“Models of tree and stand dynamics”: a differential journey through forest modelling

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Models of trees and stands exist since many decades, what nowadays has changed is our focus towards integrated forest ecosystem functioning. Managing forests in the 21st century requires efforts that go beyond empiricism. Anikki Mäkelä and Harry T. Valentine’s new book “Models of tree and stand dynamics” (Springer Nature, Cham, 2020) shows the state-of-art for knowledge applied within forest models with useful practical applications. It is a textbook for graduates and scientists interested in process-based models of stand dynamics, growth and forest management. Models represent valuable tools for tackling issues like ecosystem carbon sequestration, helping us understand the economic implications of silvicultural interventions and providing insights on the impacts of climate change on forests. The textbook is a compendium of applied research that non-pure mathematicians can understand, interiorize and take advantage of for getting precious knowledge on forest functioning.

Keywords: Forest Modelling, Carbon Balance, Forest Management, Climate Change, Forest Ecology

Forests play a relevant role in the global carbon cycle and this mitigation potential – that lies in the accumulated stock of forest ecosystem carbon – has dynamics we either ignore or we are not able to predict completely right now. Could we forecast forest productivity on large geographical areas, under several climate change scenarios? Will forests react to changing environmental conditions? If so, how?

If these questions sound rather familiar, it seems we are aware about the key role of forests and what the challenges in managing forests in the 21st century are. What some might not know, is that none of these issues could ever be faced without models.

Anikki Mäkelä and Harry T. Valentine’s new book represents a gentle introduction to the modelling of forest growth based on ecological theory; besides, it is formulated to be sufficiently clear and sharp lending into practical applications. “Models of Tree and Stand Dynamics” is a sound-based textbook that addresses both early (graduate/doctorate level) but even senior scientists, calling upon “functional” approaches in forest ecology, where particular attention is drawn by reproducing mechanistically and/or empirically eco-physiological processes. Mäkelä & Valentine’s main intent is to teach us, or refresh in some cases our blurry memory, to go beyond mathematical models per se; it shows the state-of-art trying at the same time to forecast the 21st century’s quantum leap.

This is not the first book addressing forest modelling (see Waring & Running 2007, Burkhart & Tomé 2012, Landsberg & Sands 2011), but is certainly the first one integrating an extensive documentation of theory and concepts and their translation into source codes for a prompt computer programming and testing. Thus, this is not a merely descriptive book and coherently the authors stated that the description of the plethora of existing forest models can be found elsewhere.

As a premise, the book aims at bridging the gap between empirical and process-based models using mathematical tools and numerical estimations and it perfectly does so by covering a wide range of examples with a rich set of R-codes at the end of each chapter (and including solutions, which were much appreciated). The same, the reader should not be too much concerned about sinking into complex equations, but rather the logic behind is easily comprehensible even from non-pure mathematicians. In this sense, it is more a handbook than a cookbook, because “trees and stands are complex life systems and any attempt to fully describe these systems mathematically is sure to fail”. The Mäkelä and Valentine’s book is itself the compendium of a whole career as researchers and pioneering modellers, a cradle of lectures material and applied research, from which they drew up numerous interesting and clarifying examples. The focus is immediately stated: the book mainly covers process-based models that incorporate mechanisms, hybridisation, or optimisation, singly or in combination. Yet why? Because our common understanding of stand dynamics, growth and management lacks and is generally limited by a predetermined set of empirical data which we try to rely on.

The first four chapters represent the book’s backbone for they provide a synthetic but exhaustive overview of the main concepts and theories, together with elements of carbon balance modelling applied to individual trees (individual tree models), moving then to forest stands (forest stand

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models). A first insight of a real (adapted) tree dynamics model, as synthesis from “pipe-model” (Shinozaki et al. 1964a, Shi
nozaki et al. 1964b) and carbon-balance theory, is firstly presented in chapter 5, along with the main allocation rules by
which the carbon available for growth is al
located between the components of bio-
mass (leaf, branch, stem, coarse root, and
fine root). Chapter 6 deals with individual
tree and stand-level competition thus fo-
cusing on the challenging issue of resource
limitation to total growth and productivity.
Applications of evolutionary optimisation to
tree structure and consequent carbon
allocation are introduced in chapter 7 alto-
gether with examples of models that use
this approach to derive plant structure and
carbon allocation (e.g., optimal crown
structure, stem shape, etc).

How does forest production vary region-
ally? Is climate change going to increase or
decrease productivity and carbon seques-
tration? To tackle these issues, go to Chap-
ter 8 which outlines some general ideas
and overall accepted theories about linking
models with data, moving to input quantifi-
cation for model applications by introduc-
ing different methods of parameterisation
for a chosen model (Chapter 5).

Data assimilation is widely used in other
rather different fields such as engineering,
meteorology and physical oceanography... but it surprisingly happens in forestry re-
search, too. In chapter 9 some basic con-
cepts – central to model calibration – are il-
Ilustrated, followed by some examples of
Bayesian calibration as used in ecological
modelling, in comparison with conven-
tional statistical parameter calibration. Two
examples of calibrated models for predict-
ing forest growth and estimating carbon
balance are also shown. Worth noting, a
clear definition (and distinction) of what
state variables, parameters and driving (or
forcing) variables, including model hierar-
chical organizations, is provided. What
sounds obvious in the theory not often re-

Practical delivery, and this is even a

There is an increasing demand by national
forest policies to assess sustainable har-
vest levels, forest potential for climate
change mitigation, or the supply of round-
wood and biomass to the global markets
and far more. In this sense, forest model-
ling represents a valuable toolbox to in-
spect pressing issues like ecosystem car-
bon sequestration, economic implications
of different silvicultural interventions and
policies. In chapter 10 some sound applica-
tions of modelling frameworks are pro-
vided. In conclusion, we know that models
trees and stands have existed for hun-
dreds of years, but what has changed now
is our focus towards integrated ecosystem
functioning rather than single tree growth.

Quo vadis then? Forest management rec-
ommendations in many countries are
based on economical optimization studies
that assess the impact of intervention on
economic revenue (and costs), trying to
find appropriate strategies that are benefi-
cial for the stakeholders. Consequently,
standard optimization studies in forestry
are centred and based on empirical growth
models. When applied to standard man-
agement conditions, these models can of-
fer reliable and reassuring predictions, but
at the same time we must be aware that
they may lead to serious problems in opti-
misation “where a solution may be found
outside the valid range of model develop-
dment data or, if restricted, on the border
of applicability”. And that is often the case
in forest management. It is crucial to bridge
empirical and process-based data assimila-
tion methods that combine research-based
ecological measurements with standard
forestry data. Another useful application of
process-based stand-level models relies on
the possibility to estimate forest productiv-
ity in areas not subject to forest inventory.
In this case, we should also consider incor-
porating ari-borne measurement methods
such as LiDAR, drones, and different vari-
eties of satellite-derived vegetational in-
dexes to drive our models. Nevertheless,
the biggest challenge in nowadays forest
models – at any level of spatial and tempo-
rnal resolution – is to make reliable predic-
tions under climate change, especially
when not all has been (or can be) ac-
counted for. Major phenomena that de-
servе more attention here are: (i) changes
in sink-source balance due to changes in
the annual cycle, and (ii) changes in the
carbon and nitrogen (C:N) balance due to
different above-ground and below-ground
responses to environmental change (citing
Mäkelä & Valentine 2020), indeed “we
know much less about the response of for-
est soils and nutrient availability under a
changing climate”. These are our new quan-
turn leaps, hic sunt dracones.

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