# High phenotypic plasticity, but low signals of local adaptation in a large-scale provenance trial of Norway spruce

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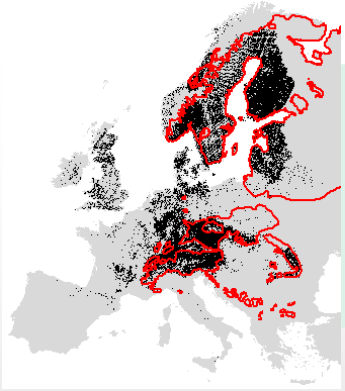
# Occurrence-based species distribution model (Model 1)

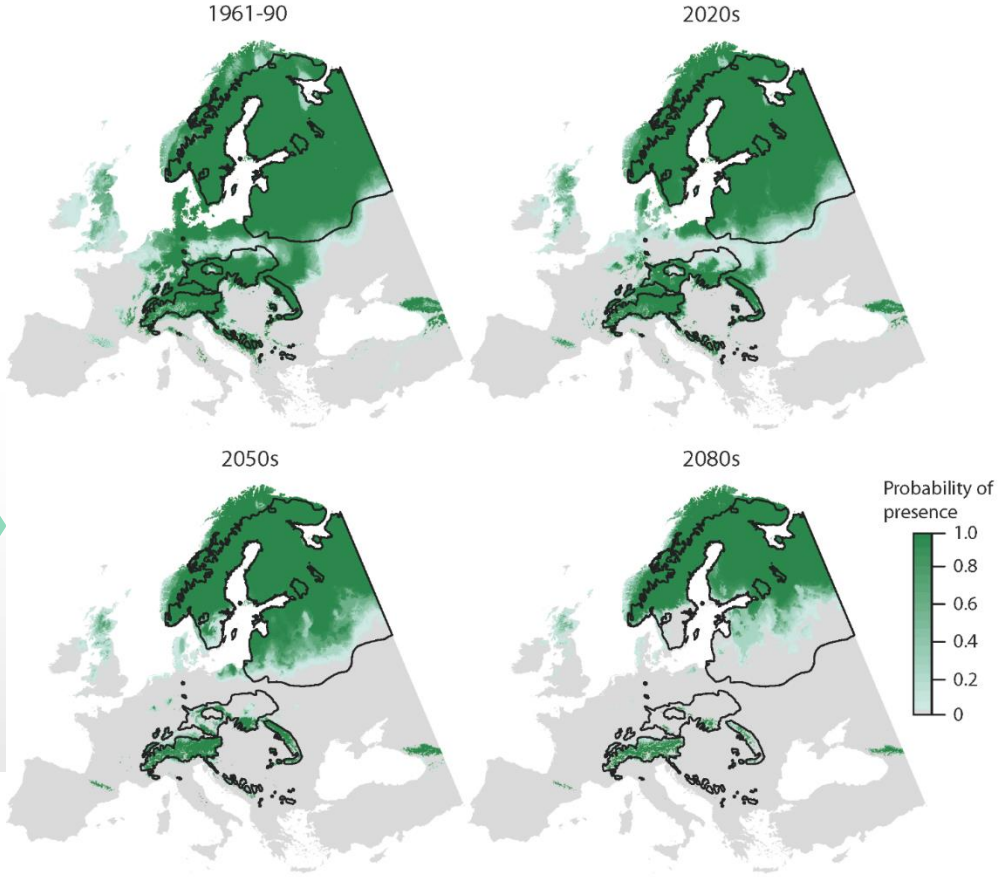
- predict the potential distribution of species based on the correlation between observed presence of species and the corresponding environmental conditions (climate, soil, antagonists, ...)



**Ensemble Model**

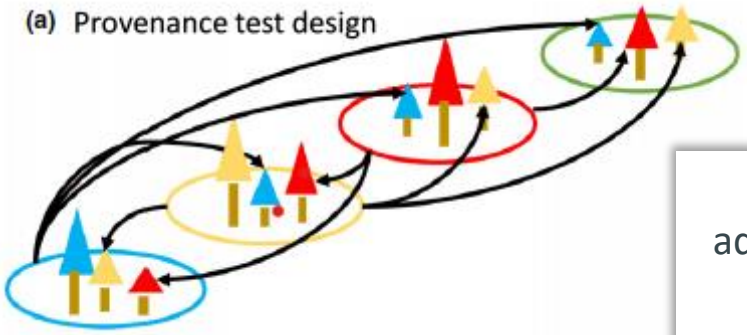
Median of 5 algorithms

4 climatic predictors (CMD, MCMT, MDMP, TD)

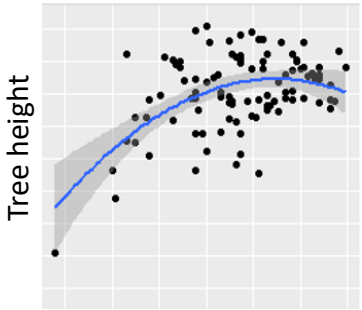



NFI Data from Mauri et al. (2017), Scientific Data
Species distribution from Skrøppa (2003), Euforgen
All climate data extracted with ClimateEU by Marchi et al. (2020), Scientific Data

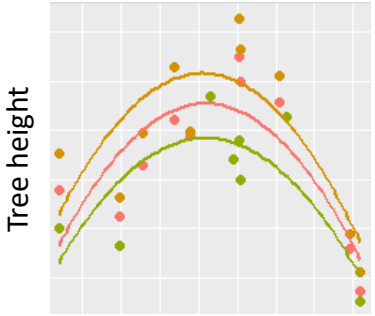
# But spruce is not everywhere the same spruce!




Populations are adapted to their local environment

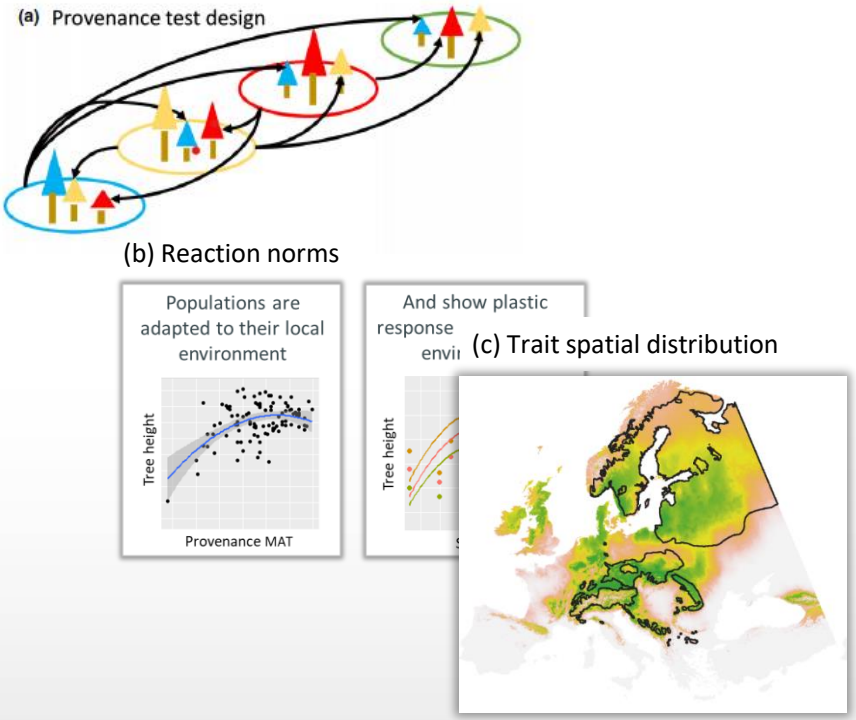



And show plastic response to a changing environment




Graph adapted from Benito-Garzón et al. (2019), New Phytologist

# Trait-based models fill this gap




- predict quantitative trait expression based on observed trait variation in the field (survival, phenology, growth)
- consider **local adaptation** and **phenotypic plasticity**, being the most important processes in response of tree populations to climate change
- prerequisite are provenance trial series spanning large geographic and climatic gradients

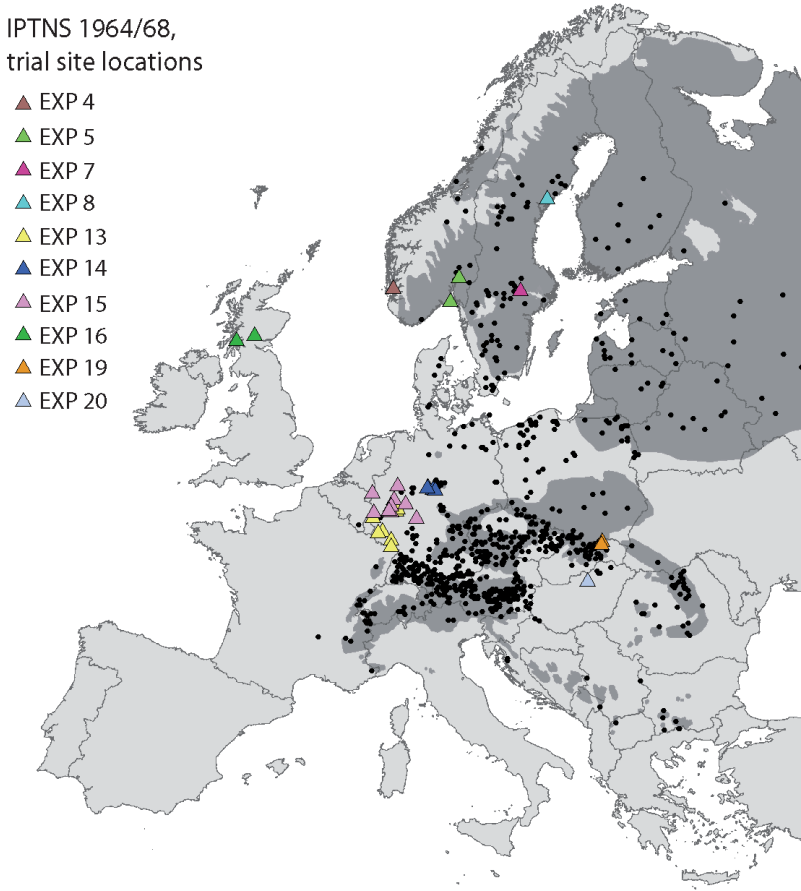
Statistic model approaches: *universal transfer functions, linear mixed models, machine learning techniques*

Graph adapted from Benito-Garzón et al. (2019), New Phytologist

# International Provenance Trial of Norway Spruce 1964/68 (IPTNS)

- sown 1964, planted 1968
- 1100 provenances
- 20 experiments with 11 blocks of 100 provenances
- 20 (-25) replicates, single-tree-plots, 2x2 m

**tree height at age 11**
available from 32 site locations
(= 97 blocks with 100 provenances)




***Universal response function***

$$\log(height_{ij}) = \beta_0 + \underbrace{\beta_1 P_i + \beta_2 P_i^2 + \beta_6 G_i + \beta_6 G^2{}_i}_{\text{provenance}} + \underbrace{\beta_3 S_j + \beta_4 S_j^2}_{\text{site}} + \underbrace{\beta_5 (P_i \times S_j)}_{\text{interaction}} + e_{ij}$$

# Trait-based model explains 75.8 % (Model 2)

| | Independent variable | Estimate | Std.Error | t-value | Model $R^2$ | Partial $R^2$ | Contribution to sum of partial $R^2$ (%) | Pr(> \|t\|) | |
|---|---|---|---|---|---|---|---|---|---|
| | (Intercept) | -1.23E+01 | 3.82E-01 | -32.14 | | | | | |
| Length of frost-free period | FFP_s | 4.75E-02 | 1.29E-03 | 36.70 | 0.442 | 0.124 | **13.7** | < 0.001 | *** |
| | FFP_s² | -1.01E-04 | 3.24E-06 | -31.09 | 0.587 | 0.092 | **10.2** | < 0.001 | *** |
| Summer-heat-moisture index | SHM_s | 1.16E-01 | 1.88E-03 | 61.74 | 0.651 | 0.286 | **31.5** | < 0.001 | *** |
| | SHM_s² | -1.30E-03 | 2.31E-05 | -56.10 | 0.730 | 0.249 | **27.4** | < 0.001 | *** |
| Geographic latitude | Latitude_p | 3.23E-01 | 1.27E-02 | 25.56 | 0.734 | 0.064 | **7.1** | < 0.001 | *** |
| | Latitude_p² | -3.11E-03 | 1.18E-04 | -26.29 | 0.753 | 0.068 | **7.5** | < 0.001 | *** |
| Continentality | TD_p | 1.71E-01 | 1.51E-02 | 11.33 | 0.755 | 0.013 | **1.5** | < 0.001 | *** |
| | TD_p² | -2.61E-03 | 3.20E-04 | -8.15 | 0.757 | 0.007 | **0.8** | < 0.001 | *** |
| Interaction | FFP_s × TD_p | -2.74E-04 | 3.89E-05 | -7.05 | 0.758 | 0.005 | **0.6** | < 0.001 | *** |

# Phenotypic plasticity largely determines growth

| | Independent variable | Estimate | Std.Error | t-value | Model $R^2$ | Partial $R^2$ | Contribution to sum of partial $R^2$ (%) | |
|---|---|---|---|---|---|---|---|---|
| | (Intercept) | -1.23E+01 | 3.82E-01 | -32.14 | | | | |
| site | Length of frost-free period | FFP_s | 4.75E-02 | 1.29E-03 | 36.70 | 0.442 | 0.124 | **13.7** | **82.8%** |
| | | FFP_s² | -1.01E-04 | 3.24E-06 | -31.09 | 0.587 | 0.092 | **10.2** | |
| | Summer-heat-moisture index | SHM_s | 1.16E-01 | 1.88E-03 | 61.74 | 0.651 | 0.286 | **31.5** | |
| | | SHM_s² | -1.30E-03 | 2.31E-05 | -56.10 | 0.730 | 0.249 | **27.4** | |
| provenance | Latitude | Latitude_p | 3.23E-01 | 1.27E-02 | 25.56 | 0.734 | 0.064 | **7.1** | **14.6%** |
| | | Latitude_p² | -3.11E-03 | 1.18E-04 | -26.29 | 0.753 | 0.068 | **7.5** | |
| | Continentality | TD_p | 1.71E-01 | 1.51E-02 | 11.33 | 0.755 | 0.013 | **1.5** | **2.3%** |
| | | TD_p² | -2.61E-03 | 3.20E-04 | -8.15 | 0.757 | 0.007 | **0.8** | |
| | Interaction | FFP_s × TD_p | -2.74E-04 | 3.89E-05 | -7.05 | 0.758 | 0.005 | **0.6** | **< 1%** |

- High phenotypic plasticity (approx. 83 % of partial $R^2$ explained by site)
- Dominant latitudinal effect, which is likely attributed to post-glacial migration history
- Local adaptation to climate has only small effect, it is disguised by the latitudinal effect

# Predictions planting ‘local’ provenance

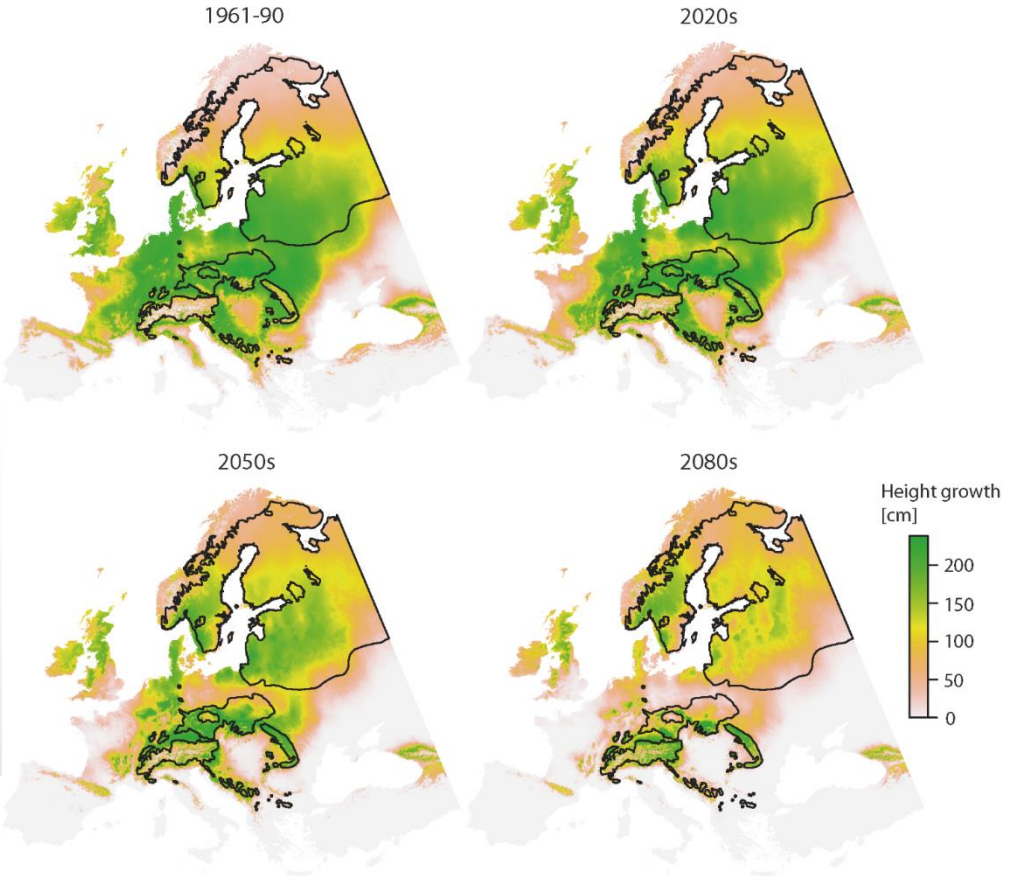
**‚local‘ = natural regeneration on the spot**

<u>To date:</u>

- High growth potential in Central Europe

<u>In future:</u>

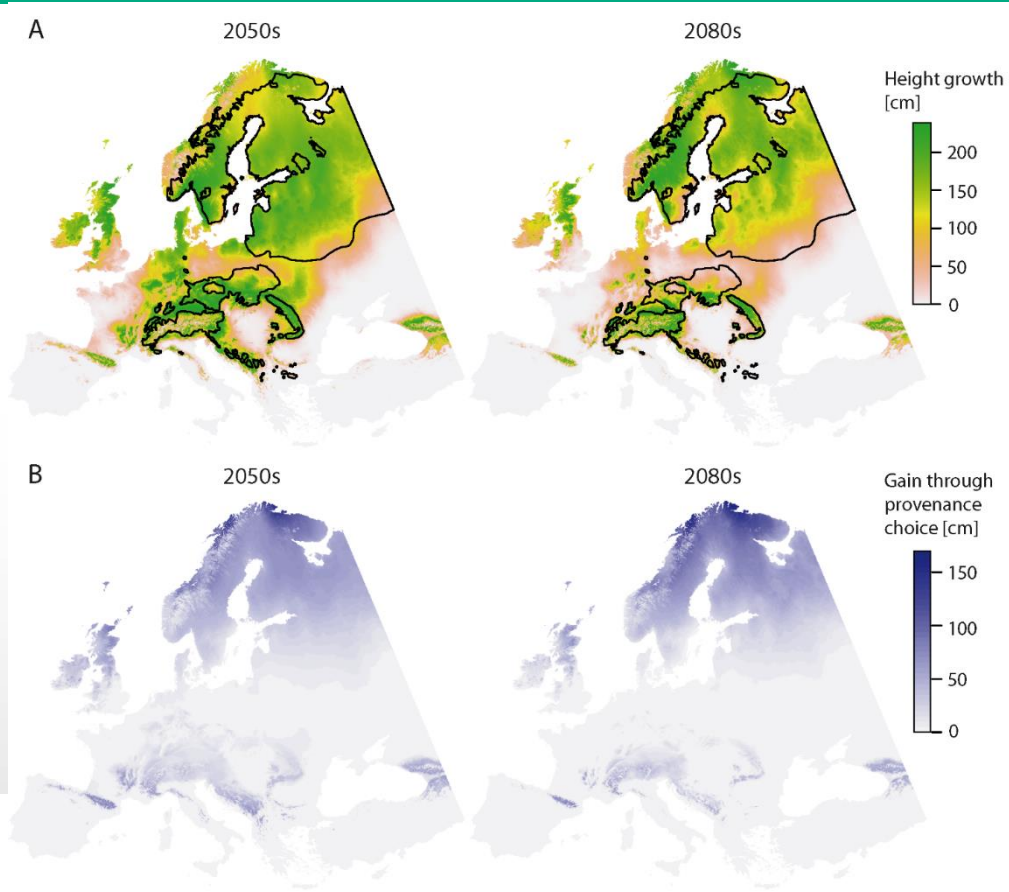
- Decreasing growth potential, particularly in the plains due to increasing SHM (temperature ↑ and water availability ↓)
- Retreat of area with good growth towards the natural distribution and further beyond
- <u>but</u> growth increases in the north and at high elevations due to the elongation of FFP



# Predictions planting ‘optimal’ provenance

**‚optimal‘ = model based transfer of reproductive material**

- Positive effect in the north and at higher elevations
- May not compensate retreat in flat and intermediate regions

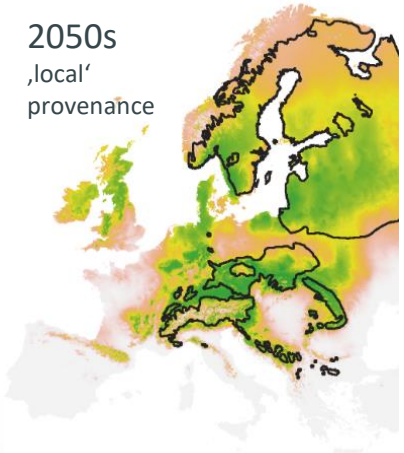


# Comparison of TraitSDM and OccurrenceSDM

- Requires translation of predicted height growth (TraitSDM) and probability of presence (OccurrenceSDM) to species occurrence

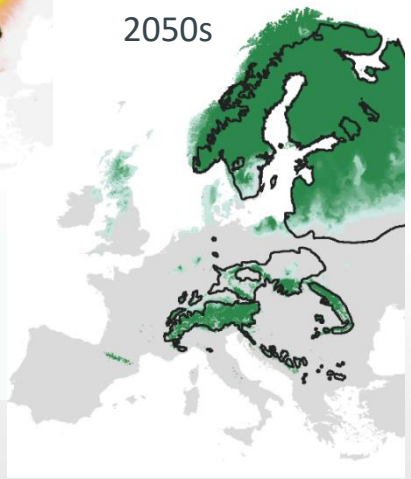
**Species range change**

| | 2050s | 2080s |
|---|---|---|
| **OccurrenceSDM** | **- 40%** | **- 55%** |
| **TraitSDM** | | |
| **‘local’ provenance** | **- 21%** | **- 43%** |
| **‘optimal’ provenance** | **- 16%** | **- 39%** |

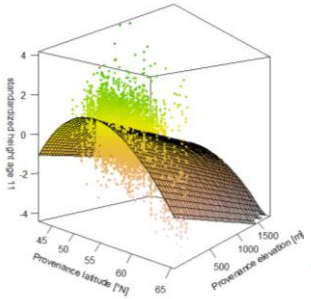



*Optimal Threshold = maximum sum of sensitivity and specificity*

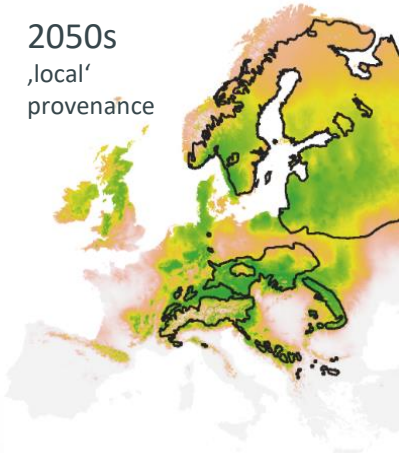
(Liu et al. 2005, Ecography)

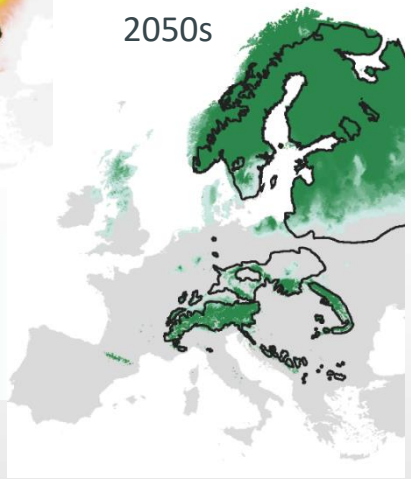


# Comparison of TraitSDM and OccurrenceSDM




Productivity-oriented threshold using regression surface (simplified $y = Lat^2 + Lat + Elev$)

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| **'local' provenance** | **- 21%** | **- 43%** |
| **'optimal' provenance** | **- 16%** | **- 39%** |

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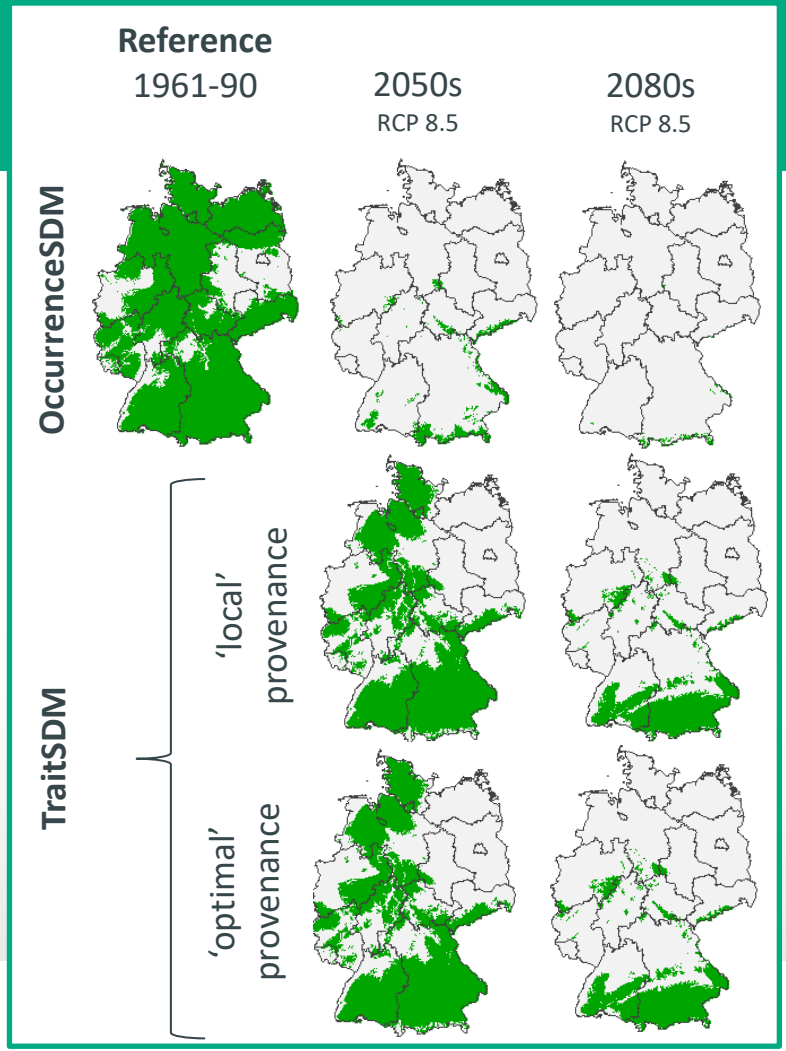
(Liu et al. 2005, Ecography)

# Regional focus

- severe decrease of suitable area by OccurrenceSDM
- phenotypic plasticity supports persistence, TraitSDM is less alarming
- very limited effect of population transfer
- where one short generation of Norway spruce appears realistic, make use of the natural regeneration

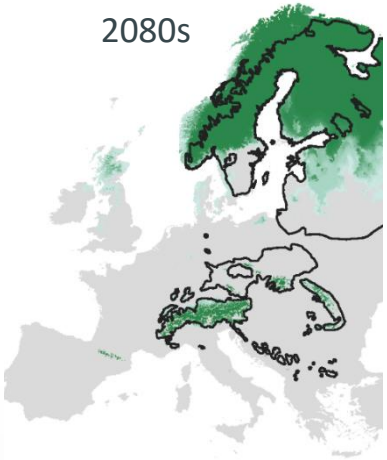
**Species range change in Germany**

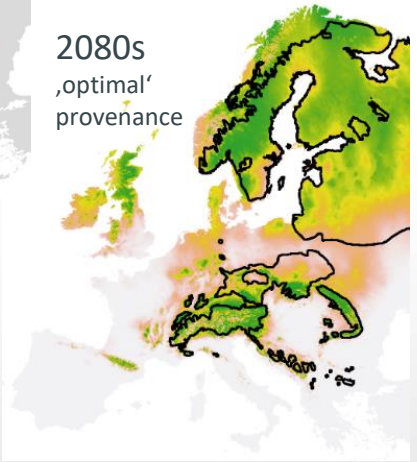
| | 2050s | 2080s |
|---|---|---|
| **OccurrenceSDM** | **- 93%** | **- 98%** |
| **TraitSDM** | | |
| **'local' provenance** | **- 43%** | **- 81%** |
| **'optimal' provenance** | **- 41%** | **- 80%** |



# Conclusions

- both models show a substantial retreat towards the species core habitat
- Norway spruce's particularly high phenotypic plasticity promotes species persistence
- increasing summer heat paired with decreasing water availability strongly restricts growth, while the elongation of the frost-free period has a positive effect within the remaining suitable area
- local adaptation to climate is disguised by the latitudinal effect
- provenance transfer may not prevent range decline, but may enhance growth within the remaining area



# Thank you for your attention!

And to all people involved in the IPTNS 1968/64 series for their immense efforts. This analysis was only possible through international collaboration, long-term maintenance and measurement of test sites, and the publication of their results.

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