ETH
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Modeling long-term forest dynamics: Interfacing succession models with empirical data leads to surprises

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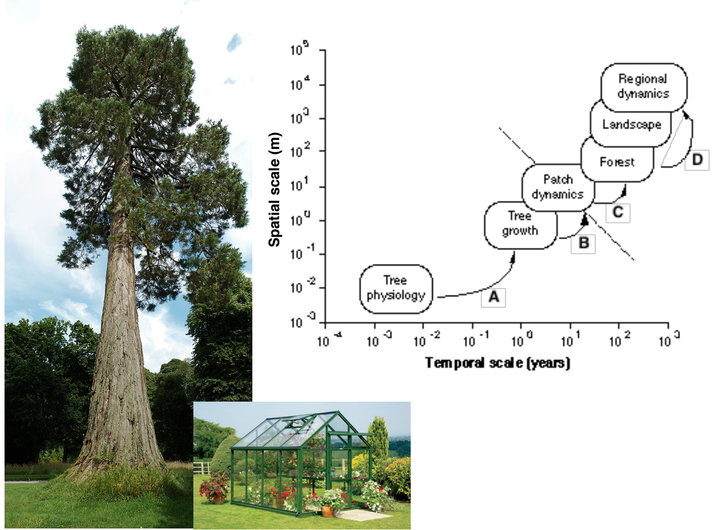
Overview

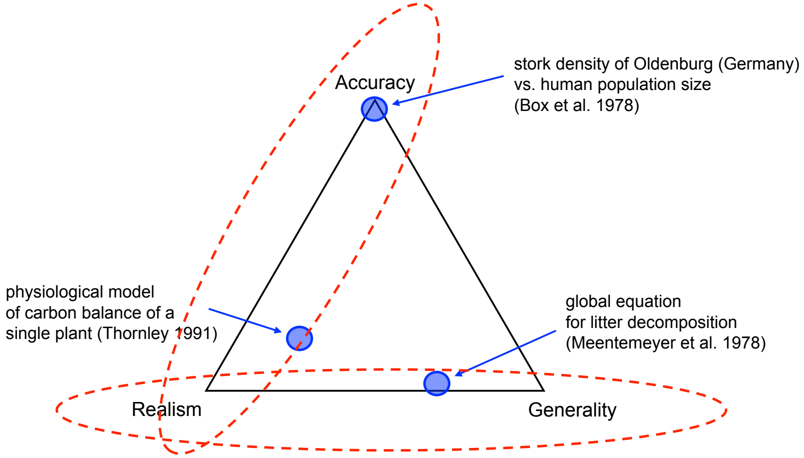
- Temporal and spatial scales and their implications
- Forest succession models and their successes
- From qualitative to quantitative model tests
- Moving to data-driven models
- The paradox: temporal and spatial scales mess up things
- Possible reasons for the paradox
- Conclusions

Forests don’t fit into greenhouses



Bugmann et al. (2000), *Clim Change*

Every modeler‘s dilemma



Accuracy

stork density of Oldenburg (Germany)
vs. human population size
(Box et al. 1978)

physiological model
of carbon balance of a
single plant (Thornley 1991)

global equation
for litter decomposition
(Meentemeyer et al. 1978)

Realism

Generality

Levins (1966), Odenbaugh (2002)

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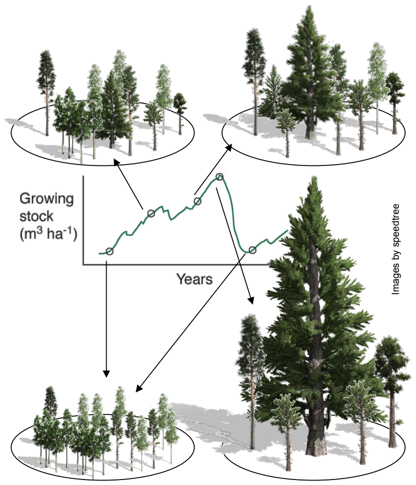
Forest succession models: approach

- Concept of small-scale mosaic of successional patches (Gleason, Botkin, Shugart): so-called „Gap models“
- Quantitative description of tree population dynamics:
  - Establishment
  - Growth
  - Mortality
- Sensitive to climatic factors
- Concept underlying most current dynamic models of (potentially) uneven-aged stands



Bugmann (2001), *Clim Change*

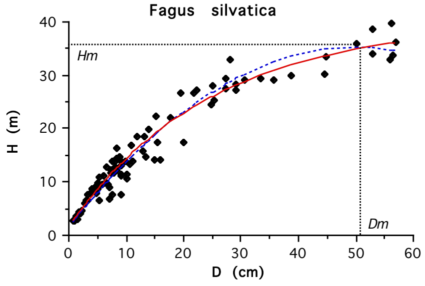
Principles underlying gap models

- Volume change of a tree:

  dV/dt = r · L – m · V

  Photosynthesis Respiration

- Allometric relationships (D = tree diameter at breast height):
  - $L = f_1(D)$
  - $V = f_2(H,D)$
  - $H = f_3(D)$



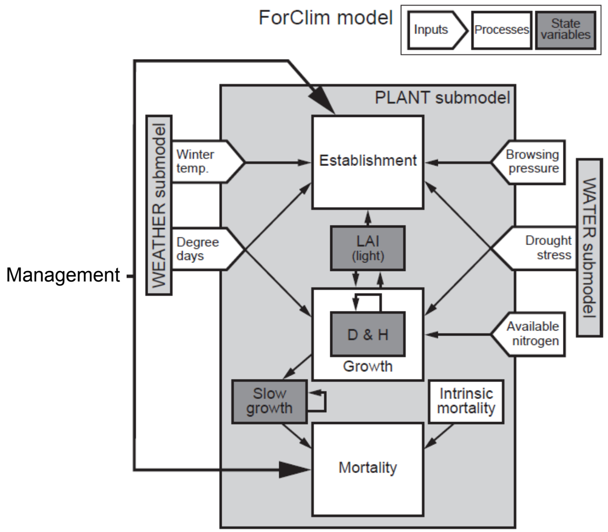
- ...from which follows (after some math):

$$\frac{\mathbf{dD}}{\mathbf{dt}} = \underbrace{g \cdot \mathbf{D}}_{\text{exponential}} \cdot \underbrace{\left(1 - \frac{\mathbf{H}}{H_{max}}\right)}_{\text{asymptote}} \cdot \underbrace{\frac{1}{\mathbf{b(D)}}}_{\text{allometry}} \cdot \underbrace{f(\mathbf{e})}_{\text{environment}}$$

Bioclimatic limits pls enter here

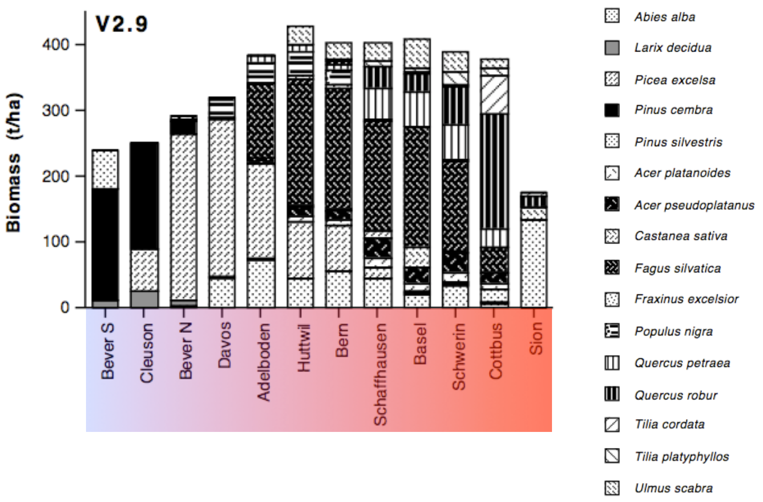
Moore (1989), *Ecol Modelling*

The FORCLIM model



Rasche et al. (2011), *J Appl Ecol*

Simulated potential natural vegetation



Bugmann & Solomon (2000), *Ecol Appl;* cf. Didion et al. (2009), *CJFR*

Challenges

If we want to **better understand** forest succession and **make 'predictions'** of the future dynamics of '**real**' forests:

- How to further develop dynamic models?
- What observations to make (or: use)?
- Which experiments to conduct?
- Relationship between data and models?

Here:
Evaluate (some of) these questions using the case of forest gap models in Europe and in the Pacific Northwest of North America

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Powerful data sources... to be unlocked...

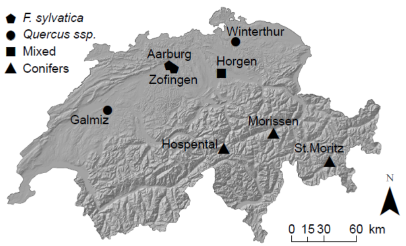
- Long-term Growth-and-Yield plots (Swiss Federal Res. Institute WSL)
  - 50+ stands
  - Partly dating back to 19th century
  - Inventories every 5-15 yrs
  - Mostly (strongly) managed stands
  - Tree positions known
  - Small, uniform plots

http://www.wsl.ch/forschung/forschungsunits/walddynamik/waldwirtschaft

- Network of Swiss forest reserves (ETH Zurich, WSL)
  - 48 reserves
  - Dating back to 1950s
  - Inventories every 5-15 yrs
  - Unmanaged for 50+ yrs
  - Tree positions unknown
  - Small permanent plots
  - Full cruises on larger areas (compartments)

http://www.waldreservate.ch

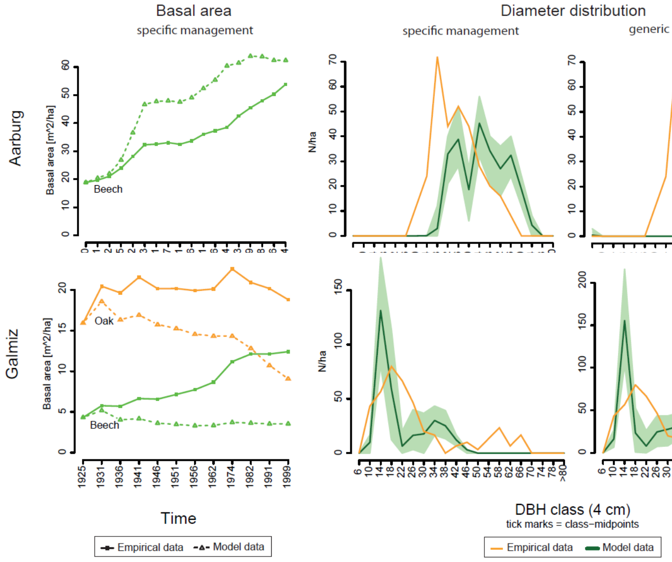
Rigorous model tests



- Eight Growth-And-Yield sites of WSL, Switzerland
- Initialized with single-tree data from first inventory (1890-1933)
- Settings of the management module:
  - „Specific“: Interventions in exactly those years in which they occurred in reality, with recorded intensity and concerning the recorded species
  - „Generic“: Use of average intensity and average intervals between interventions, affecting all species similarly

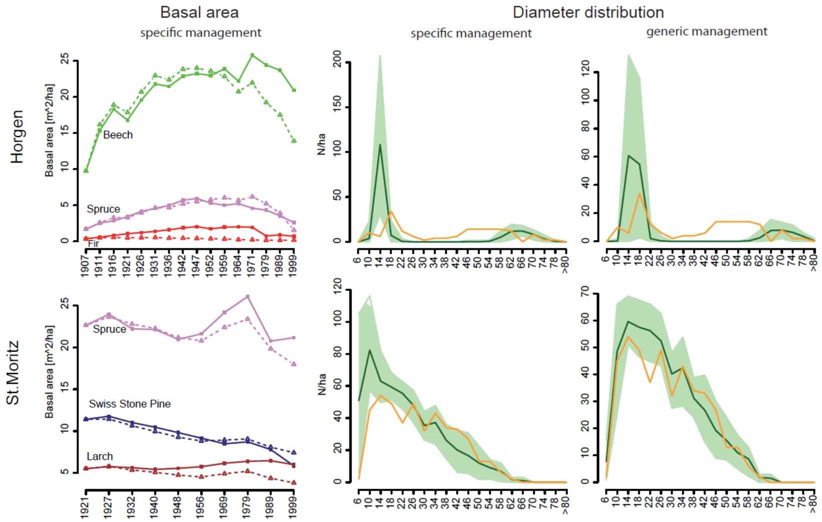
Rasche et al. (2011), *J Appl Ecol*

Results: Sometimes it‘s so-so...



Rasche et al. (2011), *J Appl Ecol*

...sometimes it‘s impressive



Rasche et al. (2011), *J Appl Ecol*

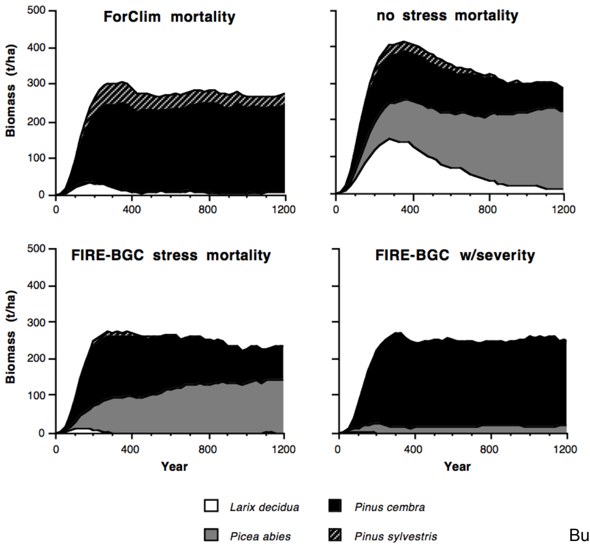
Results: Diameter distributions

	„Specific“ management		„Generic“ management	
	p value	test stats	p value	test stats
Aarburg	0.00	0.57	0.00	0.57
Galmiz	0.28	0.29	0.28	0.29
Horgen	0.01	0.48	0.01	0.48
Hospental	0.53	0.24	0.50	0.24
Morissen	0.46	0.24	0.43	0.24
St. Moritz	0.31	0.29	1.00	0.05
Winterthur	0.03	0.43	0.03	0.43
Zofingen	0.30	0.29	0.01	0.52

Kolmogorov-Smirnoff test of the cumulative frequency distributions at the end of the simulation (i.e., after 70-103 yrs)

Rasche et al. (2011), *J Appl Ecol*

Model sensitivity to tree mortality



Upper subalpine
site, Swiss Alps

Bugmann (2001), *Clim Change*

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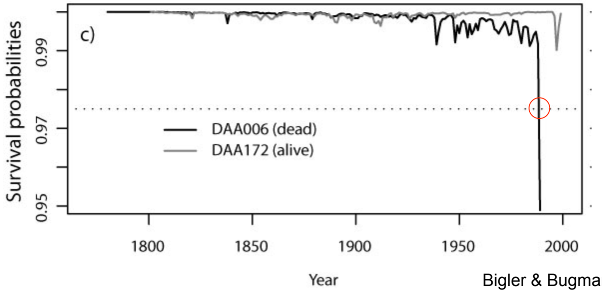
Implementing empirical mortality models



Bigler & Bugmann (2004), *Ecol Appl*

- Derived from tree-rings (TRM) vs. from inventory data (IM)
- Mortality occurs when threshold probability is exceeded (“threshold”) vs. random number (randNr)
- Old, “data-free” formulation (= ‘ForClim 3.0’) plus 4 combinations of data source (TRM/IM) and threshold/randNr

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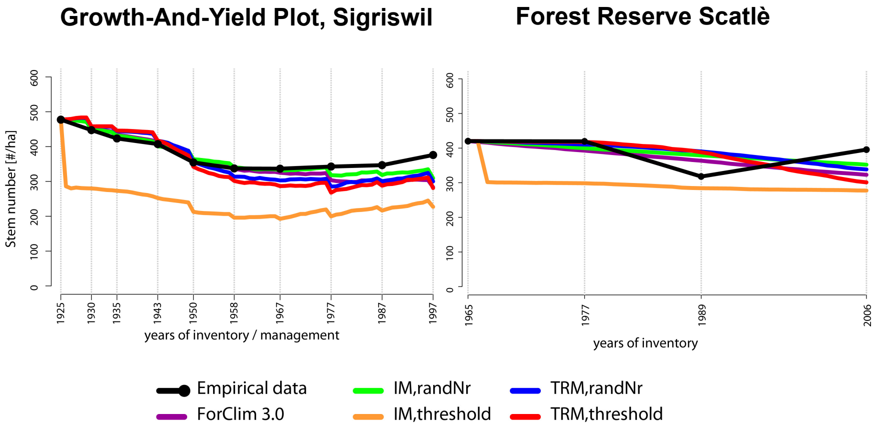
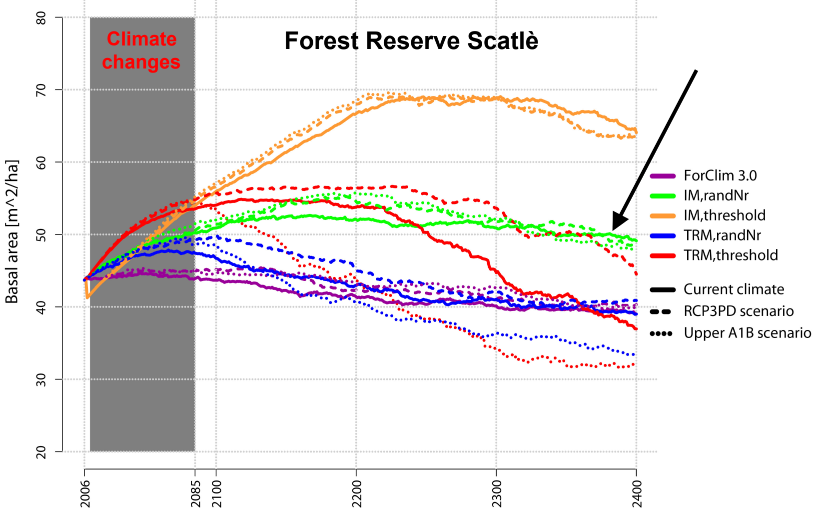
Testing against “long-term” data…



Wunder et al., *in prep.*; Bircher et al. (2015), *Ecol. Applications*

…and making extrapolations



Bircher et al. (2015), *Ecol. Applications*

Inventory-based mortality function (orig.)

→ Annual survival probability of each individual tree

Data source and method:
•Selection of Swiss National Forest Inventory plots (1985-95 / 1995-2005)
•Logistic regression model

Predictor variables:
•Diameter at breast height (DBH) [+], DBH^2 [-]
•Annual degree day sum (logDD) [-]
•Relative basal area increment
(4 classes: «very slow», «slow», «fast», «very fast») [+]
•Shade tolerance
(3 classes: «high», «intermediate», «low») [-]

Wunder et al. (2015), *in prep.*

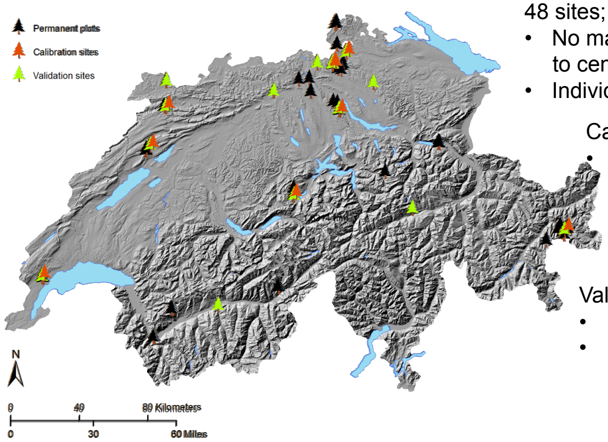
Inventory-based mortality function (Bayes)

Variables:
•**Diameter at breast height** (DBH)
•**DBH^2**
•Logarithmic annual degree day sum (logDD)
→ Not free for calibration
•**Relative basal area increment:**
4 classes («very slow», «slow», «fast», «very fast») [+]
→ Converted to continuous variable
•**Shade tolerance**: 3 classes («high», «intermediate», «low»)

Growth:
•**Diameter increment**

Bircher et al. (2015), *in prep.*

Swiss forest reserve network



48 sites; permanent plots (~300):
- No management for decades to centuries
- Individual tree data

Calibration sites (9):
- Inventory period ≥35 yr
  - Main tree species
  - No disturbance

Validation sites (23):
- Inventory period ≥35 yr
- No disturbance

Bircher et al. (2015), *in prep.*

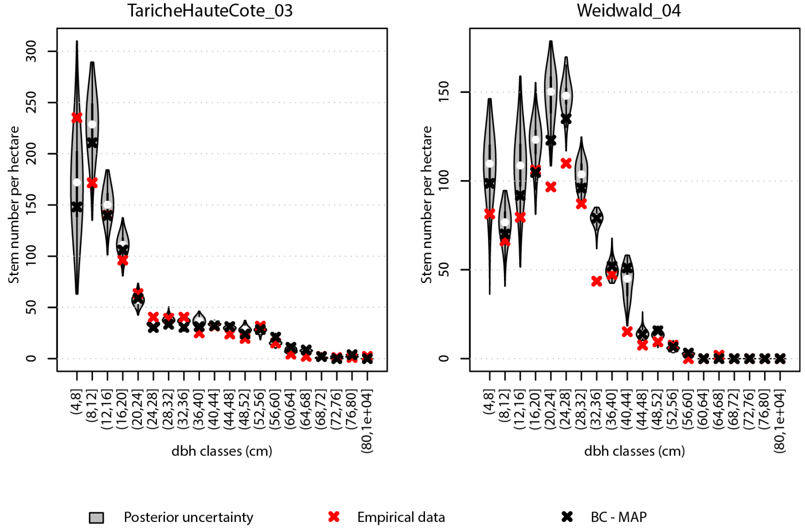
Results: Calibration

Log-likelihoods	Stem numbers			Basal area increment		
	ForClim v3.0	IM_Original	IM_Bayes (maxLL)	ForClim v3.0	IM_Original	IM_Bayes (maxLL)
Adenberg_03	-22.9	-22.6	-22.9	-7.2	-13.1	-6.9
BoisdeChenes_02	-16.8	-16.2	-15.8	-1.9	-0.5	-0.8
Fuerstenhalde_01	-13.8	-14.8	-15.0	-3.3	-32.5	-4.6
Girstel_04	-30.2	-27.8	-27.3	-17.3	-14.7	-16.2
Leihubelwald_02	-16.9	-14.3	-14.3	-21.6	-4.3	-11.7
Nationalpark_07	-10.5	-8.8	-8.9	-2.2	-6.3	-5.7
St.Jean_01	-23.1	-19.9	-19.4	-24.9	-3.9	-2.8
TaricheHauteCote_04	-30.4	-23.8	-24.8	-14.6	-17.4	-9.4
VormStein_02	-21.6	-17.5	-17.3	-29.8	-11.7	-13.3

- Empirical, calibrated mortality model performs better than original algorithm
- But: stem number vs. basal area increment

Bircher et al. (2015), *in prep.*

Results: Validation



Bircher et al. (2015), *in prep.*

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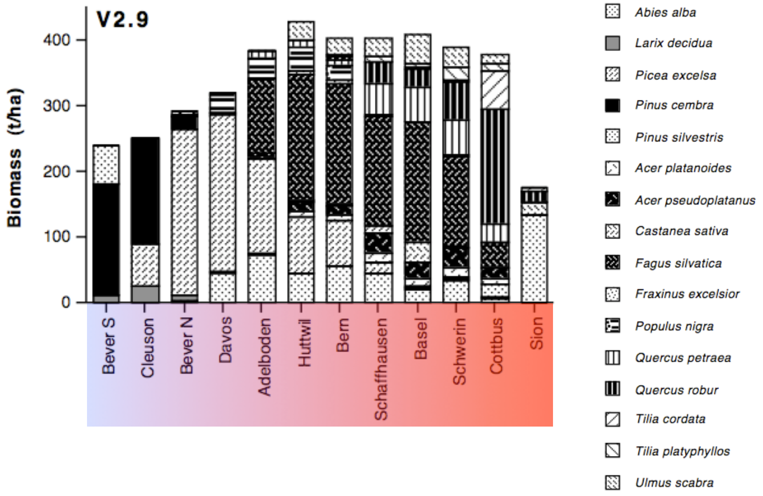
...but how about long-term PNV?



Bugmann & Solomon (2000), *Ecol Appl;* cf. Didion et al. (2009), *CJFR*

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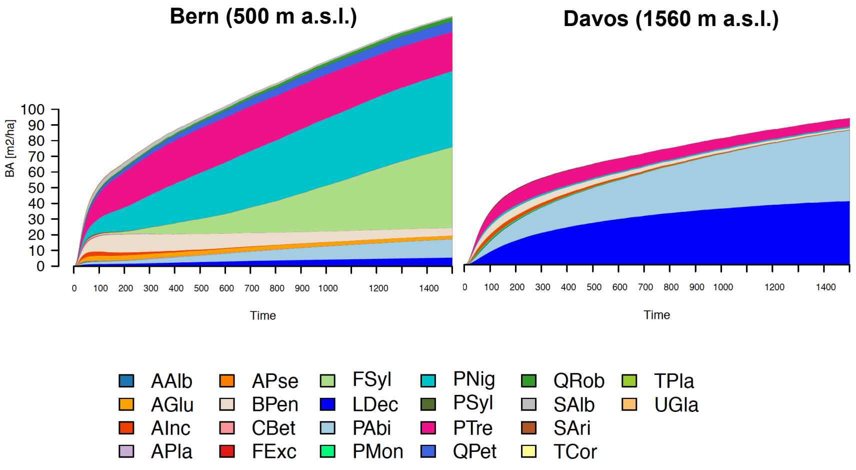

Bircher (2015), *PhD Thesis*

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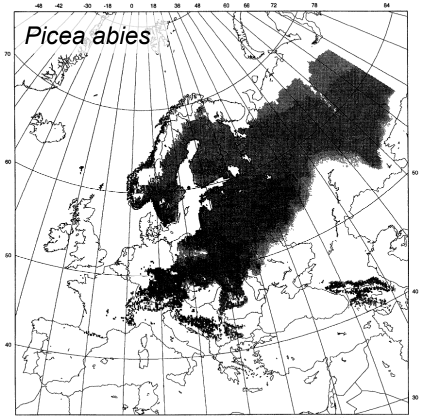
Temporal scaling issues

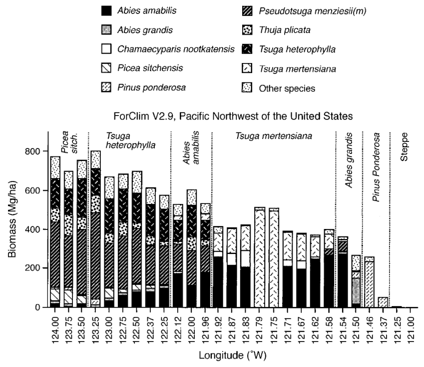
- “The biggest abstraction you can make is…
  … to take a measurement” (T. Allen)
- 50 years is *very* short for forest dynamics
- Fitting a model to a specific period in time may be problematic and hamper its predictive capability
- Calibration must be restricted to a few parameters only – this may lead to “compensation in fitted parameters for erroneous, non-fitted parameters”
- Perhaps it’s better to be
  approximately right
  than to be
  exactly wrong

Let’s look at things in space then…



Distribution = *ƒ*(DD, minTw, Dr)

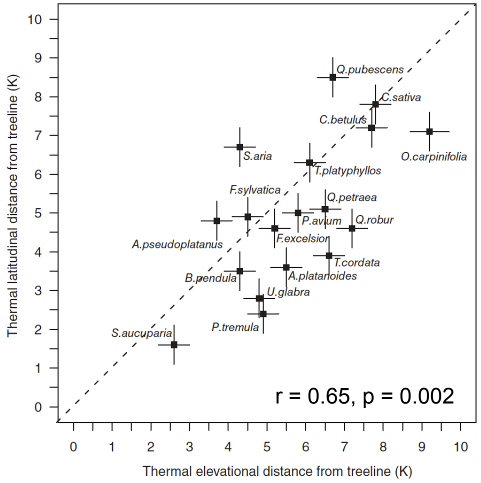
Sykes et al. (1996), *J Biogeogr*



Abundance
= *ƒ*(DD, minTw, Dr; comp)

Bugmann & Solomon (2000), *Ecol Appl*

Maybe the two worlds match?



Randin et al. (2014), *Glob Ecol Biogeogr*

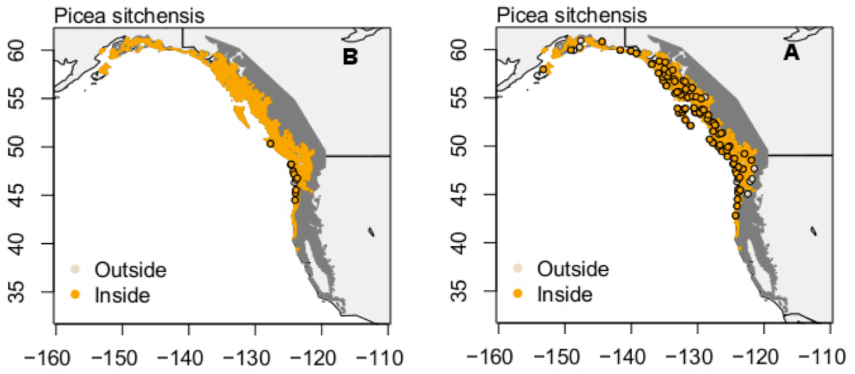
"Dynamic vegetation models should be used to [study species range dynamics] and can improve our understanding of the factors that influence species range expansions and contractions."

Snell et al. (2014), *Ecography*

Distribution-wide applicability… or not?

Performance of latest model version (yr 2014) in PNW…

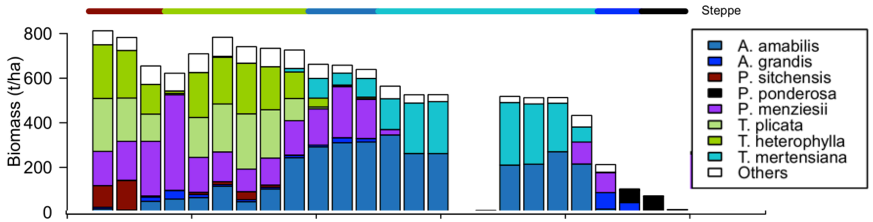
… with 'local' parameterization … with 'global' parameterization



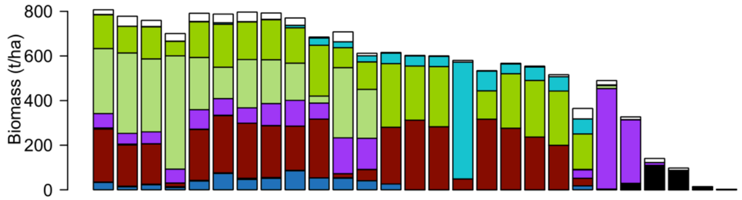
Gutierrez et al. (2015), *submitted*

Distribution-wide applicability… or not?

'Local' parameterization



'Global' parameterization



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Spatial scaling issues

- A species is a species is a species… ?
- Inaccurate parameterization… (climate data, distribution data) ?
- Large-scale bioclimatic constraints are not ‘fine’ enough for small-scale applications… ?
- We simply don’t understand well enough the biophysical limits of (tree) species… ?
- Or a combination thereof… ?

NB: If we want to do better, we need to do better for 30 / 72 / 20 / 18 species simultaneously (EUR / ENA / PNW / NEC)

Conclusions

- Dynamic models are important tools for assessing possible future trajectories of forest stands
- Succession models are remarkably ’realistic’ (e.g., simulations of PNV)
- They have become quite accurate in tracking measured ‘long-term’ data of forest structure and composition (Growth-And-Yield; Reserves)
- Data-model fusion is highly promising
- Yet, calibration to specific conditions (in time and space) leads to dramatic deterioration of performance when scaling is attempted
- Need to disentangle the various explanations that may underlie the apparent need for scale-dependent parameterizations
- The good news is: we don’t run out of work! ☺