Doñana Biological Station (Spain)
IITE Online Theoretical Ecology Seminar Series
Nov 18 2025

The effect on stability of temporal variability of species interactions

Violeta Calleja Solanas

1. Time-varying ecological interactions

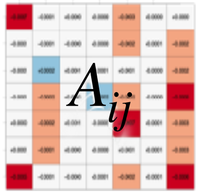
2. Case study

3. Beyond characterisation

Structure + Dynamics: the Lotka-Volterra model

abundance change $\sim$ intrinsic growth + interactions

$$\frac{dN_i}{dt} = N_i \left(r_i + \sum_j A_{ij} N_j \right)$$

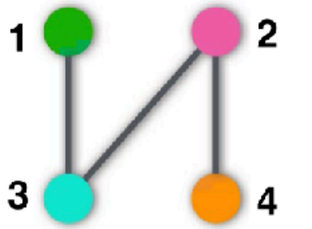


Interactions live here

Direct effect of species *j* abundance on species *i*'s per capita growth rate with all other species held constant.

(Novak 2016)

Limitation: parameters (r & A) considered fixed

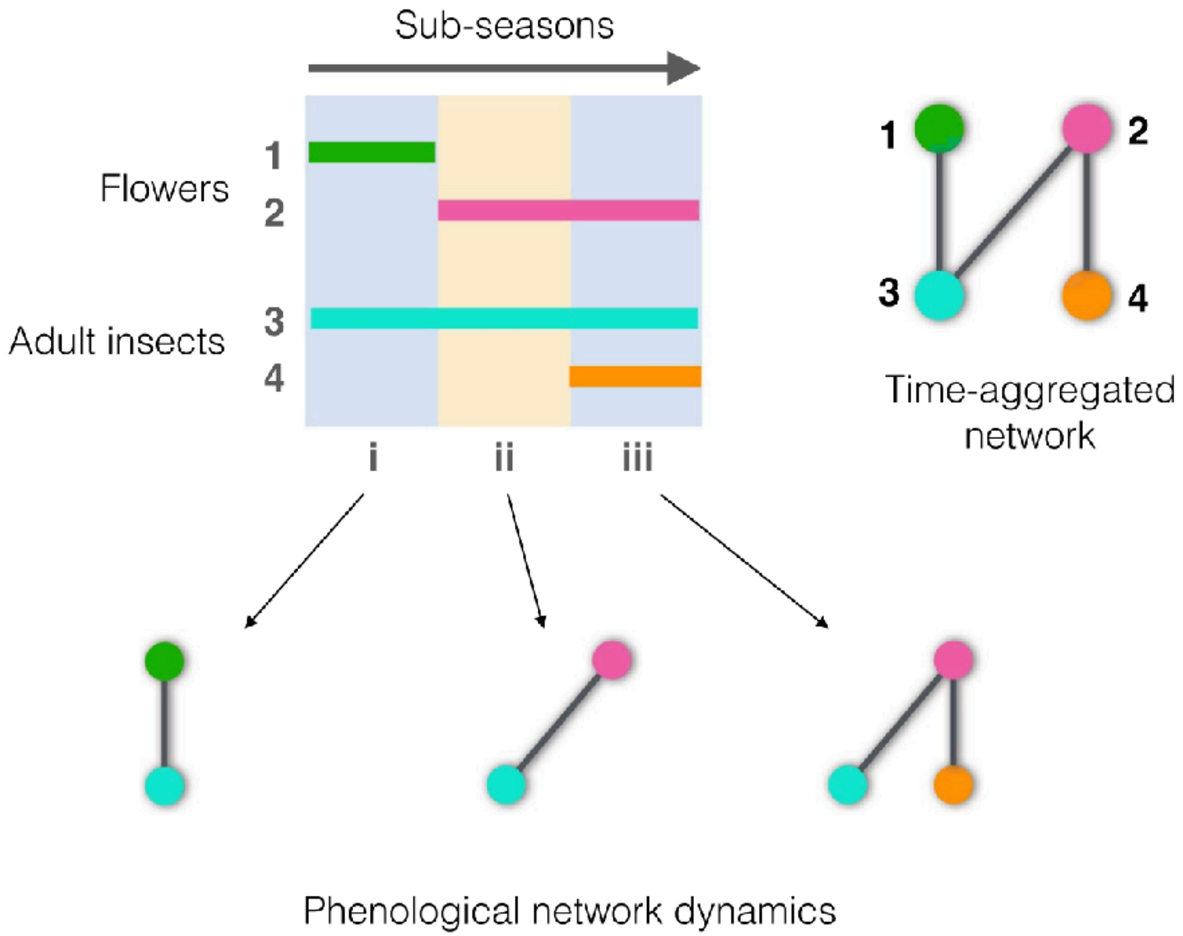


Time-aggregated network

Why would networks vary?
Phenology, migration/extinctions, environmental variability

(Ramos–Jiliberto, Sci Rep 8, 2018)

Limitation: parameters (r & A) considered fixed



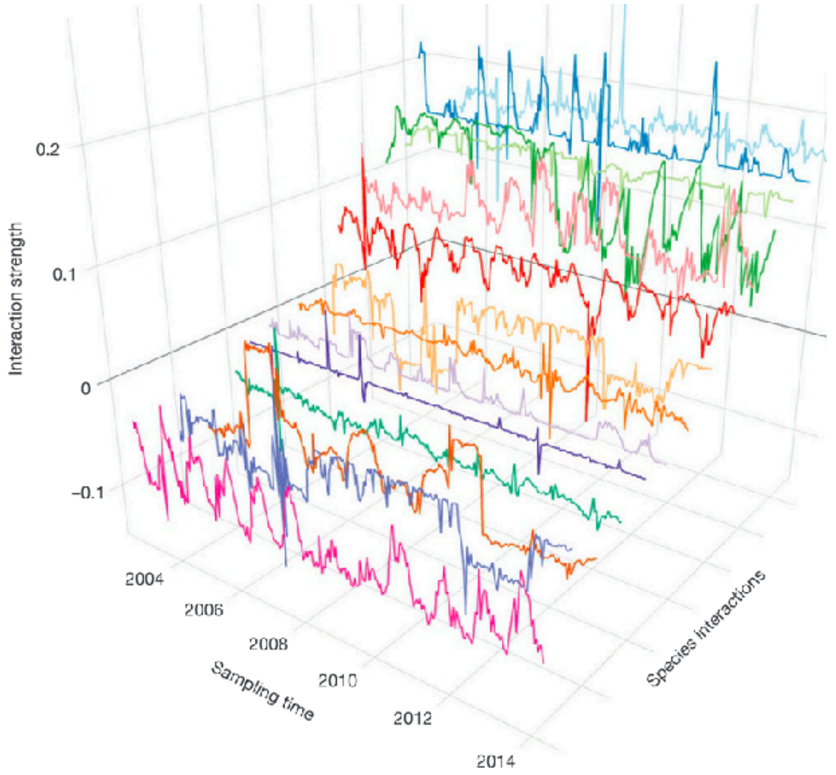
(Ramos–Jiliberto, Sci Rep 8, 2018)

How could networks vary?

Nodes turnover

Links changes of direction, weights, signs

(CaraDonna, Eco Let 20, 2017)



(Ushiro, Nat Lett 554, 2018)

Challenges to overcome

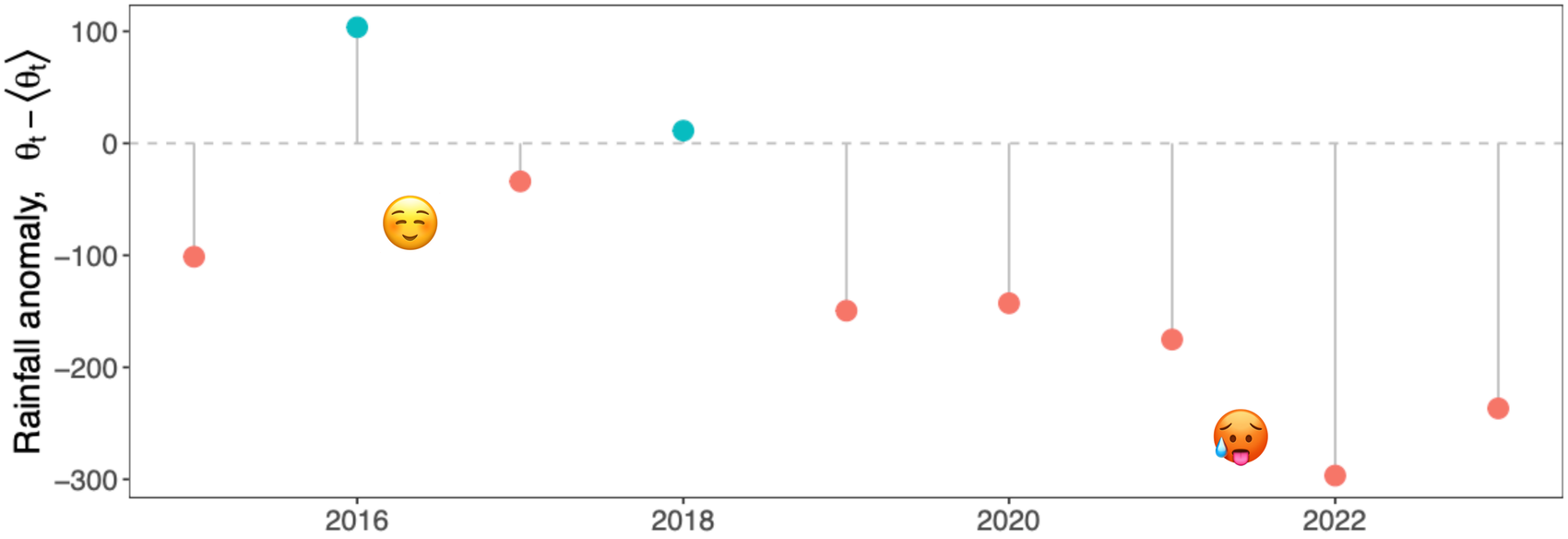
1. Need of long-term data
2. Network inference
3. Theoretical tools

1. Time-varying ecological interactions

2. Case study

3. Beyond characterisation

Shared environmental driver: annual rainfall



How does temporal variability affect coexistence opportunities?

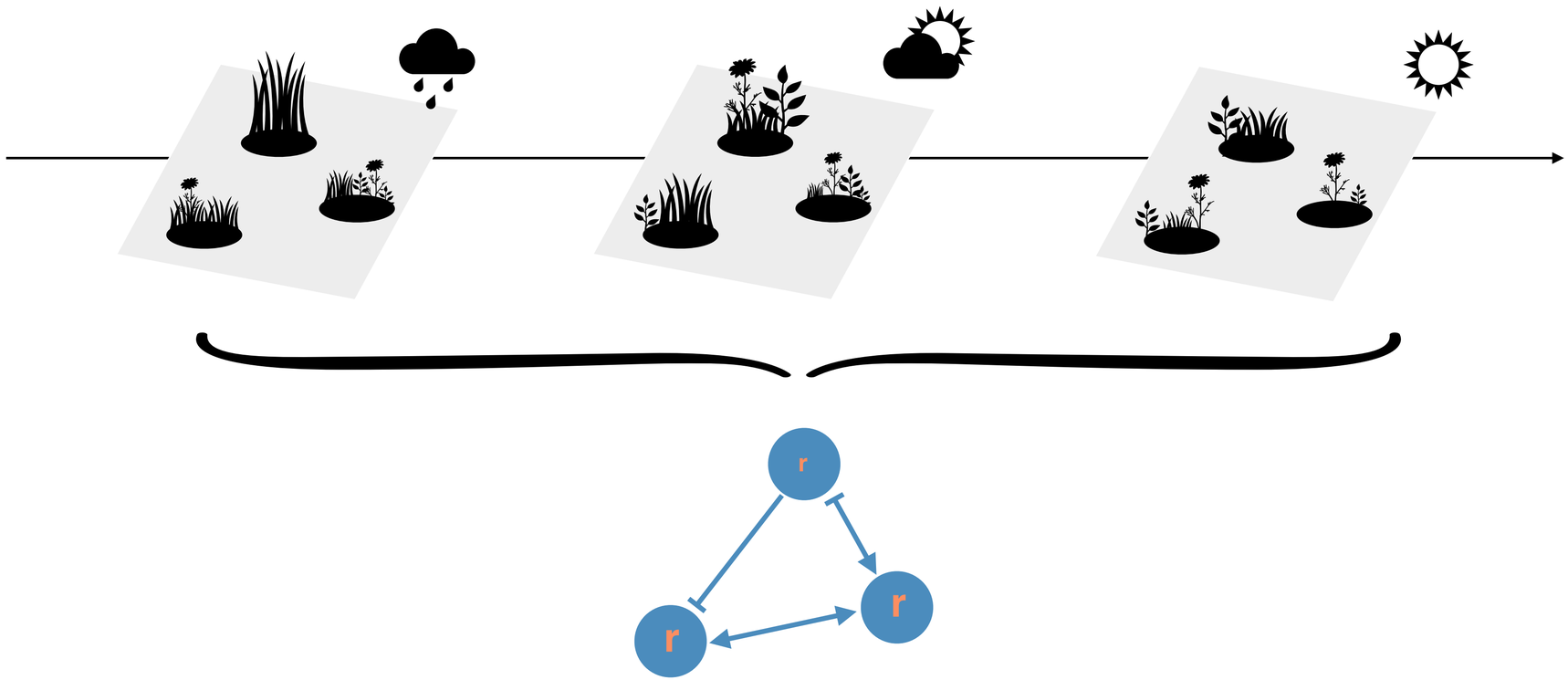
mediated by rainfall

Classical framework

abundance change = intrinsic growth + interactions

$$\log \frac{N_{t+1}^{i,b}}{N_t^{i,b}} = r_i + \sum_j A_{ij} N_t^{j,b}$$

Long-term datasets across multiple sites



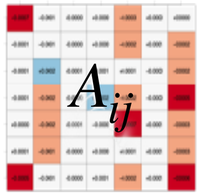
Time-varying framework

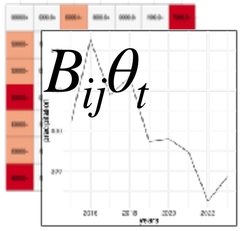
abundance change = time-varying intrinsic growth + time-varying interactions

$$\log \frac{N_{t+1}^{i,b}}{N_t^{i,b}} = r_i + r_i'\theta_t + \sum_j A_{ij}N_t^{j,b} + \sum_j B_{ij}N_t^{j,b}\theta_t + u_{i,b,t}'$$

random effects

Temporal deterministic effect = environmental (rainfall) effects r_i' and B_{ij}





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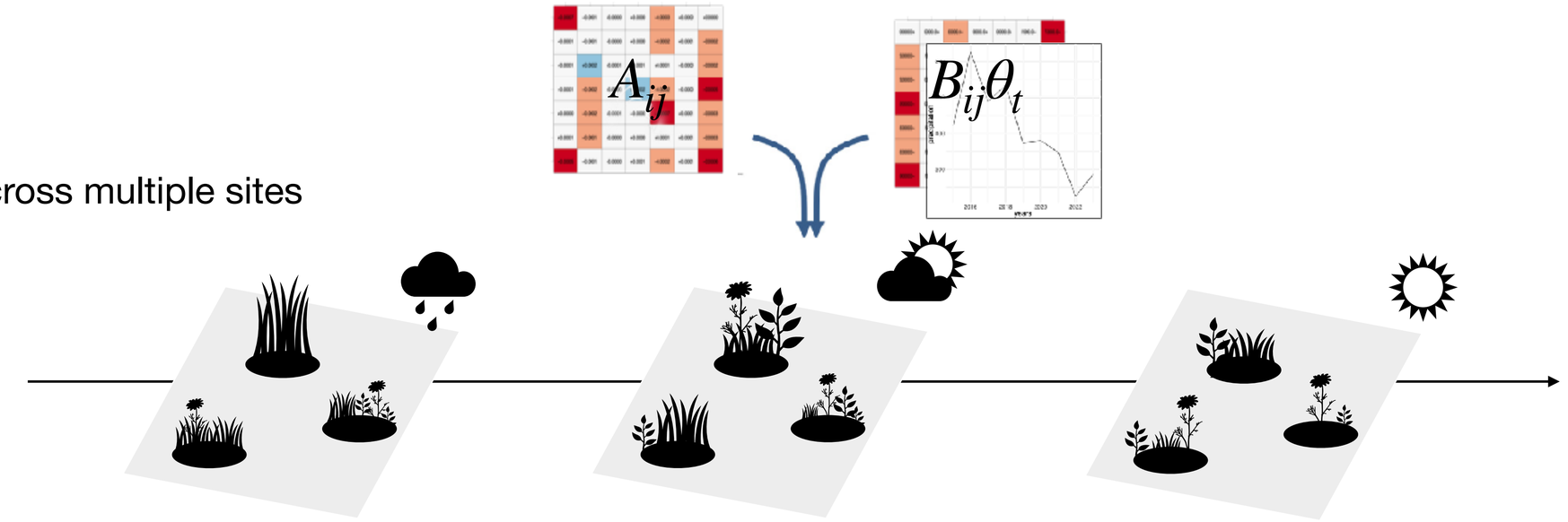
random effects

Long-term datasets across multiple sites



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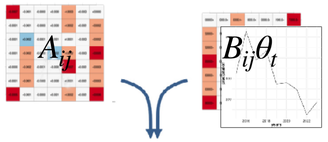
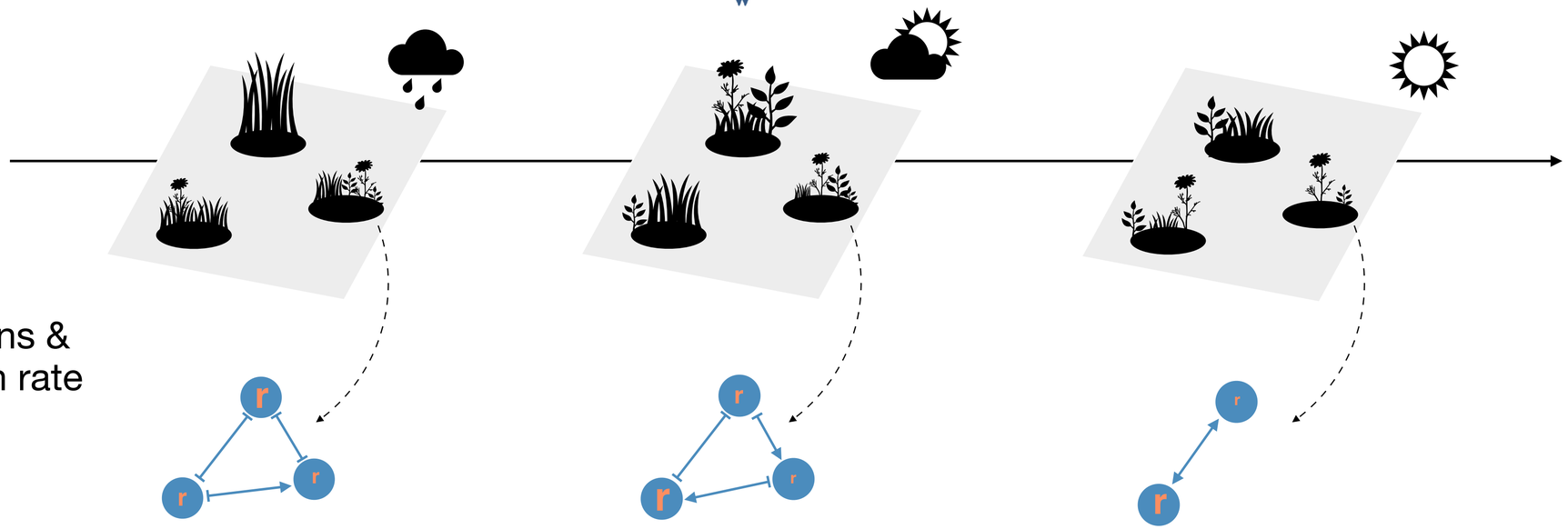
random effects

Long-term datasets across multiple sites



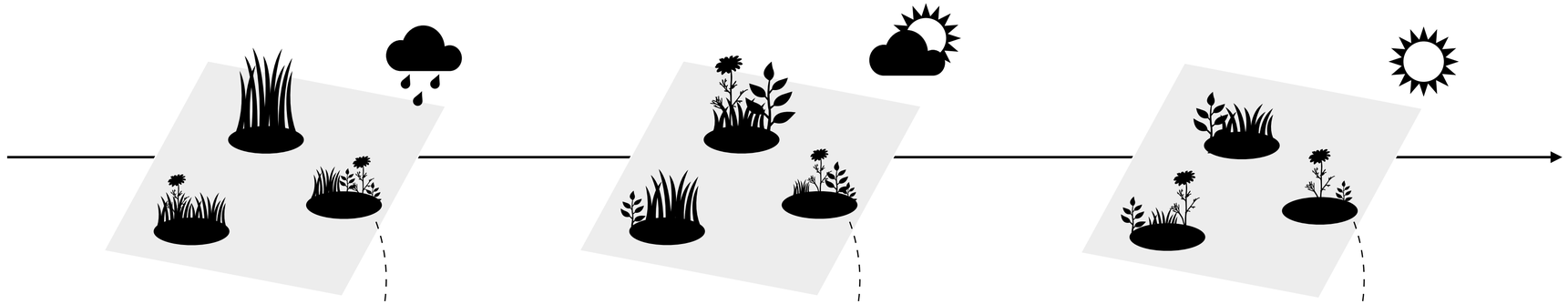


Time-varying interactions & species intrinsic growth rate

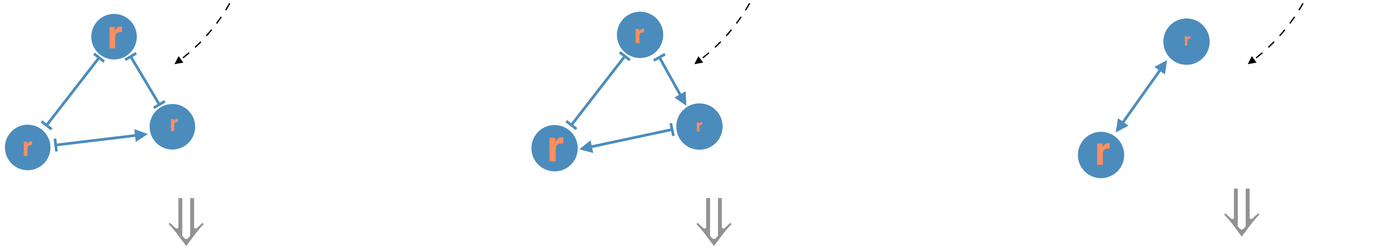
Time-varying framework

abundance change = time-varying intrinsic growth + time-varying interactions

Long-term datasets across multiple sites



Time-varying interactions & species intrinsic growth rate



Consequences for diversity

coexistence opportunities

Challenges to overcome

1. Need of long-term data → rich annual datasets
2. Network inference → GLME modelling
3. Theoretical tools → Metrics and Structural stability

Results

Time-varying interactions | temporality

Check for updates

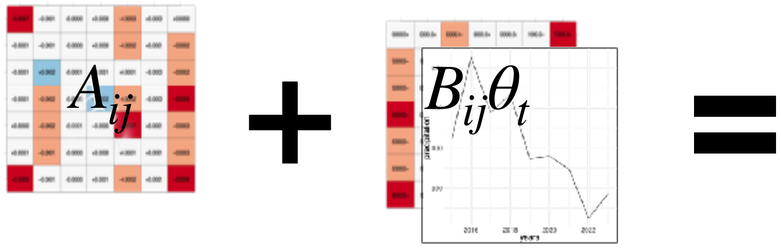
OPEN

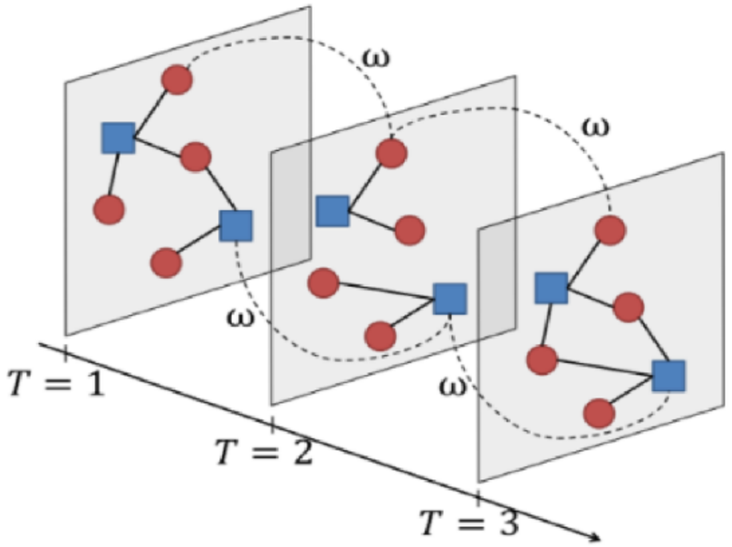
Characterization of interactions' persistence in time-varying networks

Francisco Bauzá Mingueza[1,3], Mario Floría[3,4], Jesús Gómez-Gardeñes[3,4], Alex Arenas[2] & Alessio Cardillo[2,3,5]

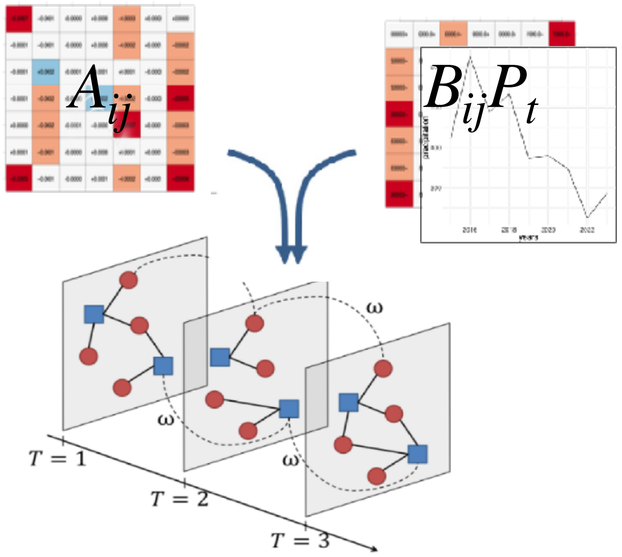
Temporality:

$$\mathcal{T}_{m,n} = 1 - \frac{|\bigcap_{m,n}|}{|\bigcup_{m,n}|}$$

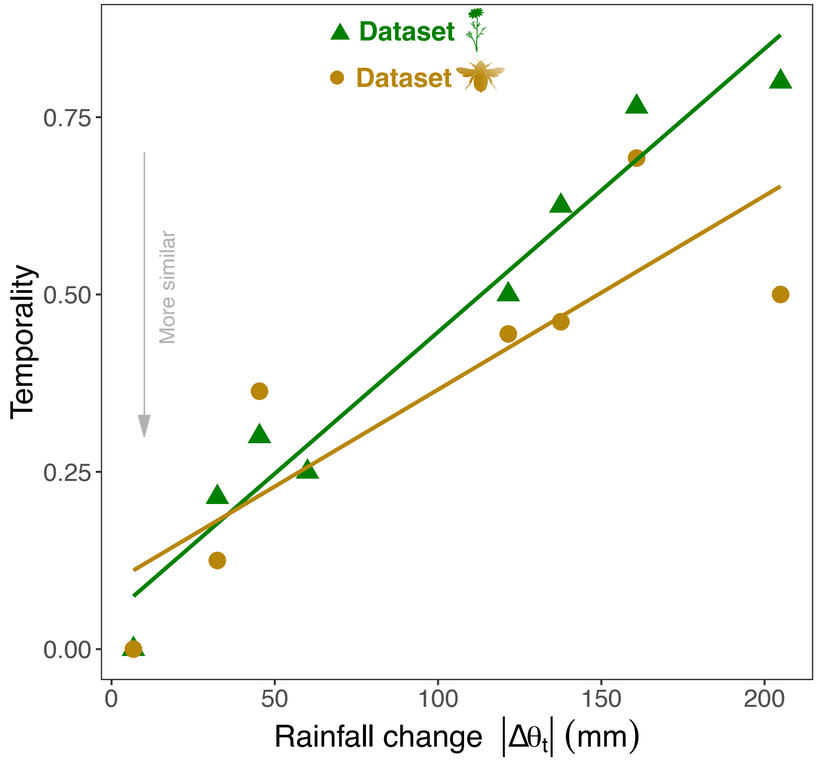




Time-varying interactions | temporality

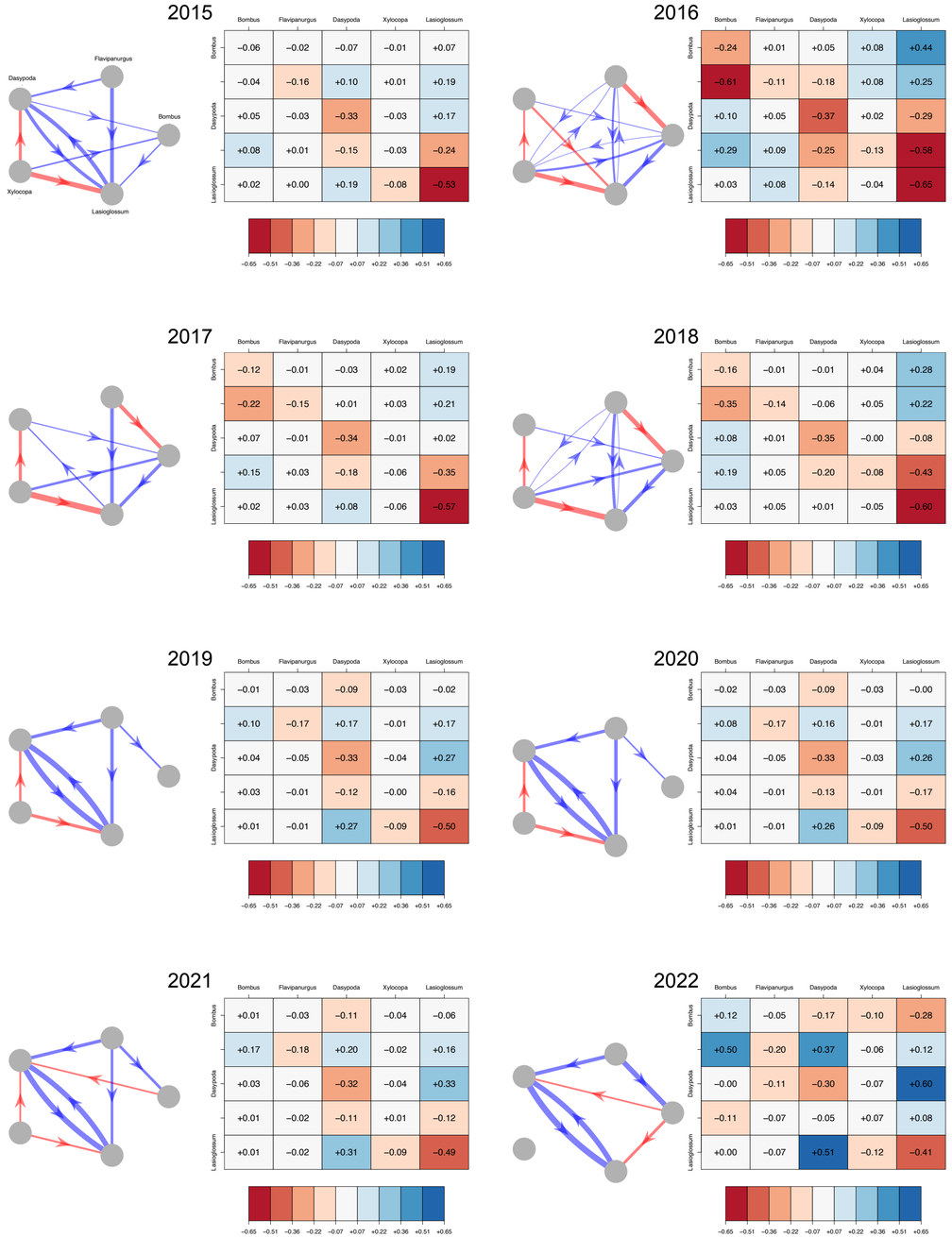


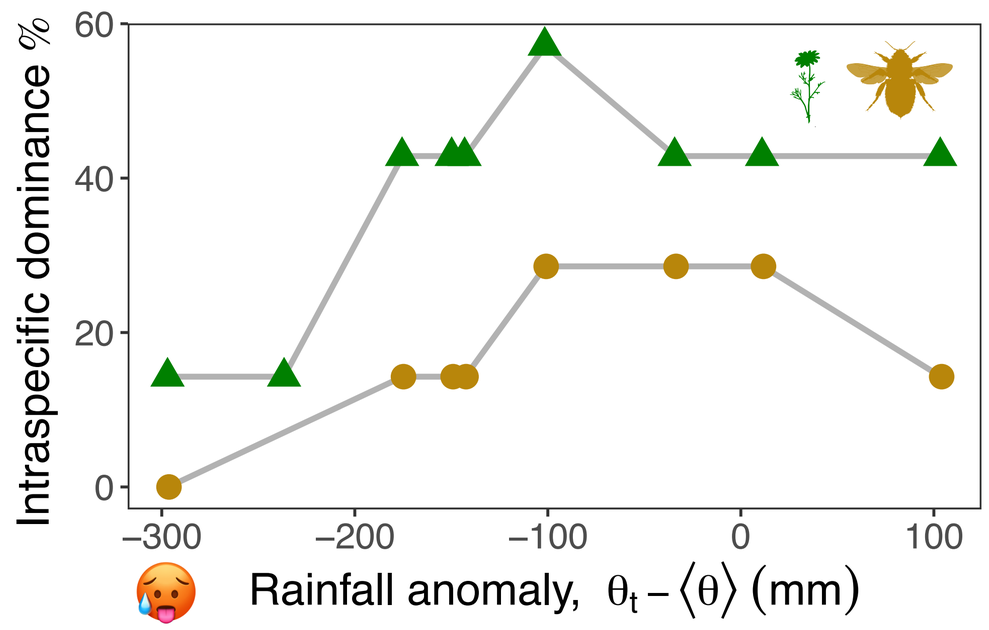
· Non negligible effect of rainfall



Time-varying interactions | intraspecific

$$\tilde{A}_{ii} = A_{ii}N_t^{i,b} + B_{ii}N_t^{i,b}\theta_t$$



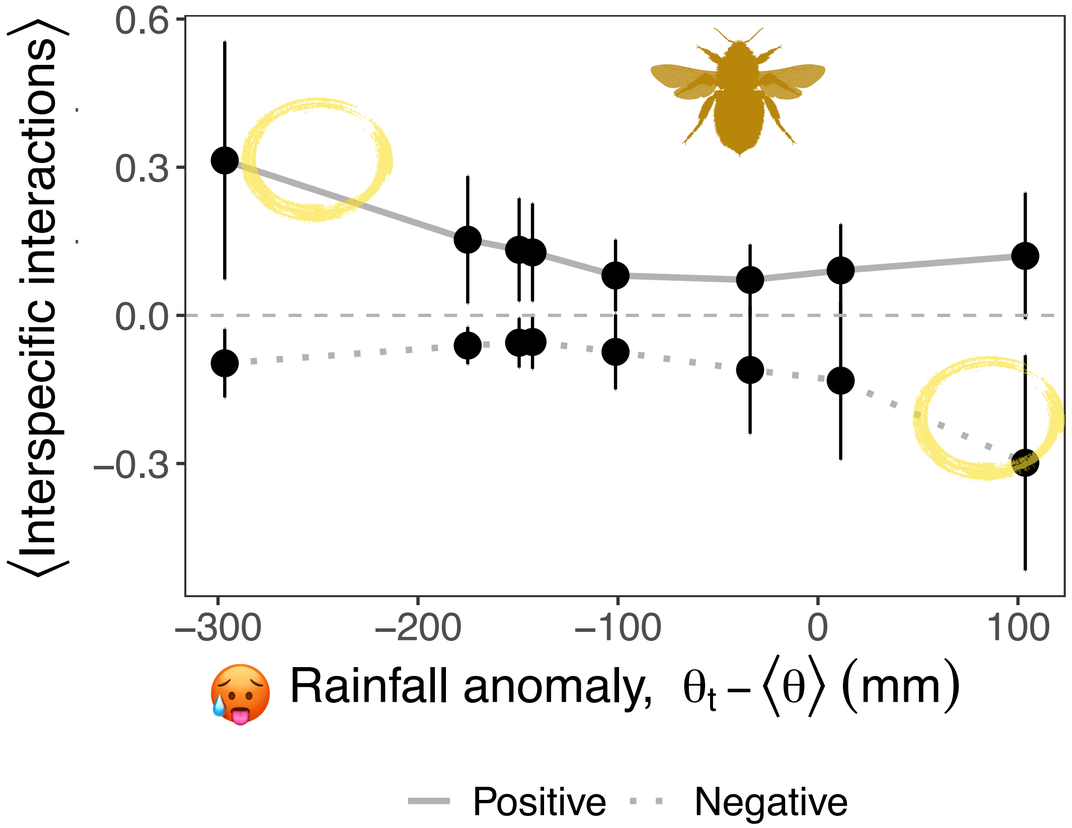


Mechanism A:
Drought lessen the stabilising effect of self regulation

Adler et al Ecol. Lett. 2018; Rohr et al, Science 2014

Time-varying interactions | interspecific

$$\tilde{A}_{ij} = \sum_j A_{ij} N_t^{j,b} + \sum_j B_{ij} N_t^{j,b} \theta_t$$



↑ in facilitation during drought
↑ in competition during typical years

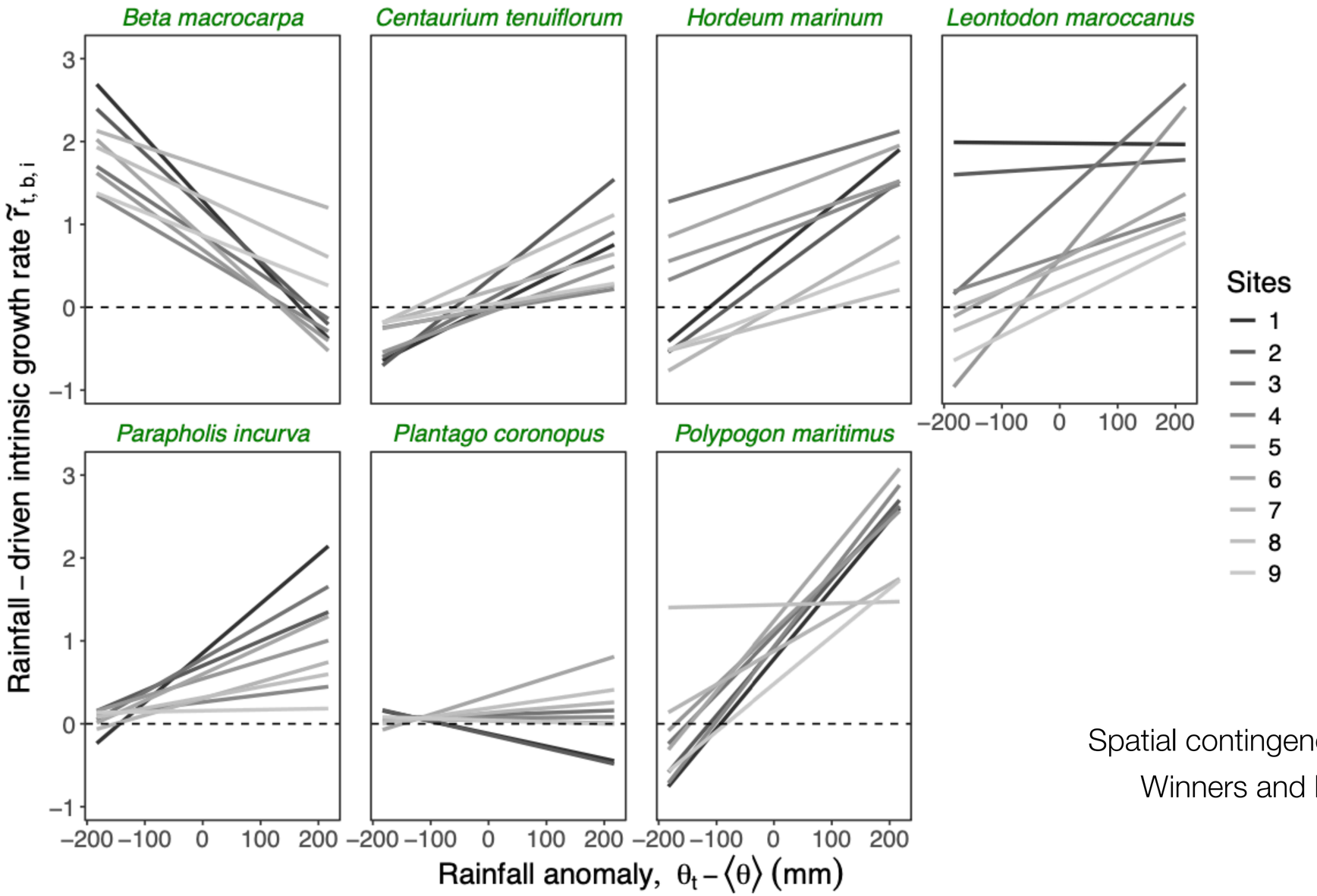
⇓

Mechanism B: Stress Gradient Hypothesis

Maestre et al. Journal of Ecology, 2009

Intrinsic growth | context-dependency

$$\tilde{r}_i = r_i + r_i'\theta_t + u'_{i,b,t}$$



Spatial contingencies: not all sites are equally suited

Winners and losers of environmental variability

Case study | Conclusions

Interactions do vary through time (strength and sign)

Variation patterns coherent with theoretical predictions (diagonal dominance & SGH)

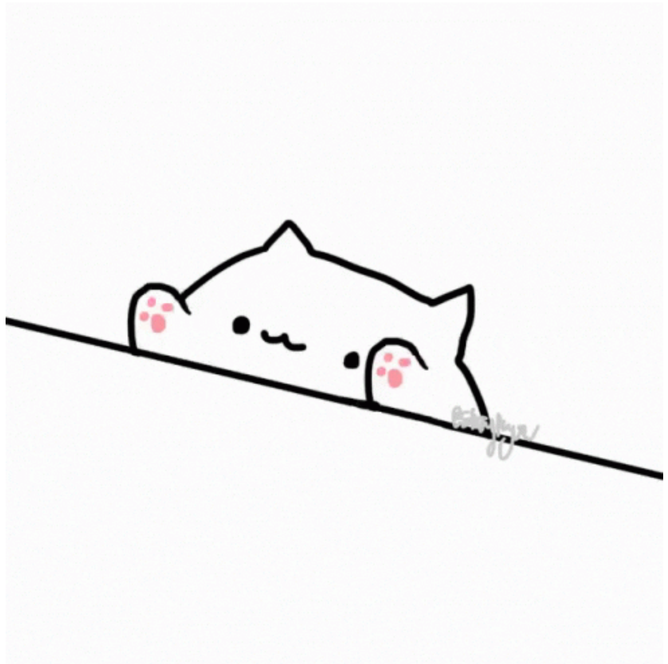
A time-varying description disentangles stochastic and deterministic effects in *r*

1. Time-varying ecological interactions
2. Case study
3. Beyond characterisation

abundance change = time-varying intrinsic growth + time-varying interactions

$$\log \frac{N_{t+1}^{i,b}}{N_t^{i,b}} = r_i + r_i'\theta_t + \sum_j A_{ij}N_t^{j,b} + \sum_j B_{ij}N_t^{j,b}\theta_t + u_{i,b,t}'$$

Let's simulate!



abundance change = time-varying intrinsic growth + time-varying interactions

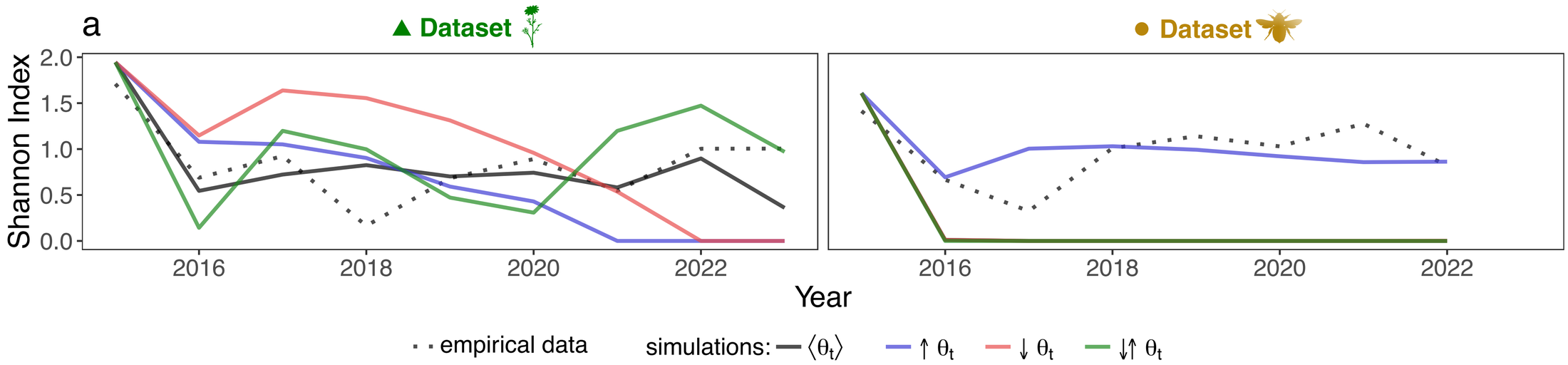
$$\log \frac{N_{t+1}^{i,b}}{N_t^{i,b}} = r_i + r_i' \theta_t + \sum_j A_{ij} N_t^{j,b} + \sum_j B_{ij} N_t^{j,b} \theta_t + u_{i,b,t}'$$

Diversity over different θ temporal series

abundance change = time-varying intrinsic growth + time-varying interactions

$$\log \frac{N_{t+1}^{i,b}}{N_t^{i,b}} = r_i + r_i'\theta_t + \sum_j A_{ij}N_t^{j,b} + \sum_j B_{ij}N_t^{j,b}\theta_t + u_{i,b,t}'$$

Diversity over different θ temporal series



Structural Stability

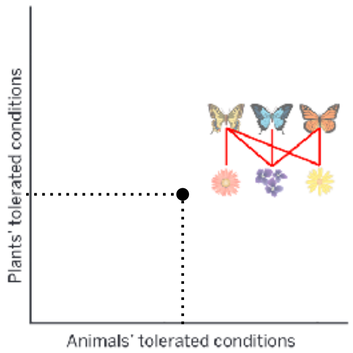
Shift in Perspective

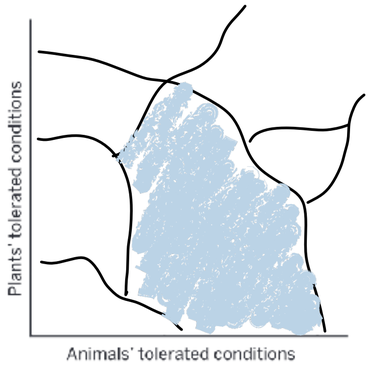
Real communities experience fluctuating growth rates, climate shifts, species invasions…

Instead of asking whether coexistence is possible under one exact set of conditions, we can ask:

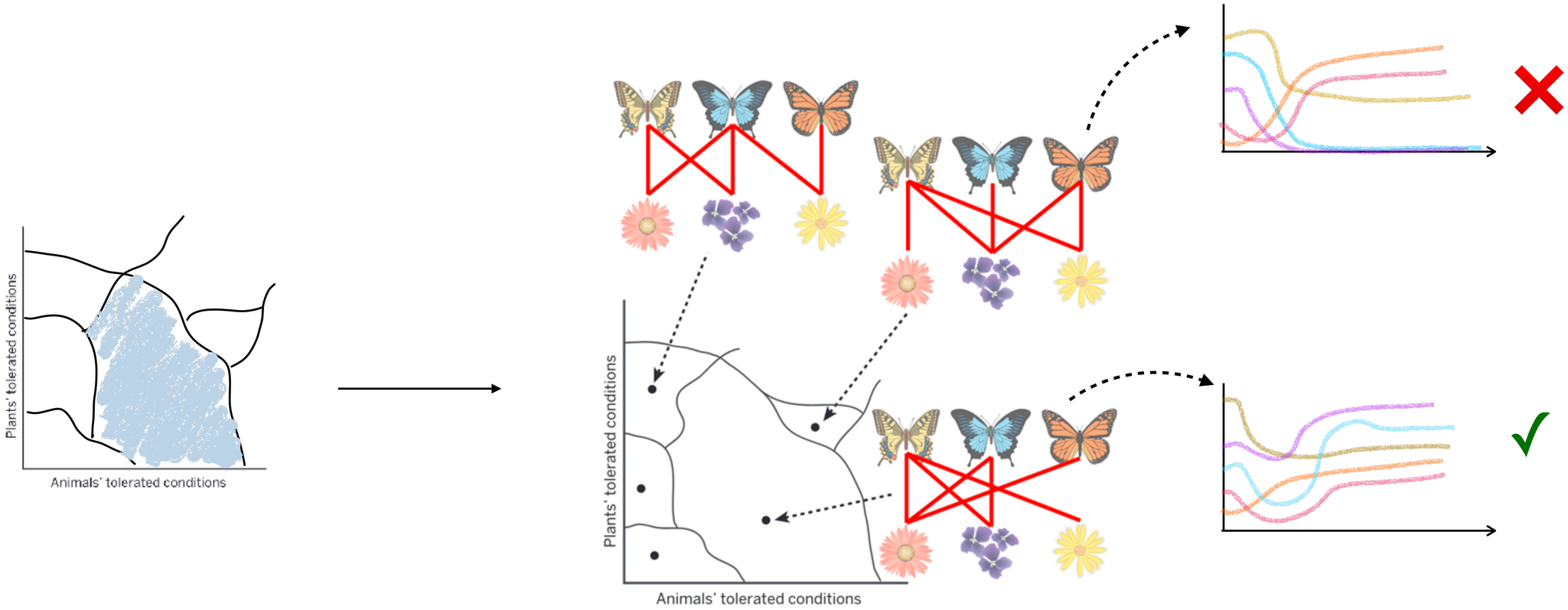
how large is the range of conditions where coexistence still works?
how much change can they tolerate before breaking apart?

That's what structural stability measures -> sensitivity



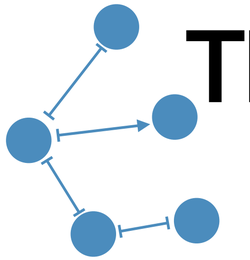


Feasibility Domain region of parameters / conditions where all species have positive abundances



Structural Stability

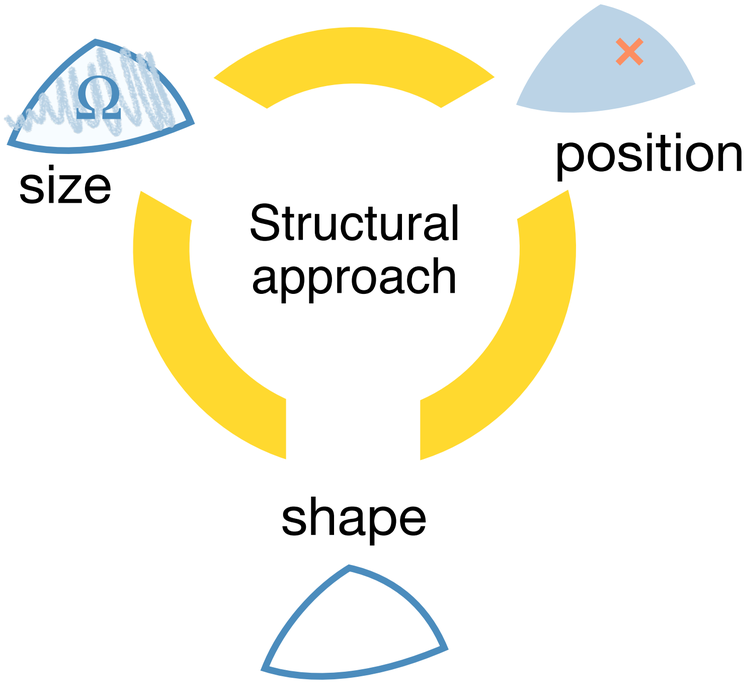
What determines the properties of the Feasibility Domain?



The interactions

What determines where my community is?

The intrinsic growth rates $\vec{r}$



Some maths

Lotka-Volterra equations:

$$\frac{dN_i}{dt} = N_i\left(r_i + \sum_j A_{ij}N_j \right)$$

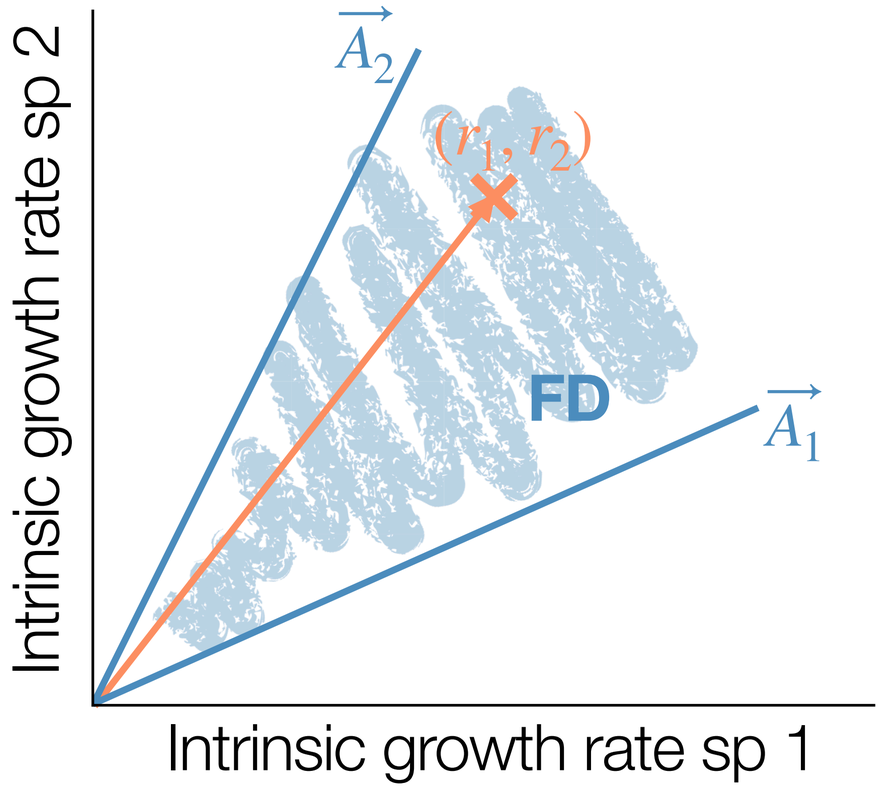
intrinsic growth rates

interactions

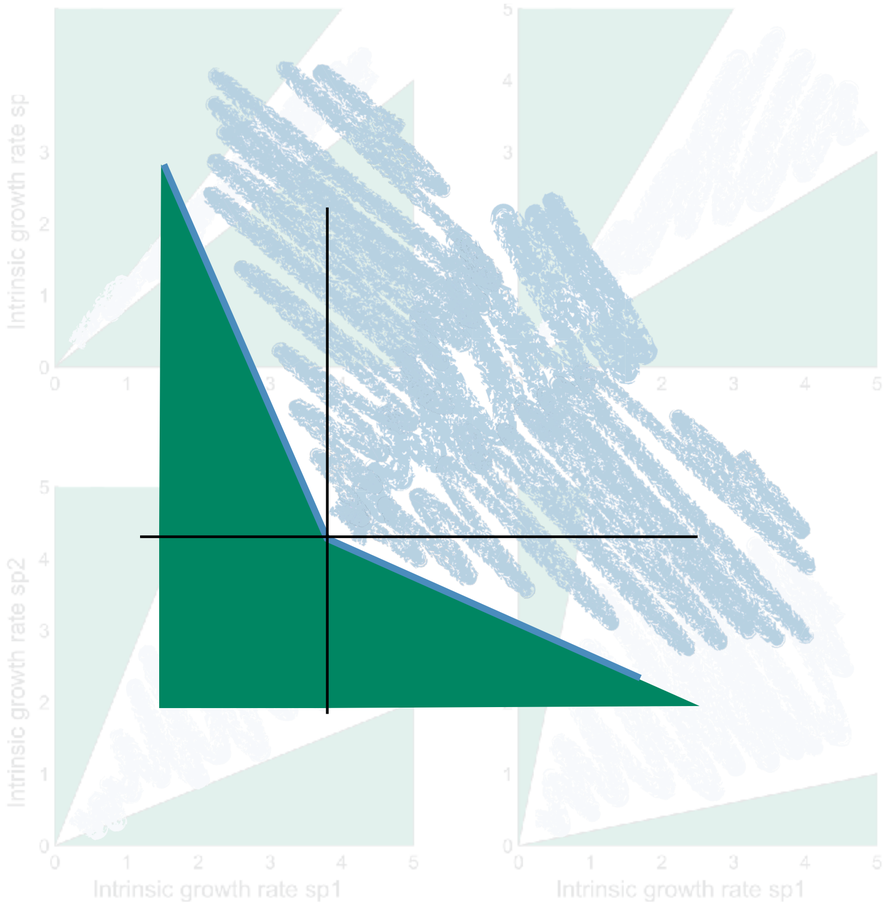
$$0 = r_i + \sum_j A_{ij}N_j^* \qquad N_i^* > 0 \,\forall i$$

$$\vec{r} = -A\vec{N}^*$$

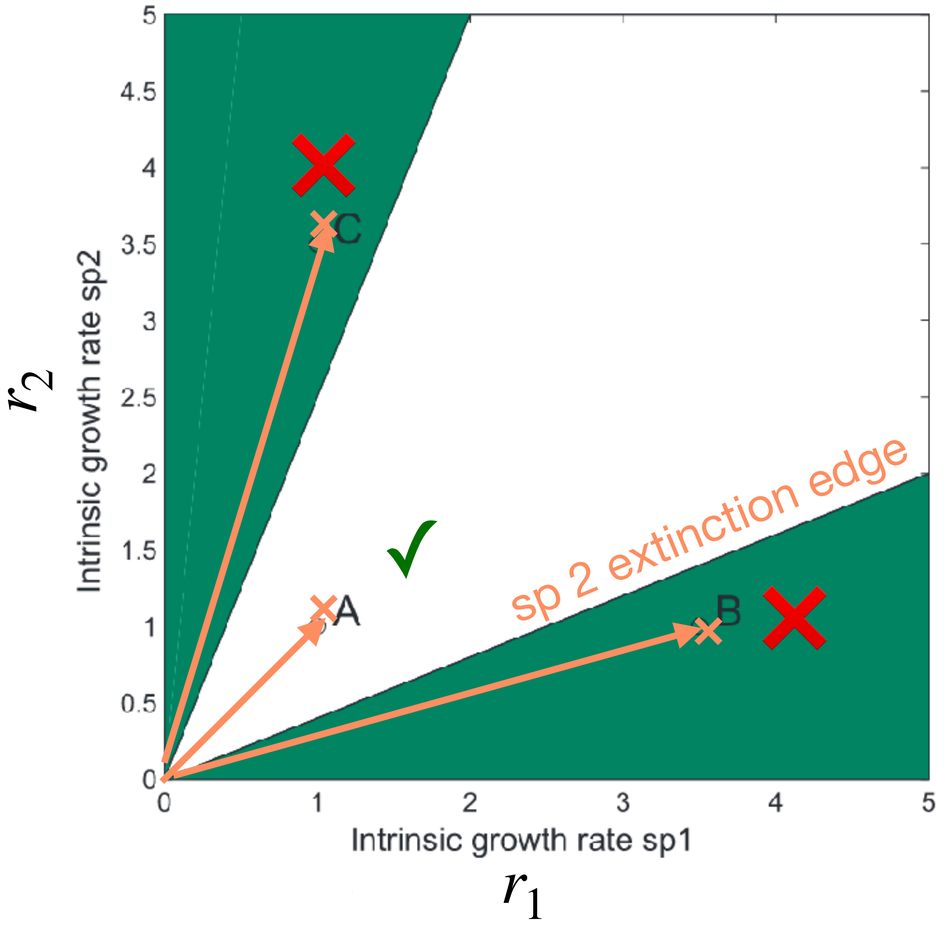
$$FD(A) = \{\ \vec{r} = N_1^*\vec{A}_1 + N_2^*\vec{A}_2 + \cdots + N_n^*\vec{A}_s\ \}$$



$$A = \begin{bmatrix} a_{11} & \cdots & a_{1S} \\ \vdots & \ddots & \vdots \\ a_{S1} & \cdots & a_{SS} \end{bmatrix} = \begin{bmatrix} \vdots & \vdots & \vdots \\ -\vec{A}_1 & -\vec{A}_2 & -\vec{A}_s \\ \vdots & \vdots & \vdots \end{bmatrix}.$$

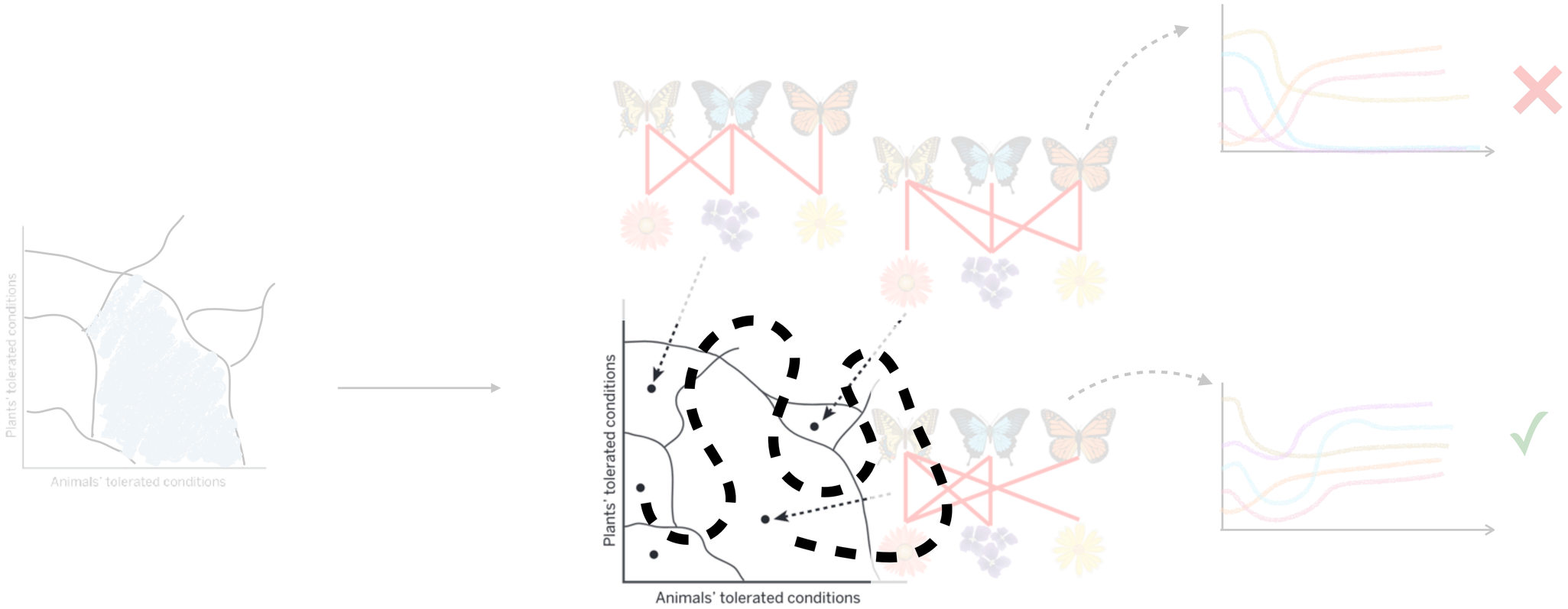


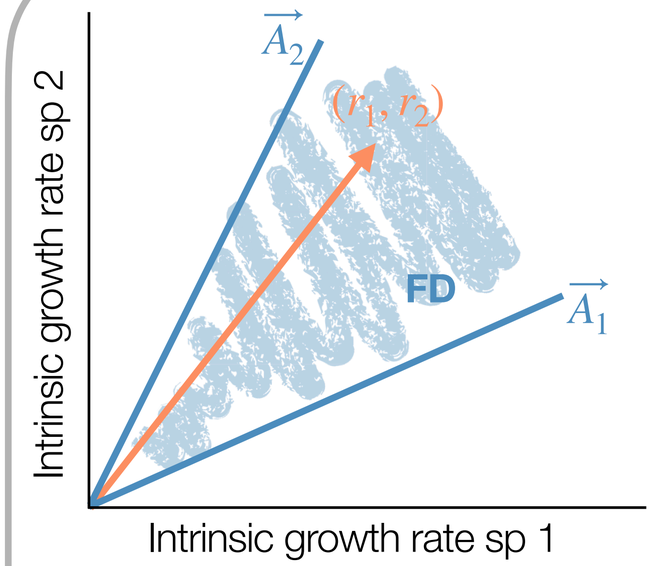
Modifying the interactions (strength, sign) gives different FD



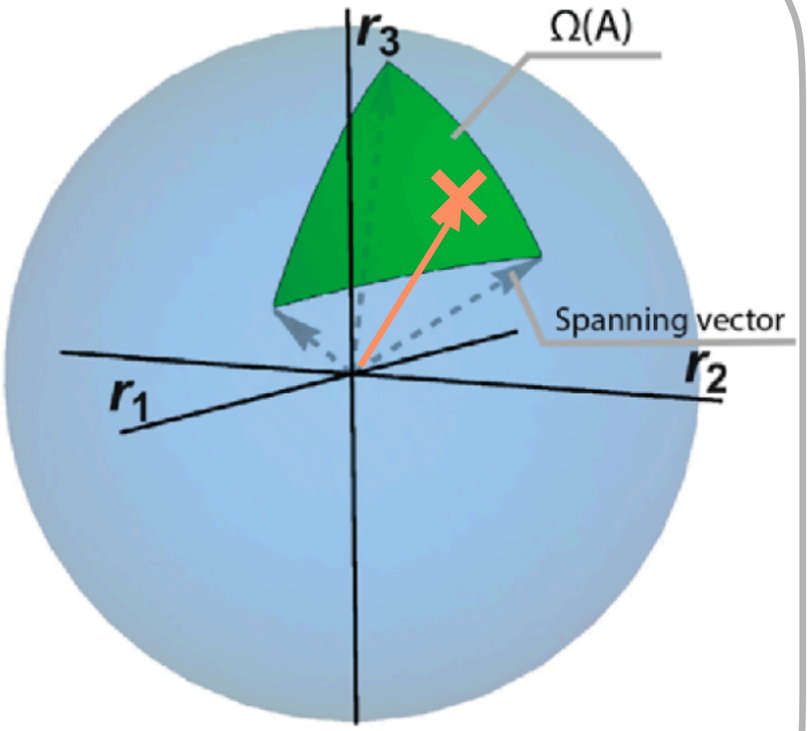
Modifying species intrinsic growth rate (strength, sign) gives different coexistence outcomes

Feasibility Domain region of parameters / conditions where all species have positive abundances





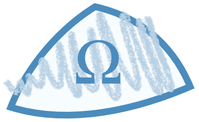
2 species

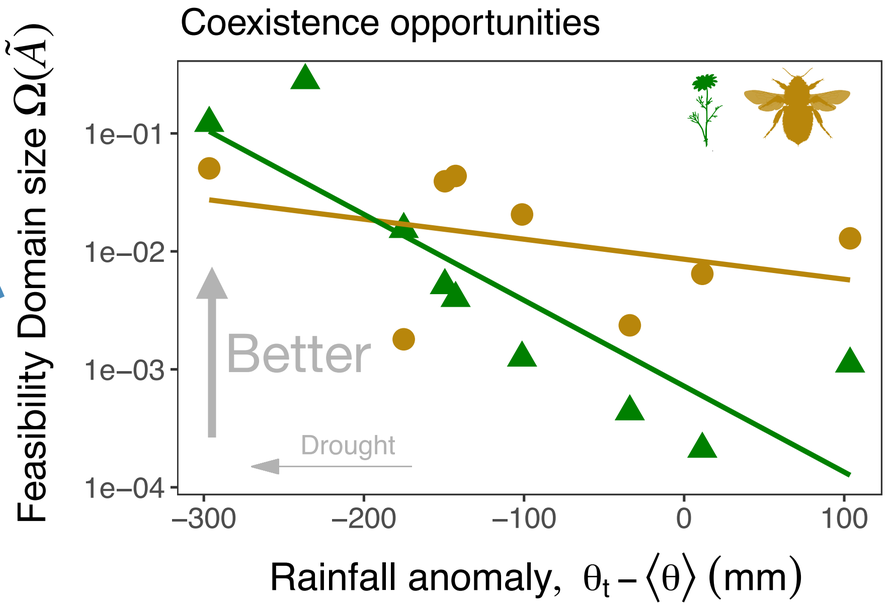


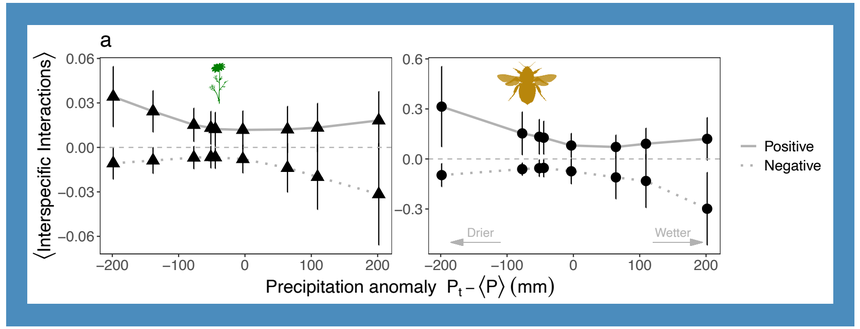
3 species

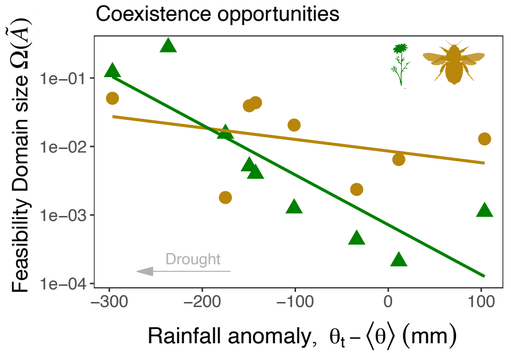
4 species

Results


Ω

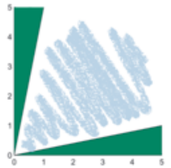

Coexistence opportunities
Feasibility Domain size $\Omega(\tilde{A})$
1e−01
1e−02
1e−03
1e−04
Better
Drought
−300
−200
−100
0
100
Rainfall anomaly, $\theta_t - \langle\theta\rangle$ (mm)



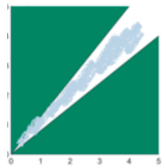


Coherent with Stress Gradient Hypothesis:

✓ More facilitation when drier (harsh) conditions ⇒ More coexistence opportunities

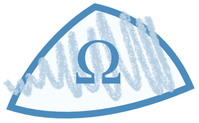


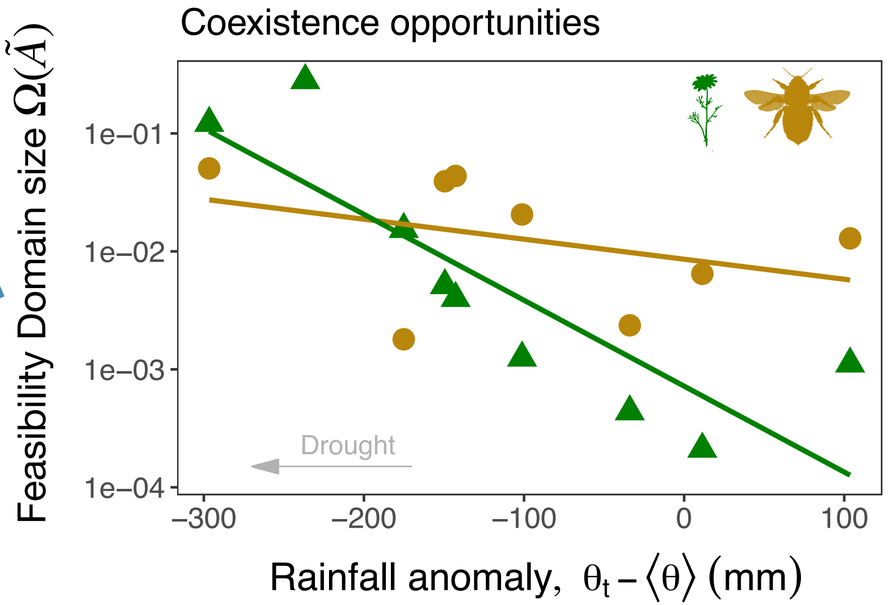
✓ Increasing competition in wet conditions ⇒ Less

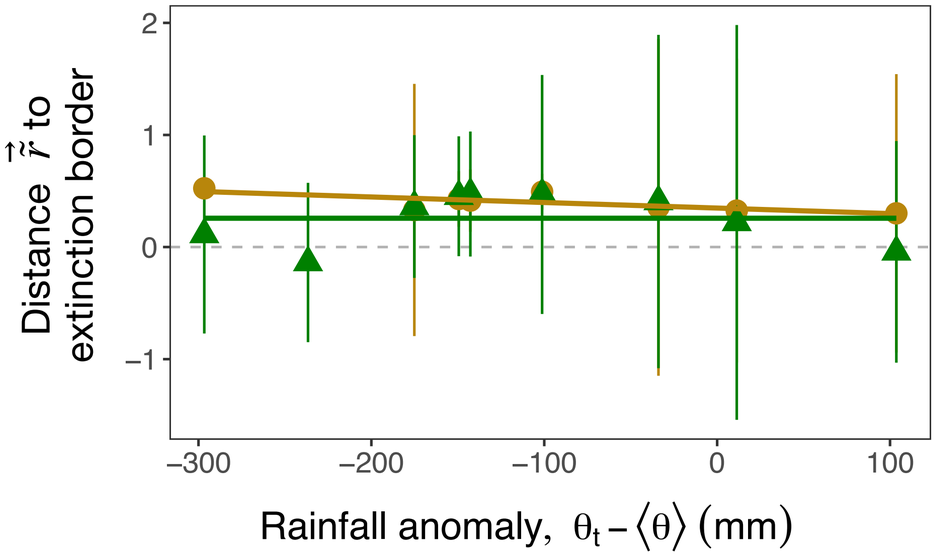


Interactions rearrangements explain the increase of coexistence opportunities

Results







The variation of both r and A maintains a certain constant level of stability

Although there are more coexistence opportunities, species need to “be able to profit” from them!

Conclusions

The story is complex…

But it is common for two different taxa!

You can simulate the outcomes of different environmental variability:
Diversity increases with variability

Although there are more coexistence opportunities, species need to “be able to profit” from them!

Collaborators in this work

Oscar Godoy

Ignasi Bartomeus

Annalisa Caligiuri
Emile Emery
Leonardo Ferreira
Juan García-Castillo
Simon D Lindner
Javier Molina-Hernández
Nelson Aloysio Reis de Almeida
Passos
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Boxuan Wang

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EXCELENCIA SEVERO OCHOA

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Doñana Biological Station (Spain)
IITE Online Theoretical Ecology Seminar Series
Nov 18 2025

Thanks!

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The effect on stability of temporal variability of species interactions

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