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A paradigm shift in empirical growth and yield modelling:

towards climate-sensitive models and large-area predictions

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Canada

Fig. 7. Aspect of a simulated forest stand generated by the visualization module of SILVA (Pretzsch and Seifert, 1999). The tree in the center of the picture is marked as a selection tree, three competitors have been marked for removal.

Source: Pretzsch et al. 2002

Evaluation of Competition Indices in Individual Tree Growth Models

Gregory S. Biging
Matthias Dobbertin

Forest Science, Vol 41, No 2, pp 360–377

Can. J. For. Res. 33: 435–443 (2003) 435

Predicting basal area increment in a spatially explicit, individual tree model: a test of competition measures with black spruce

Daniel Mailly, Sylvain Turbis, and David Pothier

Outline

1. Climate change and climate models
2. Climate sensitivity in forest growth models
3. Disturbances and upscaling

Outline

1. Climate change and climate models
2. Climate sensitivity in forest growth models
3. Disturbances and upscaling

Timeline

1988

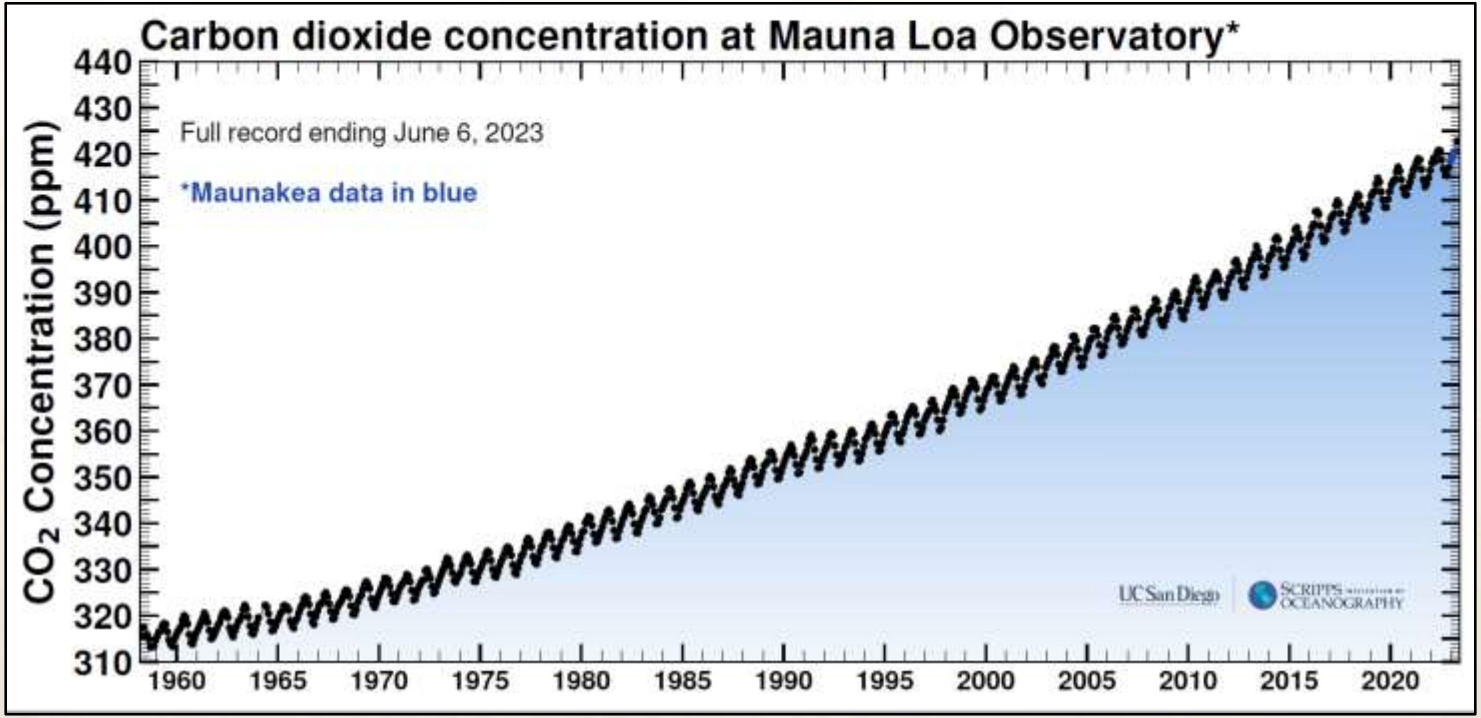
Intergovernmental Panel on Climate Change (IPCC)

1992

Earth Summit – Rio

- United Nations Framework Convention for Climate Change (UNFCCC)

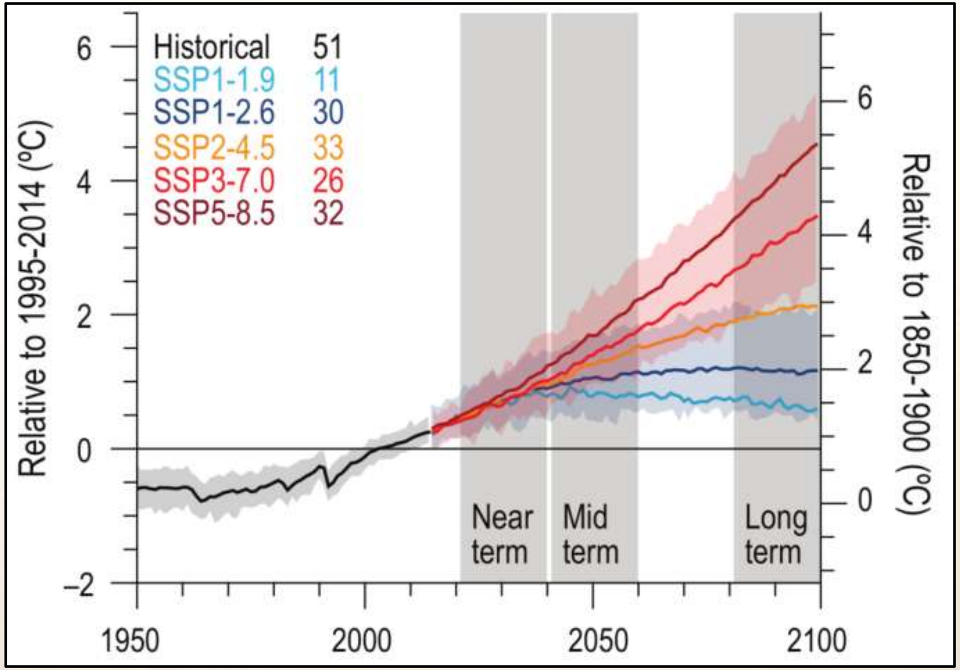
The Keeling curve



Climate change and climate models

2021

- Sixth Assessment Report
  - Shared Socio-economic Pathways (SSP)
  - Global Surface Air Temperature



IPCC 2021. Climate Change 2021: The Physical Science Basis. p.571

Climate models

Human activities

- CO_2
- Non CO_2
- Albedo
- Land use

The Canadian Earth System Model version 5 (CanESM5.0.3)

Neil C. Swart[1,3], Jason N. S. Cole[1], Viatcheslav V. Kharin[1], Mike Lazare[1], John F. Scinocca[1], Nathan P. Gillett[1], James Anstey[1], Vivek Arora[1], James R. Christian[1,2], Sarah Hanna[1], Yanjun Jiao[1], Warren G. Lee[1], Fouad Majaess[1], Oleg A. Saenko[1], Christian Seiler[4], Clint Seinen[1], Andrew Shao[3], Michael Sigmond[1], Larry Solheim[1], Knut von Salzen[1,3], Duo Yang[1], and Barbara Winter[1]

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Correspondence: Neil C. Swart (neil.swart@canada.ca)

Swart et al. 2019. Geoscientific Model Development 12(11): 4823-4873

Outline

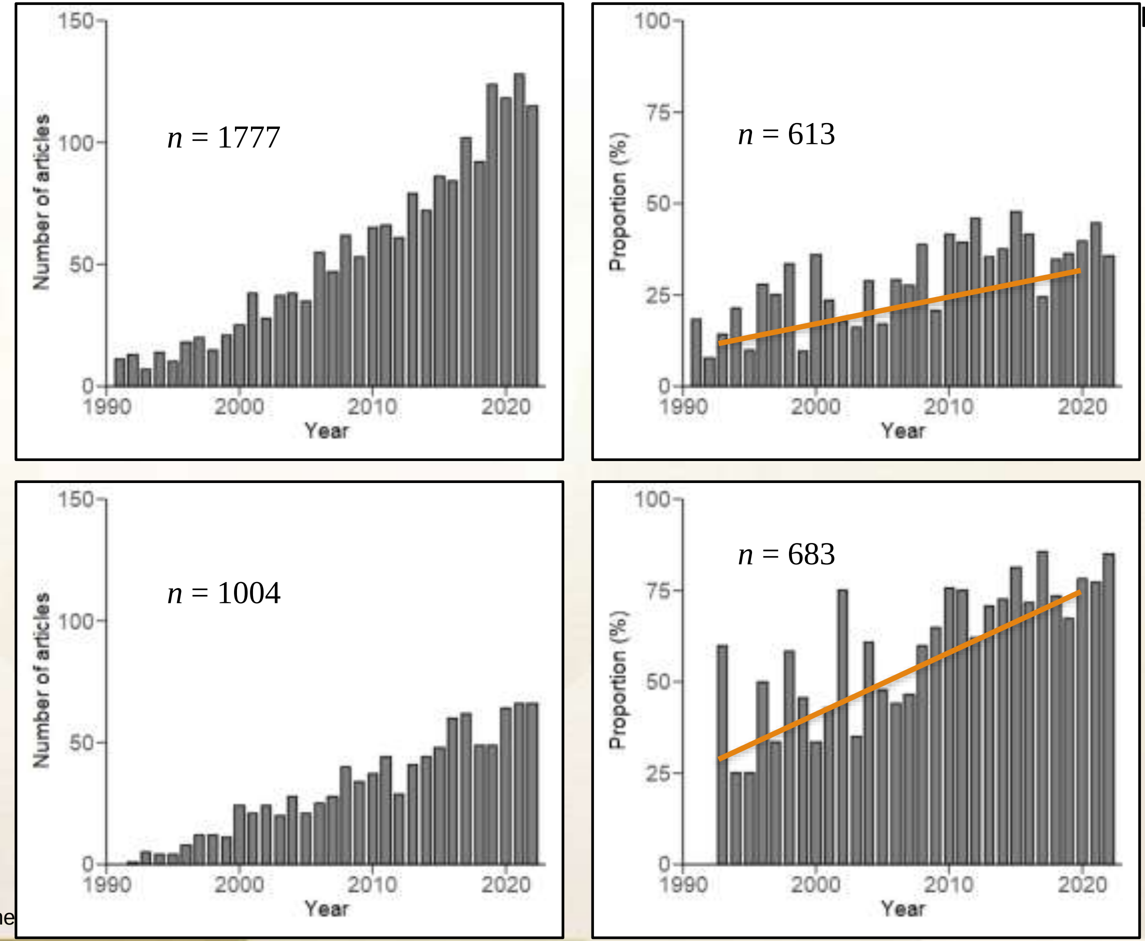
1. Climate change and climate models
2. Climate sensitivity in forest growth models
3. Disturbances and upscaling

Climate and growth models

- Web of Science
  - forest growth model empirical
  - forest growth model empirical **climate**
  - forest growth model « process-based »
  - forest growth model « process-based » **climate**

Empirical models

Process-based models



Available online at www.sciencedirect.com
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Ecological Modelling 179 (2004) 317–348
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ECOLOGICAL MODELLING

A process-based model of fo… driven by meteoro…

Christopher R. Schwalm, Al…
Department of Forest Resources, College of Natural Resou…
1530 Cleveland Avenue North, St. Paul, M…

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journal homepage: www.elsevier.com/locate/foreco
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Nationwide climate-sensitive models for stand dynamics and forest scenario simulation

Antoni Trasobares[a,*], Blas Mola-Yudego[b], Núria Aquilué[a], José Ramón González-Olabarria[a,c], Jordi Garcia-Gonzalo[a,c], Raúl García-Valdés[a], Miquel De Cáceres[a,c]

Integrating remote sens… process-based models to map forest productivity within west-central Alberta's boreal forest: Ecoleap-West[1]

by R.J. Hall[2,3], F. Raulier[4], D.T. Price[2], E. Arsenault[2], P.Y. Bernier[5], B.S. Case[2,6], X. Guo[3]

MARCH/APRIL 2006, VOL. 82, No. 2 — THE FORESTRY CHRONICLE

Process-based modelling

- 3-PG (Landsberg and Waring 1997)
  - Purely process-based

- Triplex (Peng et al. 2002)
  - Hybrid (combines 3-PG + empirical features)

Carbon allocation

Monthly time steps

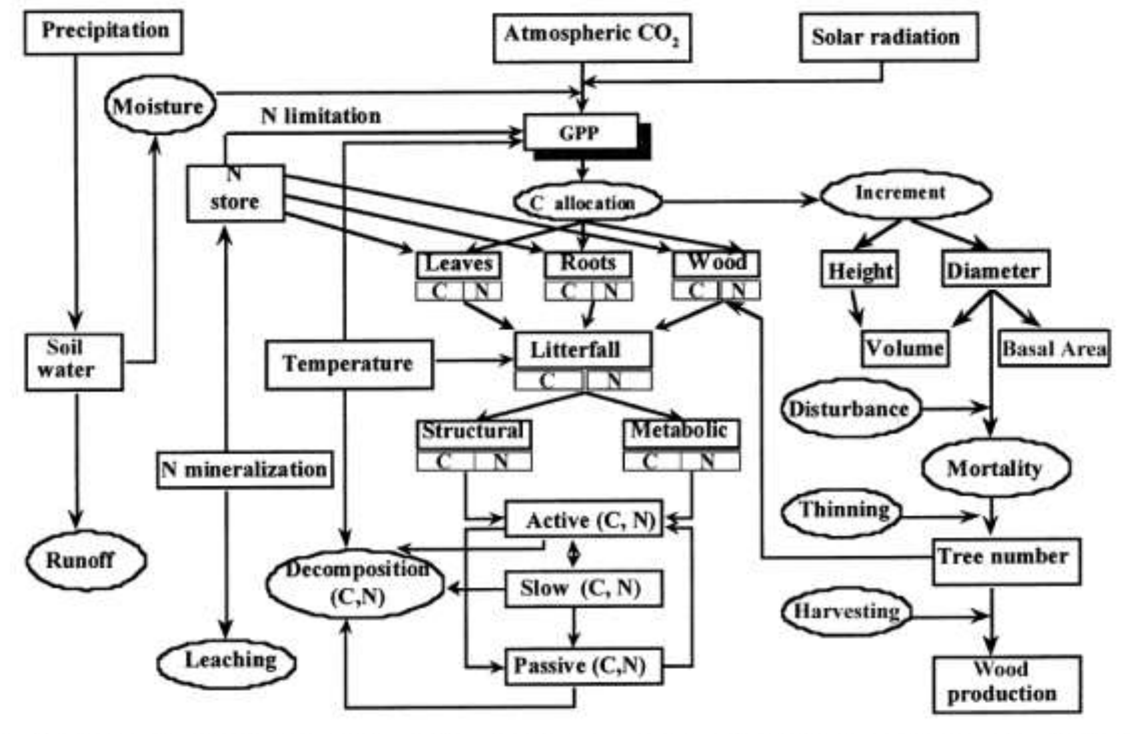


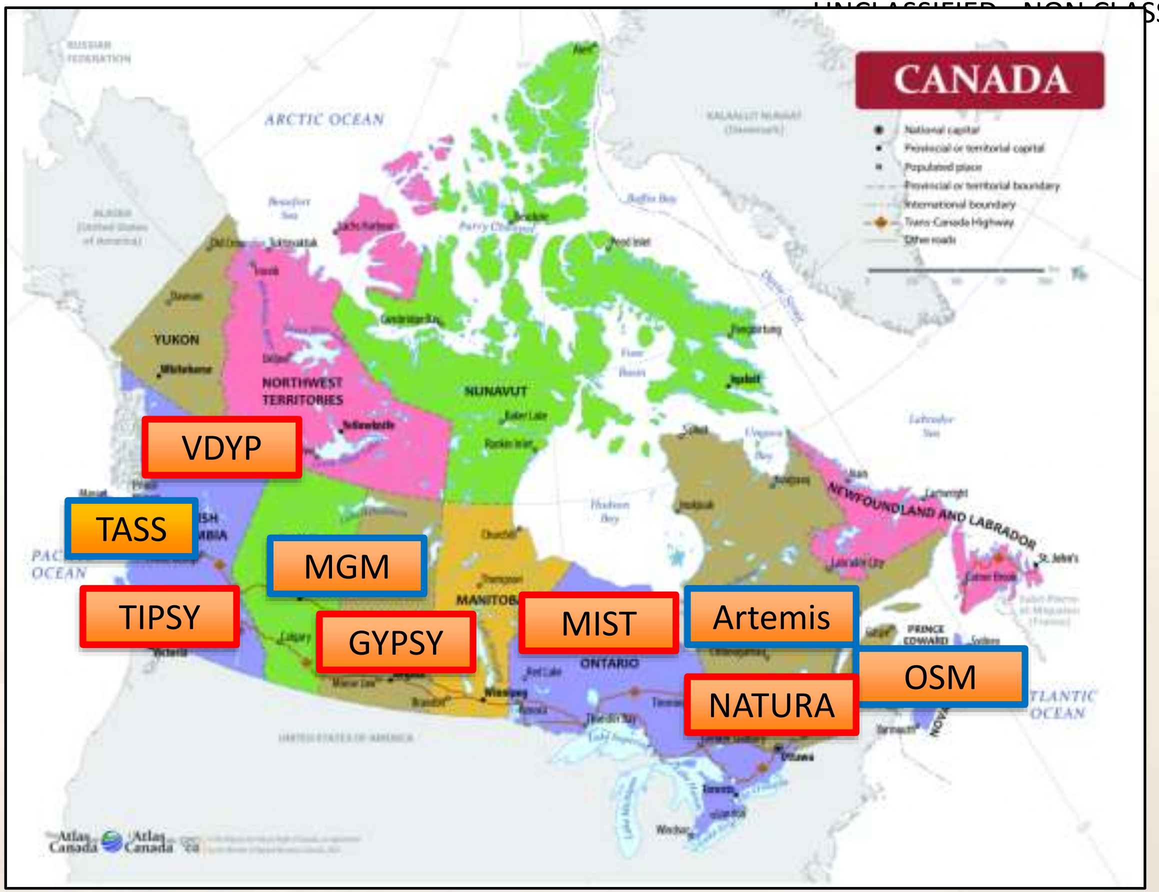
Fig. 1. Flow diagram showing the key pools and fluxes of carbon, nitrogen, and water between the forest ecosystem and external environment in TRIPLEX 1.0. Rectangles represent pools or state variables. Ovals represent simulated processes. Arrows refer to carbon (C), nitrogen (N) and water flows. GPP is gross primary productivity.

Source: Peng et al. 2002

Empirical growth modelling

- Stand-level models
- Transition matrices (1960s)
- Individual-based models (1970s)
  - Distance-dependent
  - Distance-independent

Some models used in forest management planning in Canada



Climate sensitivity implementation

1. Re-expressing some variable

Climate-sensitive site index models for N

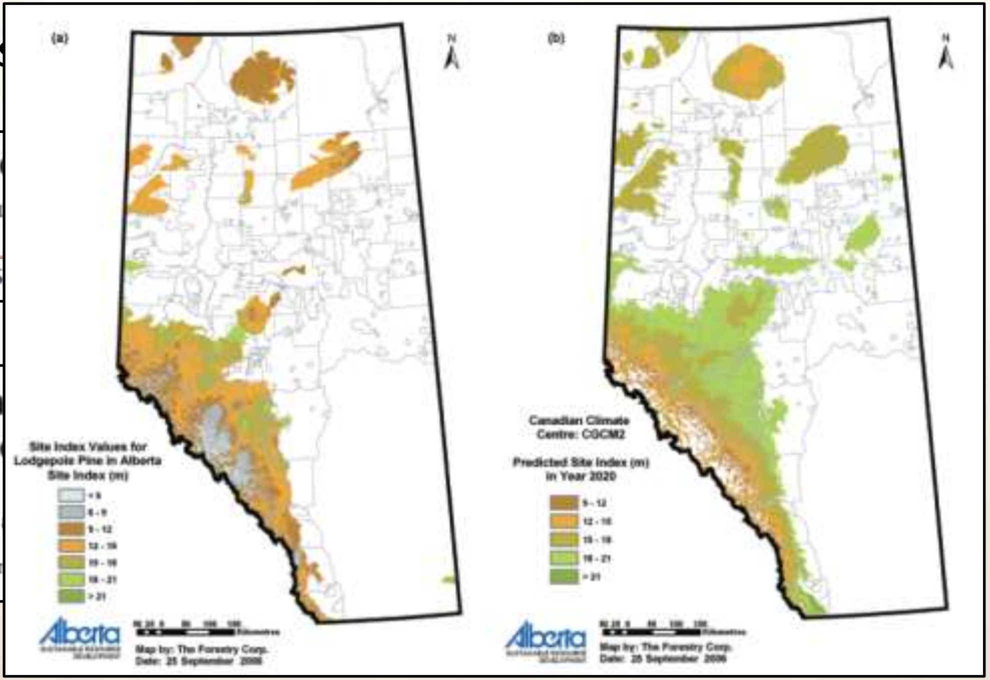
Clara Antón-Fernández, Blas Mola-Yudego, Lise Dalsgaard, and Rasm

Can. J. For. Res. 46: 794–803 (2016

Potential change in lodgepole pin distribution under climatic chang

Robert A. Monserud, Yuqing Yang, Shongming Huang,

Ca

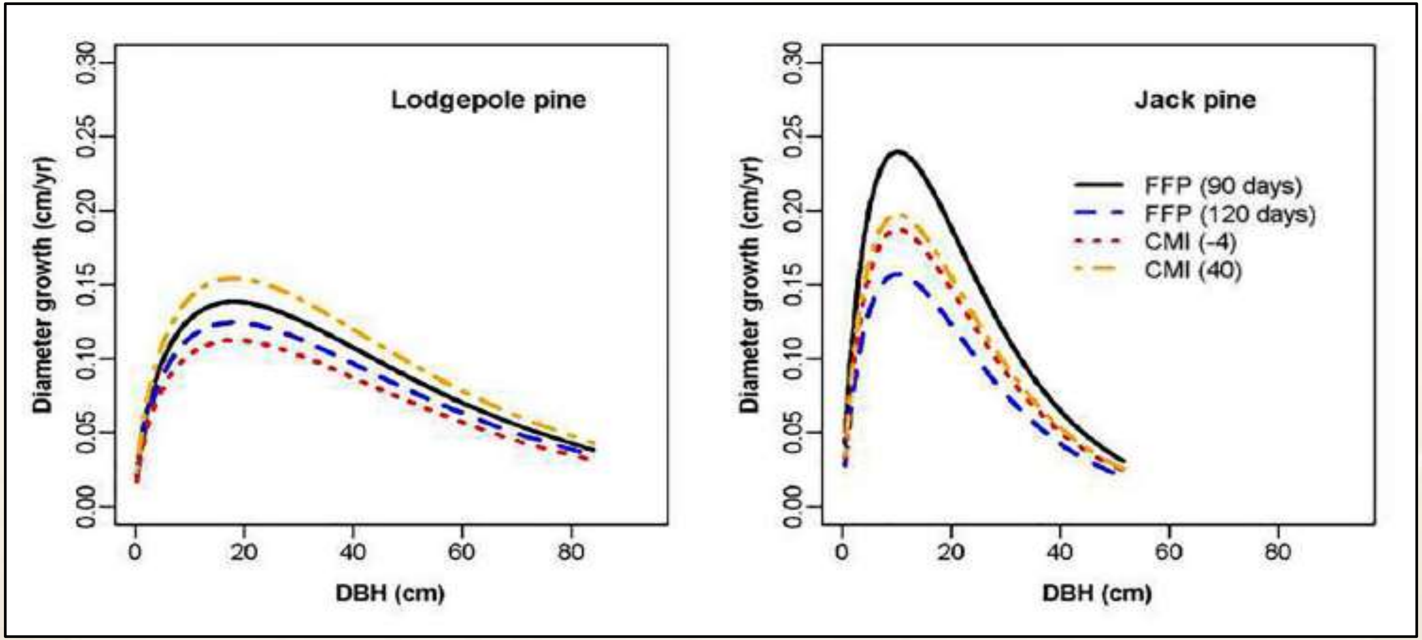


Source: [Monserud et al. 2008]

Climate sensitivity implementation

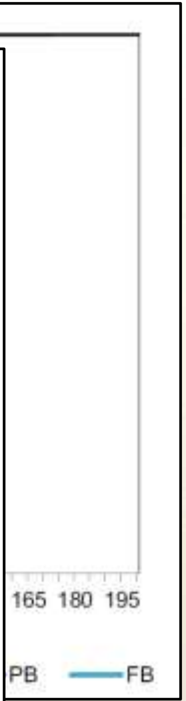
2. Including climate variables directly in individual-based models

- Tree-ring data
- Permanent-plot data
- Diameter or basal area increment
- A large variability in the climatic variables and their effects



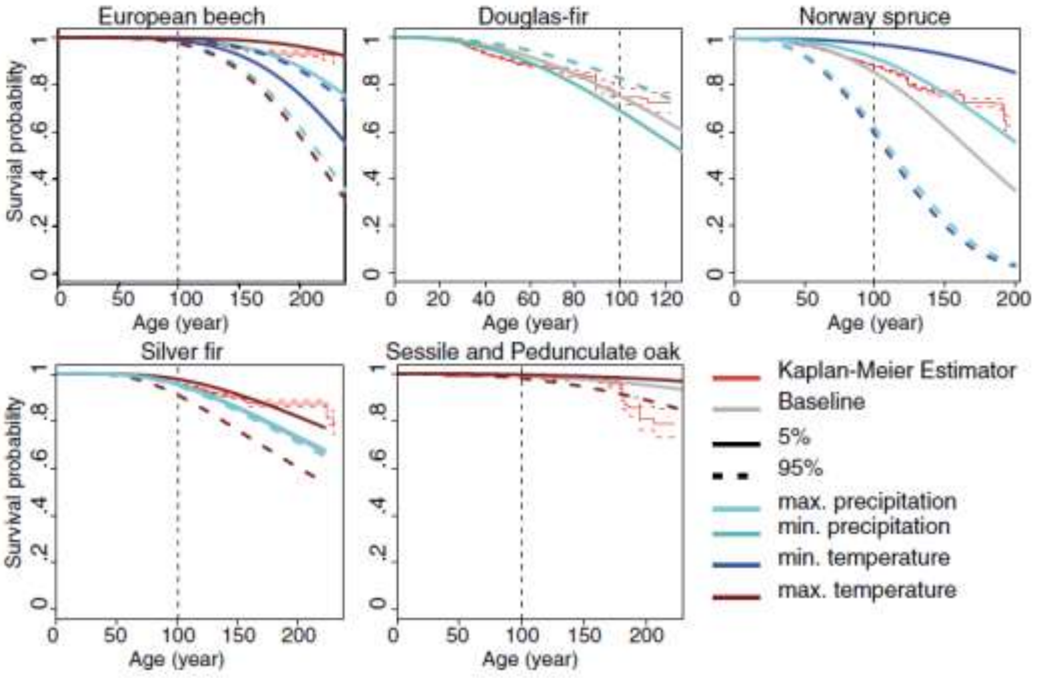
Source: [Oboite and Comeau 2021]

Mortality



t al. 2017

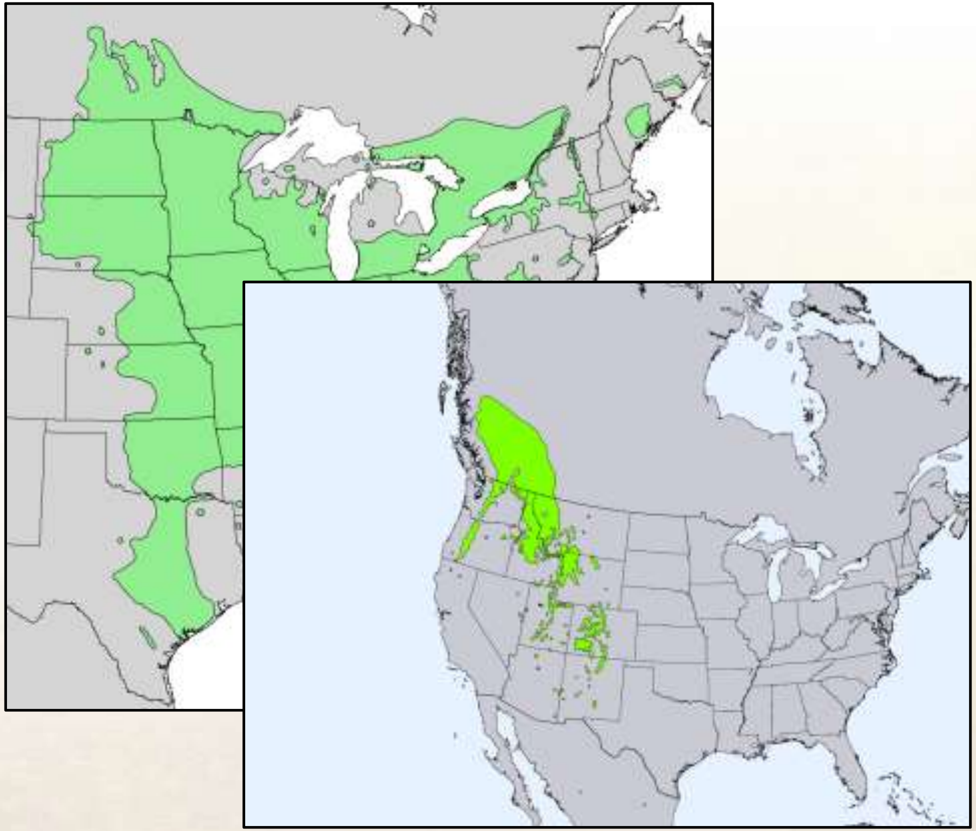
Fig. 7 Modeled influence of climatic variables on tree survival probabilities for European beech, Douglas-fir, Norway spruce, Silver fir, Sessile oak and Pedunculate oak. The solid line shows the 0.05-percentile and the dashed the 0.95-percentile for all climate variables



Source: [Maringer et al. 2021]

Recruitment

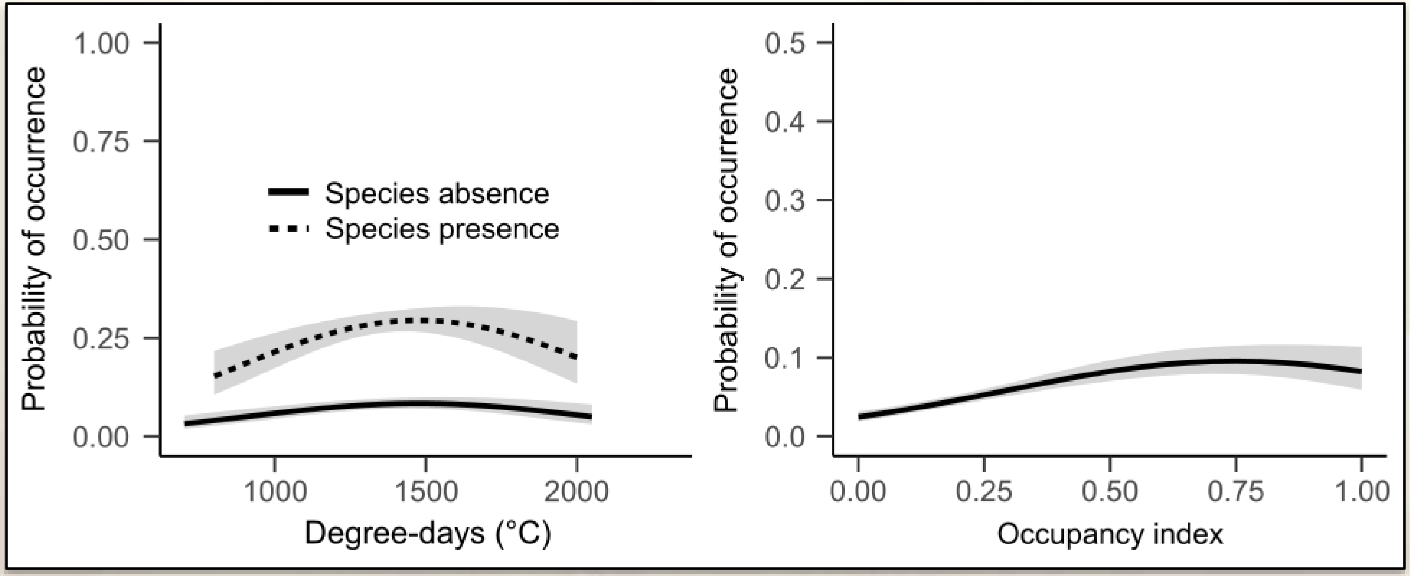
- Species migration



Picea engelmannii

Recruitment

Picea glauca

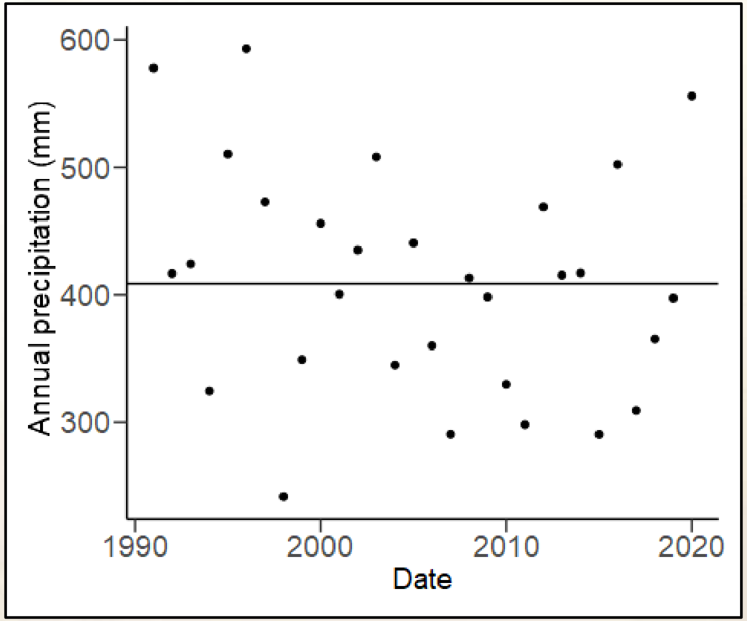


Source: Fortin et al. (in press)

Climate variables

- 30-year normals
- What about the interannual variability?

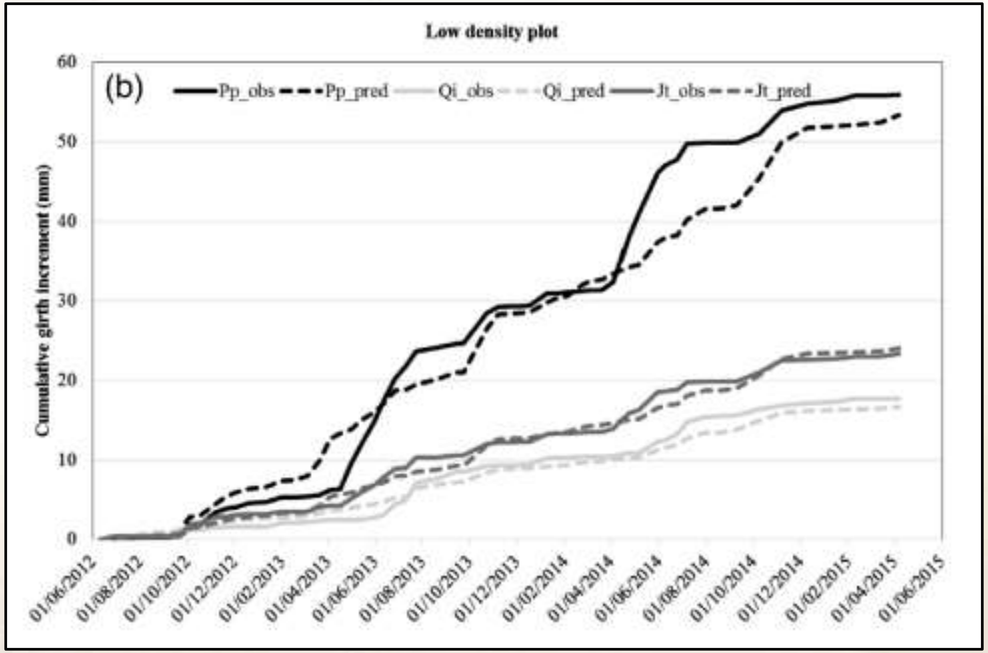
Fort McMurray, AB



Source: BioSIM Web API

Climate variables

Integrating annual climate variables in growth models?



Source: de Dios Garcia et al. 2018

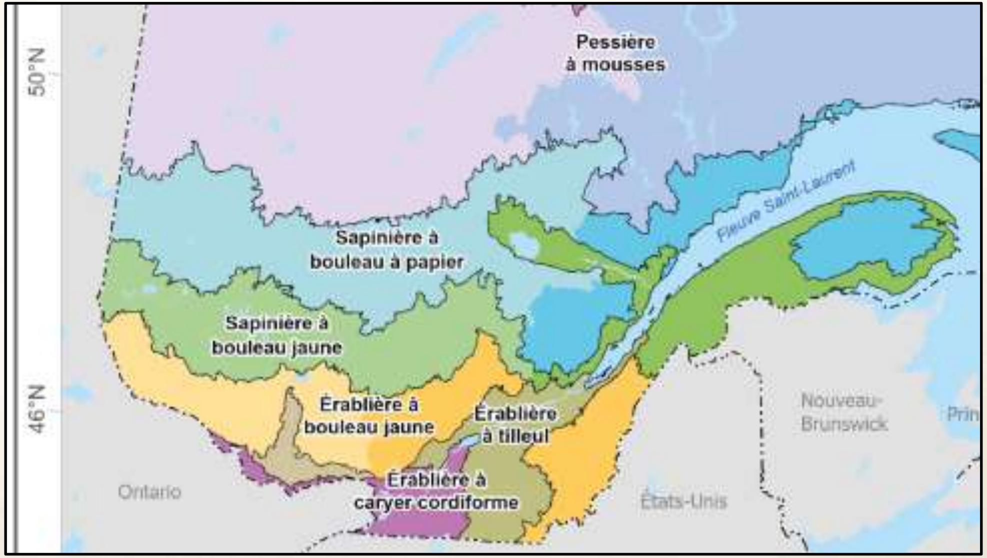
Climate sensitivity

- *Climate sensitivity* vs *climate change sensitivity*

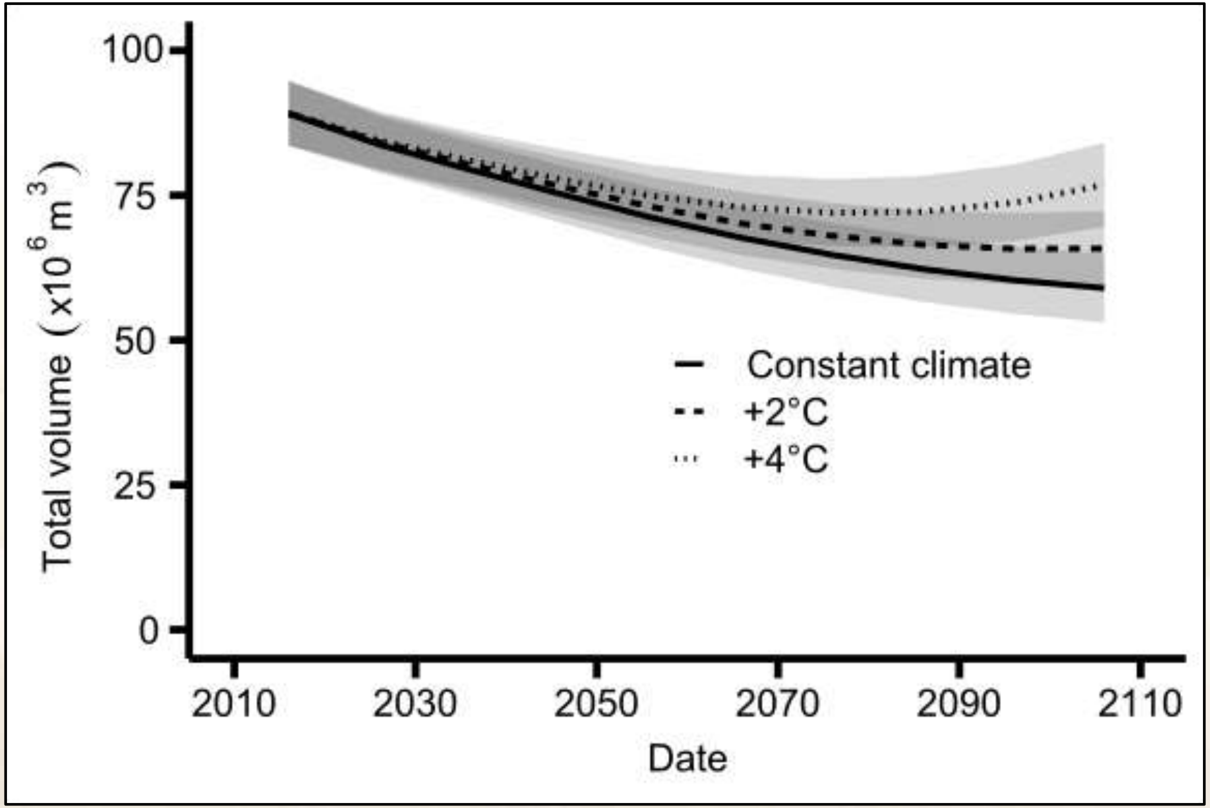
- What happens when other explanatory variables are dependent on climate (e.g. forest type, SI)

Climate sensitivity

- Artemis
  - Individual based
  - Distance independent
  - Available for 25 forest types



Source: Government of Quebec, 2022



Source: [Fortin et al. 2022]

Outline

1. Climate change and climate models
2. Climate sensitivity in forest growth models
3. Disturbances and upscaling

Disturbances

Changes in the disturbance regimes

- Intensity
- Frequency
- Severity

Source: Muratov 2001

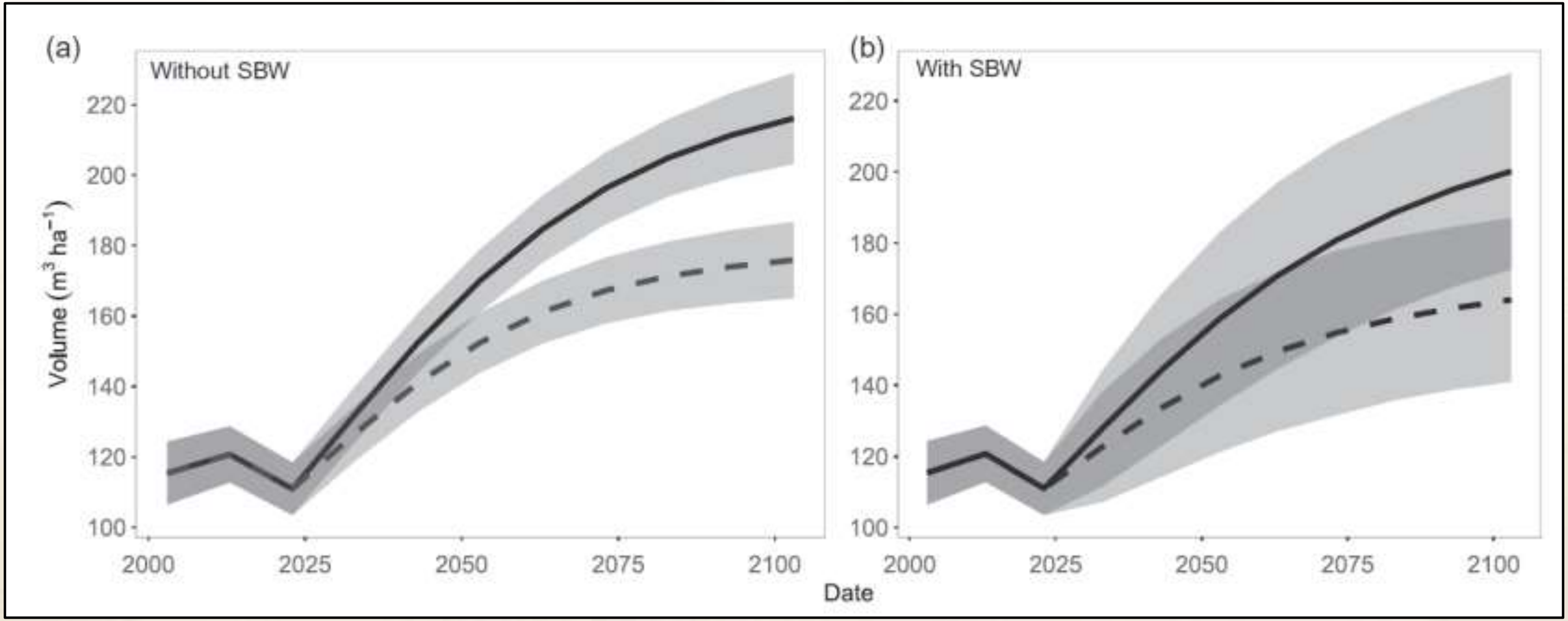
Disturbances

- Adapting mortality modelling to known disturbances

$$\log(-\log(1-\pi_{ijk})) = \beta_0 + \beta_{1,s} + \beta_2 \mathrm{dbh}_{ijk} + \beta_{3,s} \log(\mathrm{dbh}_{ijk}) + \beta_4 \mathrm{BAL}_{\mathrm{beech},ijk} + \beta_{5,s} \mathrm{BAL}_{\mathrm{oak},ijk} + e^{\beta_6 + v_k} W_{ik} + \beta_7 D_{ik} + \beta_{8,s} \mathrm{Th}_{ik} + \beta_9 \times \log(\Delta t_{ik})$$

Source: Manso et al. 2015

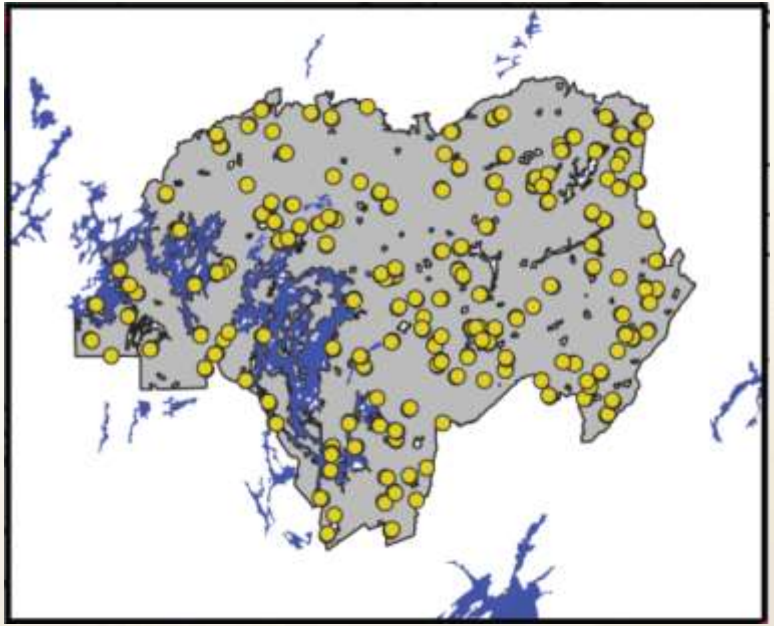
Disturbances



Source: [Melo et al. 2019]

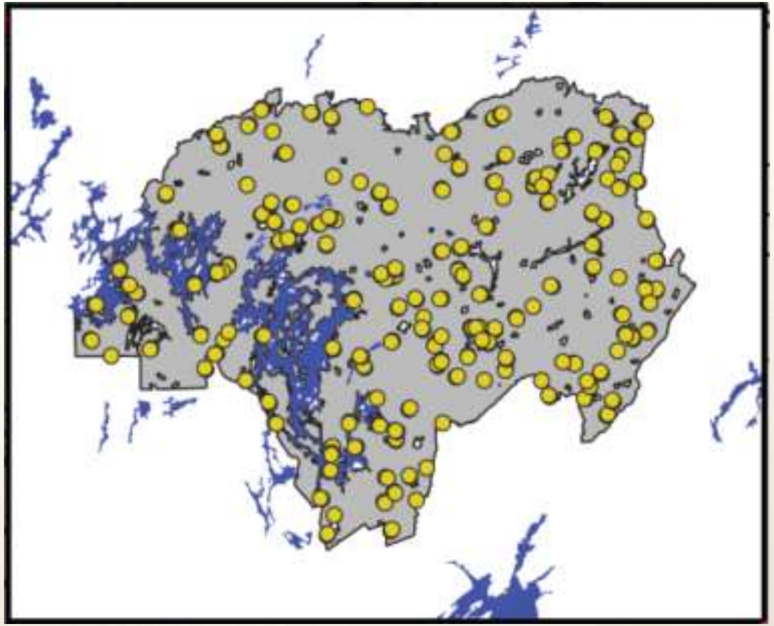
Large-area predictions

- What do we really know?

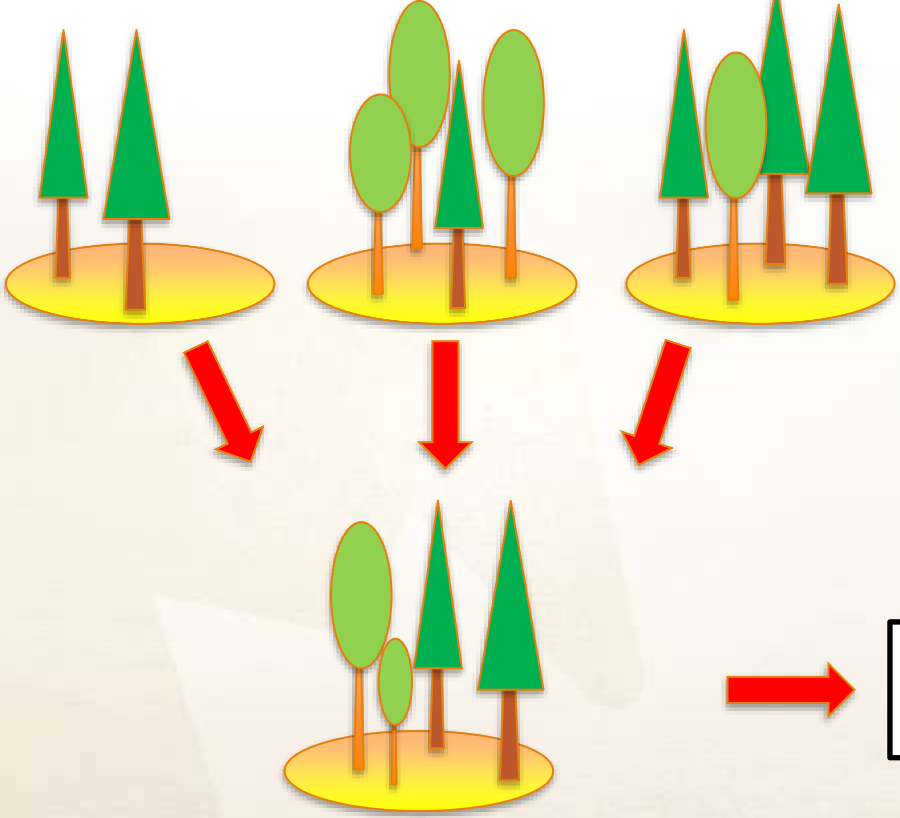


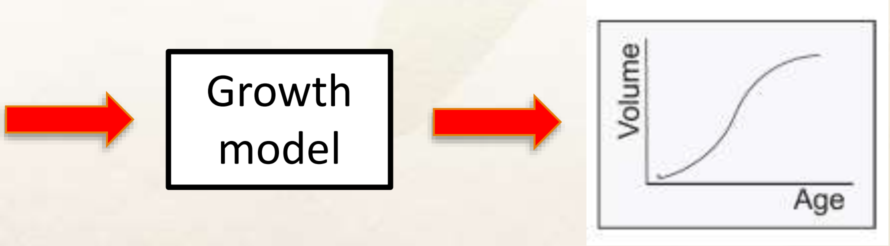
Human responses to uncertainty

- Averaging what we know
  - Consolidating our knowledge
- Bringing in new information
  - Remote sensing

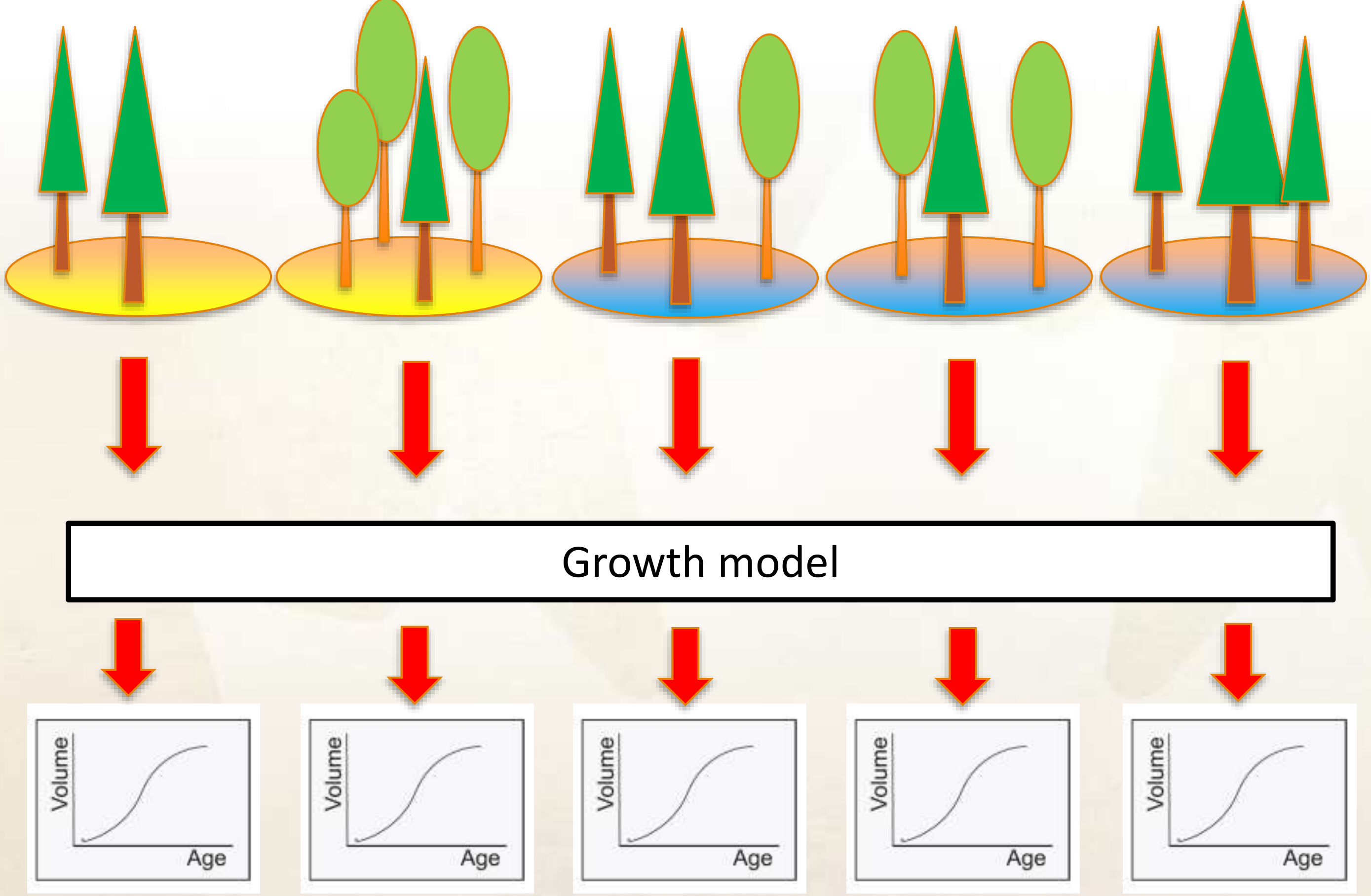


Averaging what we know



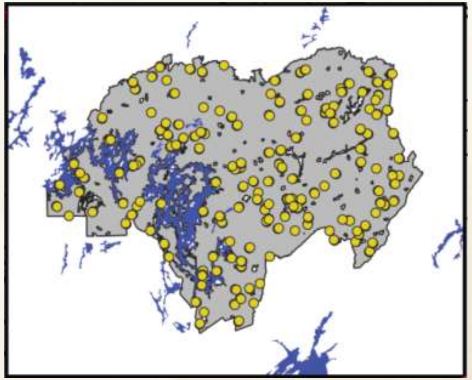


The « average » plot



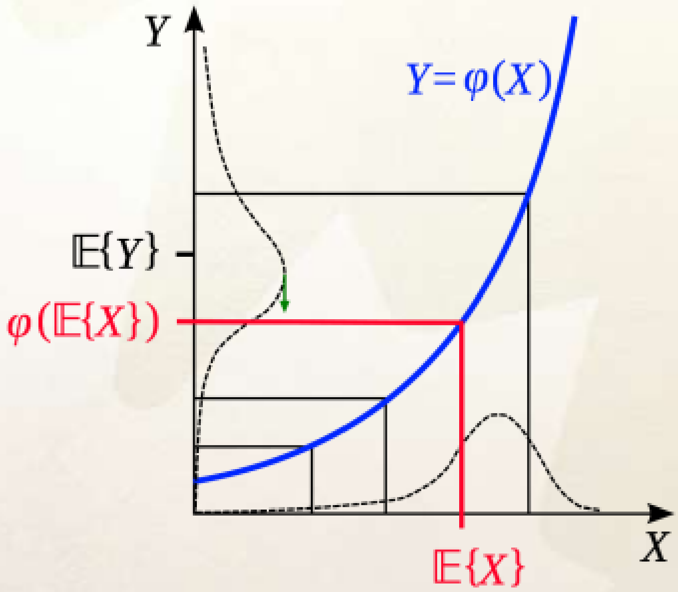
Bringing in new information to fill the gaps

(e.g. Falkowski et al. 2010)

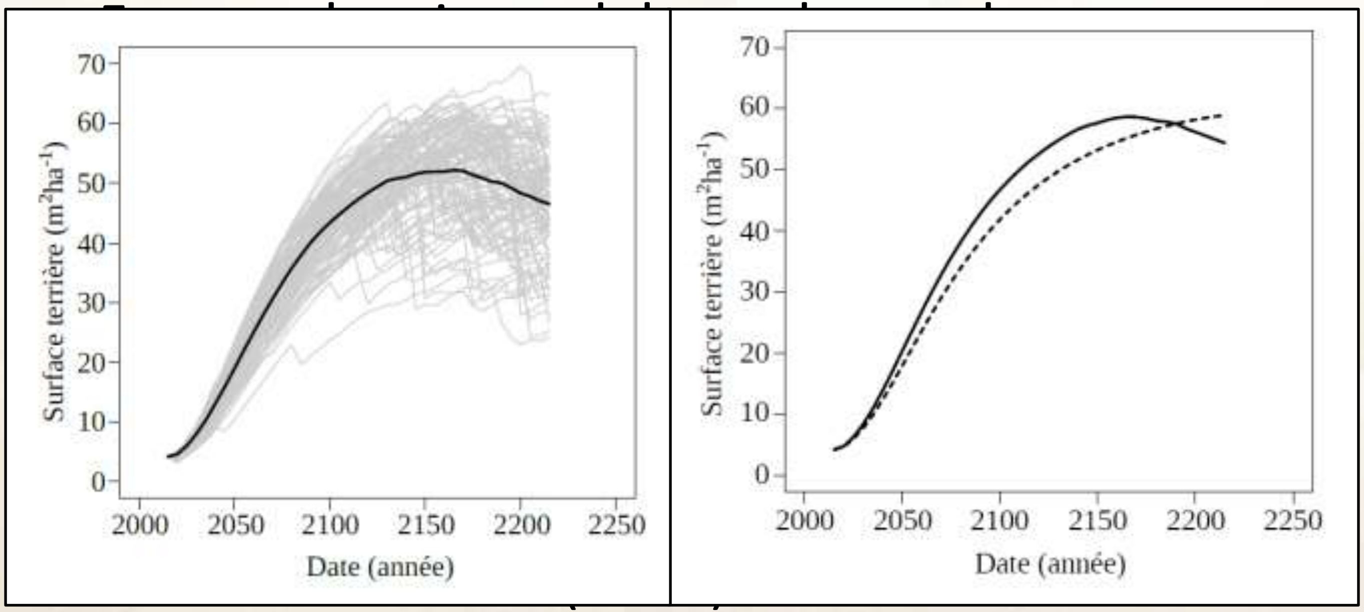


Uncertain input variables

- Jensen's (1906) inequality
- Average the predictions not the input variables

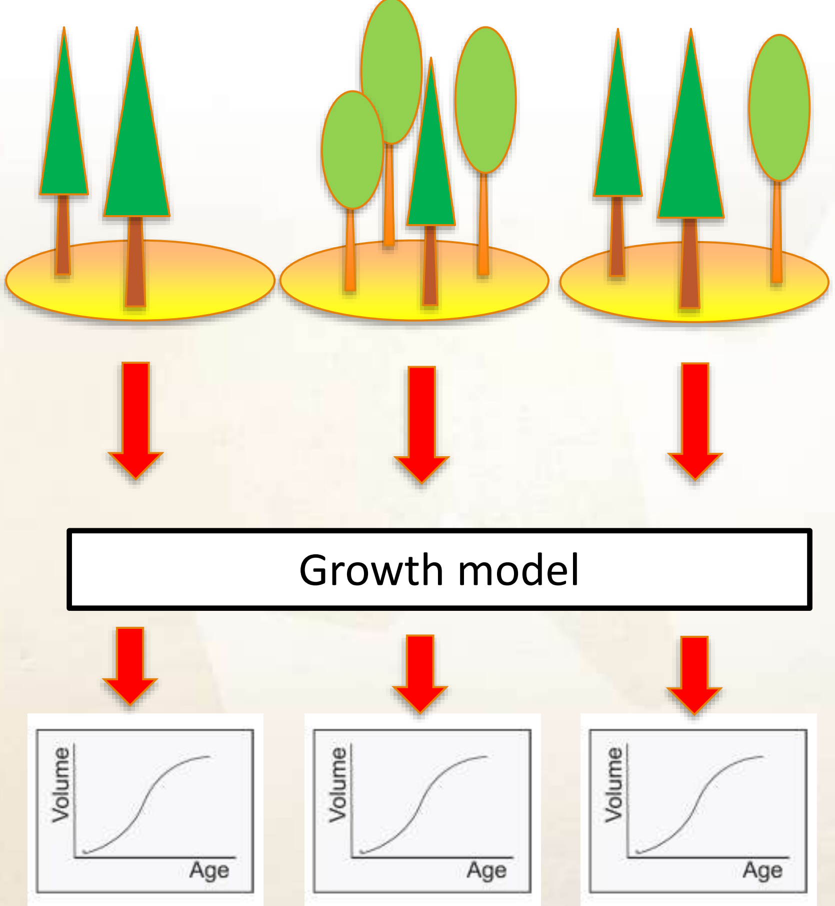


Stochastic models

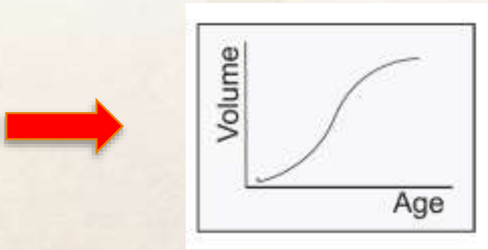


Source: Fortin 2016

Avoiding Jensen's inequality

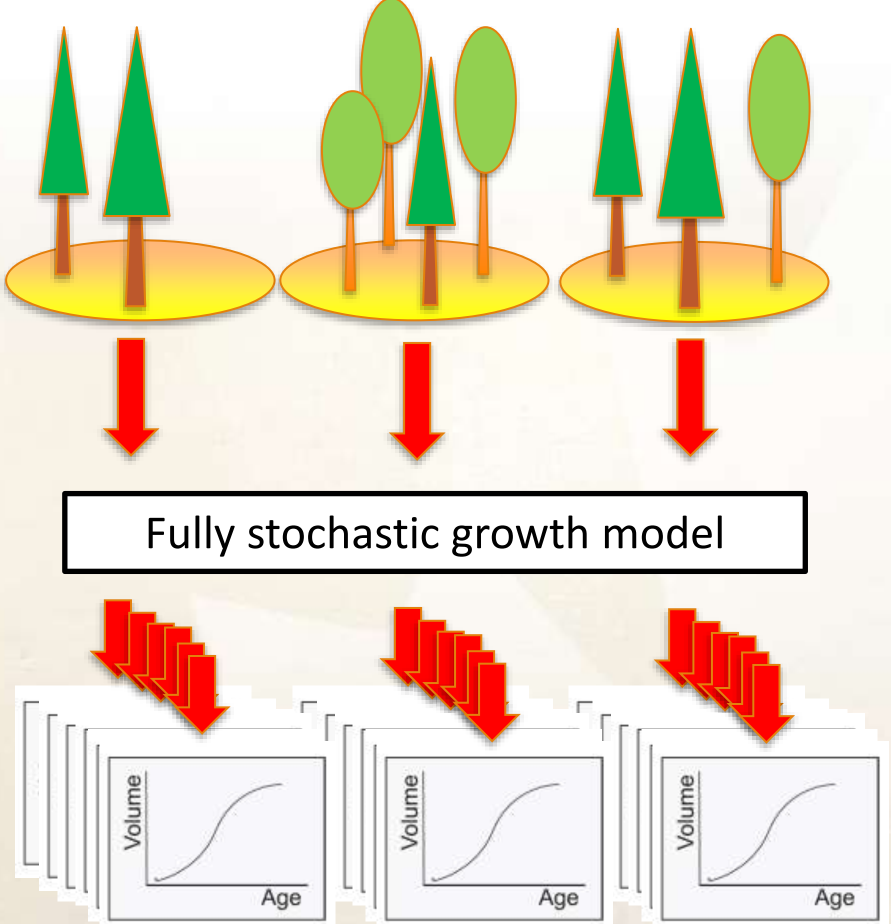


The « average » prediction

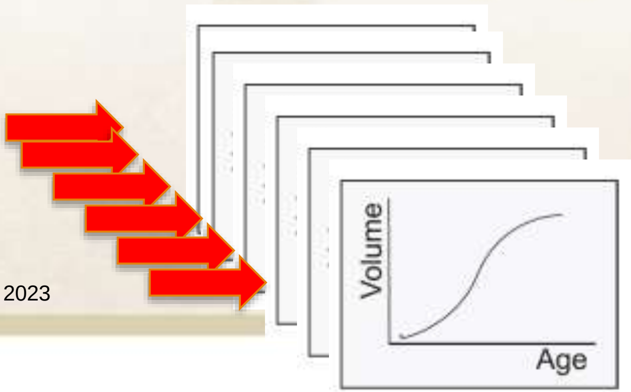


Parametric bootstrap estimators

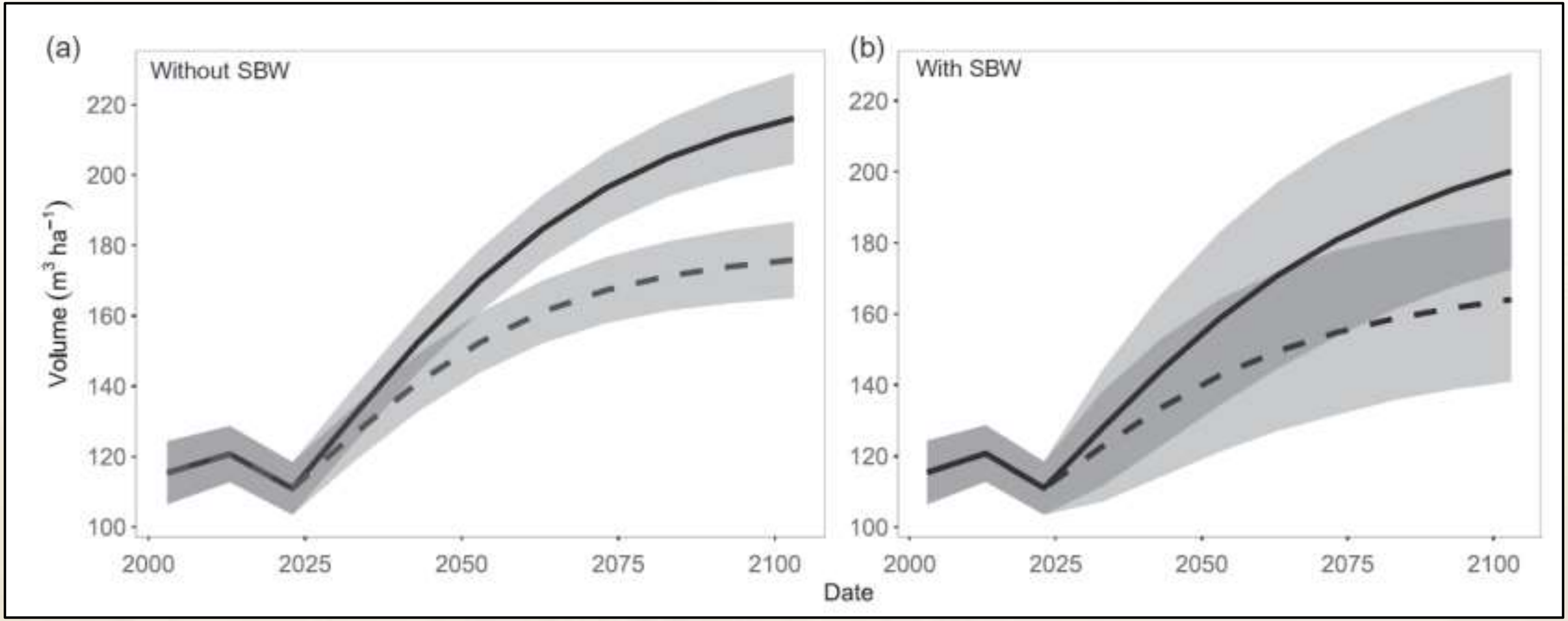
- Pfefferman and Tiller (2005)
- Fortin et al. (2018)



The « average » prediction



Large-area predictions



Source: [Melo et al. 2019]

Take home messages

1. Climate sensitivity implementation
   - Predict climate-dependent variables (SI)
   - Include climate variables directly in the model
     - 30-yr normals or annual values ?

Take home messages

2. Different species responses
   - Warmer climate does not mean better growth
   - Boreal species adapted to cold environment
   - Species migration is lagging

Take home messages

3. Disturbance regimes are changing
   – Accounting for disturbances in growth models

   – Stochastic simulations

Take home messages

4. We need large-area predictions
   - Different methods of upscaling
     - Beware Jensen's inequality

   - Bootstrap estimators allow for error propagation in these predictions
     - Need for fully stochastic models though

BioSIM Web API

Environmental Modelling and Software 157 (2022) 105476

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Position Paper

A Web API for weather generation and pest development simulation in North America

Mathieu Fortin [a,*], Jean-François Lavoie [b], Jacques Régnière [c], Rémi Saint-Amant [c]

- http://repicea.dynu.net/BioSim/BioSimWeather?lat=48.5&long=-74.5&from=2000&to=2016&model=DegreeDay_Annual

Thanks for your attention

Rubén Manso
Lara C. de Melo
Christina Howard
José Riofrio
Bianca Eskelson
Juha Metsaranta
Derek Sattler

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