Assessing the existence of alternative stable states in central African forests

FOREM seminary

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Post-doc: 15th january 2024 - 30th june 2025

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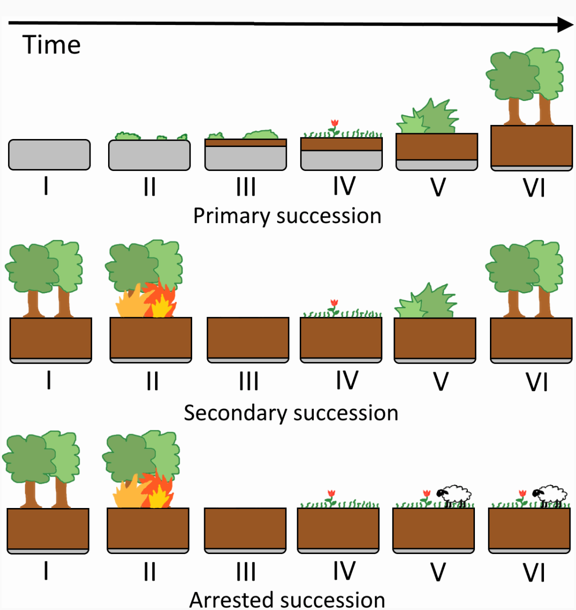
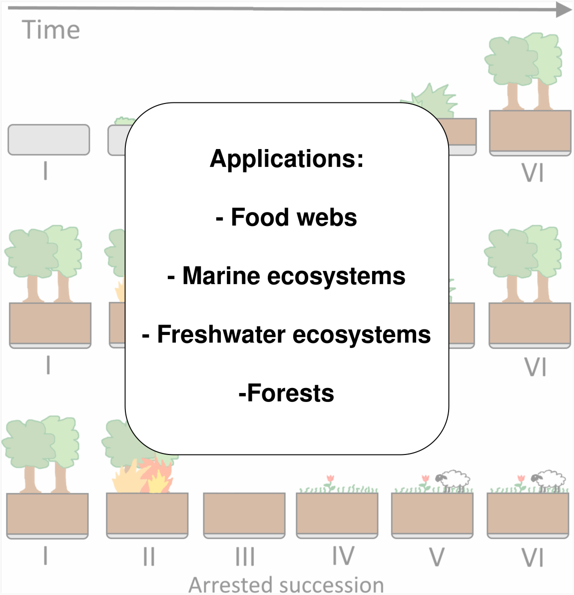
Overview

I. Conceptual framework and case of Marantaceae forests

Ecological successions



Ecological successions



Applications:

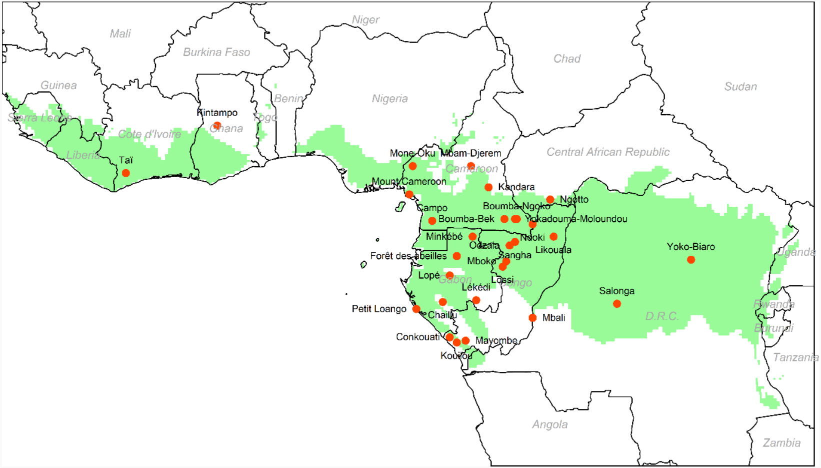
- Food webs

- Marine ecosystems

- Freshwater ecosystems

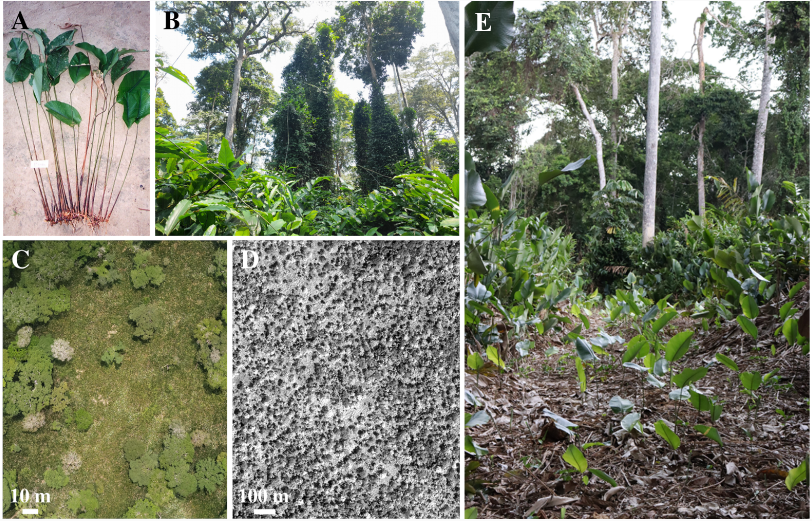
-Forests

Marantaceae forests in Africa



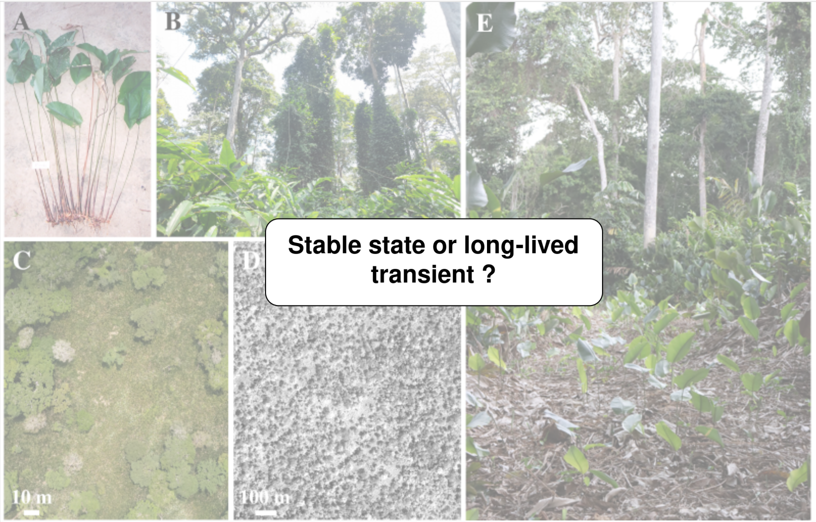
The **Marantaceae forests occurrences** in whole Africa (Pouteau et al. (2024)).

Marantaceae forests



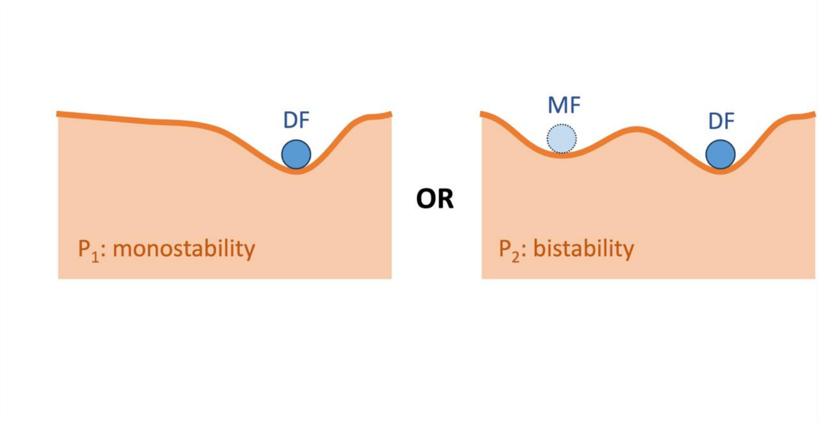
The **Marantaceae forests** at different scales (Pouteau *et al.* (2024)).

Marantaceae forests



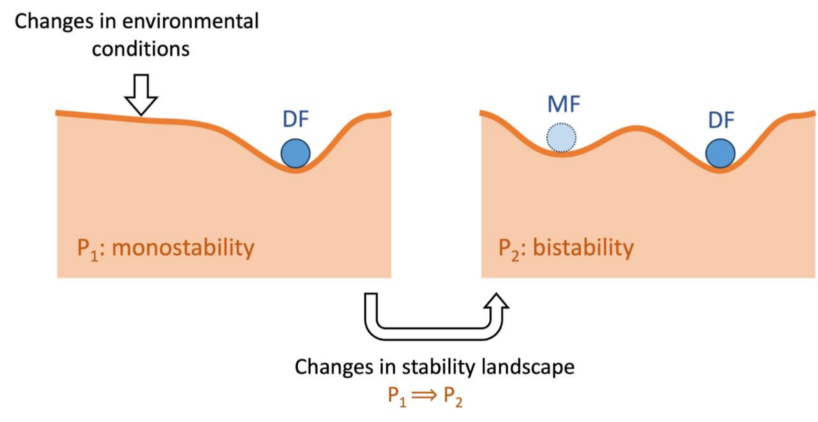
The **Marantaceae forests** at different scales (Pouteau *et al.* (2024)).

Ecological questions



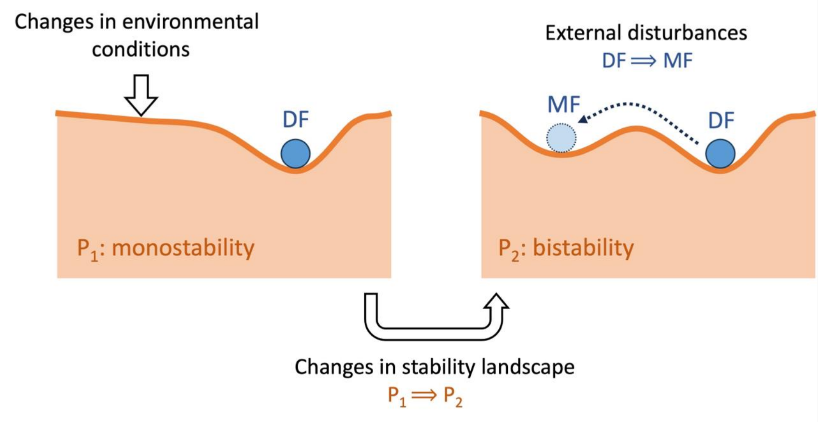
Are the Marantaceae forests stable ?

Ecological questions



What are the conditions of their stability ?

Ecological questions



What disturbances can induce a state shift ?

Literature hiatus

Theory of ASS: Lewontin (1969), Holling (1973), May (1977).

Theoretical approaches:

- Conceptual models
- Mathematical development
- Assessment of the model equilibriums
- Lack realism to conclude on the ecosystems' stability

Empirical approaches:

- Empirical model
- Field data analyses
- Embrace the complexity of real ecosystems
- Raise only probable conclusions

Our numerical approach

I. Defining a **conceptual model** of Marantaceae forests.

II. Estimating the model **parameters** together with their **variability**.

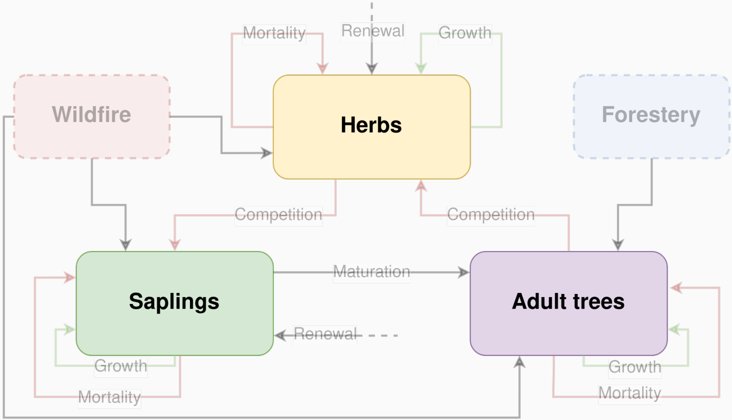
III. Identifying **key system behaviours**.

IV. Constraining the model to **reproduce the behaviours** with calibrations **around the estimates**.

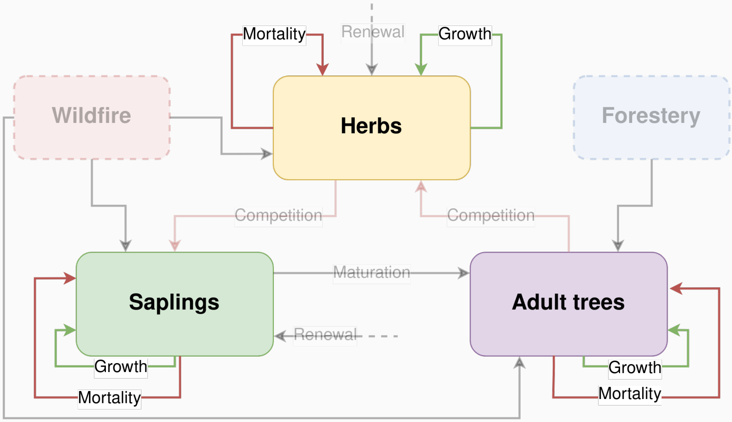
V. **Assessing equilibriums numerically** to identify stable states.

II. Defining the conceptual model

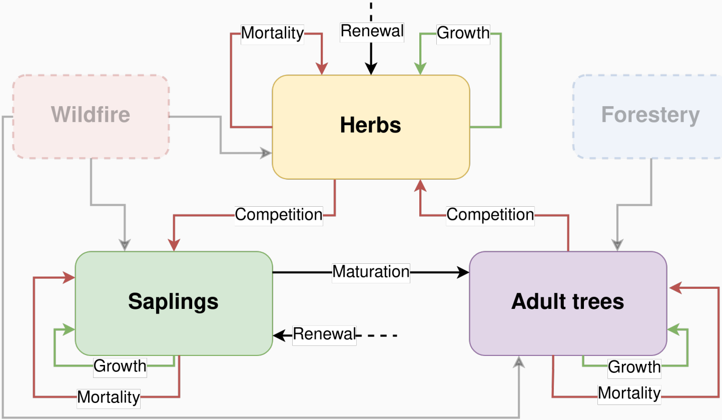
Biomass model for Marantaceae forests



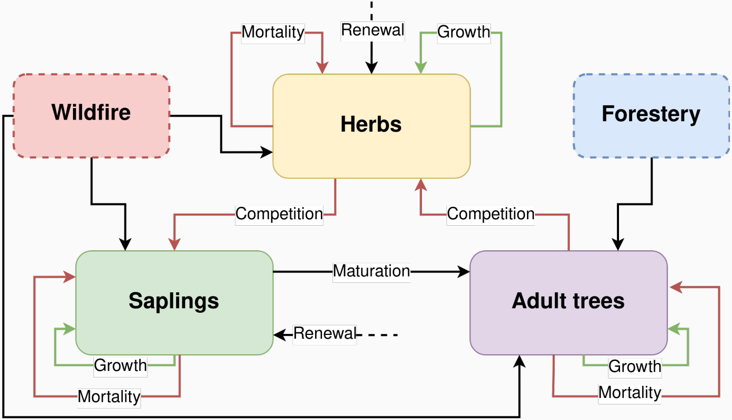
Biomass model for Marantaceae forests



Biomass model for Marantaceae forests



Biomass model for Marantaceae forests



The model: Age-Structured ODE

$$\begin{cases} \frac{dT_S}{dt} = (\gamma_S T_S + r_S)\left(1 - \frac{T_S + S_{TA}}{K_T}\right) - (\mu_S + \omega + \sigma_{H-S} H \frac{\nu T_S^2}{1+\nu T_S^2}) T_S \\ \\ \frac{dT_{A,i}}{dt} = \mathbb{1}_{i=1} \omega T_S + \gamma_{A,i} T_{A,i} \left(1 - \frac{T_S + S_{TA}}{K_T}\right) - (\mu_A + \mathbb{1}_{i<N} \Phi) T_{A,i} + \mathbb{1}_{i>1} \Phi T_{A,i-1}, \\ \\ \frac{dH}{dt} = (\gamma_H H + r_H)\left(1 - \frac{H}{K_H}\right) - (\mu_H + \sigma_{A-H} S_{TA}) H \end{cases}$$

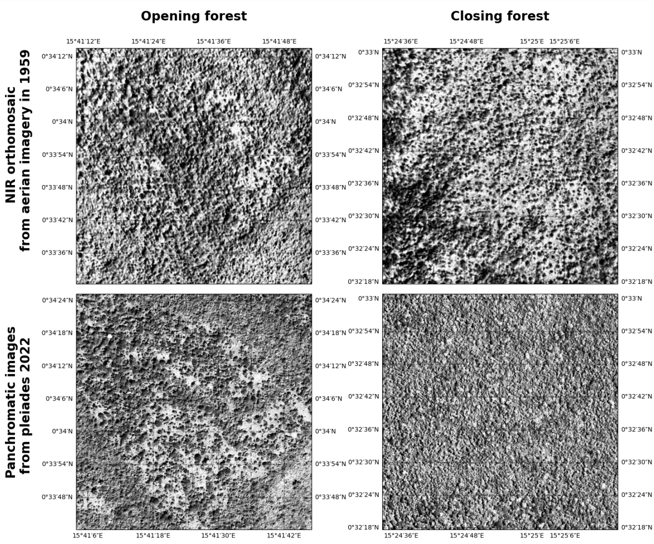
With

$$S_{TA} = \sum_{i=1}^{N} T_{A,i}$$

$$\gamma_{A,i} = \frac{log(AGB(D_i + \gamma_D)) - log(AGB(D_i))}{1}$$

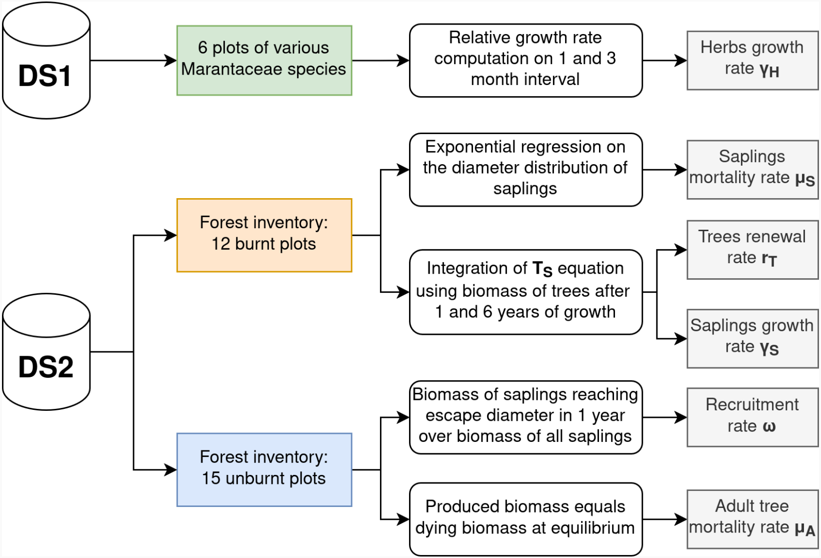
III. Analysis of remote sensing images and field data

NIR aerial images from 1959's campaign



Forest states **transitions** between 1959 and 2022.

Parameters estimation



IV. Calibration and equilibriums assessment to identify stable states

Calibration and initial conditions

- **Parameters with estimates:** $\mu_A, \mu_S, \gamma_S, \gamma_H, r_T, \omega$.
- **Parameters without estimates:** $\mu_H, r_H, K_T, K_H, \sigma_{AH}, \sigma_{HS}$.
- **Regular sampling** on ranges around estimates or very broad ranges.
- **Initial conditions:**
  - Very Open Marantaceae Forest (VOMF)
  - Dense Forest (DF)

Results classification

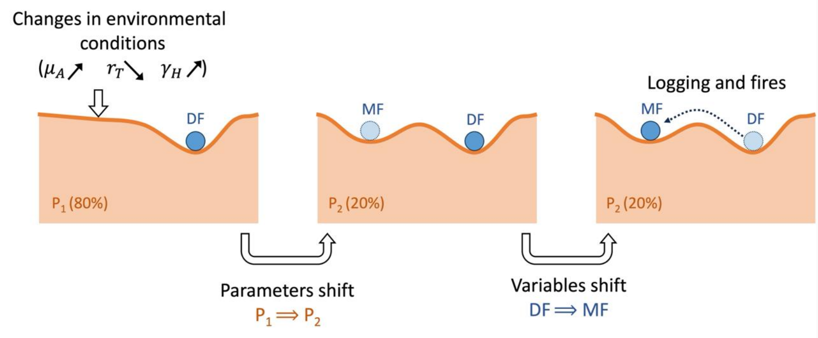
Criterion	All	Monostable DF	Persistent MF	Stable MF
Numbers of sets	6815744	382300	138974	82830
% of all	100	5.6	2.0	1.1
% of monostable DF	/	100	36.4	**20.3**
% of persistent MF	/	/	100	**55.7**

Bistability is achieved when **three environmental conditions** are met:

- Mortality rate of adult tree (μ_A) is high.
- Renewal rate of tree (r_T) is low.
- Growth rate of herbs (γ_H) is high.

Conclusion

Conclusions



- **Stability** of Marantaceae forests is expected to be **more common** in the face of **global changes**.
- **Transitions frequency** will probably **increase** following the droughts and fires intensification.

Perspectives

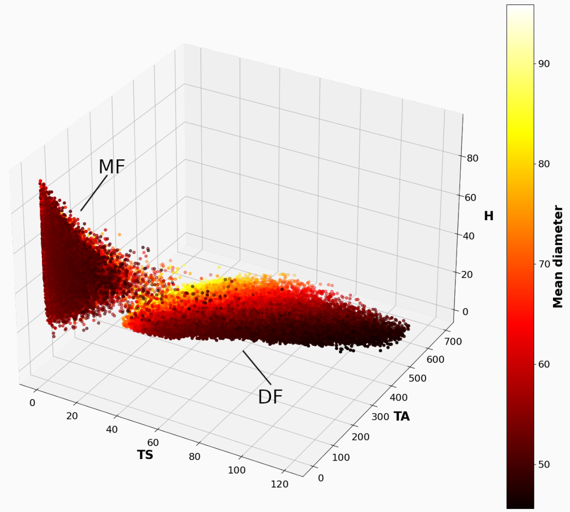
- Integrate a **representation of the disturbances** in the model.
- Links these disturbances to **global warming** in different **GIEC scenarios**.
- **Spatialize** the model.

Thank you for your attention

Bistability conditions

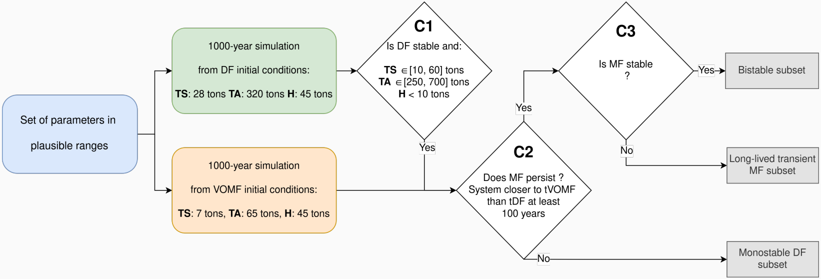
Model parameter ranges for **each behaviour**.

System equilibriums



Model stable states after 1000 years of simulation with reasonable **ranges of parameters** and **initial conditions**.

Results classification



Model result classification according to **three nested criteria** representing three attended behaviours.