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Modélisation de la dynamique forestière dans un climat changeant : robustesse des approches et perspectives d'avenir

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Contents

50+ years of individual-based forest models

- Individual-based models of forest dynamics available since (at least) 1972

> SOME ECOLOGICAL CONSEQUENCES OF A COMPUTER MODEL OF FOREST GROWTH
>
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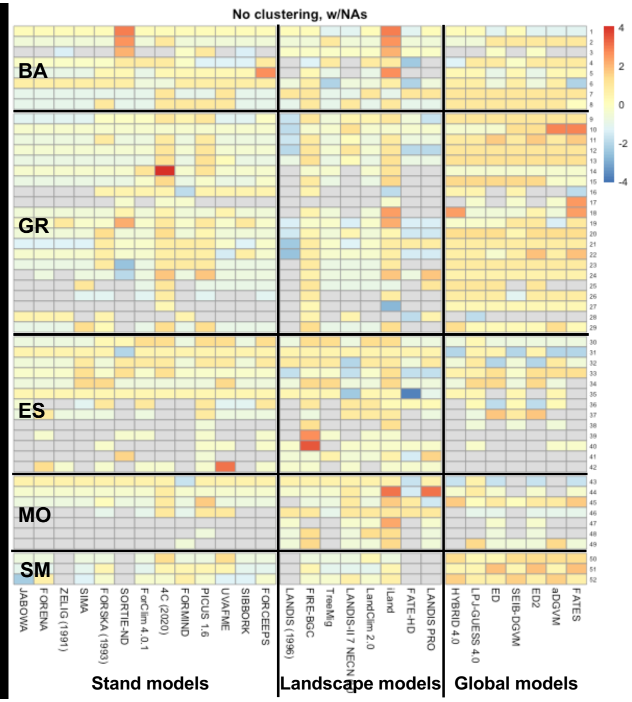
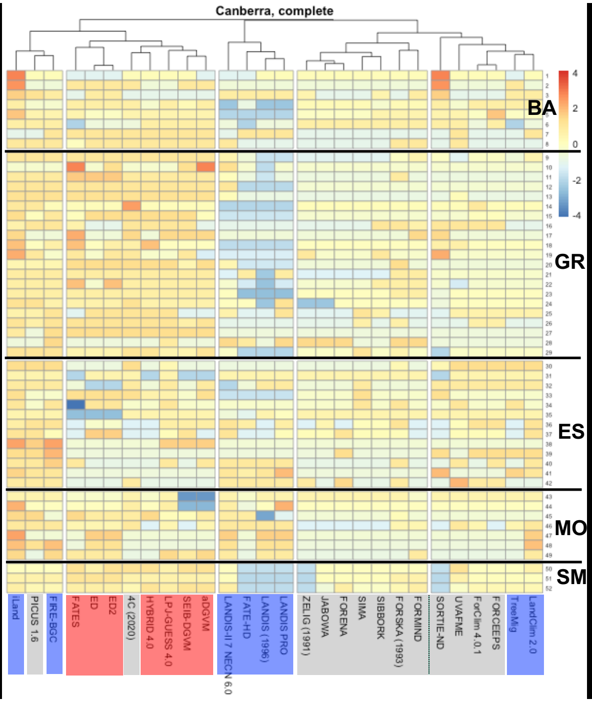
>
> INTRODUCTION
>
> The complexity of a forest ecosystem makes difficult any attempt to synthesize knowledge about forest dynamics or to perceive the implications of information and assumptions regarding forest growth. Although digital computer simulation seems to offer a potential

- Today, available at stand across landscape to global scales
- Assessment of 28 models that have been used after 1996 for simulating climate change impacts
- Criteria: complexity of model attributes

Bugmann & Seidl (2022), *J Ecol*





Summary of results

Tab. S1: a) Average complexity of the attributes of the respective process group by model type. b) Diversity (expressed as the standard deviation) of the complexity of the attributes of the respective group. Green, orange and red shading of the cells indicates highest, intermediate, and lowest complexity or diversity per attribute group, respectively.

Average complexity

a)	Stand models	Landscape models	Global models
BA	-0.01	-0.19	0.24
GR	-0.13	-0.40	0.70
ES	0.02	0.29	-0.37
MO	-0.30	0.54	-0.06
SM	-0.13	-0.56	0.88


Received: 19 March 2022 | Accepted: 1 August 2022
Journal of Ecology
RESEARCH ARTICLE
The evolution, complexity and diversity of models of long-term forest dynamics
Harald Bugmann[1,2] | Rupert Seidl[2,3]

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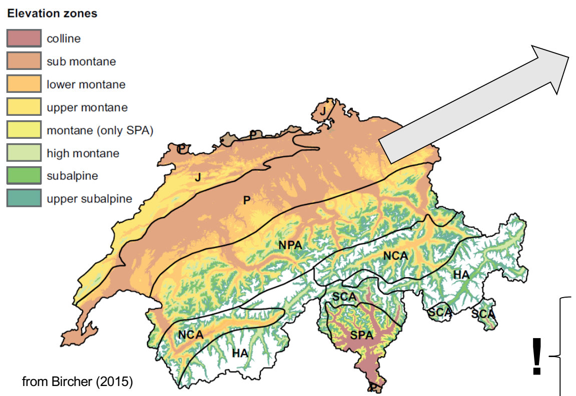
1. Where are we standing after 50+ years of individual-based modeling?
2. A climate impact study for Swiss forests
3. Drought and forest dynamics
4. Summary and conclusions

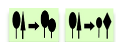
A Swiss climate impact study

Aim: *High-resolution* („local-scale") assessment of the *climate* sensitivity of *managed* forests at the *national* scale (🇨🇭)



71 typical stands derived from SNFI (Bircher 2015, *PhD ETHZ*)

2 species pools

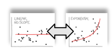


Uncertainties

3 CC scenarios + 1 historic climate

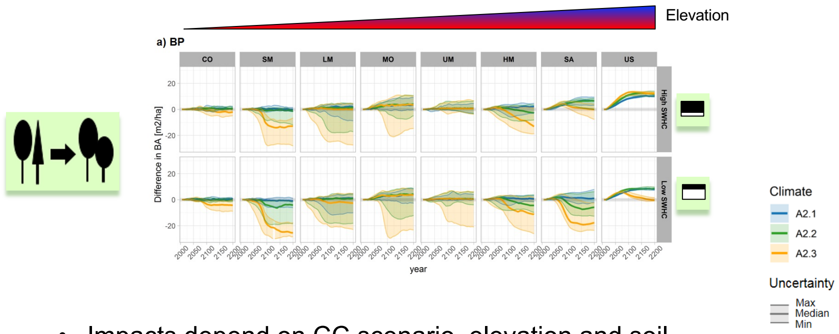
! **2 soil types**

8 versions of ForClim model



Huber et al. (2021), *Ecol Appl*

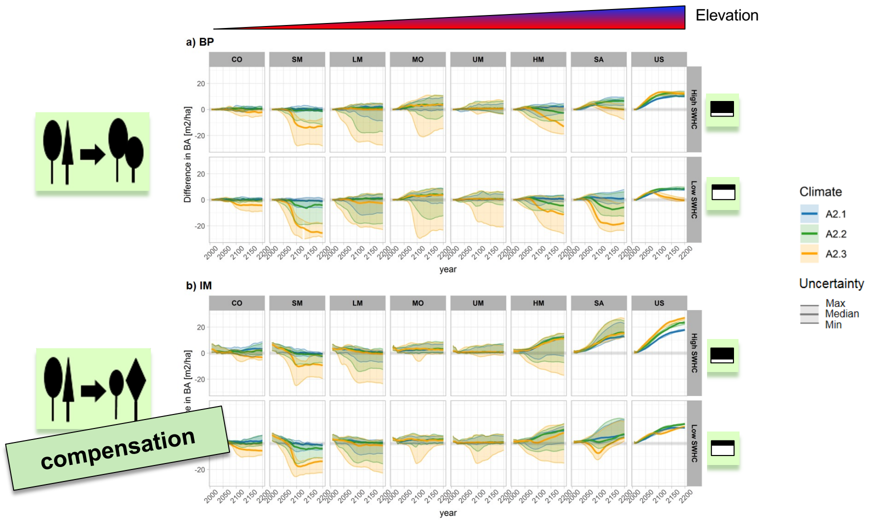
Summary results: Stand basal area



- Impacts depend on CC scenario, elevation and soil
- Increasing CC severity leads to increasingly negative impacts at low elevations
- Strong negative changes start after ≈2050

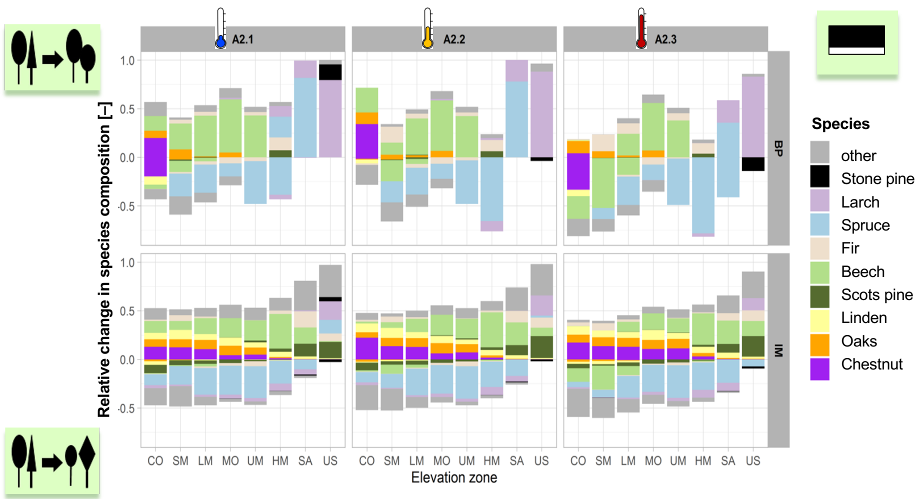
Huber et al. (2021), *Ecol Appl*

Summary results: Stand basal area



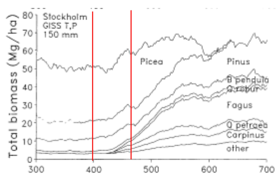
Huber et al. (2021), *Ecol Appl*

Summary results: Species composition

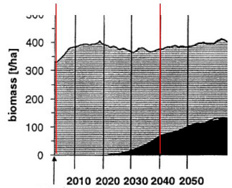


Huber et al. (2021), *Ecol Appl*

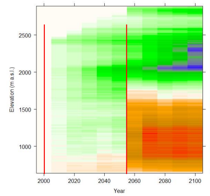
How robust are such results? A comparison



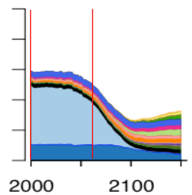
FORSKA; Prentice et al. (1991)



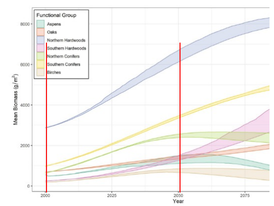
PICUS; Lexer et al. (2002)



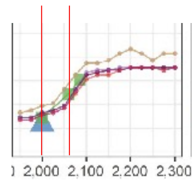
LandClim; Elkin et al. (2013)



ForClim; Elkin et al. (2013)



LANDIS-II; Olson et al. (2021)



TreeMig; Scherrer et al. (2021)

Modeling studies consistently show a **lag** of approximately **50-70 years** between the start of the climate change signal and the start of strong changes in forests: 1980 + 60 ≈ 2040 ☹

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The classical concept

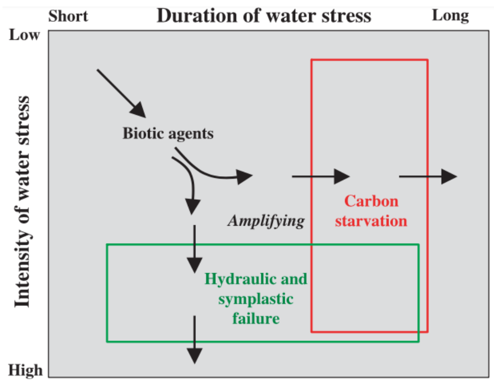


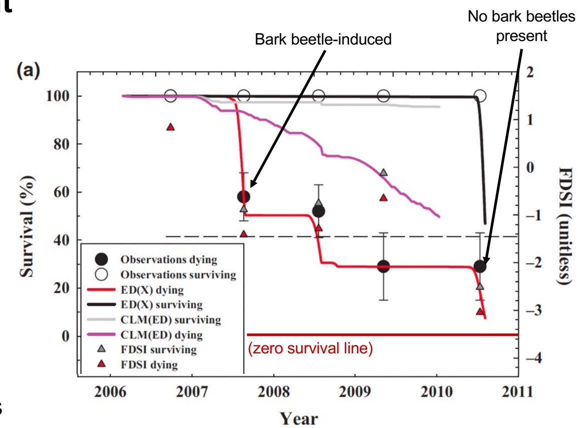
Fig. 3 Theoretical relationship, based on the hydraulic framework, between the temporal length of drought (duration), the relative decrease in water availability (intensity), and the three hypothesized mechanisms underlying mortality. Carbon starvation is hypothesized to occur when drought duration is long enough to curtail photosynthesis longer than the equivalent storage of carbon reserves for maintenance of metabolism. Hydraulic failure is hypothesized to occur if drought intensity is sufficient to push a plant past its threshold for irreversible desiccation before carbon starvation occurs. Biotic agents, such as insects and pathogens, can amplify or be amplified by both carbon starvation and hydraulic failure.

McDowell et al. (2008), *New Phytol*

But prediction is hard, even in hindsight...

Sevilleta (NM) drought experiment, model assessment

- FINNSIM
- Sperry model
- TREES
- MuSICA
- **ED(X)**
- **CLM(ED)**



Mortality rate tuned as *threshold minimum NSC* per unit leaf area

McDowell et al. (2013), *New Phytol*

A global attempt

Journal of Ecology 2015, **103**, 31–43 doi: 10.1111/1365-2745.12335

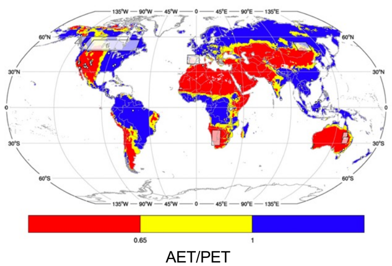
SPECIAL FEATURE

FOREST RESILIENCE, TIPPING POINTS AND GLOBAL CHANGE PROCESSES

Is drought-induced forest dieback globally increasing?

Jörg Steinkamp[1,2*] and Thomas Hickler[1,2,3]

4. *Synthesis.* Our results indeed suggest that dry forests have been experiencing increasing drought-induced mortality. However, this does not apply to forests in general and the spatial variability has been large. The poor correspondence between the simulated and reported mortality events indicates that models like LPJ-GUESS driven by standard climatologies, and soil input data do not represent drought-induced mortality well.

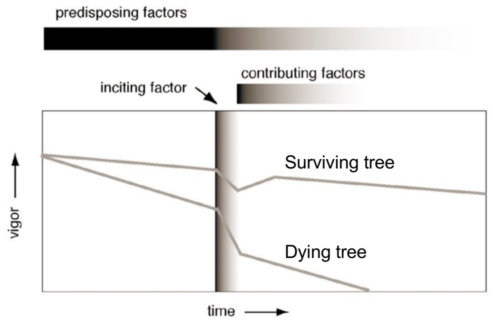


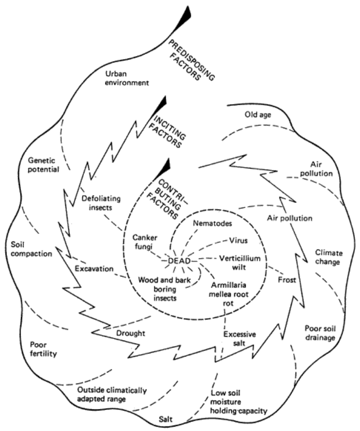
$$mort_{greff} = \frac{0.3}{1 + \left(\frac{greff_{mean}}{greff_{min}}\right)^5}$$

Steinkamp & Hickler (2015), *J Ecol*

I have questions

- Why C starvation and hydraulic failure; why either-or?
- What is cause, what is effect? Think of VPD, cavitation
- Additional mechanisms?





Manion (1981), *Tree Disease Concepts*
Bigler (2003), *PhD ETH Zurich*

A new approach (1/2)

- Predisposing factor for drought-related mortality

Material Unpublished Pls Respect

$$DrM = \begin{cases} DrM + 1, & gDr > kDrTh \cdot kDrTol_s \\ 0, & else \end{cases}$$

[0.1…0.3] chose 0.2

$$gDr = \begin{cases} 1 - \sum_{T_m \geq k} \frac{E_m}{D_m} & (annual) \\ 1 - \sum_{T_m \geq k\ m \in \{Apr \ldots Oct\}} \frac{E_m}{D_m} & (seasonal) \end{cases}$$

Bugmann & Solomon (2000), *Ecol Appl*

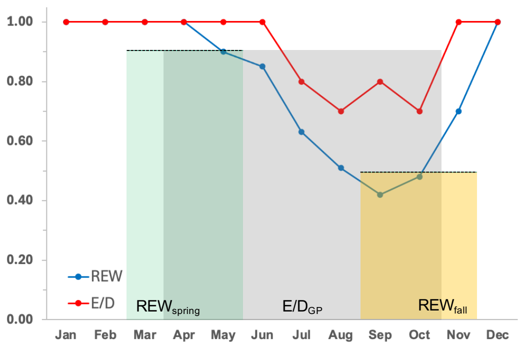
Marano et al. (2025), *in review*

A new approach (2/2)

- Inciting factor for drought-related mortality

Material Unpublished Pls Respect

$$IncFDr = \begin{cases} 1, & (SM_{spring} < kREW_{spring} \cdot kBS) \wedge (SM_{fall} < kREW_{fall} \cdot kBS) \wedge gDrD > kD \\ 0, & else \end{cases}$$



REW: Relative extractable water
(Bréda et al. 2006, *Ann For Sci*)

E/D: Ratio of supply (≈transpiration) and demand (≈PET) of soil water in the rooting zone
(Bugmann & Solomon 2000, *Ecol Appl*)

Marano et al. (2025), *in review*

Parameter estimation

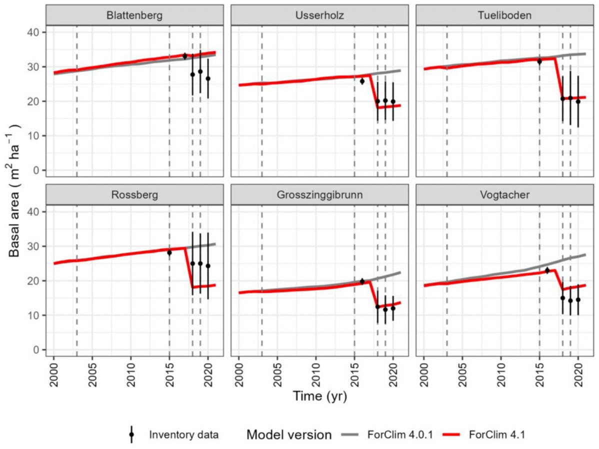
Material Unpublished Pls Respect

- All parameters derived by ecological reasoning, based on literature review
- Sensitivity test around values deemed plausible
- No formal calibration against measured mortality data

Does this make sense?

- Yes, we think so…

Test 1: Six mesic beech-dominated sites

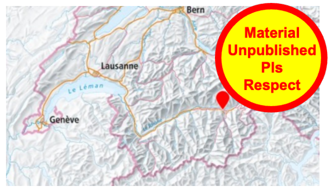


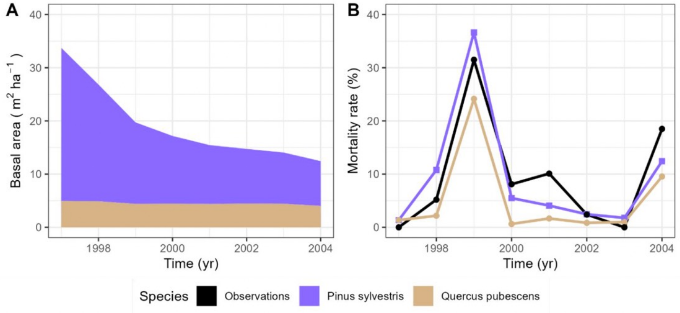
T = {8.6…9.5} ℃
P = {974…1223} mm

Observations are (reconstructed)
stand-level basal area

Data from Neycken et al. (2022), *Agr For Met*
Simulations from Marano et al. (2025), *in review*

Test 2: Xeric Scots pine (!) site



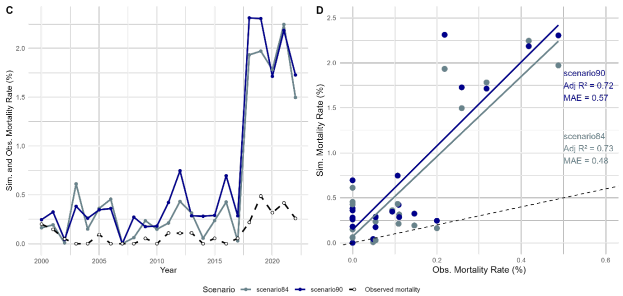


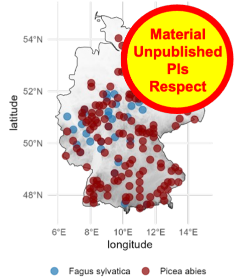
T = 9.9 ℃
P = 591 mm

Observations are
stand-level mortality rates

Data from Hunziker et al. (2022), *Front Glob Change*
Simulations from Marano et al. (2025), *in review*

Test 3: German ICP Level I sites, beech



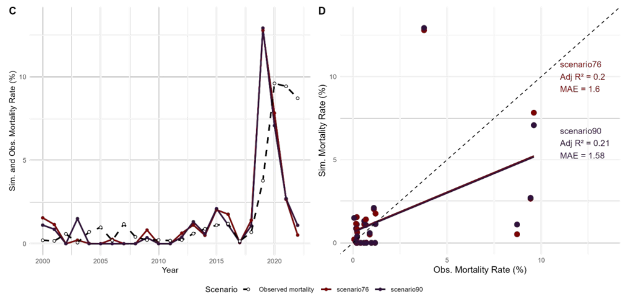


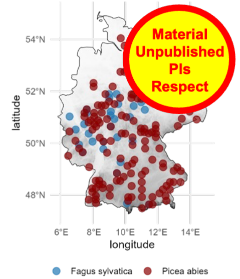
T = {5.3…10.5} ℃
P = {549…2063} mm

Observations are
drought-related mortality rates
among *24 dominant sample trees* (n_{dead} = 51)
Simulations show
all stress-related mortality, DBH > 40 cm

Data via Wellbrock et al. (2018), *Thünen Working Paper* 84
Simulations from Marano et al. (2025), *in prep.*

Test 4: German ICP Level I sites, spruce





T = {5.3…10.5} ℃
P = {655…2182} mm

Observations are
drought-related mortality rates
among *24 dominant sample trees*
Simulations show
all stress-related mortality, DBH > 40 cm

ForClim v4.2, includes a simple bark beetle submodel
Data via Wellbrock et al. (2018), *Thünen Working Paper* 84
Simulations from Marano et al. (2025), *in prep.*

So what does this imply?

- Any model represents a *hypothesis* about reality (i.e., what is going on in forest ecosystems, in our case)
- Testing that hypothesis based on approximate parameter values may be preferable over calibration (e.g., problem of overfitting)
- In the case of drought-related mortality "mechanisms", we may not know enough for a truly mechanistic representation based on ecophysiological processes
- Thus, "mechanistically inspired", phenomenological approaches may be preferable (as done here)

Summary and Conclusions

- A **wide variety of models** is available and has been used to project impacts of climate change on forests – with very different backgrounds and complexity: this is an **asset**
- Models provide a **nuanced view on regional impacts** (e.g. Switzerland along elevation), no "one size fits all"
- **Soil conditions** are quite important, need **more focus**
- Models *consistently* suggest onset of **strong forest changes** ca. 50-70 years after the start of climate change: ≈2040 (!)
- **Disturbances** (not accounted for here except for drought) will accelerate response
- **Drought-related mortality** episodes can be **predicted** better by a **phenomenological approach** than by ecophysiology
- The tension between "**simple is beautiful**" *vs.* "**complex is needed**" remains

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Thanks for listening!

Your questions, comments, concerns... ?