Impacts of nitrogen deposition and climate change on carbon sequestration by forests in Europe

Wim de Vries, Hans Kros and others Alterra Wageningen UR, Netherlands
Hubert Sterba, Daniel Laubhann, BOKU, Austria
Svein Solberg, Norwegian Forest and Landscape Institute, Norway
Matthias Dobbertin, WSL, Switzerland
Marcel van Oijen, CEH Edinburgh, United Kingdom

ALTERRA WAGENINGEN UR

skog+ landskap
NORSK INSTITUTT FOR SKOG OG LANDSKAP

BOKU
University of Natural Resources and Applied Life Sciences, Vienna
Department of Forest- and Soil Sciences

WSL

CEH Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Contents

- Introduction
  - Effects of Temperature, Nitrogen and CO_2 on growth
  - N and C interactions
  - Aim
- Methods
  - The three models and data used
- Results
- Conclusions

Introduction

- Increased net primary productivity (NPP) and forest growth can be due to increased
  - Nitrogen deposition
  - Temperature
  - Atmospheric CO_2 concentrations
- NPP is also affected by changes in
  - Forest management (e.g. type of thinning, genetic selection)
  - Water availability (in turn affected by climate change)

Nitrogen and Carbon interactions

- Some studies (e.g. Holland et al., 1997) suggested very large carbon response to N deposition (200-400 kg C/kg N)
  - These studies assumed that most (~80%) of the deposited N would be stored in woody biomass (C/N 250-500)
- Nadelhoffer et al. (1999) showed that only 5% of deposited N is stored in woody biomass and most (~70%) in soils (C/N 10-30). This implies a sequestration near 50 kg C/kg N
- Model simulations by Currie *et al*. (2004), even suggest a net sequestration of approximately 5 kg C/kg N
- Magnani *et al.* (2007), reported a strong correlation between mean lifetime net ecosystem production (NEP) and N deposition, implying a net sequestration near 475 kg C/kg N

➔ **Range of 5-500 kg C/kg N**

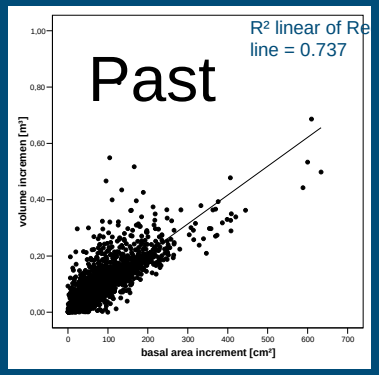
Aim study

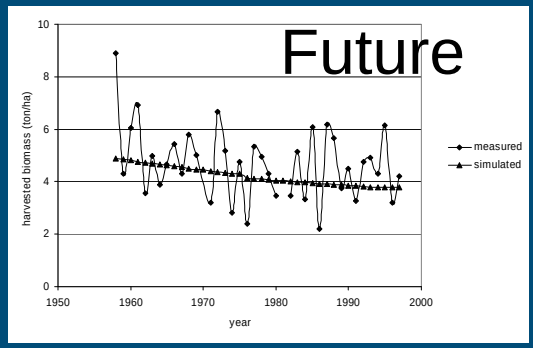
Evaluate the effect of changes in temperature and N deposition on carbon seqestration by:

- Statistical models, to explain past forest growth
  - (i) *Individual tree-growth model*
  - (ii) *Stand-based model*
  - Using stand growth data on Intensive Monitoring plots (1995-2000)
- Process model, to evaluate future analysis
  - *(iii) Integrated soil-forest model*
  - Using future changes (1990-2070) in climate, CO_2 and N deposition

Methods

Data and Models used

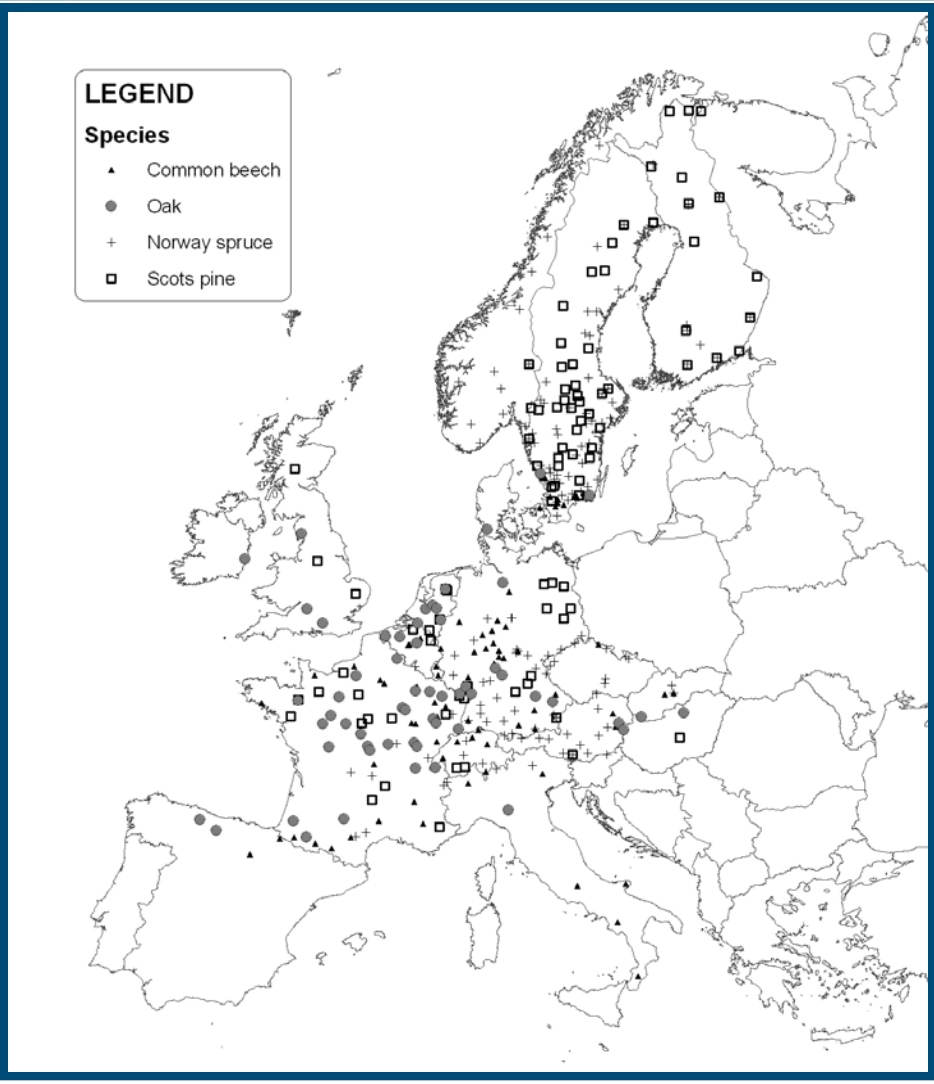




ALTERRA
WAGENINGEN UR

Monitoring data set used

- Individual tree growth model:
  - Trees must be identifiable
  - Growth measurements (dbh) (2-times)
  - Main species (Norway spruce, Scots pine, beech, oak)
- Stand level model:
  - +/- even-aged stands
  - At least 70% of main species
  - Growth measurements (dbh) (2-times)
  - Tree height measurement (1-time)
- Process Model:
  - Calibration
  - Validation



Tree level model

- **Basal area increment** (BAI) of each individual tree as responding growth factor
- **Diameter at breast height**, dbh), **tree competition** (basal area of larger trees and stand density index), **site factors** (soil C/N ratio, temperature) as influencing site parameters.
- **Environmental factors** (temperature change compared to long-term average, N and S deposition) as environmental parameters.
- **Multi-factor analysis** to asses the site factor and environmental influence

Stand level model

- **Stand height** and **stand age** and various yield tables from the 1950-1970s or expert judgement to determine site index (growth potential)
- Calculate **expected growth** per species using site index, stand age and stand density
- Compare **actual** 1995-2000 growth with **expected** growth at plot level
- Relate **differences** between **expected** and **actual growth** to changes in **N deposition** and **temperature**

Integrated soil-water-forest model

- An Integrated soil, water and forest model (SMART-WATBAL-SUMO)
  - Calibration: at the sites using measured soil solution data (only few sites in southern Europe).
  - Validation: Computed growth was compared with measured growth
- Scenario analysis for projections 1990-2070
  - N deposition, temperature, precipitation and CO_2
- Evaluation
  - Comparison of results to a reference scenario
  - Constant CO_2 concentration and nitrogen deposition (data of 1990) while repeating the temperature and precipitation between 1960 and 1990 up to 2070

Results Individual Tree Model

Multivariate regression results at tree level indicating the relative change in stem volume growth per unit change in influencing factor. Note: - implies that the effect was insignificant ($p>0.05$).

Tree species	BAL[1]	SDI	C/Nsoil[2]	N dep	Temp[3]	Temp change
Norway spruce	-0.39	-0.00056	-0.023	**0.013**	-	-
Scots pine	-0.29	-0.00066	-	**0.015**	0.053	-
Common beech	-0.16	-	-	**0.012**	-	0.064
Oak	-0.38	-0.00062	-	**0.013**	0.080	-

[1]BAL is basal area of larger trees (m^2 ha^{-1}), [2] C/N soil is the C/N ratio of the mineral topsoil (0-30cm) and [3]Temp is Avg temperature 1993-2000 (^0C). '-' not significant at $p < 0.05$.

Pseudo R^2 (log-likelihood): 0.33-0.44

ALTERRA
WAGENINGEN UR

Results Individual Tree Model

- N increase corresponds to an increase in basal area increment of 1.2 - 1.5 %
- 20 - 25 kg C sequestration per kg N deposition (depending on species)
- An increase in temperature shows a significant positive effect on growth (except for Norway spruce)
- Competition shows up as an important parameter in all analyses

Results Stand Growth Model

Regression results for stand level model for Norway spruce and Scots Pine

Tree species	Site prod[1]	Age[2]	SDI[3]	N dep[4]	Drought[5]	Temp change[6]
All plots						
Norway spruce	0.054	-0.005	-	**0.020**[7]	-	**0.524**
Scots pine	-	-0.017	-	**0.010**	-0.0032	**-**
Sensitive plots						
Norway spruce	0.039	-0.004	-	**0.022**	-	**0.32**
Scots pine	-	-0.017	0.001	**0.013**	-0.002	**-**

[1] *Site prod* : site productivity (m^3/ha/year)
[2] *Age* is stand age (yr), [3]
[3] *SDI* = stand density index (indexed number of trees/ha), [4]
[3] *Ndep* is total N deposition (kg/ha/yr), [5]
[3] *Drought* is a variable describing drought given as a relative value (in %) to the normal (30 years me
[5] *Temp change* is the temperature difference during the growing period compared with the 30-year av
'-' not significant at p <0.05.

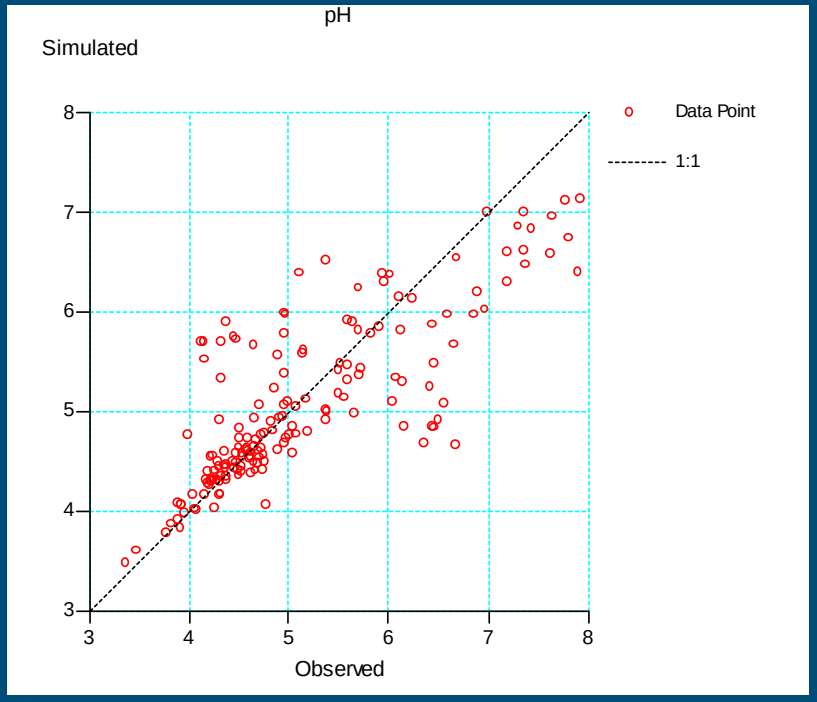
% Variance accounted for: 18 – 39%

ALTERRA
WAGENINGEN UR

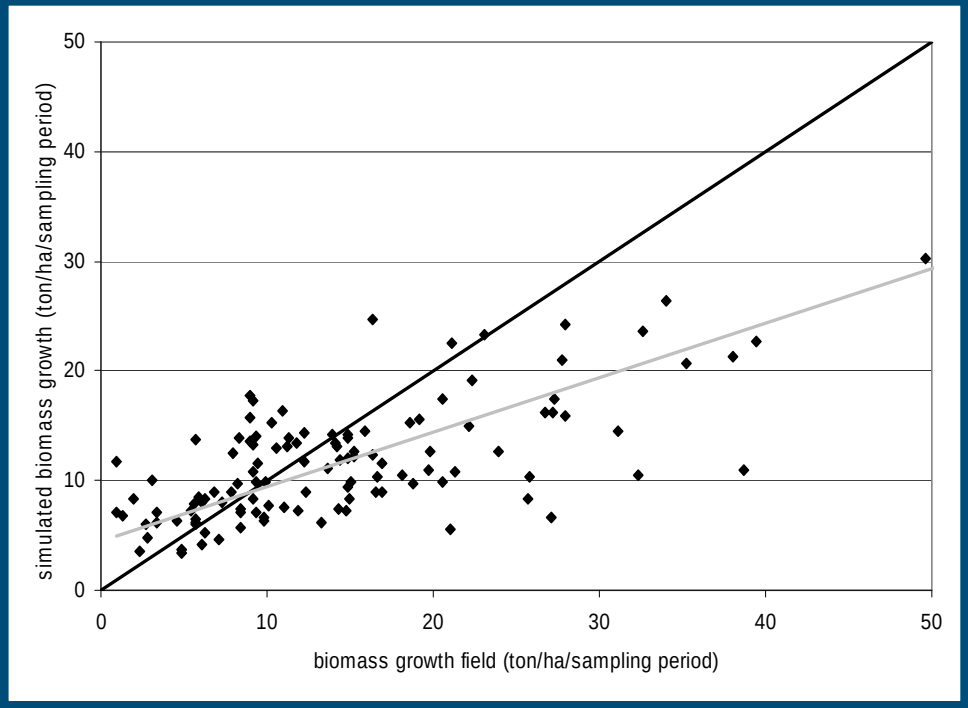
Results Stand Growth Model

- N increase corresponds to an increase in basal area increment of 1 - 2.2 %
- 16 - 25 kg C sequestration per kg N deposition
- An increase in temperature shows a significant positive effect on growth

Results Integrated Soil-Forest Model; validation



Measured versus modelled pH in soil solution

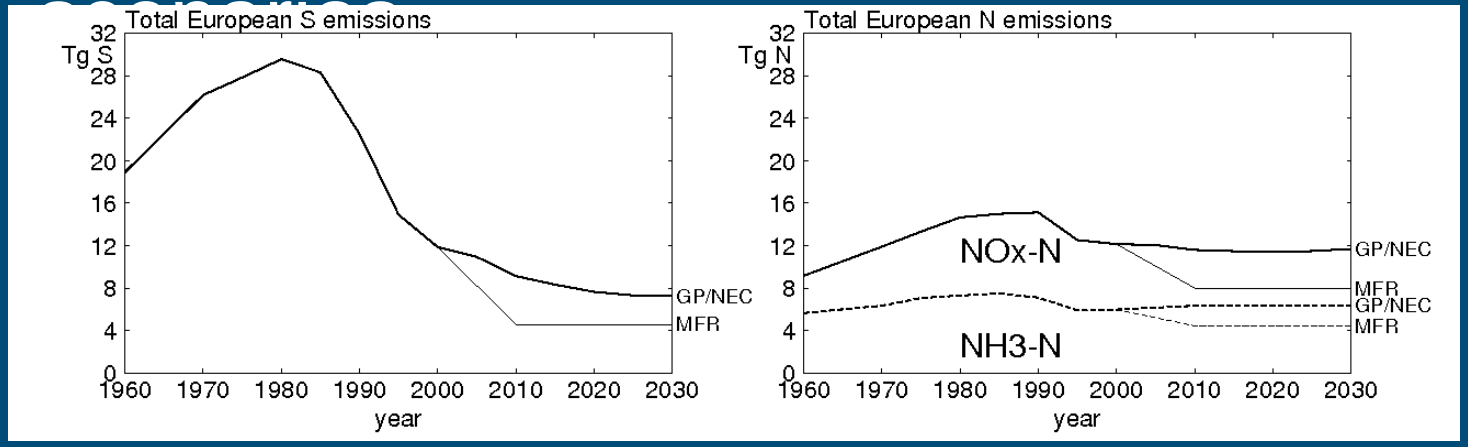


Measured versus modelled growth

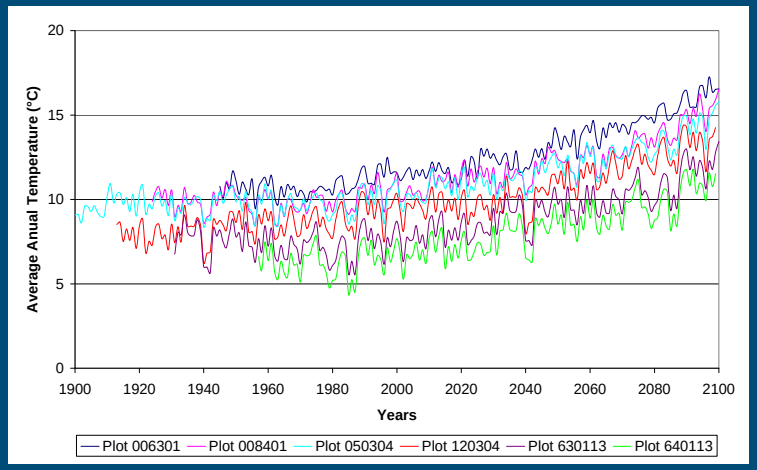
ALTERRA
WAGENINGEN UR

Results Integrated Soil-Forest Model;

S and N emission scenarios



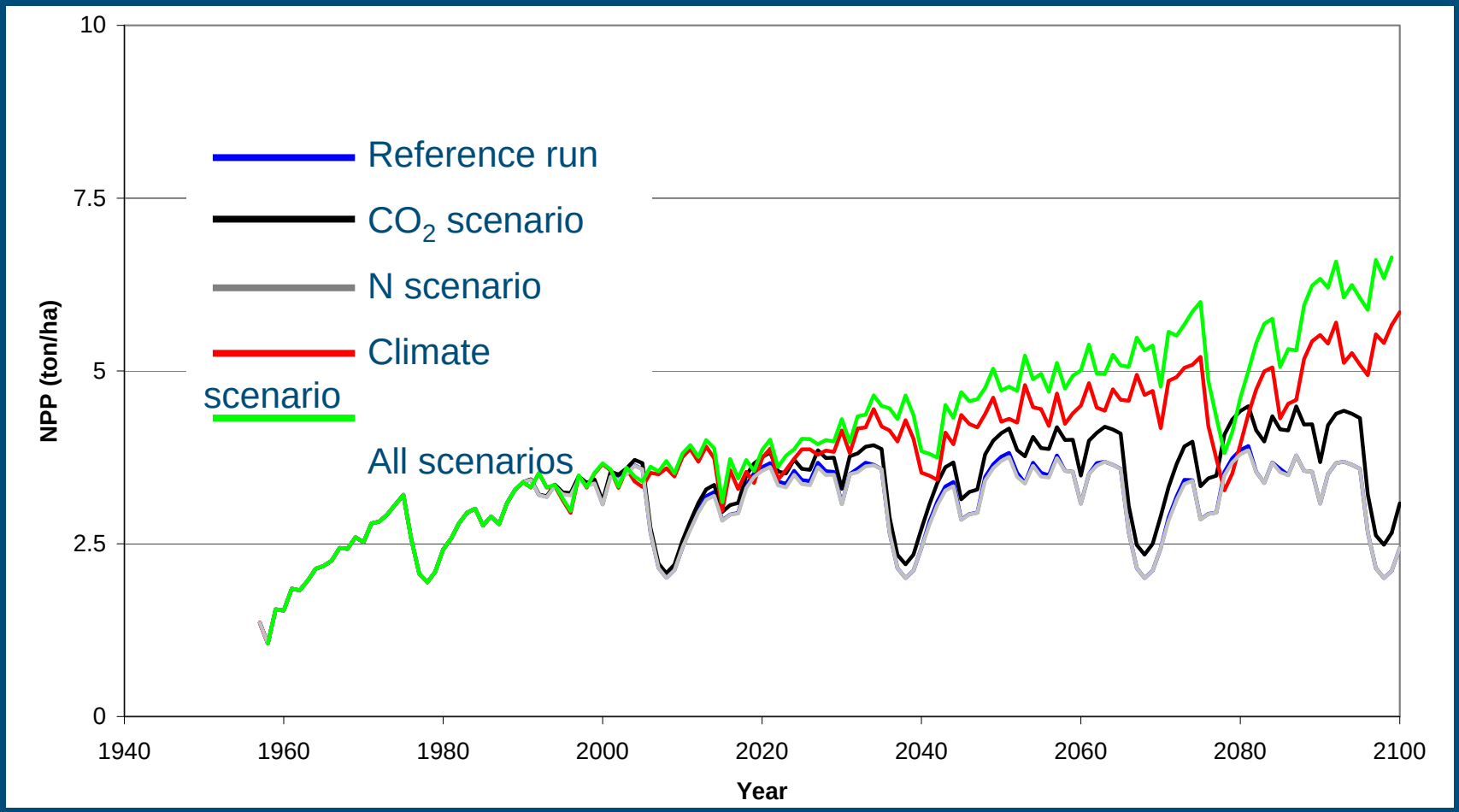
Temperature scenario for six selected plots; IPCC A2 scenario evaluated with HADCM3 m



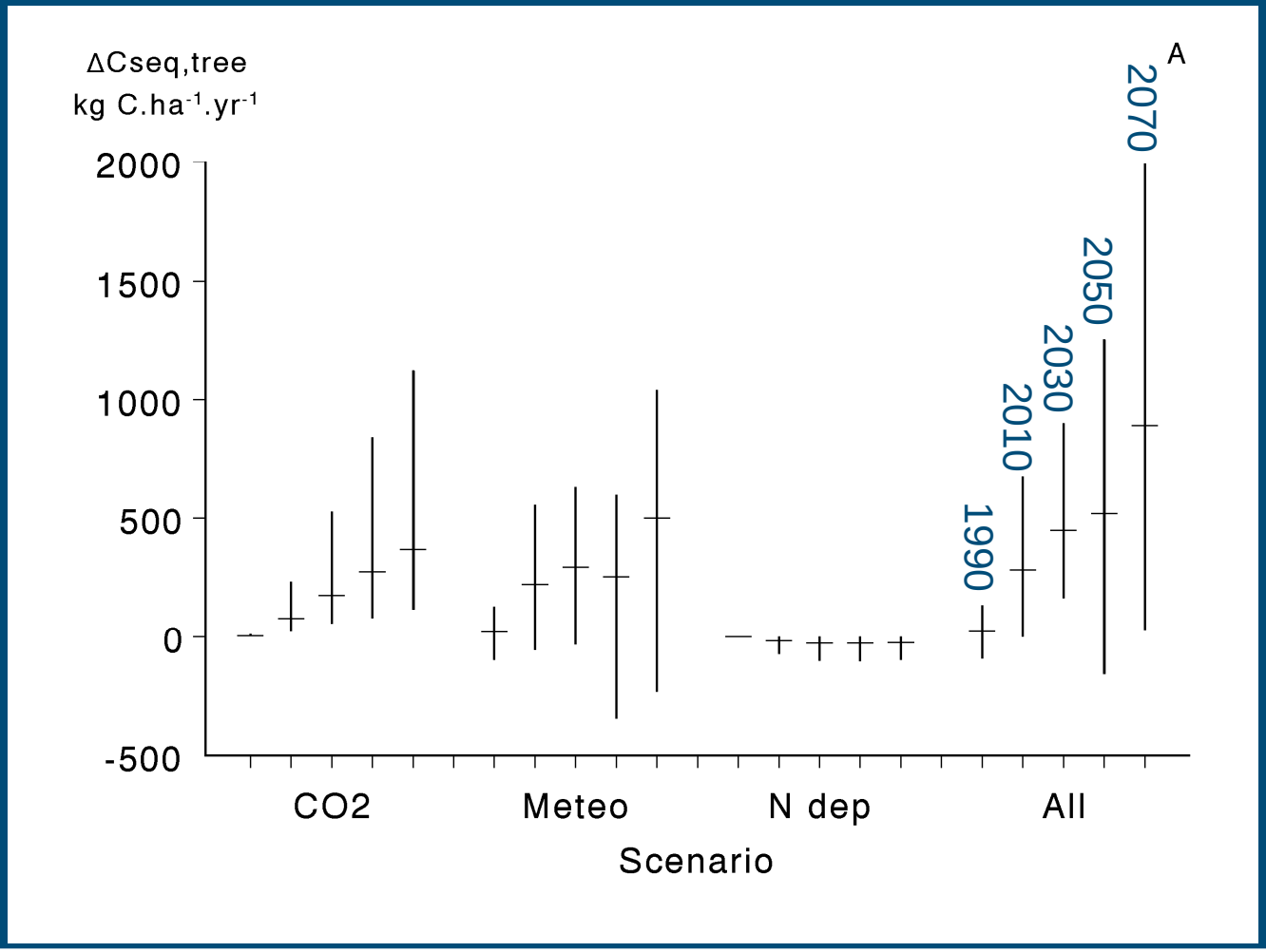
ALTERRA
WAGENINGEN UR

Results Integrated Soil-Forest Model; effects on NP

Effect of scenario on NPP for Fagus sylvatica in Central Europe

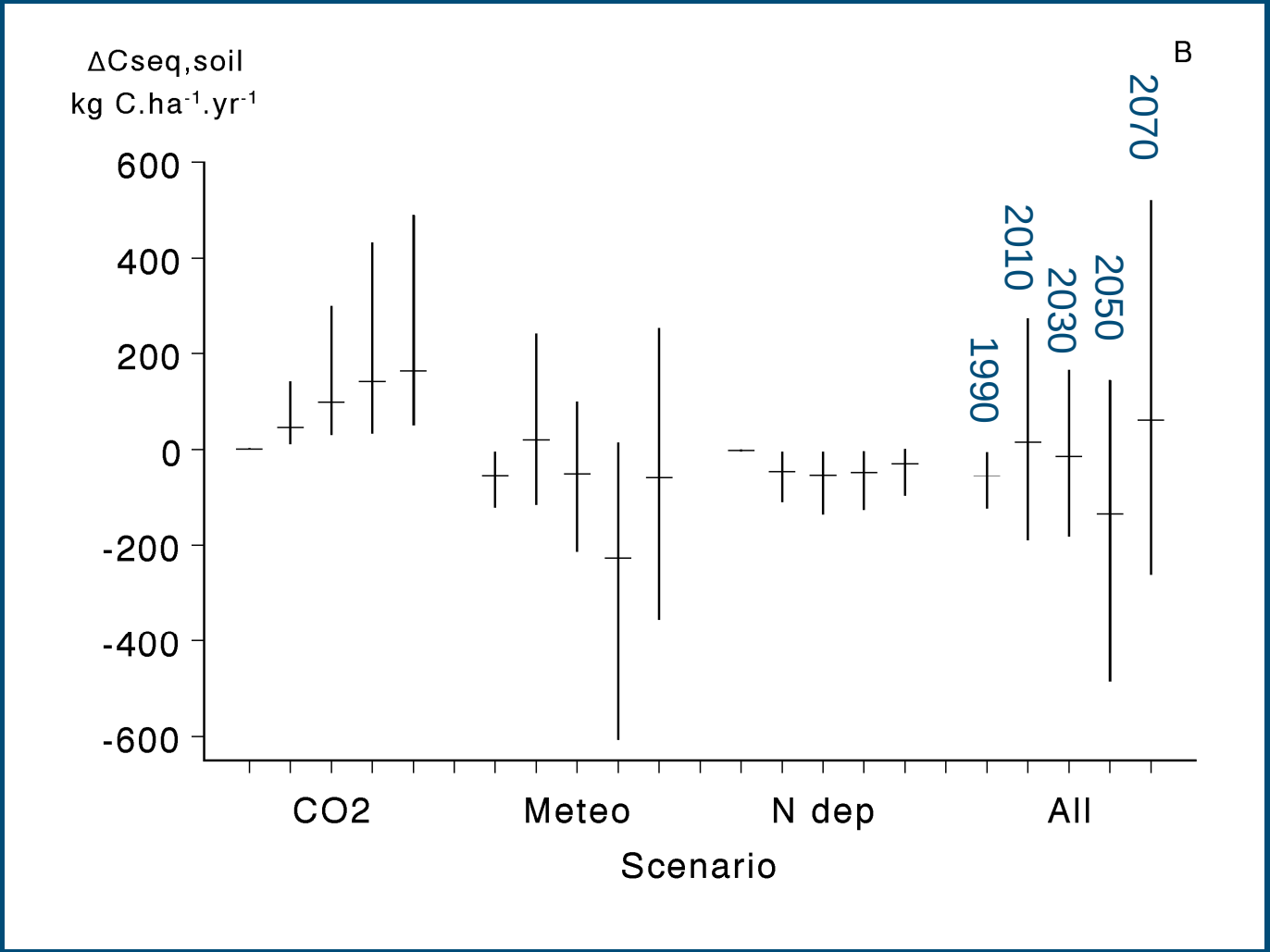


Results Integrated Soil-Forest Model; effects on NPP



ALTERRA
WAGENINGEN UR

Results Integrated Soil-Forest Model; effects on C-seq soil



ALTERRA
WAGENINGEN UR

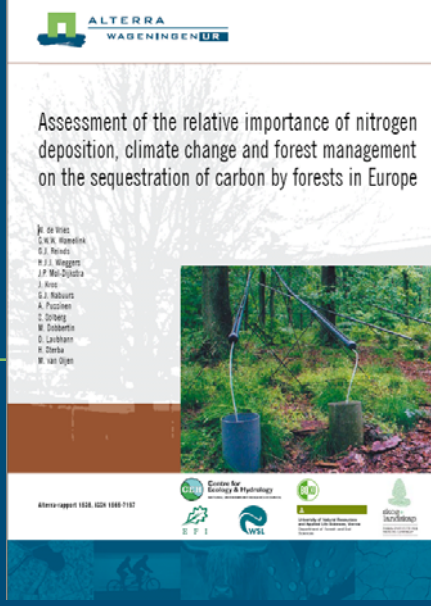
Results Process Model

- 3 – 13 kg C seq per kg N deposition in biomass (NPP)
- 5 – 11 kg C seq per kg N deposition in soil
- 7 - 25 kg C seq per kg N deposition in ecosystem (NEP)

Conclusions

- All models show positive effects of increase in temperature and N deposition on growth
- The results of the various studies are all well in agreement and show that the range in above ground accumulation of carbon in forests is generally within 15 - 30 kg C/kg N
- Scenario studies:
  - Future changes in NPP are related to climate change since the small decline in N deposition does not reduce growth according to the model
  - Results are uncertain as there is no perfect match between model and measurements
  - Results are not valid for southern Europe due to lack of verification plots
- Continued monitoring could strengthen these types of studies through larger data sets and repetitive measurements

Thank You!



- Common Report (Alterra Report 1538):
  - http://www2.alterra.wur.nl/Webdocs/PDFFiles/Alterrarapporten/AlterraRapport1538.pdf
- Special Issue In Forest Ecology and Management (in review)

ALTERRA
WAGENINGEN UR