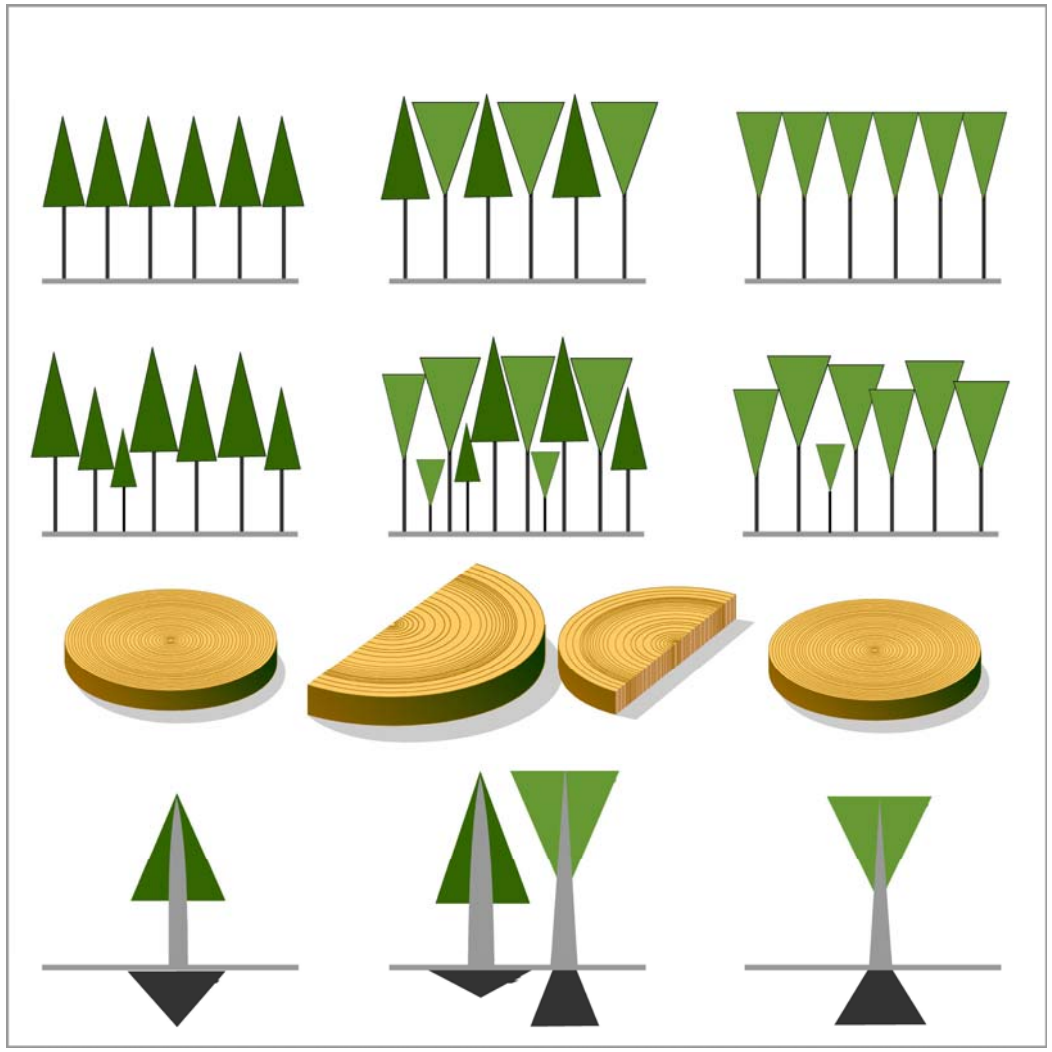
# Tracing tree species mixing effects from the stand to the tree level

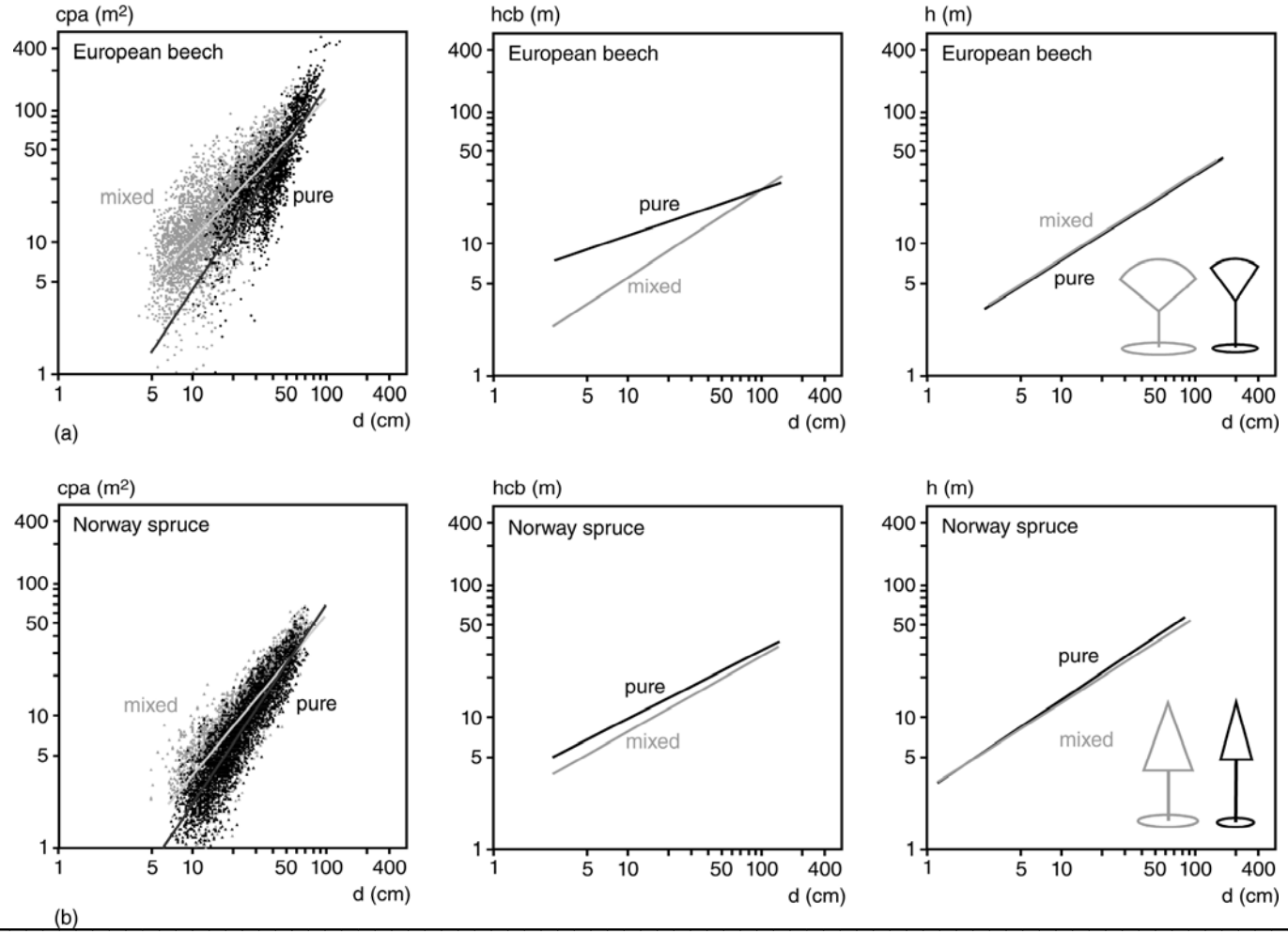
Stand and mean tree level

Size-structure level

Tree and organ level

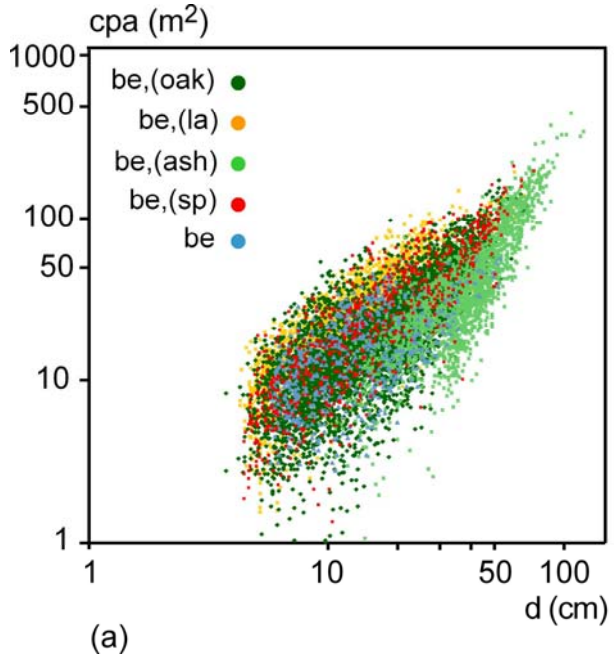


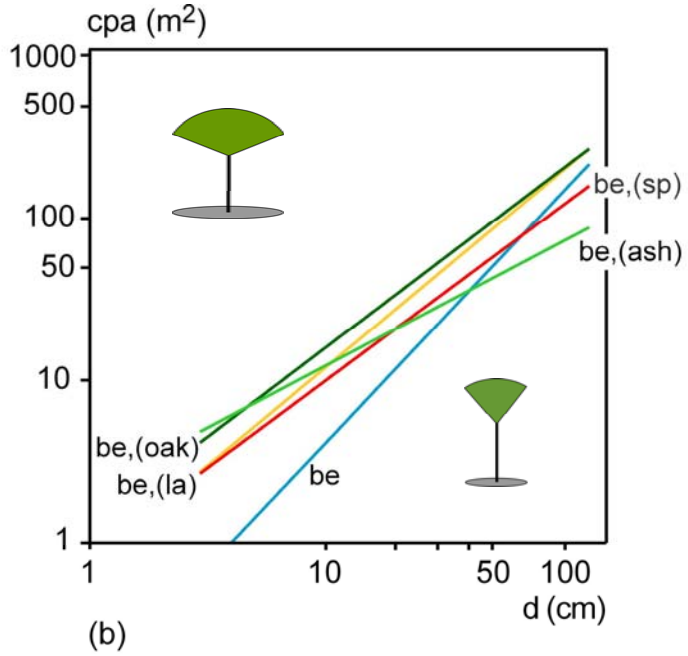
# Effect of species mixing on the crown allometry of European beech and Norway spruce




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

# Allometry between crown projection area and stem diameter of European in pure stands and when mixed with other tree species




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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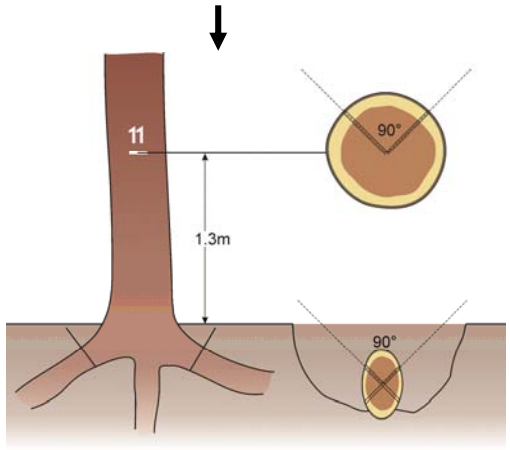
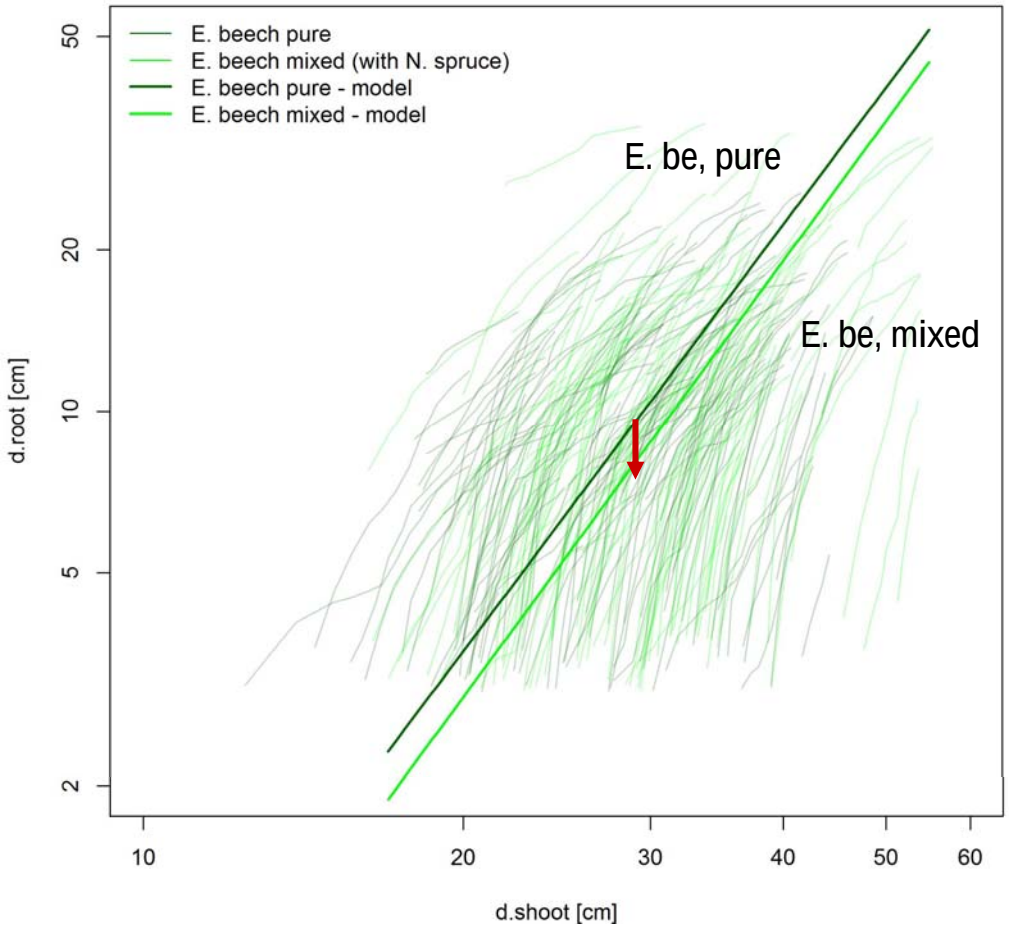
# Allometry between coarse root and stem growth of E. be. in pure stands and mixed with N. sp.

n=230 trees
($n_{be=63}$, $n_{(sp),be}$=56)
sampled along the ecological gradient from Arnstein to Kelheim, Allershausen, Wasserburg, Traunstein




Pretzsch, H., Heym, M., Pinna, S., and Schneider, R. (2014) Effect of variable retention cutting on the relationship between growth of coarse roots and stem of Picea mariana. *Scand. Journal of Forest Research*, *29*(3), 222-233.

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n=230 trees
($n_{be=63}$, $n_{(sp),be}$=56)
sample
ecologi
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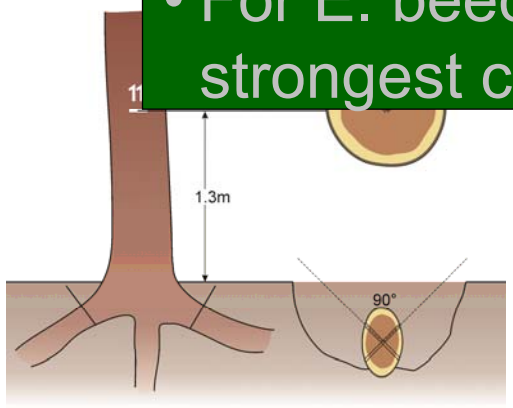
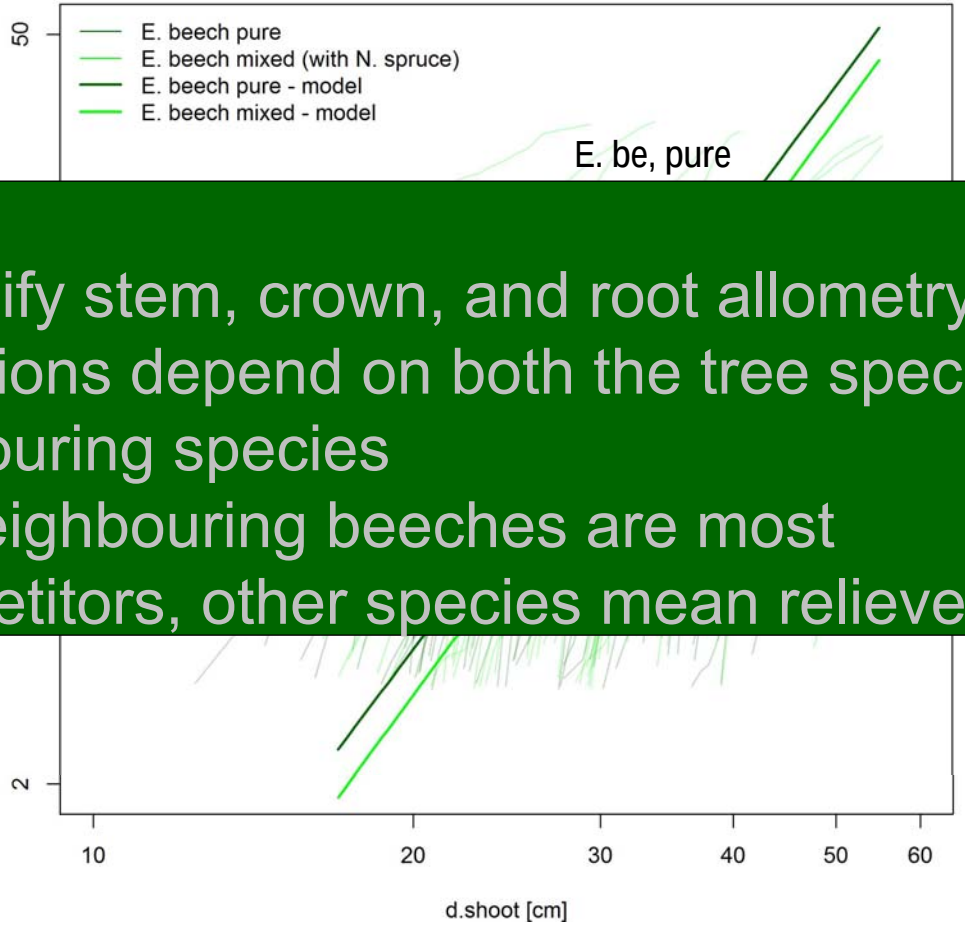


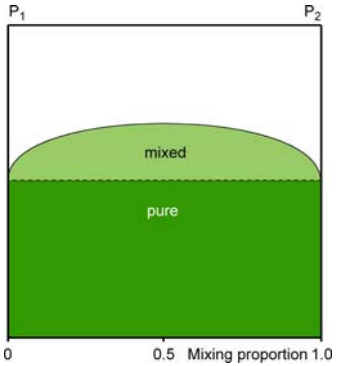



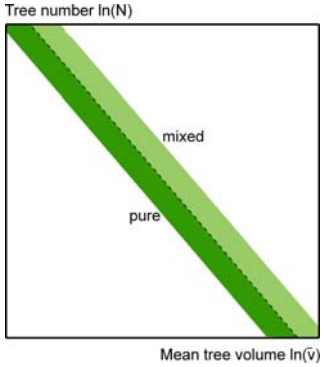

*Summary 3:*

- Mixing can modify stem, crown, and root allometry
- Allometric reactions depend on both the tree species and the neighbouring species
- For E. beech neighbouring beeches are most strongest competitors, other species mean relieve

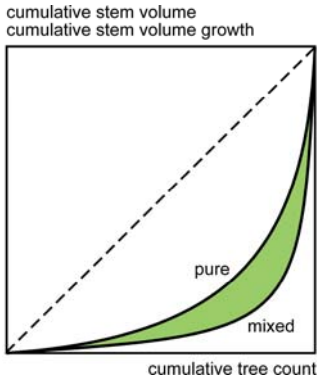
Pretzsch, H., Heym, M., Pinna, S., and Schneider, R. (2014) Effect of variable retention cutting on the relationship between growth of coarse roots and stem of Picea mariana. *Scand. Journal of Forest Research*, *29*(3), 222-233.

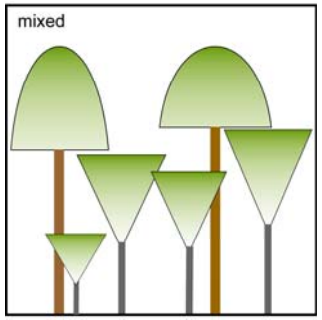
# Overall summary: Mixing reaction patterns at the stand, size distribution and tree level




*stand productivity and stand density can be increased by species mixing*




*size-asymmetry, crown extension and canopy space filling can be increased by mixing*

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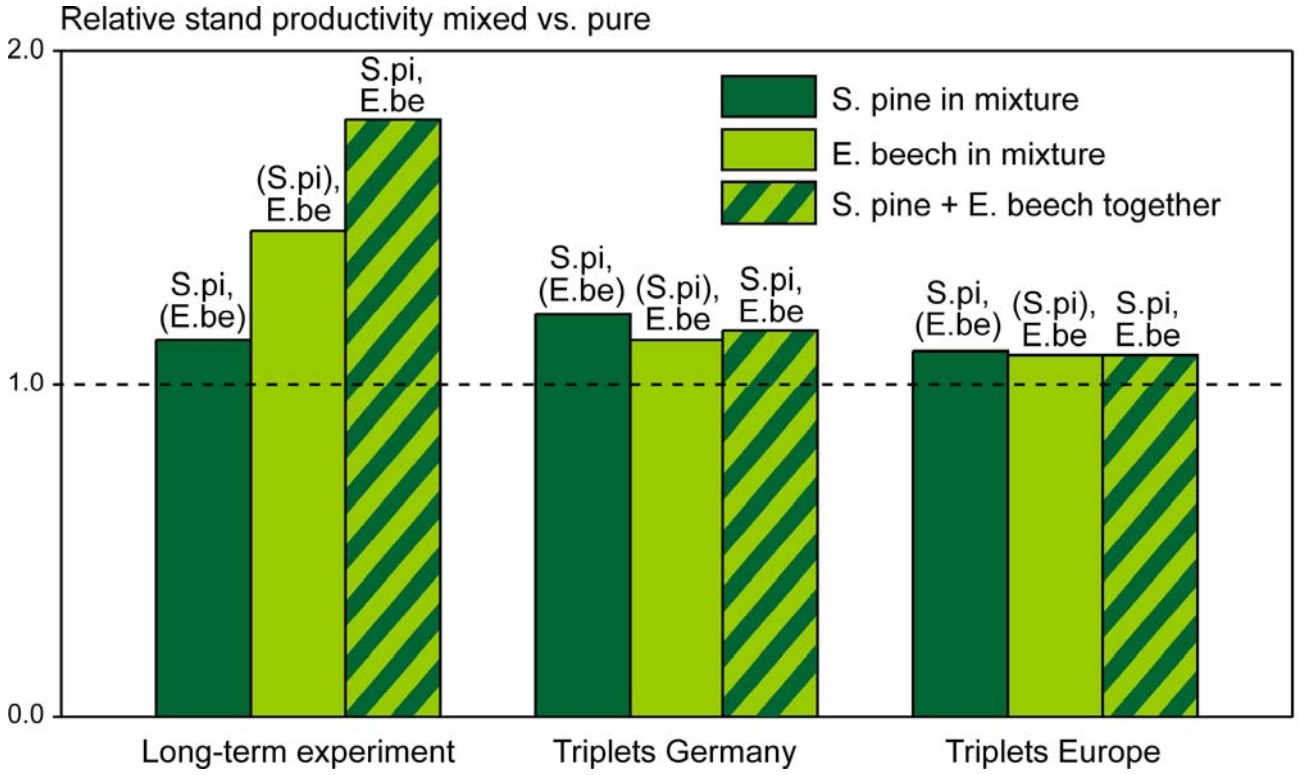
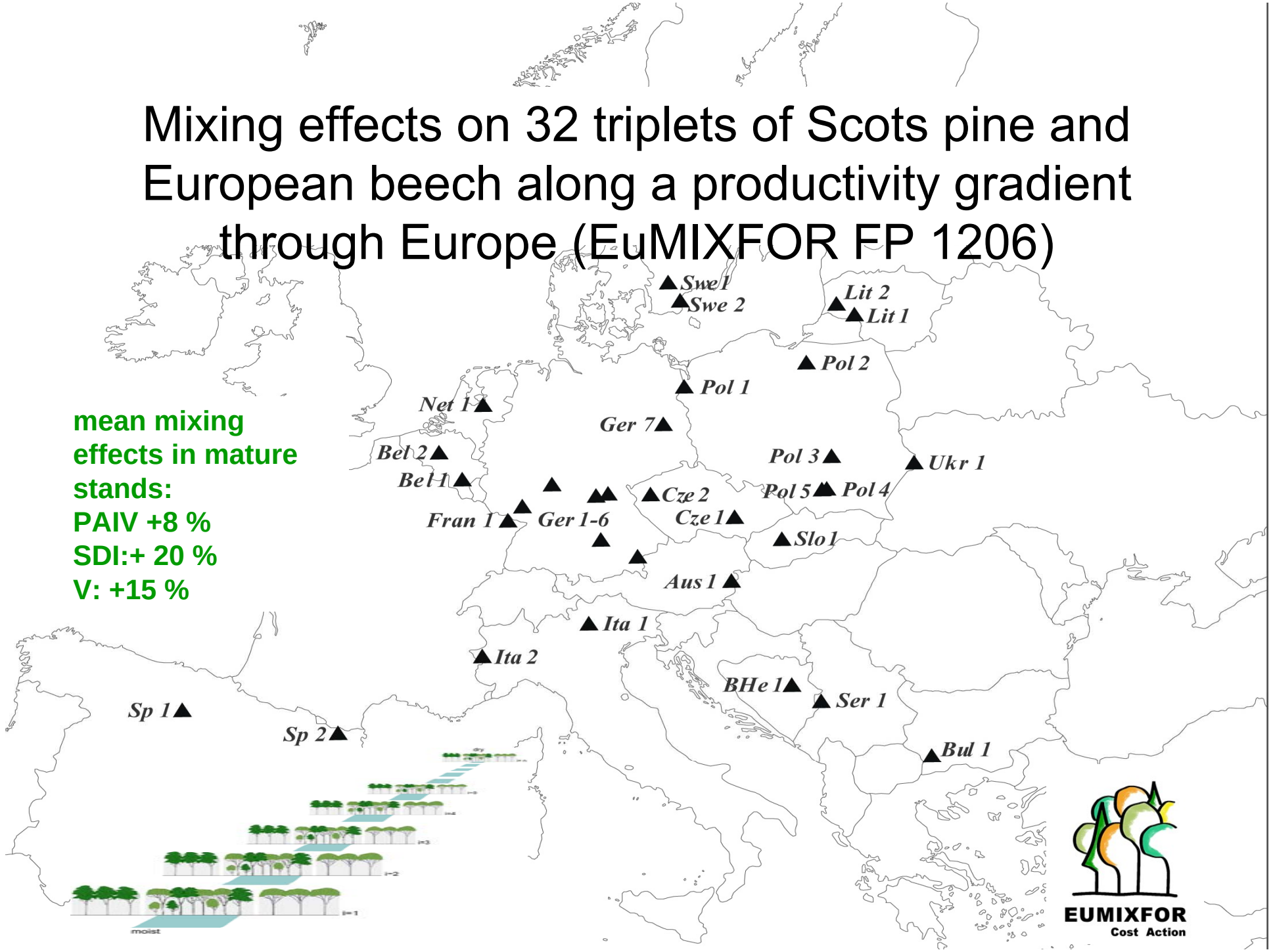
# Discussion and perspectives: Improving the strength of evidence of mixing effects




Forrester, D. I., Pretzsch, H. (revised) On the strength of evidence when comparing ecosystem functions of mixtures with monocultures, Forest Ecology and Management, A. Tamm Review

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



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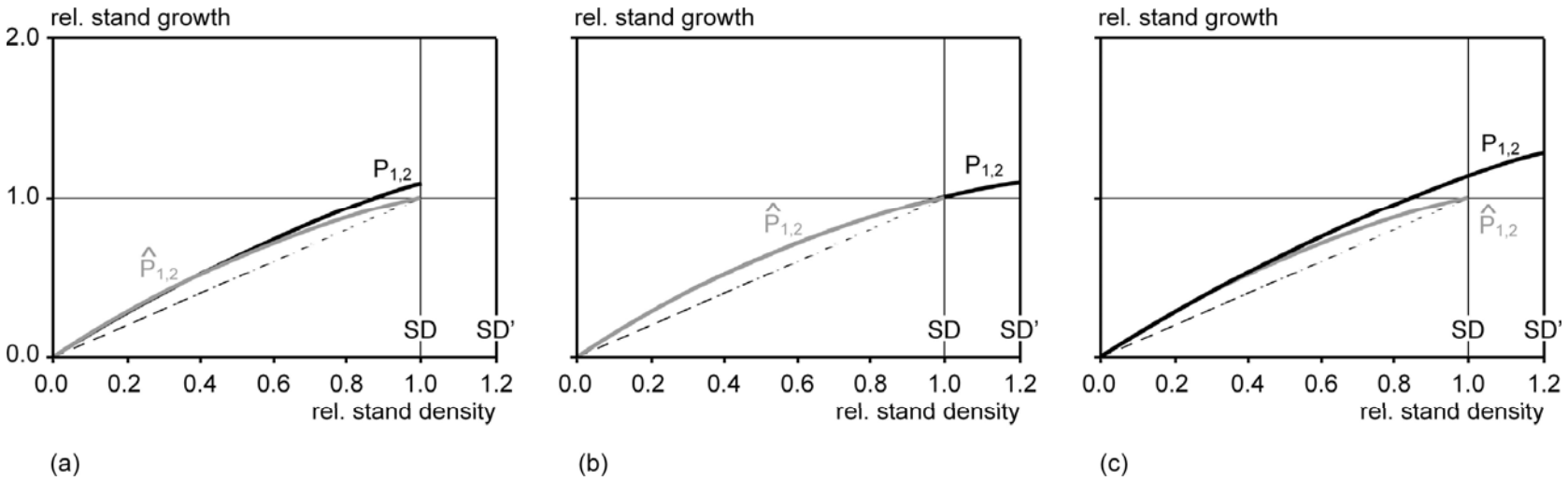
# Discussion and perspectives: Revelation how stand density modifies mixing effects



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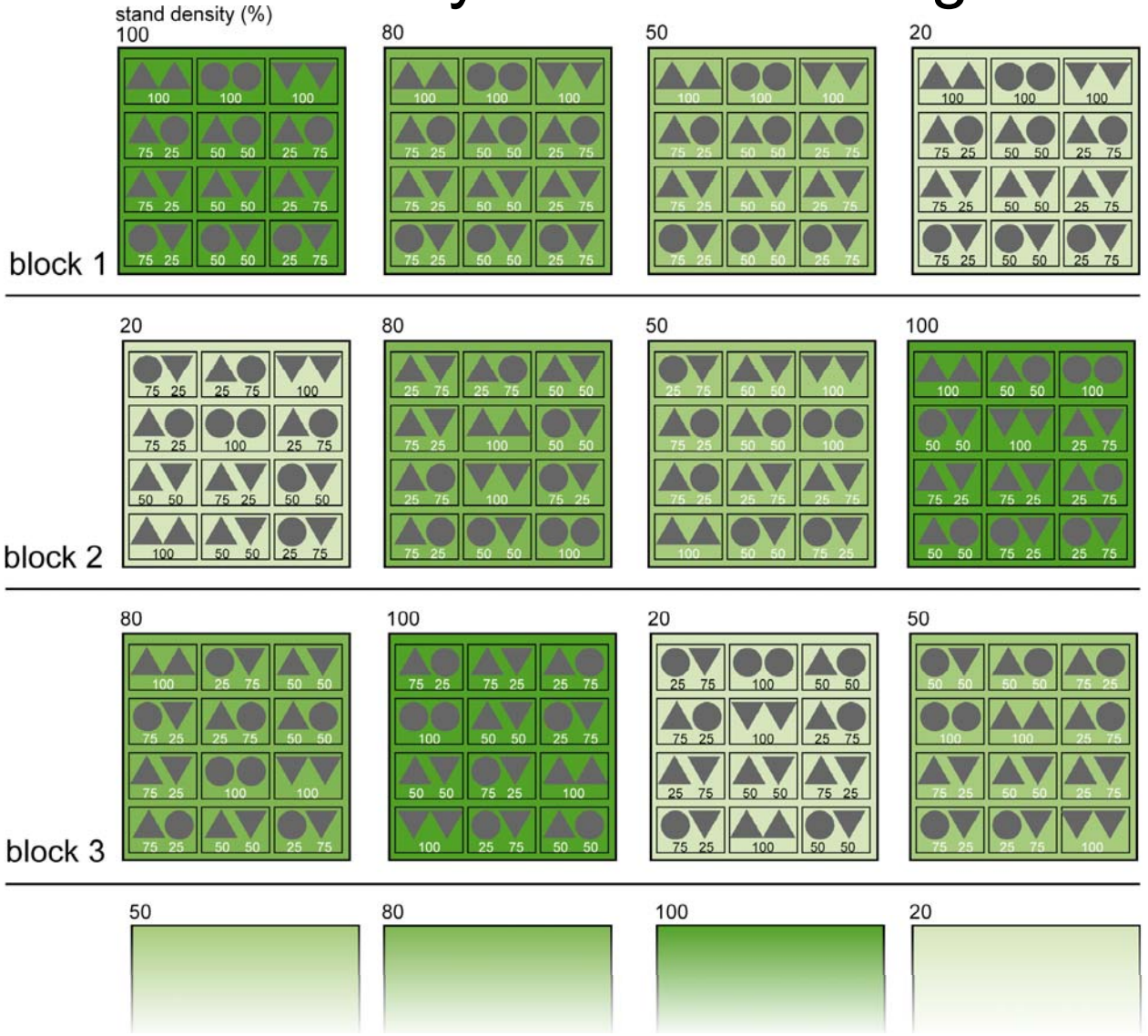
# Discussion and perspectives: Revelation how stand density modifies mixing effects



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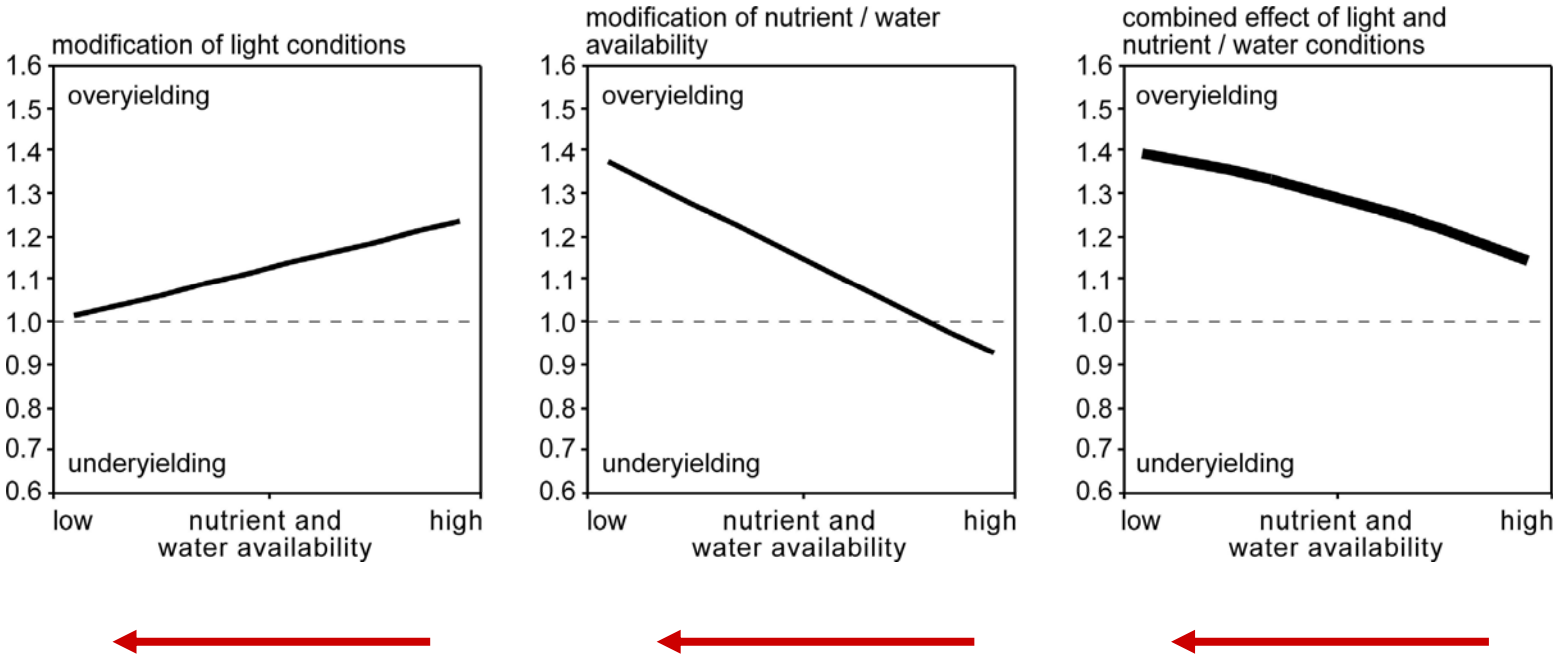
# Discussion and perspectives: Analyzing how site conditions modify mixing effects




Forrester, D. I., (2014) The spatial and temporal dynamics of species interactions in mixed-species forests: From pattern to process. Forest Ecology and Management 312: 282-292.

Pretzsch, H., del Río, M., Ammer, Ch., ....Bravo-Oviedo, A. (2015) Growth and yield of mixed versus pure stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) analysed along a productivity gradient through Europe. Eur F Forest Res, DOI 10.1007/s10342-015-0900-4.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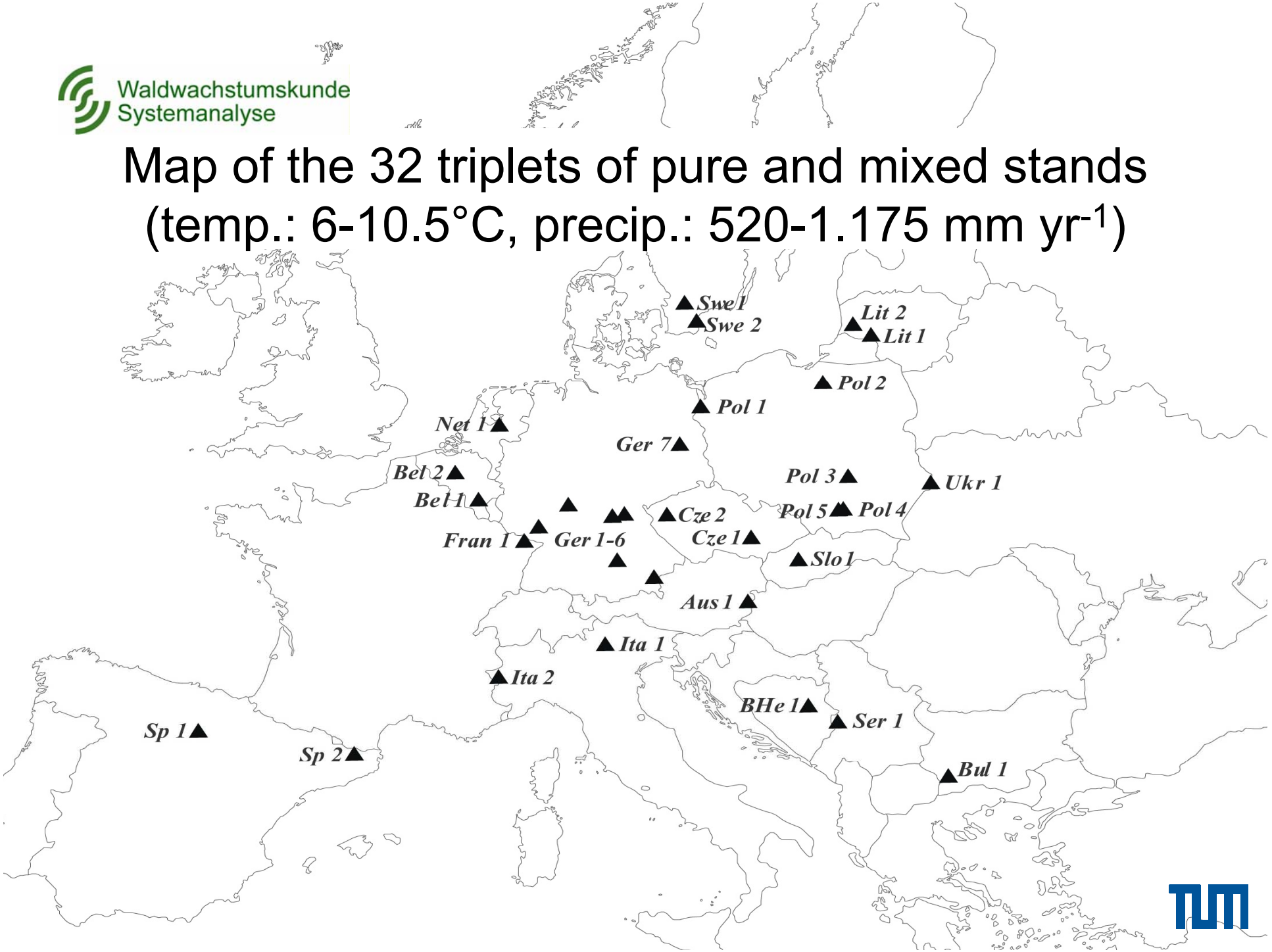
# Map of the 32 triplets of pure and mixed stands (temp.: 6-10.5°C, precip.: 520-1.175 mm $yr^{-1}$)

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about 30 researchers from 20 countries
for providing tree and stand data of pure and mixed stands

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Bavarian Ministry for Environment and Consumer Protection
European Union EuMIXFOR
AUDI foundation for the Environment

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# Overview of own publications about species mixing


Pretzsch H, Schütze G. (2009) Transgressive overyielding in mixed compared with pure stands of Norway spruce and European beech in Central Europe: evidence on stand level and explanation on individual tree level. Eur J Forest Res 128: 183-204.

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

Pretzsch H., Schütze G., Uhl E., (2012) Resistance of European tree species to drought stress in mixed versus pure forests, Plant Biology, 15 (3):483-495.

Río del, M., Schütze, G. & Pretzsch, H., (2013) Temporal variation of competition and facilitation in mixed species forests in Central Europe, Plant Biology, 16(1): 166-176

Bayer, D., Seifert, S., Pretzsch, H., (2013) Structural crown properties of Norway spruce and European beech in mixed versus pure stands revealed by terrestrial laser scanning, Trees, 27(4): 1035-1047

Pretzsch H., Bielak K., Block J., Bruchwald A., Dieler J., Ehrhart H-P., Kohnle U., Nagel J., Spellmann H., Zasada M., Zingg A. (2013) 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. Eur. J. For.Res. 132 (2), 263-280.

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

Pretzsch, H., Rötzer, T., Matyssek, R., Grams, T. E. E., Häberle, K. H., Pritsch, K., Kerner, R., Munch, J. C. 2014: Mixed Norway spruce (Picea abies [L.] Karst) and European beech (Fagus sylvatica [L.]) stands under drought: from reaction pattern to mechanism. Trees Structure and Function, 28:1305-1321

Pretzsch, H., Forrester, D. I., Rötzer, Th, (2015) Representation of species mixing in forest growth models. A review and perspective. Ecological Modelling, DOI 10.1016/j.ecolmodel.2015.06.044

Pretzsch, H., del Río, M., Ammer, Ch., Avdagic, A., Barbeito, I., Bielak, K., Brazaitis, G., Coll, L., Dirnberger, G., Drössler, L., Fabrika, M., Forrester, D. I., Godvod, K., Heym, M., Hurt, V., Kurylyak, V., Löf, M., Lombardi, F., Matović, B., Mohren, F., Motta, R., den Ouden, J., Pach, M., Ponette, Q., Schütze, G., Schweig, J., Skrzyszewski, J., Sramek, V., Sterba, H., Stojanović, D., Svoboda, M., Vanhellemont, M., Verheyen, K., Wellhausen, K., Zlatanov, T., Bravo-Oviedo, A. (2015) Growth and yield of mixed versus pure stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) analysed along a productivity gradient through Europe. Eur F Forest Res, DOI 10.1007/s10342-015-0900-4.