Forest stand modelling: Achievements and future challenges

Annikki Mäkelä
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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

- Stand growth
- C balance
- PBMS
Major model families
Major model families

4C

Stand growth

C balance

Populations
Combining carbon balance and population structure

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

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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, every simulation model should be validated applied. Evaluation of PFBMs is not a trivial task because suitable validation data are often difficult to come by. Mathematical methods are available that aid model properties with respect to data, e.g., sensitivity analysis (Miller 1974, Dale et al. 1988) and Monte Carlo methods. Despite the applicability of these methods, validation of PFBMs is not a straightforward process.

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

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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 process-based forest growth models (PFBMs) from field measurements. The models examined were the Swedish Forest Category System (SFCS), the Potsdam-Baustein Growth and Yield Model (PBGYM), the Pennsylvania State University (PSU) model, and the Finnish Forest Research Institute (FFRI) model. The VGS method was found to be a useful tool for evaluating the performance of the models, particularly in identifying areas where the models may be in need of further refinement.
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

- Initial state
- Site and climate
- State of stand - dynamics
- Sustainability indicators

Management-sensitive

- Management regime
- Value
- Multiple objectives

Runs with accessible input data

Monitoring

Mäkelä et al. 2012 Review in FORECO

Predicts physical sustainability indicators

Stand-level policy indicators from multiobjective analysis
<table>
<thead>
<tr>
<th>CRITERION</th>
<th>Indicator</th>
<th>MODEL PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1: Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles</td>
<td>Growing stock, Total volume, Age structure and/or diameter distribution, Carbon stocks, GHG emissions</td>
<td>4C growth, carbon, structure</td>
</tr>
<tr>
<td>C2: Maintenance of forest ecosystem health and vitality</td>
<td>Soil condition, Fire hazard, Wind hazard, Pest and disease hazard, Broadleaved tree mixture is maintained, Felling and skidding damage, Water use (of forest ecosystem), Forest resources/growing stock, Forest biodiversity (delayed DCP)</td>
<td>4C soil and water, wood quality, structure</td>
</tr>
<tr>
<td>C3: Maintenance and encouragement of productive functions of forests (wood and non-wood)</td>
<td>Wood products, Non-wood products, Productivity of the principal forest production, Value and quantity of marketed roundwood, Other productions</td>
<td>4C socioeconomic, protection, structure</td>
</tr>
<tr>
<td>C4: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems</td>
<td>Understoreey shrub diversity, Tree species composition/structural diversity, Long-lived and cavernous trees, Volume of standing and lying deadwood, Evidence of erosion, Water quality, Recreational services</td>
<td>4C biodiversity, protection, soil and water</td>
</tr>
<tr>
<td>C5: Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water)</td>
<td>Evidence of erosion, Water quality, Recreational services</td>
<td>4C soil and water, protection, socioeconomic</td>
</tr>
<tr>
<td>C6: Maintenance of other socioeconomic functions and conditions</td>
<td></td>
<td>4C socioeconomic, protection, protection</td>
</tr>
</tbody>
</table>

Mäkelä et al. 2012 Review in FORECO
More efficient data assimilation

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


PROFOUND

Reyer et al. 2015
Minunno et al. 2019
Realizing Mitigation Efficiency of European Commercial Forests by Climate Smart Forestry

Rasoull Yousefpour, Andrey Lessa Derci Augustynczik, Christopher P. O. Reyen, Petra Lasch-Born, Felicitas Suckow & Marc Hanewinkel

Forest Policy and Economics

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

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

Rita Sousa-Silva, Bruno Verbis, Ángela Lomba, Peter Valenta, Monika Sušević, Olivier Picard, Marjanke A. Hoogstra-Klein, Vasile-Cosmin Cosofret, Laura Bouriaud, Quentin Ponette, Kris Verheyen, Bart Muys
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

\[ \text{NPP} = \text{Photosynthesis} - \text{Respiration} \]

\[ \text{Stem Growth} = (\text{Stem allocation}) \times \text{NPP} \]

Explains well large geographical variation at monthly to annual scale

**Pinus radiata growth as a function of intercepted PAR**

**Grace et al. 1987**
NPP = Photosynthesis – Respiration
Stem Growth = (Stem allocation) x NPP

Explains well large geographical variation

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

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

- Long term: Supply limitation
  Short term: Sink limitation

- Interactions & acclimation => consequences for CC impacts

Schiestl-Aalto et al. 2015 NP
The decomposition paradigm

- C allocation
  - Fine roots
    - Fine root litter
    - C in SOM
  - Microbes
    - Microbial litter
    - Decomposition
    - C in SOM
  - Priming
  - Exudates
  - RPE
  - RH
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

- 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?

Time under climate change
Mäkelä et al. 2017 IUFRO
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/](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 transparency
  - 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


- Stomatal control (Prentice et al. 2015)
- Carbon – nitrogen co-allocation (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 exceptional 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!