Forest stand modelling: Achievements and future challenges

Annikki Mäkelä

Potsdam 27 February 2019

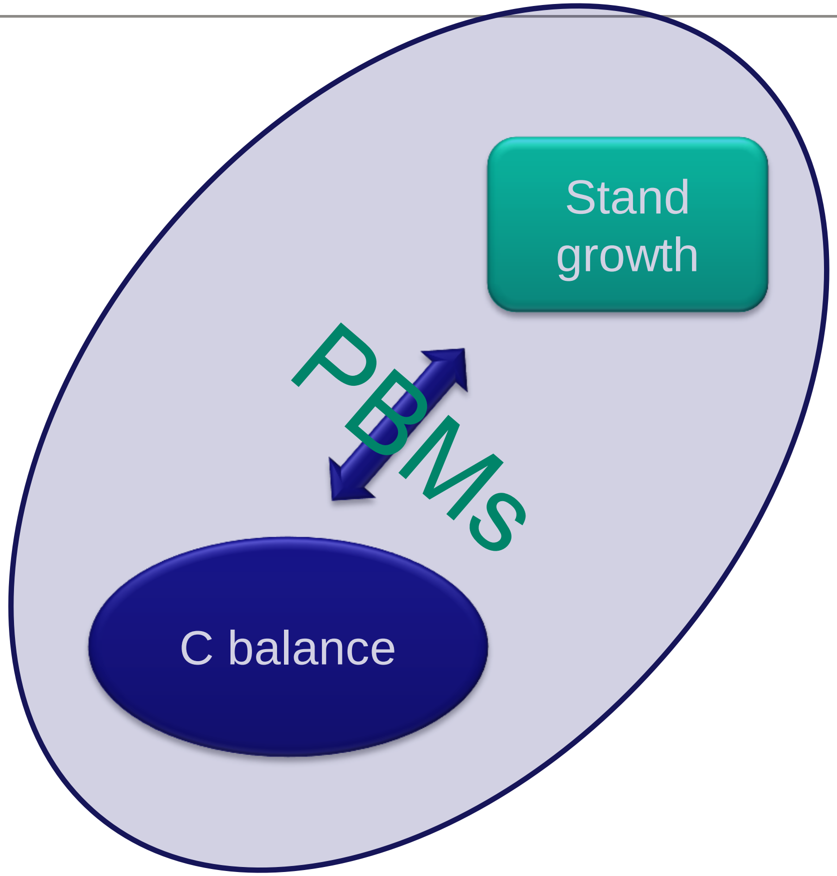
HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

Forest stand models – the beginnings

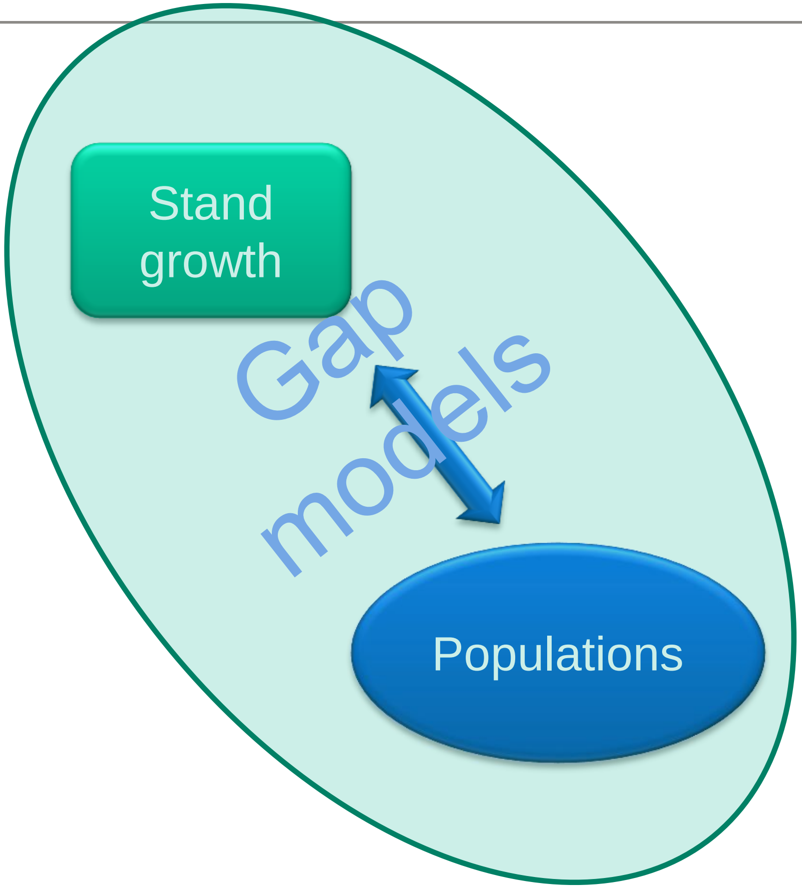
- Rapid model development phase 1970s – 1990s

- Resulted in families of models on the basis of
  - purpose
  - drivers
  - scale

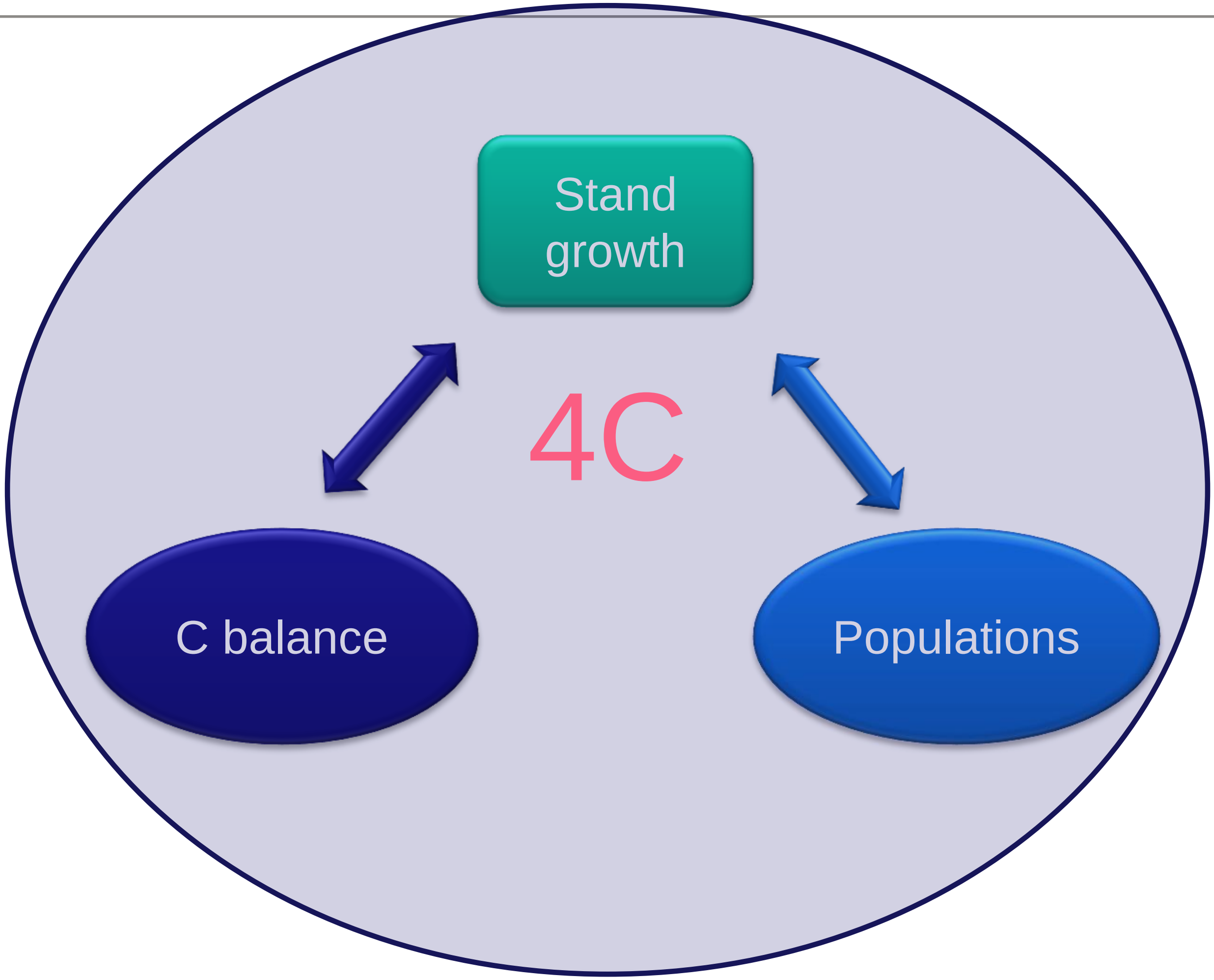
Major model families



Major model families



Major model families



Combining carbon balance and population structure

Tree Physiology 20, 357–365

Volume growth and survival graphs: a method for evaluating process-based forest growth models

RISTO SIEVÄNEN,[1] MARCUS LINDNER,[2] ANNIKKI MÄKELÄ[3] and PETRA LASCH[2]

[1] *Vantaa Research Centre, Finnish Forest Research Institute, Vantaa, Finland*

[2] *Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany*

[3] *Department of Forest Ecology, P.O. Box 24 (Unioninkatu 40) FIN-00014, University of Helsinki, Helsinki, Finland*

Received October 22, 1998

Summary We investigated the relationships within forest stands between tree size and (a) stem volume growth rate and (b) risk of mortality for individual trees. Values of both *x* and *y* variables were plotted relative to the the largest value in the stand. We refer to the resultant presentations as relative volume growth and relative survival graphs (VGSs). A pair of VGSs can be produced readily from an individual-tree growth model.

ciple, every simulation model should be validat applied. Evaluation of PBMs is not a trivial t because suitable validation data are often difficu

Mathematical methods are available that aid model properties with respect to data, e.g., sensit (Miller 1974, Dale et al. 1988) and Monte Ca 1996) methods. Despite the applicability of thes

Potsdam
1998

Tree Physiology 20, 347–355

Application of volume growth and survival graphs in the evaluation of four process-based forest growth models

ANNIKKI MÄKELÄ,[1] RISTO SIEVÄNEN,[2] MARCUS LINDNER[3] and PETRA LASCH[3]

[1] *Department of Forest Ecology, P.O. Box 24 (Unioninkatu 40), FIN-00014, University of Helsinki, Helsinki, Finland*

[2] *Finnish Forest Research Institute, Vantaa Research Centre, Vantaa, Finland*

[3] *Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany*

Received October 22, 1998

Summary Volume growth and survival (VGS) graphs, which show volume growth rate and risk of mortality for individual trees (or tree size classes), have been proposed as a tool for assessing the validity of models that describe the development over time of tree size distributions within forest stands. We examined the utility of the VGS method in evaluating four

trees at different positions in the stand have seldom been tested.

In one of the few tests focusing on individual trees, Korol et al. (1996) evaluated the performance of the model TREE-BGC against field measurements. They compared size distributions and growth of individual trees after 20 simula-

Forest stand models – fine tuning

- Fine tuning and application phase 2000 –

- Basic structures established

- Model development towards applications in sustainable forest management
  - Climate change impacts and adaptation
  - Biodiversity
  - Ecosystem services in general

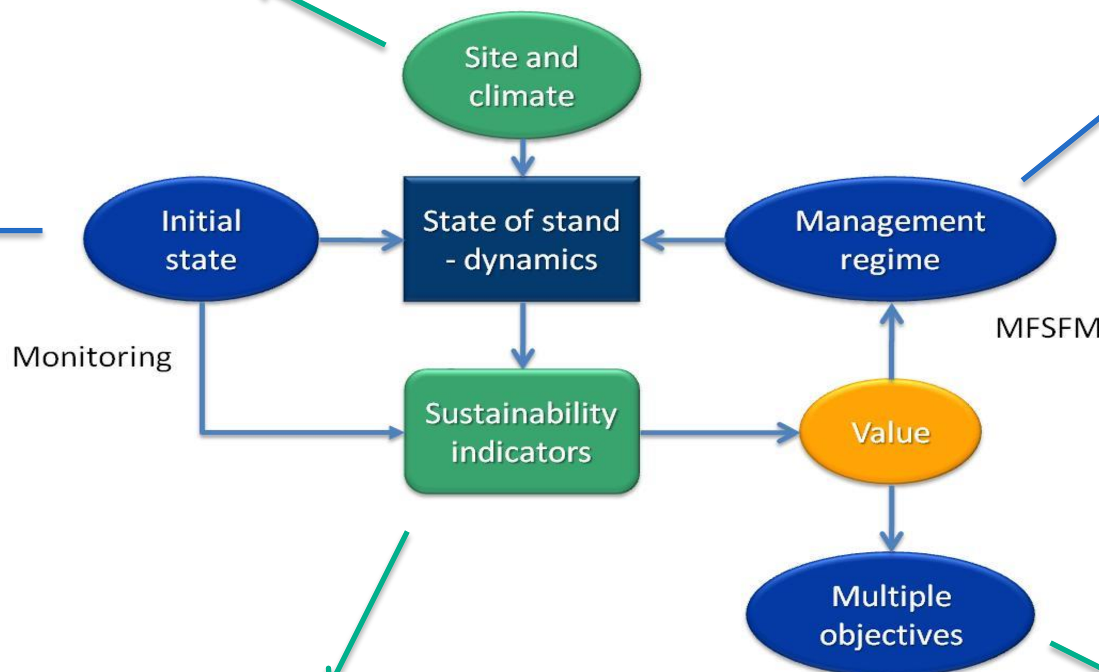
- More efficient data assimilation
  - Model testing
  - Bayesian calibration

Models for sustainability assessment

Climate-sensitive

Management-sensitive

Runs with accessible input data



Predicts physical sustainability indicators

Stand-level policy Indicators from multiobjective analysis

Mäkelä et al. 2012 Review in FORECO

CRITERION

CRITERION

4C
MODEL PROPERTIES

Criterion	Indicator	Model types
C1: Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles	Growing stock	GYM growth
Carbon cycle	Total volume	GYM
	Age structure and/or diameter distribution	GYM
	Carbon stocks	PBM carbon
	GHG emissions	PBM
C2: Maintenance of forest ecosystem health and vitality	Soil condition	BGC structure
Health and vitality	Fire hazard	Models with explicit stand structure
	Wind hazard	Models with explicit stand structure
	Pest and disease hazard	Models with explicit stand structure
	Broadleaved tree mixture is maintained	Models with explicit stand structure
	Felling and skidding damage	BGC, models of soil physics
	Water use (of forest ecosystem)	BGC
	Forest resources/growing stock	GYM soil and water
	Forest biodiversity (delayed DCP)	Biodiversity models
C3: Maintenance and encouragement of productive functions of forests (wood and non-wood)	Wood products	Wood quality models
	Non-wood products	Non-wood products models
Productive functions	Productivity of the principal forest production	GYM
	Value and quantity of marketed roundwood	GYM, wood quality wood quality
	Other productions	Non-wood products models
C4: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems	Understorey shrub diversity	Models with explicit stand structure
Biodiversity	Tree species composition/ structural diversity	Models with explicit stand structure structure
	Long-lived and cavernous trees	Models with explicit stand structure
Protection	Volume of standing and lying deadwood	Models with explicit stand structure, models of SOM
C5: Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water)	Evidence of erosion	BGC, models of soil physics soil and water
	Water quality	BGC, models of soil physics
Socioeconomic		
C6: Maintenance of other socioeconomic functions and conditions	Recreational services	Non-woody products, models with explicit stand structure

Mäkelä et al. 2012 Review in FORECO

More efficient data assimilation


Forest Ecology and Management 289 (2013) 255–268

Contents lists available at SciVerse ScienceDirect

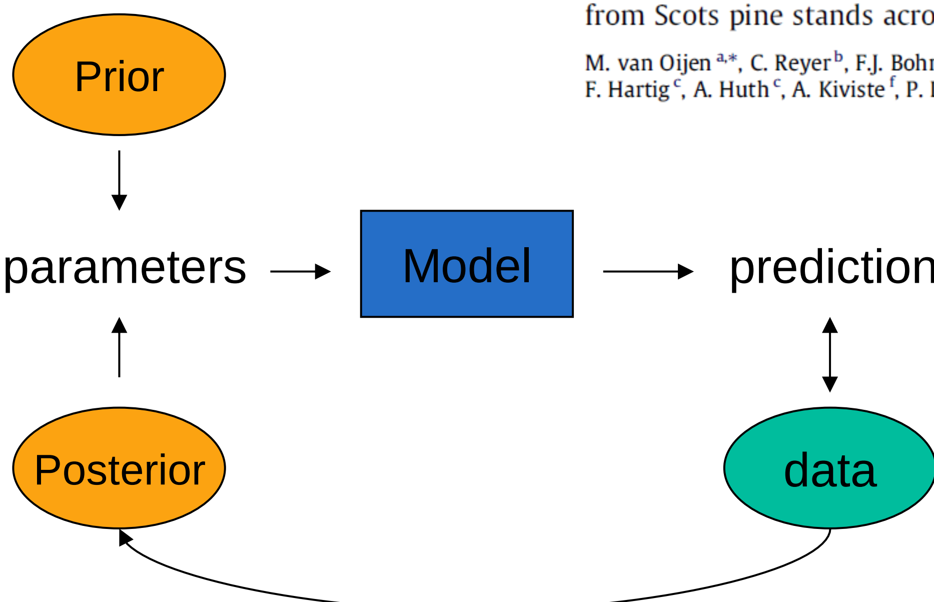
Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

ELSEVIER

Bayesian calibration, comparison and averaging of six forest models, using data from Scots pine stands across Europe

M. van Oijen [a,*], C. Reyer [b], F.J. Bohn [c], D.R. Cameron [a], G. Deckmyn [d], M. Flechsig [b], S. Härkönen [e], F. Hartig [c], A. Huth [c], A. Kiviste [f], P. Lasch [b], A. Mäkelä [g], T. Mette [h], F. Minunno [i], W. Rammer [j]



PROFOUND

Reyer et al. 2015
Minunno et al. 2019

Annals of Forest Science (2014) 71:211–225
DOI 10.1007/s13595-013-0306-8

ORIGINAL PAPER

Proj
prod
by cl

Christo
Martin

Annals of Forest Science (2016) 73:401–410
DOI 10.1007/s13595-015-0532-3

ORIGINAL PAPER

Evaluating
under

SCIENTIFIC REPORTS

OPEN

Realizing Mitigation Efficiency of European Commercial Forests by Climate Smart Forestry

Rasoul Yousefpour[1], Andrey Lessa Derci Augustynczik[1], Christopher P. O. Reyer[2], Petra Lasch-Bornn[2], Felicitas Suckow[2] & Marc Hanewinkel[1]

Received: 5 June 2017
Accepted: 15 December 2017
Published online: 10 January 2018

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

ELSEVIER

Adapting forest management to climate change in Europe: Linking perceptions to adaptive responses

Rita Sousa-Silva[a,*], Bruno Verbist[a], Ângela Lomba[b], Peter Valent[c], Monika Suškevičs[d], Olivier Picard[e], Marjanke A. Hoogstra-Klein[f], Vasile-Cosmin Cosofret[g], Laura Bouriaud[g], Quentin Ponette[h], Kris Verheyen[i], Bart Muys[a,j,*]

LETTER

Balancing
Germany

OPEN ACCESS

RECEIVED
29 November 2016

REVISED
5 March 2018

ACCEPTED FOR PUBLICATION
7 March 2018

Martin Gutsch
1 Potsdam Institu
Germany
2 Author to whom

Forest stand models – challenges

- New basic research challenges underlying ecological paradigms
- Requirements of wide spatial and temporal application challenge modelling paradigms

Some key paradigms under change

Growth

- The production ecology paradigm
- Source limitation

Soil processes

- The decomposition paradigm
- First order dynamics

Parameterisation

- The species and functional groups paradigm
- Constant group-specific parameters

The production ecology paradigm

NPP =

Photosynthesis – Respiration

Stem Growth =

(Stem allocation) x NPP

Explains well large geographical variation at monthly to annual scale

Pinus radiata growth as a function of intercepted PAR

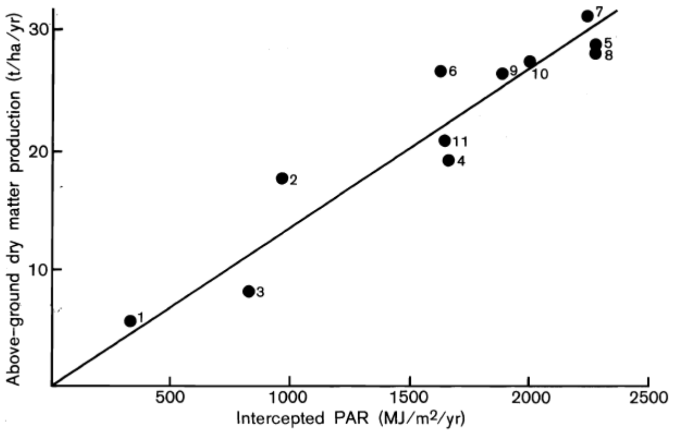


FIG. 3—Relationship between above-ground dry matter production and intercepted PAR for stands of **Pinus radiata** growing at Puruki (numbers correspond with Table 8).

Grace et al. 1987

The production ecology paradigm

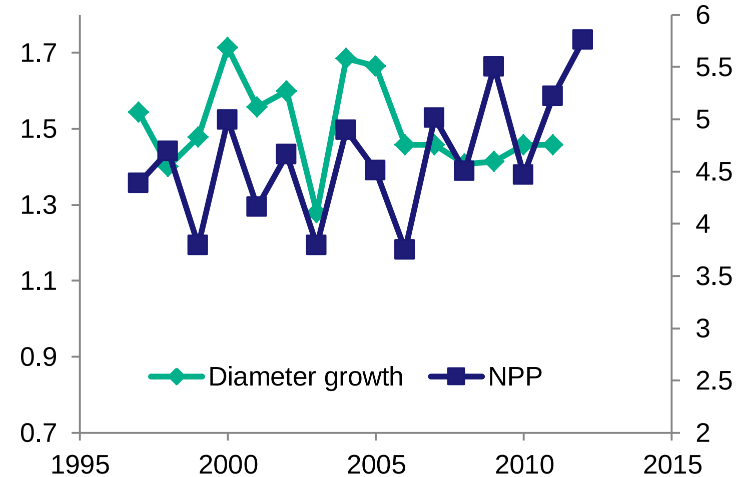
NPP =

Photosynthesis – Respiration

Stem Growth =

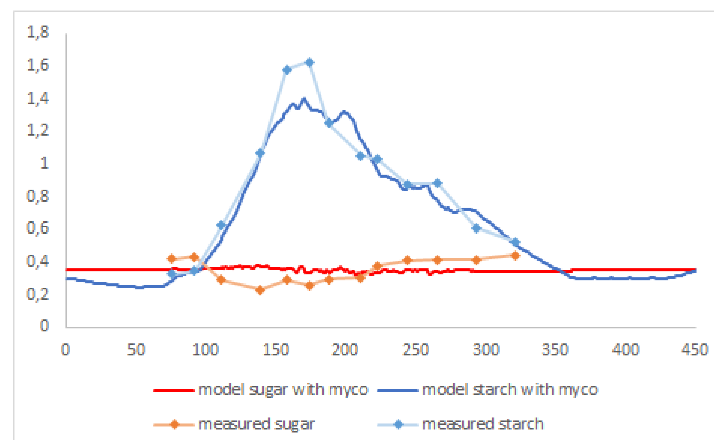
(Stem allocation) x NPP

Measurements Hyytiälä



Explains well large geographical variation

Does not do so well for year-to-year nor day-to-day variability



Schiestl-Aalto et al. 2019

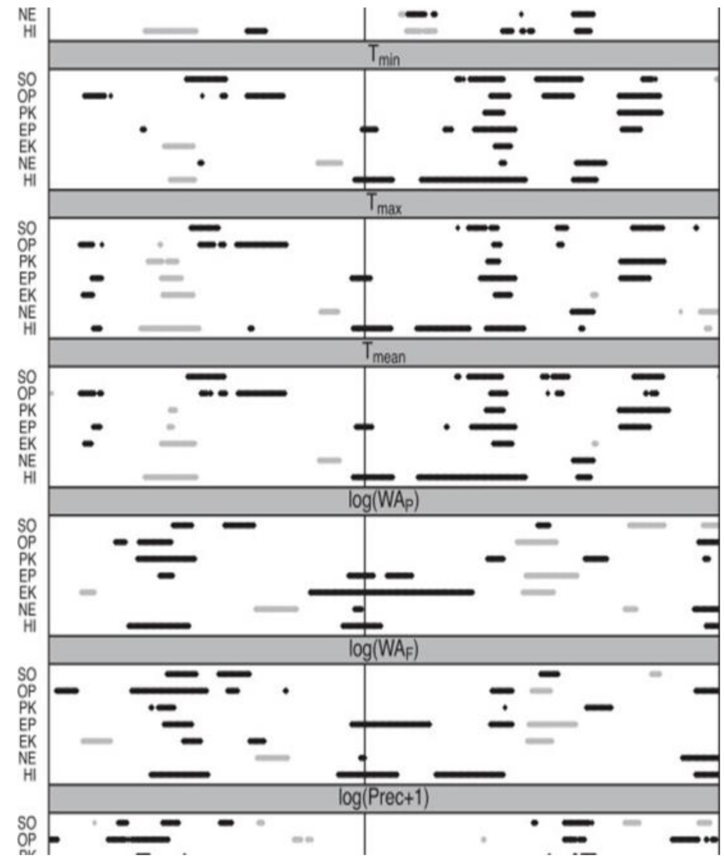
The production ecology paradigm vs Sink limitation

- Better explanation for inter-annual growth variations from
  - Temp, Precip, Soil W
  - Timing of influence
- Christian Körner 2003 J Ecol Appl

C is always abundant

Growth is limited by direct drivers

SINK LIMITATION



Henttonen et al. 2014. ***AFM***198–199: 294 - 308

The production ecology paradigm: How to reconcile sink-source interactions?

- PBMs of intra-annual growth combine environment driven phenology with C balance

  Grote 1998

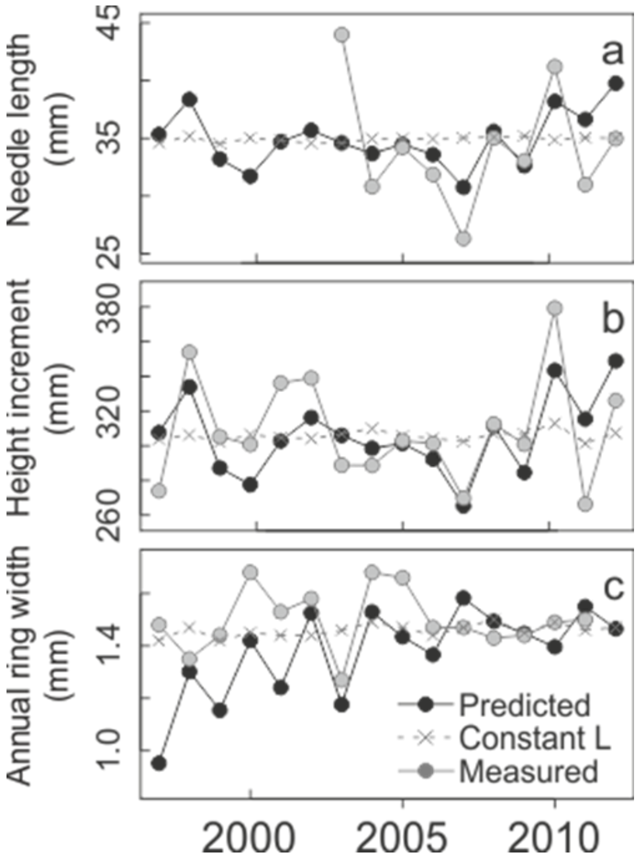
  Drew et al. 2010 JTB

  Schiestl-Aalto et al. 2015 NP

  Guillemot et al. 2017 NP

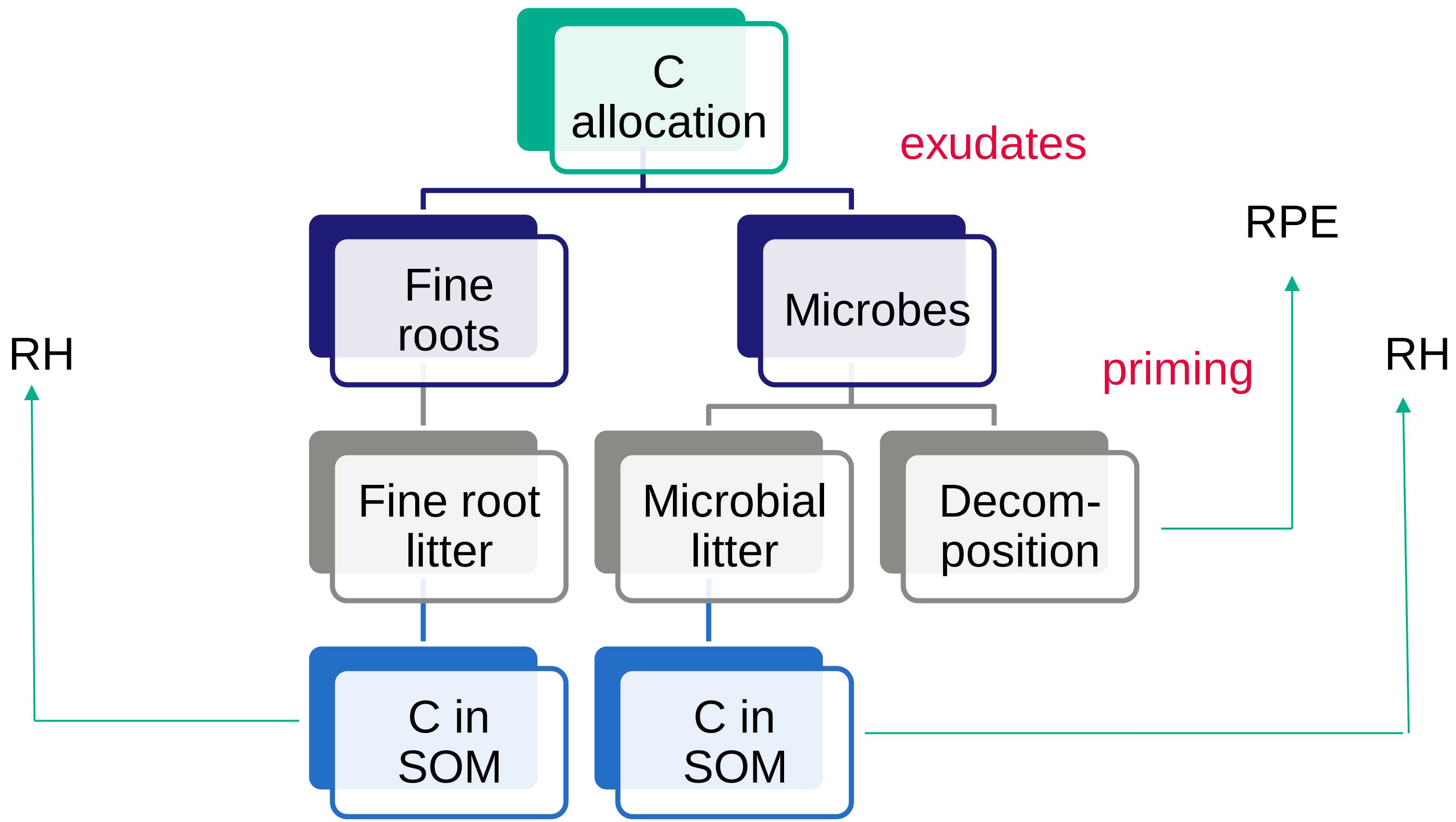
  Review: Sala et al. 2012 Tree Phys.

- Long term: Supply limitation
  Short term: Sink limitation
- Interactions & acclimation => consequences for CC impacts



Schiestl-Aalto et al. 2015 NP

The decomposition paradigm



The decomposition paradigm
Evidence on priming and exudates

- RPE observations

    La Fontaine et al. 2004 Ecology Letters

    Heinonsalo et al. 2017

- Plants gain N with exudation

    Näsholm 1998 Science, Schimel and Weintraub 2003

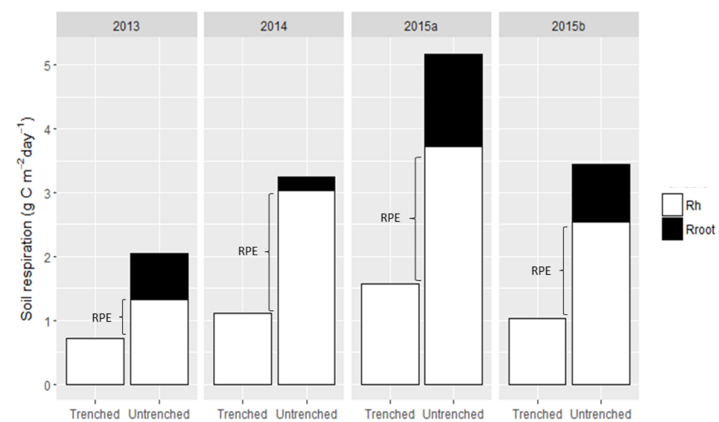
- N fertilisation enhances C accumulation in soil

    Högberg et al. 2014 Plant and Soil

- Implications on stand growth and C sequestration under climate change?

    Näsholm et al. 2013 NP

Soil respiration



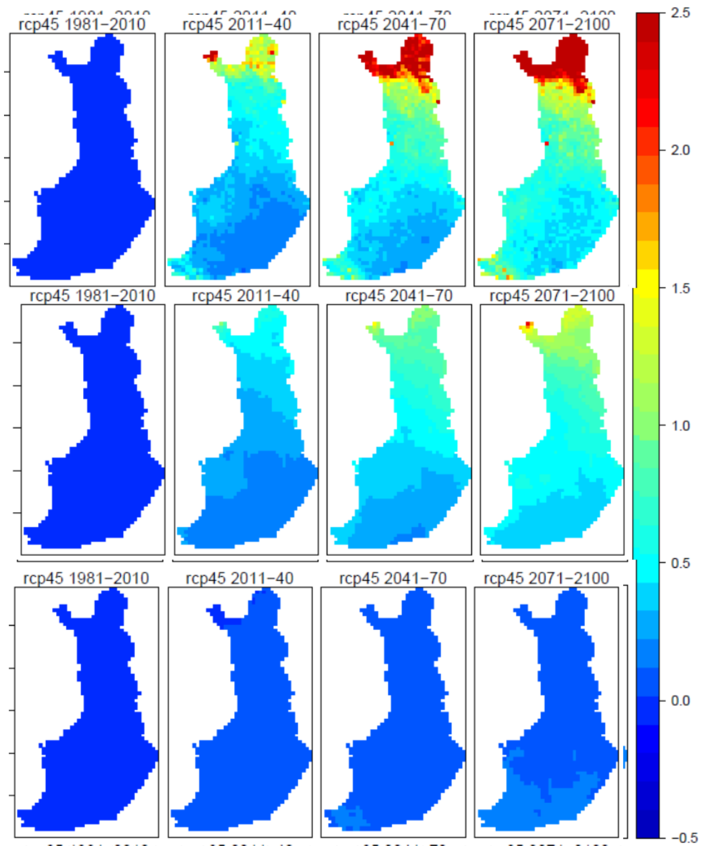
Heinonsalo et al. 2017 EGU

The decomposition paradigm
Possible implications on stand growth under climate change

Unlimited N

High N

Low N



Time under climate change
Mäkelä et al. 2017 IUFRO

- N availability matters for growth
- Soil N-C interactions matter for N release and soil C sequestration
- How would these change if exudates and priming are accounted for?

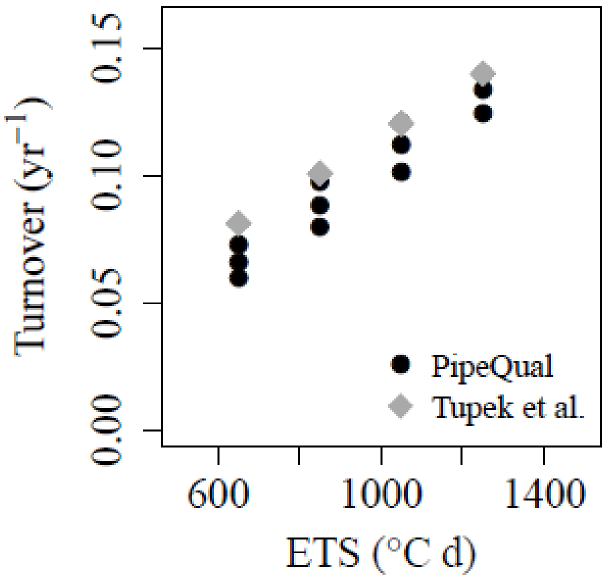
The species and functional groups paradigm: Replace with traits

- Some traits quantified as species-specific parameters actually vary with environment
  - SLA
  - Specific respiration rates
  - Turnover rates
  - etc…

- Evolutionary acclimation => no ”space-for-time” substitution

- ”SPECIES” => ”COLLECTION OF TRAITS”
  - Derive all traits and their combinations on a physiological basis
  - Modified by environment

New generation DVMs https://ar17.iiasa.ac.at/dynamic-vegetation/ ; Kunstler et al. 2016 Nature



Tupek et al. 2014 BER
Mäkelä et al. 2016 FORECO

Large-scale spatial and temporal applications challenge reductionist modelling paradigm

- Modellers tend to find lack of realism in models and predictions

- Solving this by adding more processes and inputs leads to
  - Increased data requirements
  - Decreased trasparercy
  - Increased uncertainty

- Especially in DGVMs!

Spatial and temporal applications challenge modelling paradigms Eco-evolutionary models

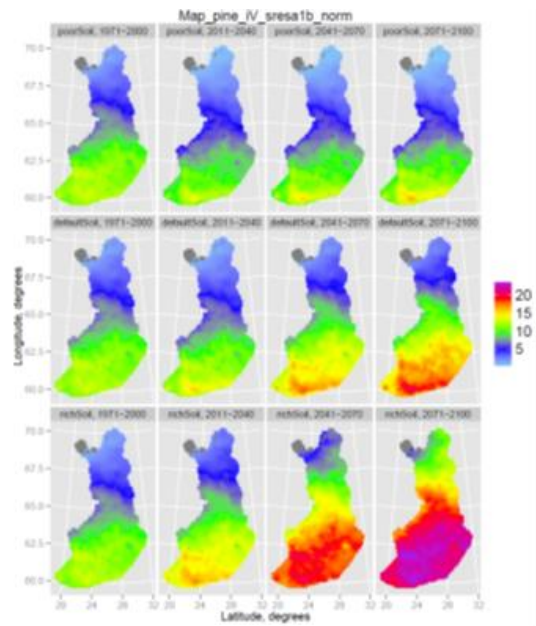
- Process-based models with evolutionary optimisation
- Optimise processes with trade-offs in new environments

  Reviews: Mäkelä et al. 2000 SF, Dewar et al. 2009 BioScience, Franklin et al. 2012 Tree Phys

- Stomatal control (Prentice et al. 2015)
- Carbon – nitrogen coallocation (Valentine & Mäkelä 2012 NP)
- Plant-microbe relationships and priming (Franklin et al. 2014)

- Trait-based models?
- Sink-source balance?

Optimal co-allocation of N and C at different sites under climate change



Mäkelä et al. 2014 AGU

Summary

- Rapid model development 1970s – 1990s resulted in a number of stand growth models with established & convergent theoretical basis
- 2000s have seen an increasing number of model testing, fine-tuning and use for applications in sustainable forest management
- The 4C model is exeptional among stand models in its wide scope and applicability as well as the wide efforts in model parameterisation and validation
- New challenges of model development are emerging from both new basic research in trees and soils, as well as modelling methods
- The rigorous modelling work up to now provides a sound basis for further development responding to the challenges

Petra and Felicitas
Thank you for your collaboration and insights

All the best for the future!