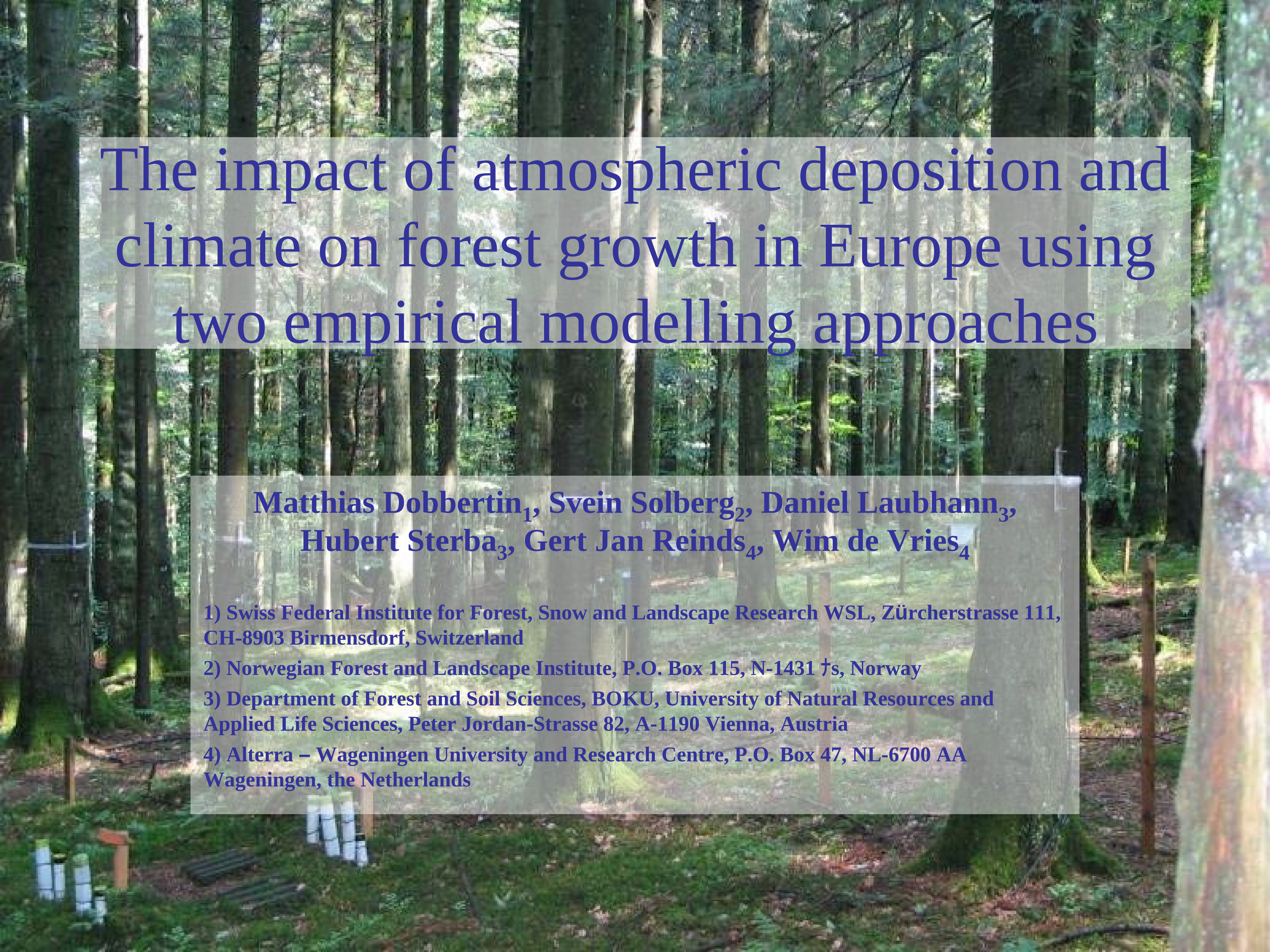

The impact of atmospheric deposition and climate on forest growth in Europe using two empirical modelling approaches

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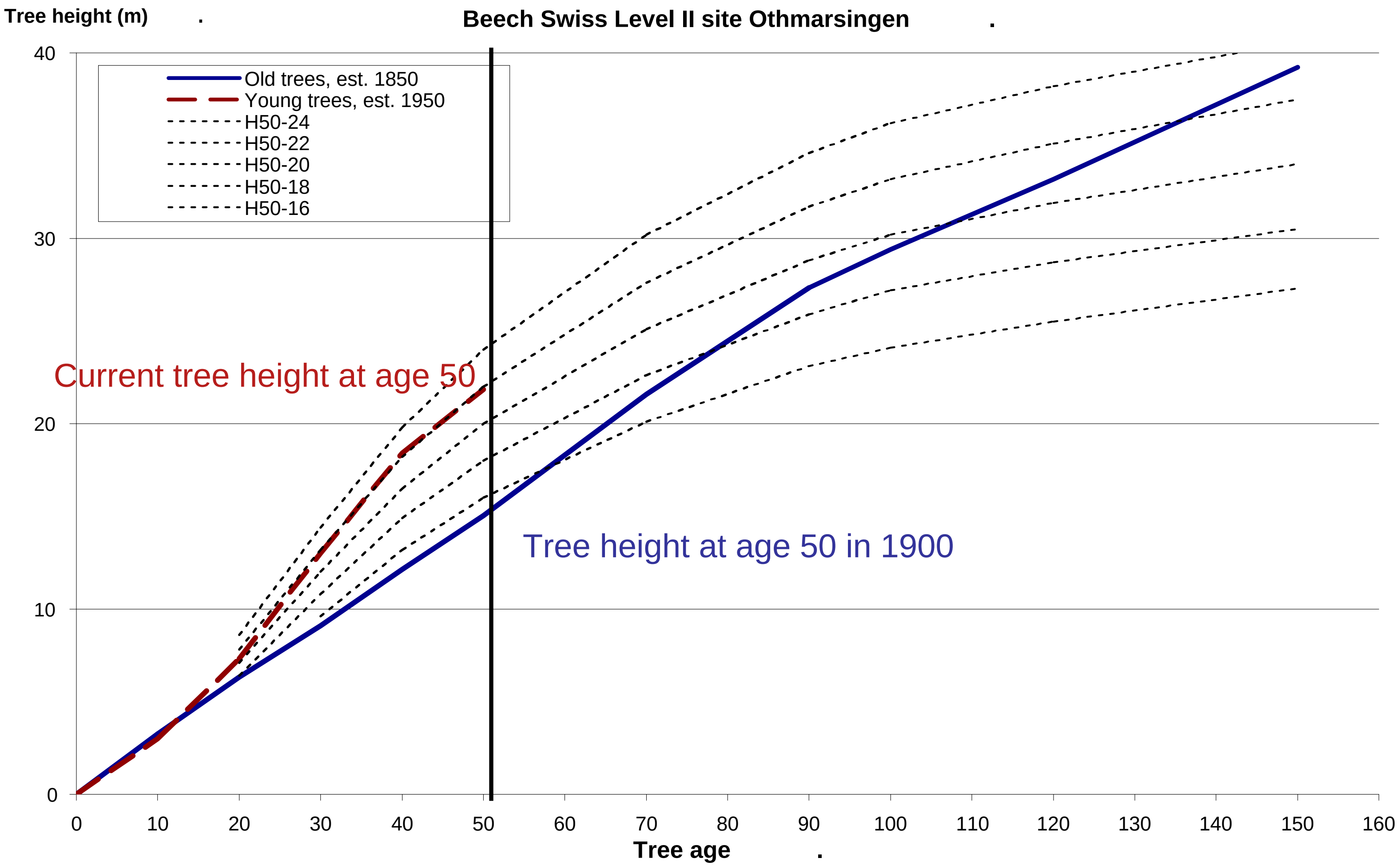
Outline

- Background
  - Increasing forest growth, N deposition, temperature
- Methods
  - Space for time approach: tree increment data from Eurpean ICP Forests network
  - two different empirical tree growth regression models
- Results
  - Determine the significant factors in growth models
  - Calculation of effects of N deposition on C sequestration
- Discussion
  - Are the results reasonable?
  - How do they compare to other studies?

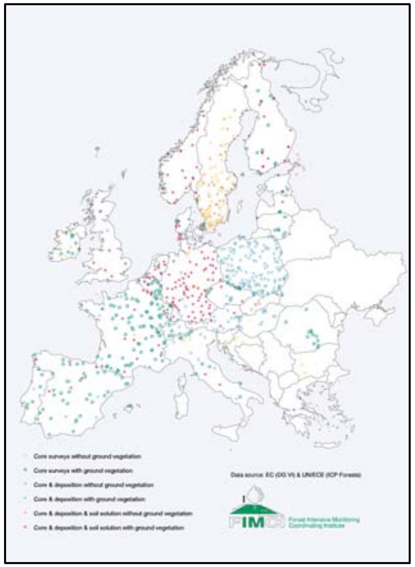
Background: Tree growth has increased in parts of Europe



Tree height growth increased by 25% in last 40 years; RECOGNITION (Kahle et al. 2008)

Aims of the Project

- To quantify the effect of **atmospheric deposition** and **climate** on **above-ground** forest growth in Europe using a **large-scale** data set covering many different conditions (space-for-time approach).
- Use monitoring plots with actual **measured** forest increment, deposition and climate.



Methods

To relate **forest stem increment (1994-1999)** on Level II plots to:

- **site** and **stand conditions** (stand age, tree size, stand density, tree competition, site productivity...)

- **climate** (precipitation, temperature, drought index)

- **atmospheric deposition** (N, S, acidic deposition)

Laubhann et al., 2009, Solberg et al. 2009

Two Growth Model Approaches

- An **individual tree growth model** for 5-year basal area increment (Laubhann et al. 2009)

- A forest **stand-based model** for 5-year stand volume increment (Solberg et al. 2009)

Requirements for the two approaches

- **Individual tree growth (382 plots, 40‘000 trees):**
  - Trees must be identifiable
  - Two-time growth measurements (dbh)
  - Main species (Norway spruce, Scots pine, beech, oaks)
- **Plot-based models (363 plots):**
  - +/- even-aged stands
  - At least 70% of main species
  - Two-time growth measurements (dbh), one-time tree height measurement

Laubhann et al., 2009, Solberg et al. 2009

The two models

- Model 1: Mixed-effect model for individual tree basal area (BAI) growth
  - $Ln(BAI) = a + b^T \text{ size} + c^T \text{ comp} + d^T \text{ site} + f^T \text{ siteenv} + \mu + \varepsilon$
- Model 2: Two-step stand volume growth model approach
  - Estimate potential volume growth (VI) based on site index, age and stand density:
    - $Ln(VI) = a + b_1 \text{ siteindex} + b_2 \text{ age} + b_3 \text{ stand density} + \varepsilon$
  - Regress residuals (RI) against environmental variables
    - $RI = a + b^T \text{ siteenv} + \varepsilon$
  - Plus apply an analysis of covariance and multiple regression

Laubhann et al., 2009, Solberg et al. 2009

Plots in Model 1

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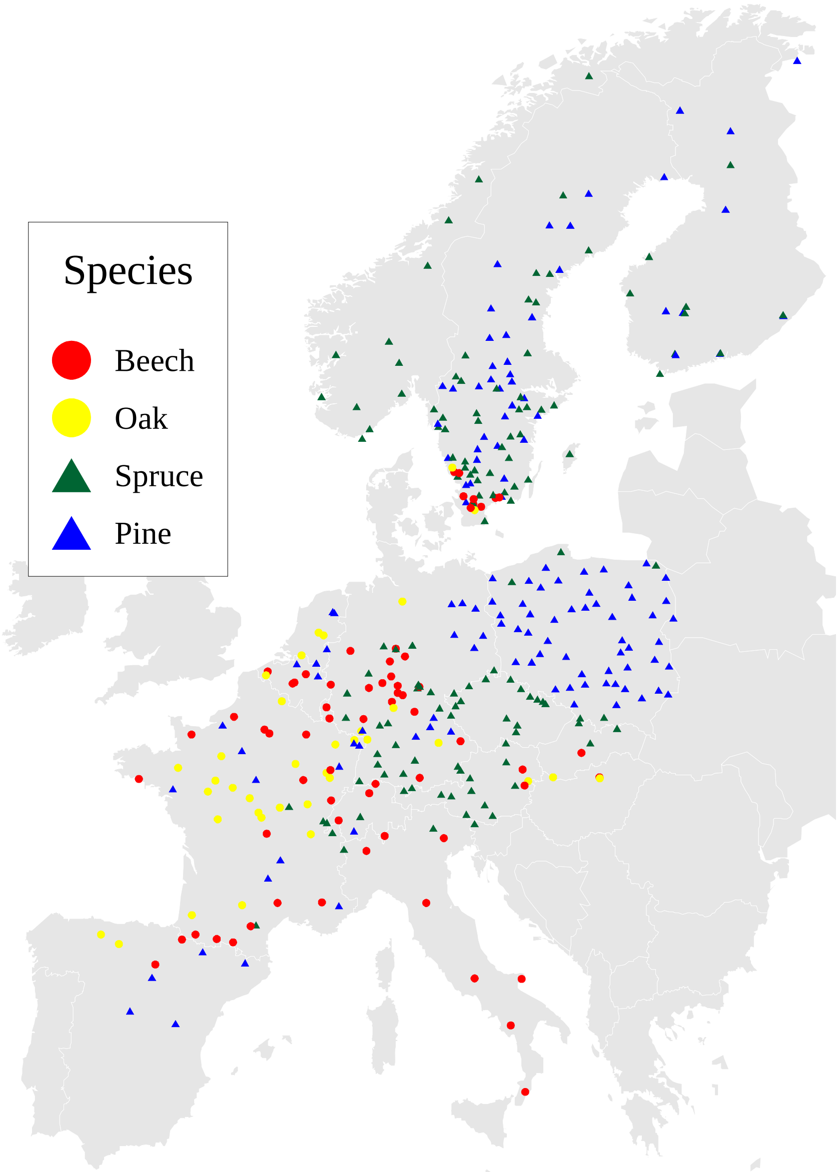
Laubhann et al. 2009

Plots in Model 2



Solberg et al. 2009

Results Model 1

Models with measured plots only, with EMEP model data on plots with measurements and all plot with EMEP data for Norway Spruce (only sign. parameters)

Models	N trees	N plots	Intercept	dbh	BALrel	SDI	CNrat	Ndep
Spruce								
Measured data	13620	111	-0.873	1.737	-0.498	-0.00066	-0.0212	0.0141
Measured-EMEP	13620	111	-0.950	1.734	-0.502	-0.00068	-0.0198	0.0174
All EMEP	17608	152	-0.875	1.720	-0.494	-0.00056	-0.0227	0.0126

Models all plot with EMEP data for all species with all significant parameter

Species	Intercept	dbh	dbh^2	BALrel	SDI	CNrat	Temp	Tempdif	Ndep.	Ndep x BALre
Spruce	-0.875	1.720	-	-0.494	-0.0006	-0.023	-	-	0.013	-
Pine	-1.176	1.300	-0.0003	-0.343	-0.0007	-	0.052	-	0.015	-0.008
Beech	-3.820	2.357	-0.0001	-0.183	-	-	-	0.062	0.012*	-
Oaks	-2.776	1.987	-0.0002	-0.482	-0.0006	-	0.077	-	0.013	-

* p = 0.077

Laubhann et al. 2009

Relation in Model 1 between N deposition and basal area increment, having all other values set to their means.

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Laubhann et al. 2009

Model 2: Nitrogen deposition and percent of actual to predicted growth as f(site index, age, density)

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Solberg et al. 2009

Model II: Simple linear Regression - All plots versus sensitive sites only

	N dep		S dep		Net acid dep		Temp dev		Drought dev	
Spruce	all	sens	all	sens	all	sens	all	sens	all	sens
1 class values	**2.02**	**3.04**	**0.51**	**0.52**	**0.0078**	0.01	**42**	**45**	**-0.25**	**-0.37**
2 site index	**0.94**	**1.28**	0.19	0.19	0.00		**24**	**26**	-0.01	**-0.26**
Pine										
1 class values	**1.06**	**1.23**	**0.46**	**0.59**	**0.0050**	0.01	**36**	**39**	**-0.23**	-0.14
2 site index	**1.01**	**1.17**	**0.38**	**0.40**			**30**	**45**	**-0.19**	-0.12
Beech										
1 class values	0.99	-	0.39	-	0.0043	0.02	**39**	25	0.13	-0.02
2 site index	0.52	-	0.13	-			28	17	-0.06	-0.07
Oak										
1 class values	-0.35	-	-0.41	-	0.0038	0.02	-53		0.19	
2 site index	**1.51**	-	0.37	-			**-55**		**0.55**	**0.51**

Solberg et al. 2009

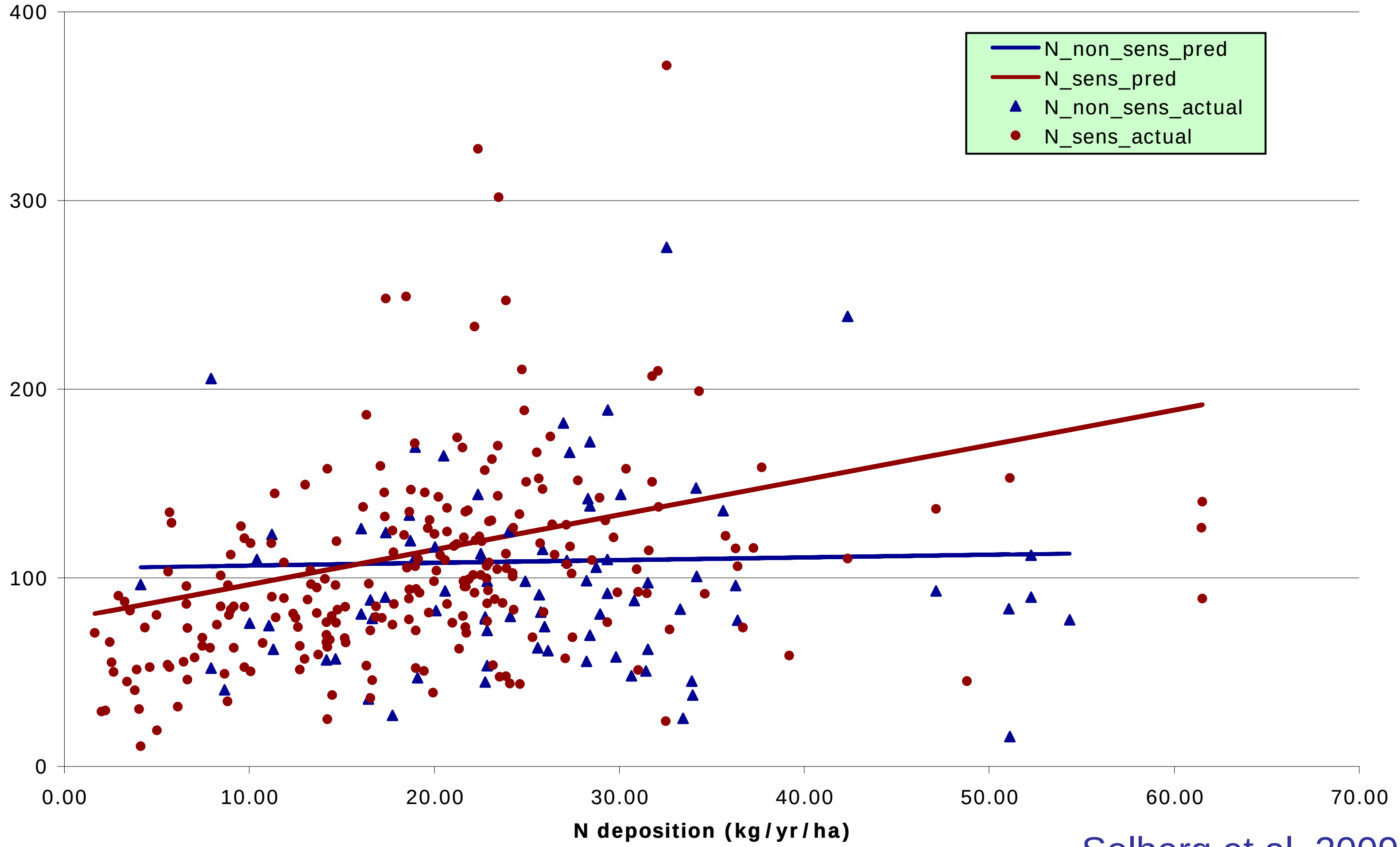
Multivariate regression

Model	Site index	age	SDI	N dep	Temp	Drought	Adj R^2	N
All plots								
Spruce-class	0.047***	-0.005**	-	-	0.529***		0.33	125
Spruce-mean SI	0.104***	-		-	0.359***		0.50	131
Pine-class	-	-0.017***	-	0.010*	-	-0.0032**	0.27	121
Pine-mean SI	0.078**	-0.010**	-	0.009*	-	-0.0012**	0.37	129
Beech-class	-	-0.005*	-	-	0.700***	-	0.26	56
Beech-mean SI	0.117***	-	-	-	0.363*	-	0.29	61
Oak-class	-	-0.009**	-	-	-	-	0.29	29
Oak-mean SI	0.220*	-	-0.008*	0.024*	-	-	0.20	34
N sensitive plots								
Spruce-class	0.039*	-0.004**		0.022**	0.342**	-	0.44	85
Spruce-mean SI	0.087***			0.023***	-	-	0.56	89
Pine-class	-	-0.017***	0.004*	0.013***	-	-0.002*	0.33	114
Pine-mean SI	0.090***	-0.009**	-	0.014***	-	-	0.40	121

Solberg et al. 2009

N deposition, C/N ratio in soil and relative growth

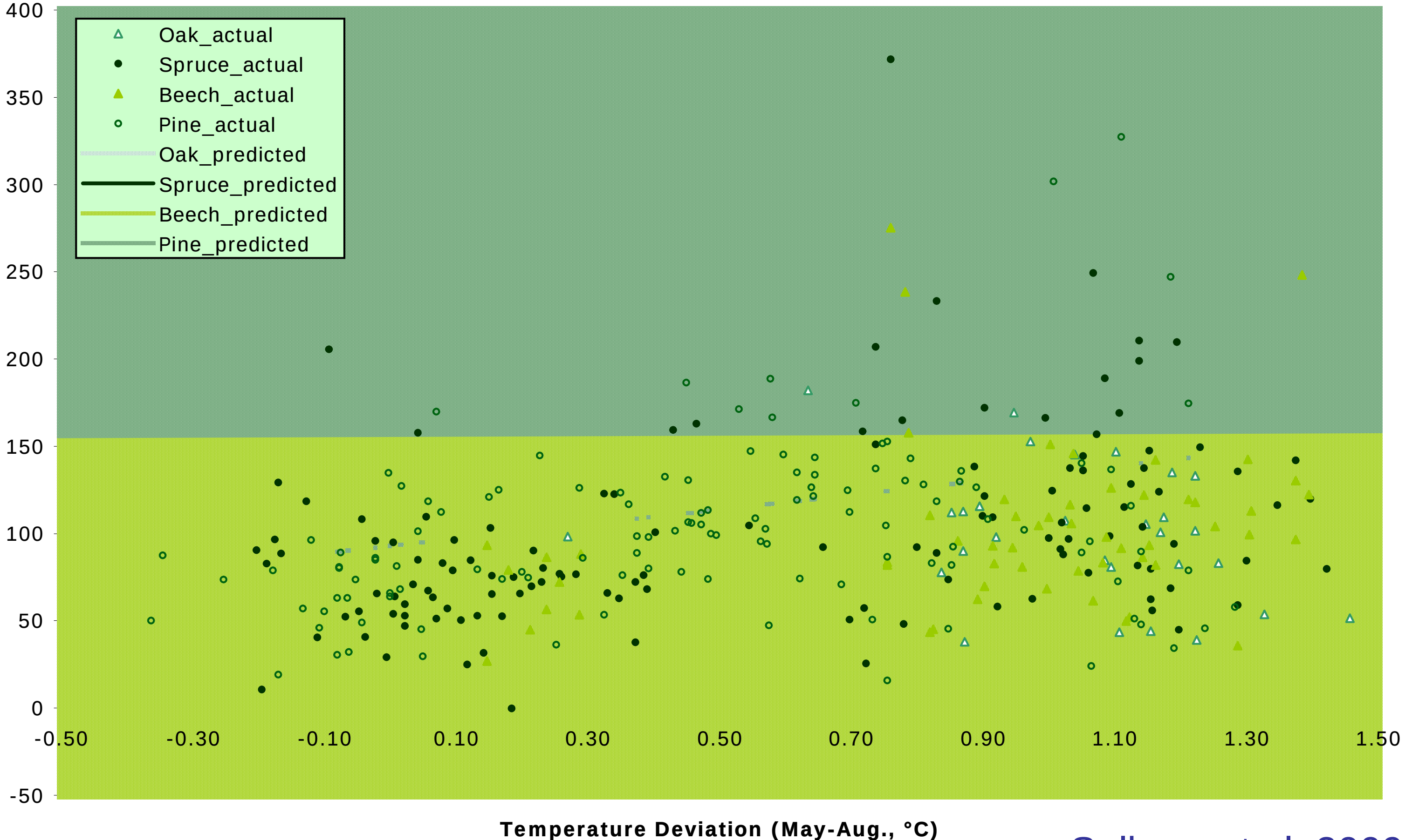
Analysis of covariance model



Solberg et al. 2009

Temperature deviation during the vegetation period and relative growth by species

Analysis of Covariance model



Solberg et al. 2009

Relative stem growth change in percent per 1 kg/N/ha deposition for both models and species:

Tree species	Model 1	Model 2
Norway spruce	+ 1.3 %	+ 0.9 - 2.0 %
Scots pine	+ 1.5 %	+ 1.0 - 1.1 %
Common beech	(+ 1.2 %)	(+0.5 - 1.0%)
Oak spec.	+ 1.3 %	(-0.4) - 1.6%
All combined	+ 1.3 %	+ 1.2 %

Solberg et al. 2009, Laubhann et al. 2009, de Vries et al. 2008, 2009

Calculation of C sequestration for the two approaches

- Model 1:
  - % BAI per 1 kg N ha/yr approximates % VI 1 kg N ha/yr
  - Use calculated mean C growth for Europe (1729 kg/ha/yr) from de Vries et al. 2006 => compute C per 1 kg N ha/yr
  - => 20.7 - 25.8 kg C per 1 kg N ha/yr, mean **23 kg** C ha/yr
- Model 2:
  - Use actual measured VI and VI% per 1 kg N ha/yr
  - Compute C sequestration per model:

    Weighted mean of VI% per species x wood density(species) x 0.5

  => Between 14 - 29 kg C per 1 kg N ha/yr, mean **19 kg** C ha/yr

Conclusions

- N deposition has most likely increased above-ground forest growth in Europe
- The effect of N deposition is slightly more than 1 % growth per 1 kg N ha/yr or roughly around 20 kg C per 1 kg N ha/yr
- This effect is higher on soils with low N contents
- The results are in line with experimental and modelling studies
- Warmer temperatures possibly contributed to increased growth, but the effects were less clear


Thank you very much!