Developing simulation models and decision support tools for adaptation to climate change in forest ecosystems

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Outline of presentation

➢ Introduction
  - Impacts of climate change on forests – synthesis
  - Research related to climate change
➢ Overview of forest simulation models
➢ Usefulness of models for climate change prediction
➢ Research needs and challenges
  - Integration of models
  - Adapting models
➢ Adapting a model: example using a succession model
➢ AMSIMOD
➢ Conclusion
Introduction

Climate change is expected to have impacts on forest ecosystems (IPCC 2014):

- Physiological processes
- Phenology
- Competitive interactions

- Carbon cycling
- Carbon allocation
- Tree and stand growth

- Disturbance rate (e.g., wildfire, insect outbreaks, environmental pollution)

- Wood quality (e.g., density)
- Resistance to stress

- Forest succession
- Species composition (e.g., biodiversity, species migration)
Introduction

- Research related to climate change (1):
  1) Field & growth chamber experiments (e.g., FACE)
  2) Development of statistical relationships between growth indices and climatic variables
  3) Development of simulation models
Introduction

- Research related to climate change (2):
  - Each type of research project contributes to better understanding the impacts of climate change on forest ecosystems
  - Improved understanding is essential for adaptation to climate change
  - But, adaptation needs for simulation models and decision-support tools to evaluate long-term effects of forest management practices
Introduction

➢ Many forest simulation models have been developed
➢ On-going activities are impressive and complex:
  ▪ Tree species differ in ecophysiological characteristics
  ▪ Forest types: even- & uneven-aged pure and mixed forest types
Overview of simulation models

Four general categories

➢ Statistical empirical growth and yield models
➢ Succession models: gap and landscape
➢ Process-based models (physiological and carbon cycling)
➢ Forest management models
Overview of simulation models

Statistical empirical growth and yield models

- Whole-stand and single-tree models
- Models derived from empirical knowledge
- Use of data collected in inventory surveys
- Statistical methods used to estimate their parameters
- Example of a typical equation form:
  \[ \Delta \text{dbh} \text{ (e.g., cm/year)} = f(\text{mean } bbh_t, \text{ basal area}, \text{ site index}) \]
  \[ Dbh_{t+1} = Dbh_t + \Delta \text{dbh} \]
- Examples of recognized models:
  1- Forest Vegetation Simulator (USDA Forest Service)
  2- Prognosis\textsuperscript{BC}
Overview of simulation models

Statistical empirical growth and yield models

Some limitations

➢ Their development is based on past history
➢ They do not focus on explaining the underlying mechanisms
➢ They may be accurate, but their predictions are reliable only under the conditions within which they were derived
➢ They are not very flexible to predict the development of:
  - Uneven-aged mixed stands
  - Effects of perturbations or changing conditions
Overview of simulation models

Succession models: Gap type

➢ Individual-tree models
➢ Mechanistic basis
➢ Adapted for uneven-aged mixed forest types with complex structures
➢ Simulated processes:
  ▪ Light interception
  ▪ Environmental constraints on growth
  ▪ Competition
  ▪ Tree mortality
  ▪ Treefall gaps
  ▪ Regeneration establishment
Overview of simulation models

Succession (gap) models

Environmental constraints on growth

Available light - $R(Q_h)$

Temperature - $R(DJ)$
Overview of simulation models

Succession (gap) models

Environmental constraints on growth

Site fertility - R(F)

Soil moisture - R(D)

Responsive
Intermediate
Stress-tolerant

Drought intolerant
Intermediate
Drought tolerant

Relative growth rate

Relative drought-days

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Overview of simulation models

Succession (gap) models

Examples of models:
FORET
ZELIG
ZELIG-CFS
ZELIG-TROP
FORMIND
UVAFME
Overview of simulation models

Process-based models

Contain mathematical statements that represent the ecophysiological processes that govern tree and stand growth:

- Photosynthesis, evapotranspiration
- Maintenance and growth respiration
- Mineralization
- Allocation
- Mineralization
- Absorption, adsorption
- Translocation

Climate

Water cycle

Ecological cycle

Carbon

Ecophysiological process

Nitrogen
Overview of simulation models

Process-based models

Schematic diagram of FOREST-BGC

Examples: BIOME-BGC, CBM-CFS, EFIMOD, CENTURY

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Overview of simulation models

Process-based models

Why process-based models?

Climate change

Temperature
Precipitation
Length of growing season

Climate processes

Carbon allocation

Tree and stand growth

Wood quality

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Overview of simulation models

Process-based models

Availability of growth hormones and photosynthates
Temperature
Precipitations
Length of growing season
Other effects?
# Usefulness of models for climate change prediction

<table>
<thead>
<tr>
<th>Model type</th>
<th>Modelling scope</th>
</tr>
</thead>
</table>
| Empirical Growth & yield | Limited potential:  
- Long history of development;  
- **But**: models based on past history.                                                                                           |
| Succession          | Good potential:  
- Long history of development;  
- **But**: do not contain sufficient details on the interactive effects of CO₂ increase and changes in temperature and precipitation. |
| Process-based       | Strong potential:  
- Short history of development  
- Detailed representations of ecophysiological processes  
- **But**: still in their infancy                                                                                                  |
# Usefulness of models for climate change prediction

<table>
<thead>
<tr>
<th>Model type</th>
<th>Projection time frame</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical Growth &amp; yield</td>
<td>Short-term</td>
<td>- Prediction of annual allowable cut</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Effects of silvicultural treatments</td>
</tr>
<tr>
<td>Succession</td>
<td>Short- &amp; long-term</td>
<td>Information on forest succession (e.g., Do management activities affect the long-term dynamics in such a way that undesirable succession takes place?)</td>
</tr>
<tr>
<td>Process-based</td>
<td>Long-term</td>
<td>Research &amp; information on the impacts of major disturbances</td>
</tr>
</tbody>
</table>
Research needs and challenges: Integration of models

- Hybrid models (new generation of models)?
- Combined use of different model types (1)?

Process-based models

\[\text{\uparrow}\]

Gap models

\[\text{\downarrow}\]

Empirical growth and yield models

e.g., FVSBGC (Milner et al. 2003*)
Research needs and challenges: Integration of models

➢ Combined use of different model types (2) ?

Comparison of the errors generated from different models (uncertainty analysis)
Research needs and challenges: Adapting models

➢ There is still little understanding of the complexity of the ecophysiological processes

➢ But, prediction needs for climate change adaptation policy development still remain important

➢ It is not realistic to wait for the “perfect” model(s) for climate change prediction

➢ Models can be adapted to make realistic predictions of the impacts of climate change
Adapting a model to predict the impacts of climate change: example using a gap model

On-going efforts with ZELIG-CFS (1)

- Mechanistic basis;
- Initialized with ecological variables:
  - Species-specific ecological variables
  - Mean monthly temperatures and precipitations
  - Soil texture
  - Tree dbh values

- Validation for boreal forest types in northwestern Ontario indicated good agreement between predictions and observations
Simulation results for northern Ontario Validation dataset

➢ Three historical datasets in Northwestern Ontario

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Number of sample plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Can*</td>
<td>152</td>
</tr>
<tr>
<td>Kimberly Clark</td>
<td>118</td>
</tr>
<tr>
<td>Spruce Falls Power and Paper</td>
<td>122</td>
</tr>
</tbody>
</table>

*Results presented for this dataset.

➢ Pure and mixed even- & uneven-aged boreal forest types

<table>
<thead>
<tr>
<th>Trembling aspen</th>
<th>Jack pine</th>
<th>Balsam fir</th>
</tr>
</thead>
<tbody>
<tr>
<td>White birch</td>
<td>Black spruce</td>
<td>Northern white cedar</td>
</tr>
<tr>
<td>Larch</td>
<td>Balsam poplar</td>
<td>White spruce</td>
</tr>
</tbody>
</table>

➢ Re-measurements: between 4 and 15, maximum year: 57
Results – Balsam fir

Average observed and predicted basal area

Note: Error bars are standard deviations

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Results – Black spruce

Average observed and predicted basal area

![Graph showing average observed and predicted basal area over years]

Note: Error bars are standard deviations

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Results – White birch

Average observed and predicted basal area

Note: Error bars are standard deviations

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Results – White spruce

Average observed and predicted basal area

Note: Error bars are standard deviations

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Adapting a model to predict the impacts of climate change: example using a gap model

On-going efforts with ZELIG-CFS (2)

➢ Development of model components to gradually increase mean annual temperature and precipitations

➢ The effect of CO$_2$ increase can be emulated using species-specific fertility factors (from the literature)

➢ Development of uncertainty analysis algorithms to capture variability in the predictions
AMSIMOD
(Application for the Management of Simulation MODEls)

➢ A modelling software platform that facilitates the development and application of forest models and use of analytical tools for decision support
➢ Fills a gap in modelling software by allowing users to manage different types of models (e.g., forest growth models, succession models, carbon cycle models, wood quality models or management models)
➢ Policy development for climate change adaptation requires the use of different models
Basic framework of AMSIMOD

- Model 1
- Model 2
- Model n

Results
- Ecosystem level
- Landscape level
- Regional level

Analytical & numerical processing
- Sensitivity analysis
- Uncertainty analysis
- Statistical analysis
- Spatial analysis
- Optimization (linear or nonlinear programming)
- Artificial intelligence

Reporting tools
- Graphs
- Geographic Information Systems
- Virtual imagery applications

Generation of management scenarios
A project in AMSIMOD

Workspace

Active project

Succession

Model: ZELIG_CFS_Model_v34.exe
ZELIG-CFS is a gap model

Initialization file(s):
Input_LeMauricie_Controls_Version3
Input file for LaMauricie National Park

Output file(s):
Treedbh_output
Individual tree dbh output
Basal/Area_Output
Basal area results over time for each plot by species
Density_Output
Table that summarizes density results
PlotsInfo_Output
Information on simulation density results
QGIS_Output
For each plot, this file provides the name of the files that contains location information

Photosynthesis

Model: FORECAM_mod.exe
Photosynthesis model
AMSIMOD utilities to display simulation results
Dynamic visualization on QGIS
AMSIMOD

End-users can add extensions (tools) to facilitate the decision-making process:
Examples: - Biodiversity indices
- Carbon sequestration
- Forest management applications

Available extensions:
- eFRI application for the boreal forest of northern Ontario (plugin in Q-GIS)
- Partial cut applications
Conclusion

➢ The impacts of climate change are not limited to tree and stand productivity
➢ Many forest simulation models have been developed, but it is imperative to improve their realism and precision for climate change prediction
➢ Forest simulation models are essential for adaptation to climate change
Conclusion

For more information on forest models