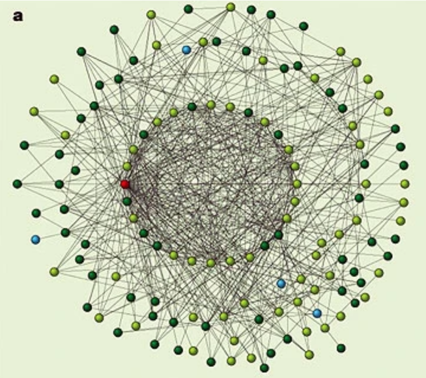
Modelling the ecology and evolution of interaction networks using mathematical tools and computer simulations

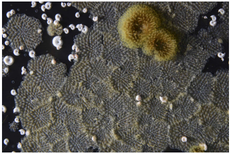
What are ecological networks?



Montoya, Pimm and Sole; Ecological networks and their fragility. Nature (2006). https://doi.org/10.1038/nature04927

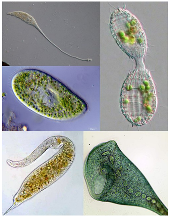
- **nodes = species** (or groups of species)
- **links = interactions**
  - antagonistic (-/+)
  - mutualistic (+/+)
  - competitive (-/-)

What types of interaction do we study?



Credit: Gail Ashton

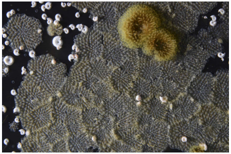
bryozoans (-/-)



https://en.wikipedia.org/wiki/Ciliate

freshwater ciliates (-/-)

What types of interaction do we study?

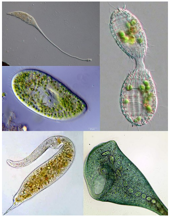


Credit: Gail Ashton

bryozoans (-/-)

https://en.wikipedia.org/wiki/Entomophily

pollination (+/+)



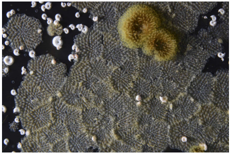
https://en.wikipedia.org/wiki/Ciliate

freshwater ciliates (-/-)

Credit: Korinna Allhoff

herbivory (-/+)

What types of interaction do we study?


Credit: Gail Ashton

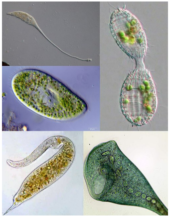
bryozoans (-/-)


https://en.wikipedia.org/wiki/Entomophily

pollination (+/+)


https://en.wikipedia.org/wiki/Nectar_robbing

nectar robbering (-/+)

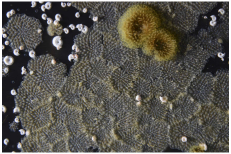

https://en.wikipedia.org/wiki/Ciliate

freshwater ciliates (-/-)


Credit: Korinna Allhoff

herbivory (-/+)

What types of interaction do we study?



Credit: Gail Ashton

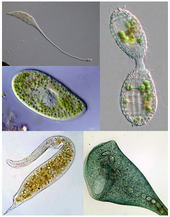
bryozoans (-/-)

https://en.wikipedia.org/wiki/Entomophily

pollination (+/+)

https://en.wikipedia.org/wiki/Nectar_robbing

nectar robbering (-/+)



https://en.wikipedia.org/wiki/Ciliate

freshwater ciliates (-/-)

Credit: Korinna Allhoff

herbivory (-/+)

Credit: Bismark Ofosu-Bamfo

tree-liana (-/+)

How do we study interaction networks?

- **mathematical modelling**
  (linear algebra, dynamical systems theory, bifurcation theory, adaptive dynamics,...)

How do we study interaction networks?

- **mathematical modelling**
  (linear algebra, dynamical systems theory, bifurcation theory, adaptive dynamics,...)
- **numerical simulations**
  (Python, C/C++, R, ...)

How do we study interaction networks?

- **mathematical modelling**
  (linear algebra, dynamical systems theory, bifurcation theory, adaptive dynamics,...)
- **numerical simulations**
  (Python, C/C++, R, ...)
- **individual-based simulations**
  (NetLogo, Julia, ...)

Our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?

Our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?
- How do these networks respond to **external stressors and disturbances**?

Our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?
- How do these networks respond to **external stressors and disturbances**?
- How do these networks **emerge** from an eco-evolutionary perspective?

Project 1: **Competitive hierarchies** in bryozoan assemblages mitigate network instability

Photograph by Gail Ashton: "Antarctic bryozoans fighting for space"

Talking about competition networks with...

Anje-Margriet Neutel
Theoretical ecologist
British Antarctic Survey (UK)

David Barnes
Marine biologist
British Antarctic Survey (UK)

Korinna T. Allhoff
Theoretical ecologist
Universität Hohenheim

Talking about competition networks with...

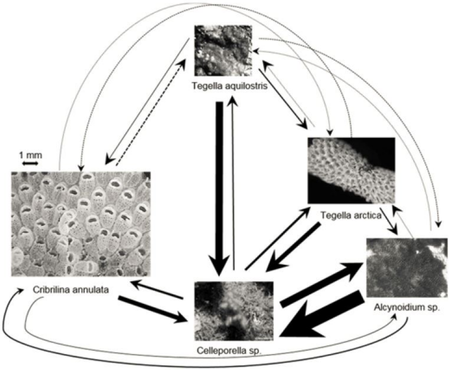
Anje-Margriet Neutel
Theoretical ecologist
British Antarctic Survey (UK)

David Barnes
Marine biologist
British Antarctic Survey (UK)

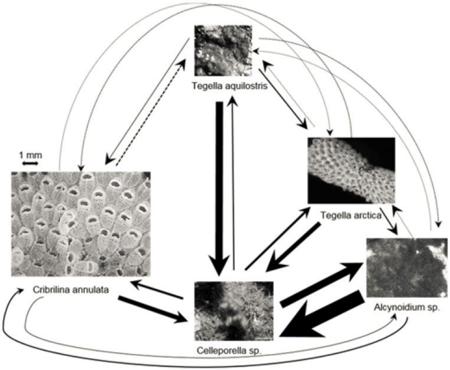
Korinna T. Allhoff
Theoretical ecologist
Universität Hohenheim

Franziska Koch
PhD student
funded by the DFG

Idea: Let's use bryozoan assemblages as a study system to construct **energy loss webs**

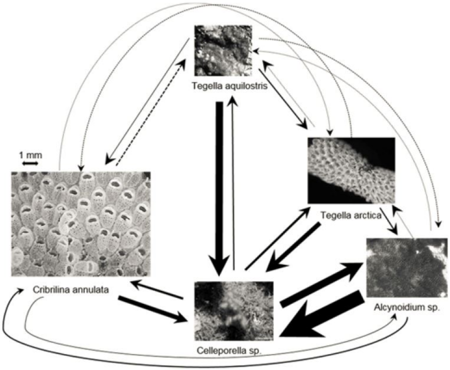


Idea: Let's use bryozoan assemblages as a study system to construct **energy loss webs**



Q1) Do such networks have a specific **structure**?

Idea: Let's use bryozoan assemblages as a study system to construct **energy loss webs**

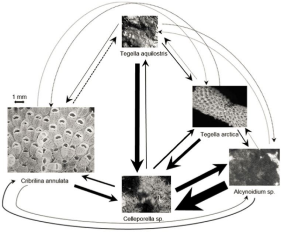


Q1) Do such networks have a specific **structure**?

Q2) If yes, how does this structure affect network **stability**?

How can we answer these questions?

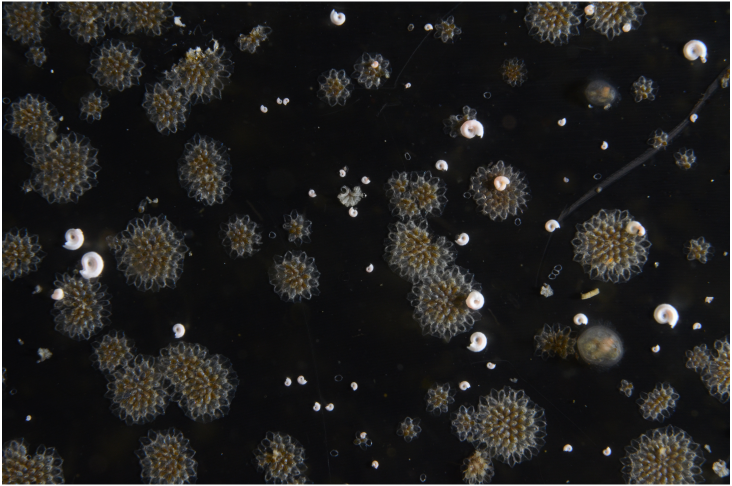
The dynamics (at equilibrium) can be captured using the Jacobian matrix. Its elements $a_{ij} < 0$ describe the effect of species j on species i.



$$\Leftrightarrow \qquad \mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix}$$

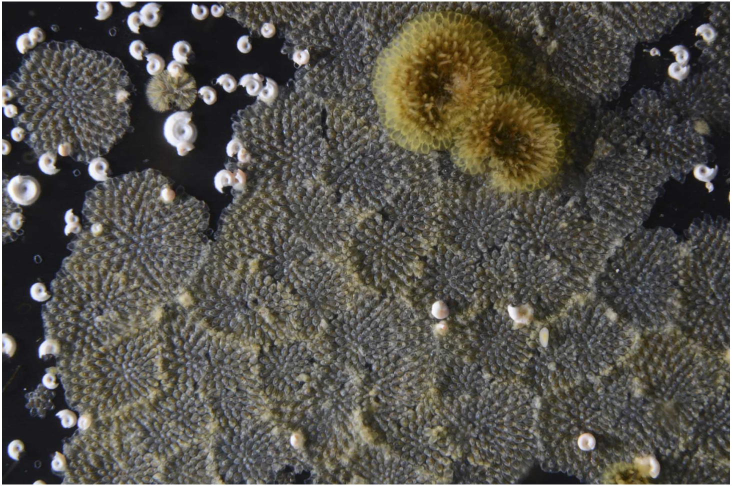
The properties of the matrix can be analysed using **linear algebra**!

How do we get the raw data?



Photograph by Gail Ashton: “Antarctic bryozoans fighting for space”

How do we get the raw data?



Photograph by Gail Ashton: “Antarctic bryozoans fighting for space”

How do we get the raw data?

Photograph by Gail Ashton: “Antarctic bryozoans fighting for space”

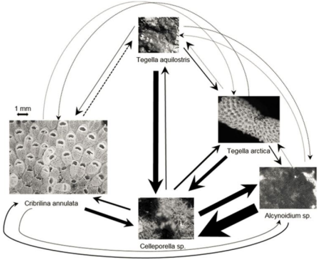
How does the raw data look like?

	T. armifera	*T. aquilirostris*	*M. plana*	*Cauloramphus* sp.
Tegella armifera		2 5 9 16	4 3 3 10	2 1 1 4
Tegella aquilostris			0 11 8 19	0 0 1 1
Myriozoella plana				0 0 3 3
Cauloramphus sp.				

(David Barnes, Proc. R. Soc. B (2002))

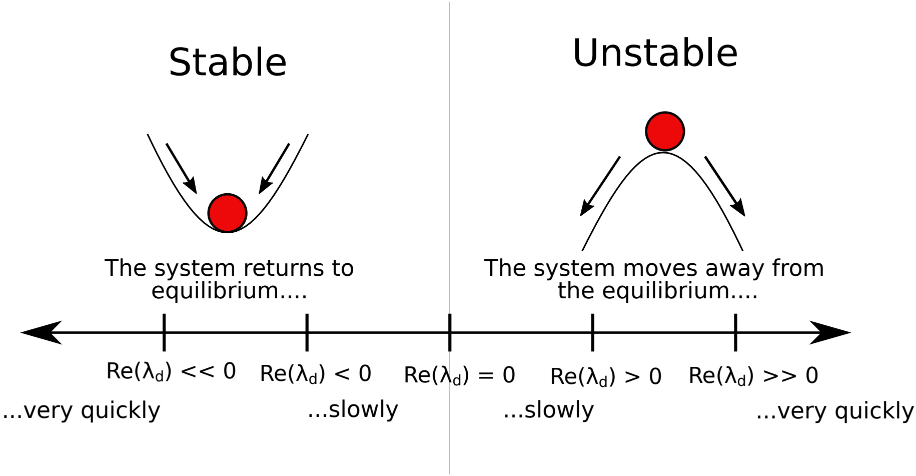
How do we process the data?

1. Collect raw data from different study sites
2. Translate raw data into estimates of biomass loss rates
3. Use biomass loss rates to parametrize Lotka-Volterra competition models
4. Calculate Jacobian matrices and determine dominant eigenvalues λ_d.



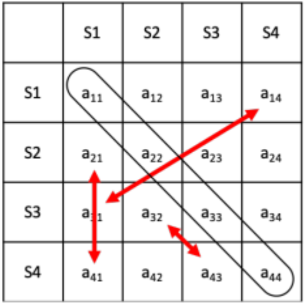
How do we measure stability?

The dominant eigenvalue λ_d of the Jacobian matrix captures network (in-)stability:

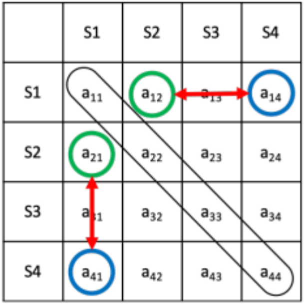


How do we connect network structure and stability?

Idea: Let's destroy the internal structure of our matrix by randomising the matrix elements. How does this affect network stability ($= Re(\lambda_d)$)?



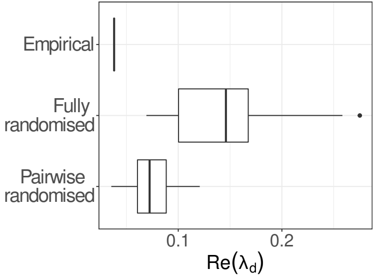
(a) Full randomization



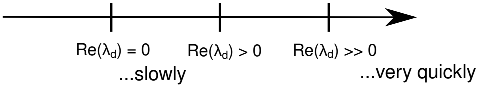
(b) pairwise randomization

Effect of randomisation on stability

Results for one exemplary data set:

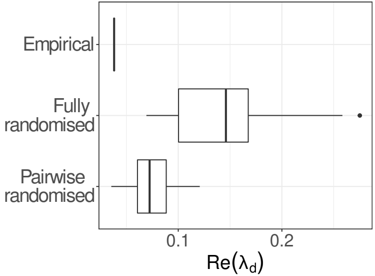


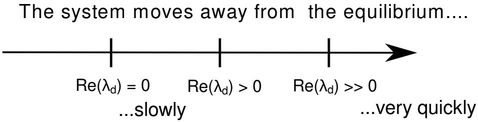
The system moves away from the equilibrium....



Effect of randomisation on stability

Results for one exemplary data set:

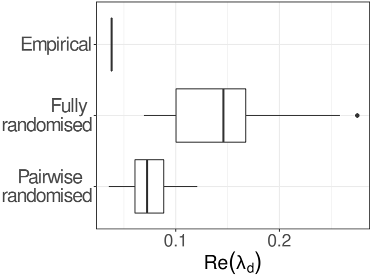


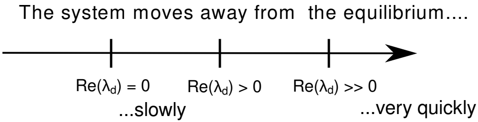


- The empirical network is **not** stable because $\lambda_d > 0$.

Effect of randomisation on stability

Results for one exemplary data set:

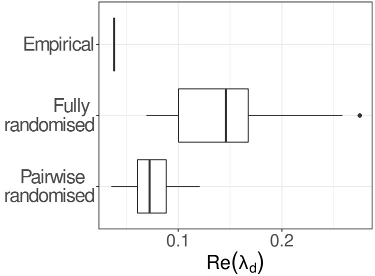




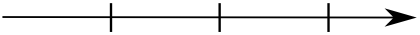
- The empirical network is **not** stable because $\lambda_d > 0$.
- Its randomised counterparts are **even less** stable!

Effect of randomisation on stability

Results for one exemplary data set:



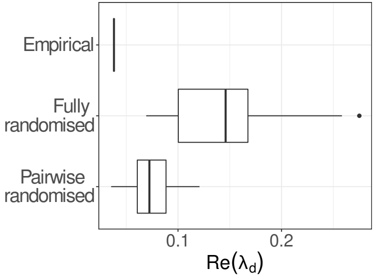
The system moves away from the equilibrium....

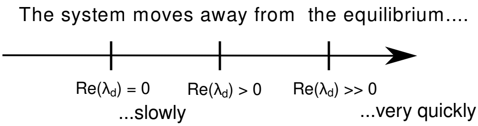


- The empirical network is **not** stable because $\lambda_d > 0$.
- Its randomised counterparts are **even less** stable!
- Keeping the pairs intact preserves at least some level of stability.

Effect of randomisation on stability

Results for one exemplary data set:





- The empirical network is **not** stable because $\lambda_d > 0$.
- Its randomised counterparts are **even less** stable!
- Keeping the pairs intact preserves at least some level of stability.

$\Longrightarrow$ **There is a specific network structure and it does affect stability.**

Why is this interesting? A bit of background...

Will a Large Complex System be Stable?

Gardner and Ashby[1] have suggested that large complex systems which are assembled (connected) at random may be expected to be stable up to a certain critical level of connectance, and then, as this increases, to suddenly become unstable. Their conclusions were based on the trend of computer studies of systems with 4, 7 and 10 variables.

Here I complement Gardner and Ashby's work with an analytical investigation of such systems in the limit when the number of variables is large. The sharp transition from stability to instability which was the essential feature of their paper is confirmed, and I go further to see how this critical transition point scales with the number of variables n in the system, and with the average connectance C and interaction magnitude α between the various variables. The object is to clarify the relation between stability and complexity in ecological systems with many interacting species, and some conclusions bearing on this question are drawn from the model. But, just as in Gardner and Ashby's work, the formal development of the problem is a general one, and thus applies to the wide range of contexts spelled out by these authors.

Based on random matrix theory, May (Nature 1972) predicts that **more complex systems are less stable**.

Why is this interesting? A bit of background...

Will a Large Complex System be Stable?

Gardner and Ashby[1] have suggested that large complex systems which are assembled (connected) at random may be expected to be stable up to a certain critical level of connectance, and then, as this increases, to suddenly become unstable. Their conclusions were based on the trend of computer studies of systems with 4, 7 and 10 variables.

Here I complement Gardner and Ashby's work with an analytical investigation of such systems in the limit when the number of variables is large. The sharp transition from stability to instability which was the essential feature of their paper is confirmed, and I go further to see how this critical transition point scales with the number of variables n in the system, and with the average connectance C and interaction magnitude α between the various variables. The object is to clarify the relation between stability and complexity in ecological systems with many interacting species, and some conclusions bearing on this question are drawn from the model. But, just as in Gardner and Ashby's work, the formal development of the problem is a general one, and thus applies to the wide range of contexts spelled out by these authors.

Based on random matrix theory, May (Nature 1972) predicts that **more complex systems are less stable**.

Following May, we should see no difference between empirical and randomized matrices because they share the exact same level of complexity.

Why is this interesting? A bit of background...

Will a Large Complex System be Stable?

Gardner and Ashby[1] have suggested that large complex systems which are assembled (connected) at random may be expected to be stable up to a certain critical level of connectance, and then, as this increases, to suddenly become unstable. Their conclusions were based on the trend of computer studies of systems with 4, 7 and 10 variables.

Here I complement Gardner and Ashby's work with an analytical investigation of such systems in the limit when the number of variables is large. The sharp transition from stability to instability which was the essential feature of their paper is confirmed, and I go further to see how this critical transition point scales with the number of variables n in the system, and with the average connectance C and interaction magnitude α between the various variables. The object is to clarify the relation between stability and complexity in ecological systems with many interacting species, and some conclusions bearing on this question are drawn from the model. But, just as in Gardner and Ashby's work, the formal development of the problem is a general one, and thus applies to the wide range of contexts spelled out by these authors.

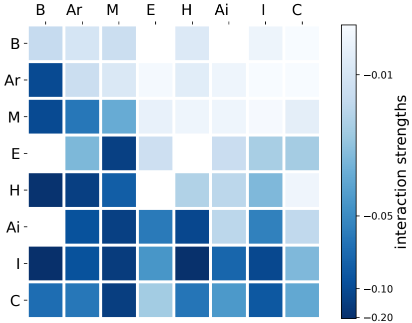
Based on random matrix theory, May (Nature 1972) predicts that **more complex systems are less stable**.

Following May, we should see no difference between empirical and randomized matrices because they share the exact same level of complexity.

But we do! This indicates that **stability is driven by internal organisation, not by complexity!**

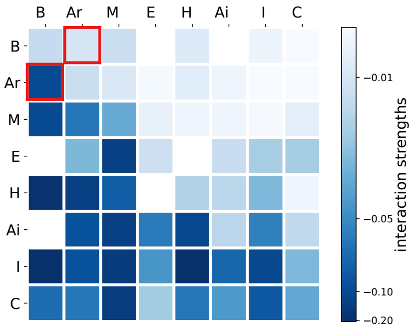
Hierarchy translates into asymmetric patterns in interaction strengths

strongest ⟶ weakest

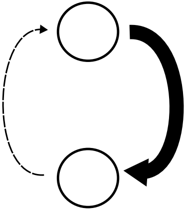


Hierarchy translates into asymmetric patterns in interaction strengths

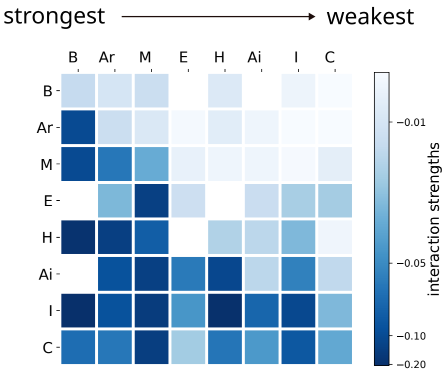
strongest → weakest



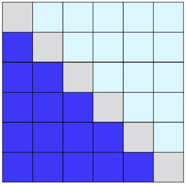
- **Pairwise asymmetry**: Strong links are paired to weak links



Hierarchy translates into asymmetric patterns in interaction strengths

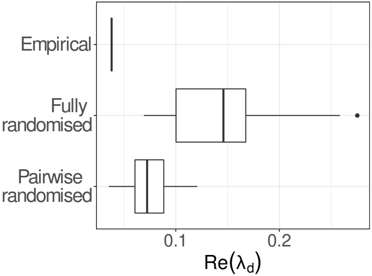


- **Pairwise asymmetry**: Strong links are paired to weak links
- **Community asymmetry**: Strong links on one side of the diagonal

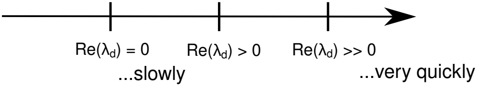


Effect of randomisation on stability

Results for one exemplary data set:

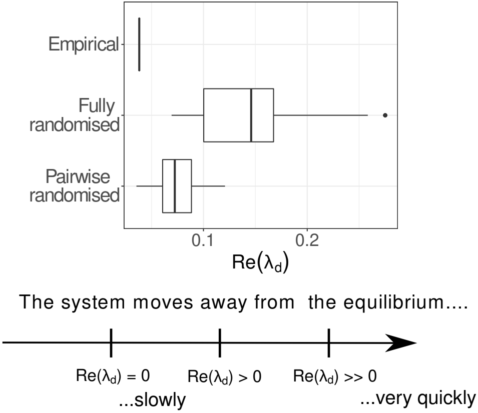


The system moves away from the equilibrium....



Effect of randomisation on stability

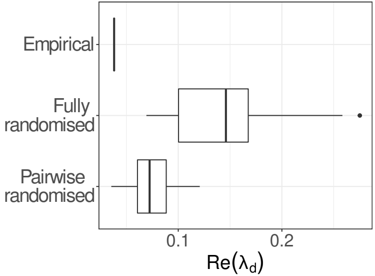
Results for one exemplary data set:

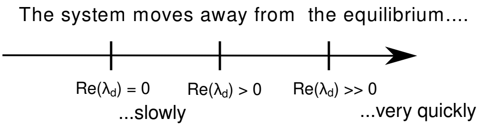


- Both types of asymmetry are **intact**.

Effect of randomisation on stability

Results for one exemplary data set:

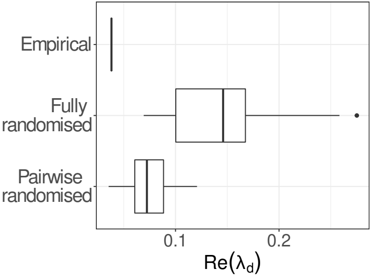


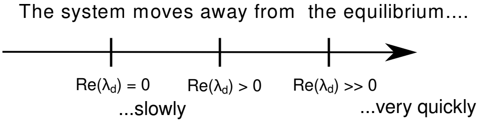


- Both types of asymmetry are **intact**.
- Both types of asymmetry are **destroyed**.

Effect of randomisation on stability

Results for one exemplary data set:

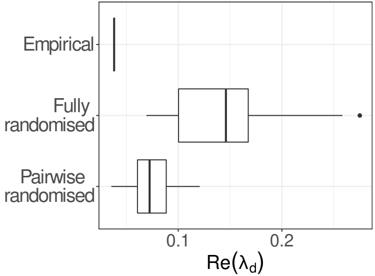


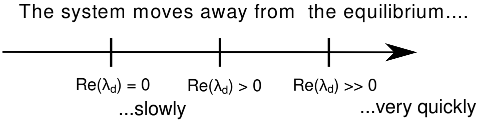


- Both types of asymmetry are **intact**.
- Both types of asymmetry are **destroyed**.
- Pairwise asymmetry is intact, but community asymmetry is destroyed.

Effect of randomisation on stability

Results for one exemplary data set:

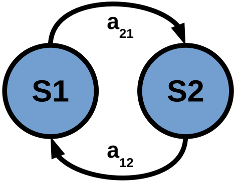


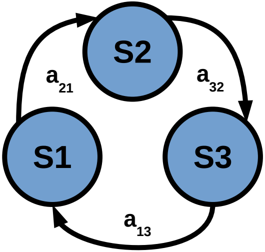


- Both types of asymmetry are **intact**.
- Both types of asymmetry are **destroyed**.
- Pairwise asymmetry is intact, but community asymmetry is destroyed.

$\Longrightarrow$**Both types of asymmetry matter for network (in-)stability!!**

What is a feedback loop?





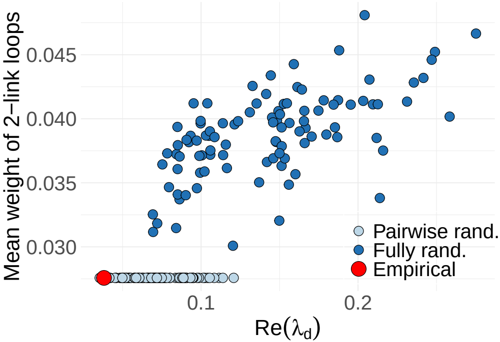
Competitive loops with an even number of links are **positive / self-reinforcing**:

$S1 \downarrow \Longrightarrow S2 \uparrow \Longrightarrow S1 \downarrow\downarrow$

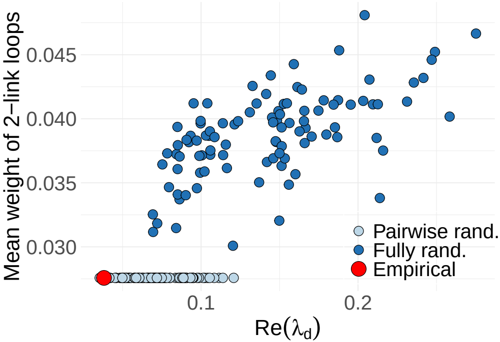
Competitive loops with an odd number of links are **negative / self-dampening**:

$S1 \downarrow \Longrightarrow S2 \uparrow \Longrightarrow S3 \downarrow \Longrightarrow S1 \uparrow$

What happens to the 2-link loops during randomisation?

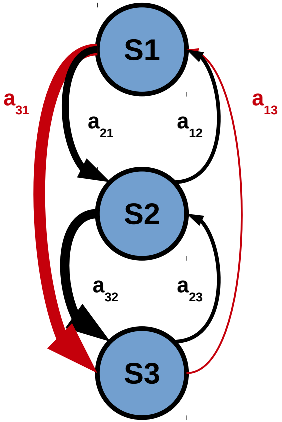


What happens to the 2-link loops during randomisation?

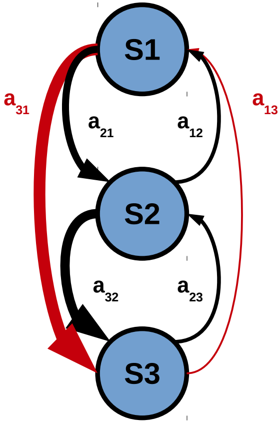


The **original network** based on empirical observations contains weaker 2-link loops and is hence less unstable compared to its **fully randomised counterparts**!

Hierarchy increases **pairwise asymmetry** and hence mitigates network instability



Hierarchy increases **pairwise asymmetry** and hence mitigates network instability



Empirical networks:

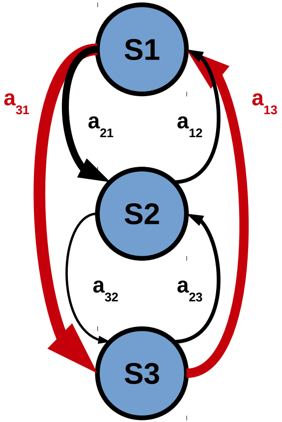
$\Longrightarrow$ Strong links are always coupled to weak links

$\Longrightarrow$ 2-link loops are relatively weak

$\Longrightarrow$ Reduced positive feedback

$\Longrightarrow$ **Systems are relatively stable!**

Hierarchy increases **pairwise asymmetry** and hence mitigates network instability



Fully randomised networks

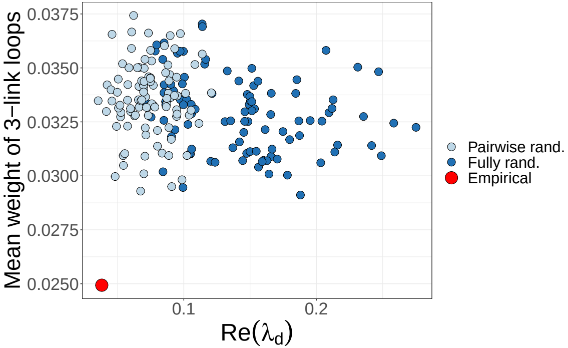
$\Longrightarrow$ Pairwise asymmetry is destroyed!

$\Longrightarrow$ Strong links can be coupled to other strong links

$\Longrightarrow$ Strong positive feedback

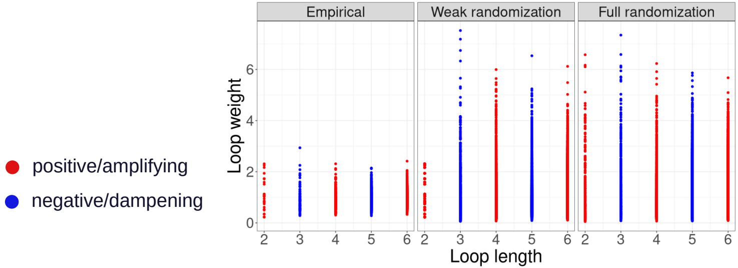
$\Longrightarrow$ **Systems are very unstable!**

What happens to the 3-link loops during randomisation?



Both types of randomisations increase the weight of 3-link loops.
But this does **not** result in a stabilising effect! **WHY???**

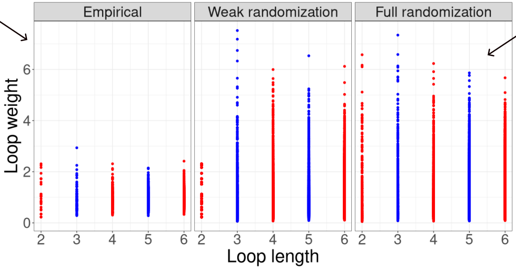
Feedback loop spectra



Feedback loop spectra

All loops are weak

All loops are strong



● positive/amplifying

● negative/dampening

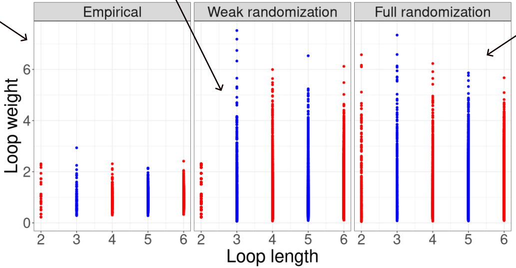
Asymmetry:	Empirical	Weak randomization	Full randomization
Community	✓	✗	✗
Pairwise	✓	✓	✗

Feedback loop spectra

Destroying community asymmetry increases long, negative loops

All loops are weak

All loops are strong

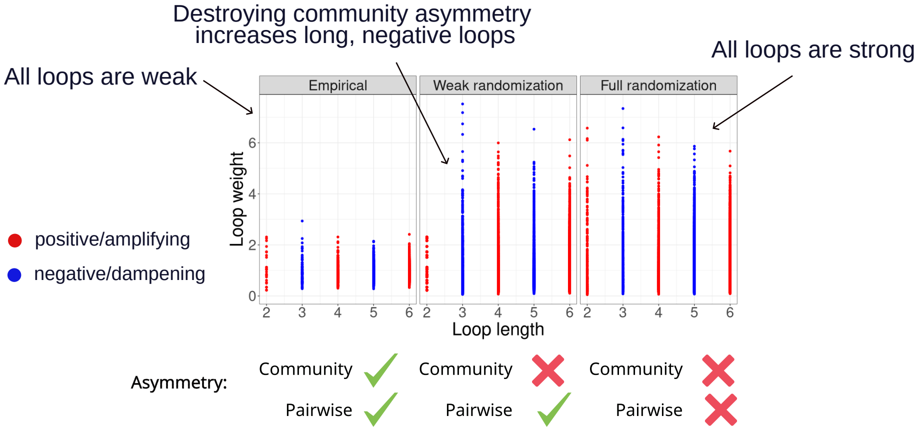


- positive/amplifying
- negative/dampening

Asymmetry:

	Empirical	Weak randomization	Full randomization
Community	✓	✗	✗
Pairwise	✓	✓	✗

Feedback loop spectra



→ Destroying community asymmetry creates an imbalance between short and long loops!

Even more background

DISCUSSION PAPER:
THE QUALITATIVE ANALYSIS OF PARTIALLY SPECIFIED SYSTEMS

Richard Levins

Department of Biology
University of Chicago
Chicago, Illinois 60637

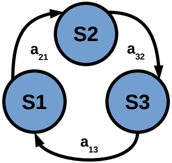
The most difficult general problem of contemporary science is how to deal with complex systems as wholes. Most of the training of scientists, especially in the United States and Great Britain, is in the opposite direction. We are taught to isolate parts of a problem and to answer the question "What is this system?" by telling what it is made of. The dramatic advances in science in our generation have almost all been in areas where such an approach is practicable. The notable stagnations have been in areas of complex systems approached in pieces.

It is now a commonplace, at least in ecology, that systems are complex and that the one-step linear causality is a poor predictor of ultimate outcome. Consider, for example, the problem of providing more food for hungry people. Since insects destroy a significant portion of the world's crops, and since insecticides can be shown in the laboratory to kill insect pests, it is a plausible inference that the use of insecticides will control insects and increase food available to the hungry. Furthermore, to avoid side effects, laboratory tests may show that insecticides such as heptachlor are relatively nontoxic to mammals. Therefore, it is reasonable to expect that the use of such insecticides would reduce insect pests, increase yields, and alleviate hunger.

There are two types of instability: A system can become **unstable**...

- when positive feedback dominates
- or due to **excessive negative feedback** in longer loops

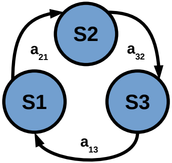
What is "excessive negative feedback"?



Small perturbations are counteracted **too strongly**:

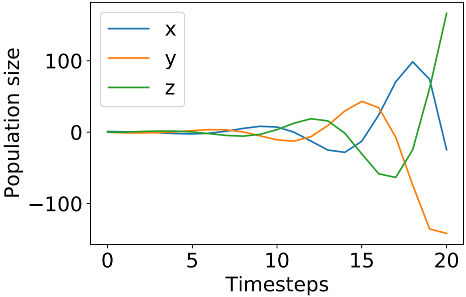
$$\begin{aligned} S1 \downarrow &\implies S2 \uparrow\uparrow \\ &\implies S3 \downarrow\downarrow\downarrow \\ &\implies S1 \uparrow\uparrow\uparrow\uparrow \\ &\implies \ldots \end{aligned}$$

What is "excessive negative feedback"?

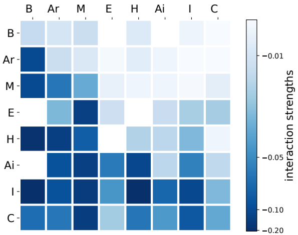


Small perturbations are counteracted **too strongly**:

$$S1 \downarrow \implies S2 \uparrow\uparrow$$
$$\implies S3 \downarrow\downarrow\downarrow$$
$$\implies S1 \uparrow\uparrow\uparrow\uparrow$$
$$\implies \ldots$$



Summary



Koch et al. (2023). Competitive hierarchies in bryozoan assemblages mitigate network instability by keeping short and long feedback loops weak. Communications Biology, 6(1), 690.

Q1) Do these networks have a specific **structure**? $\longrightarrow$ **YES! Hierarchy!**

Q2) If yes, how does this structure affect network **stability**?
$\longrightarrow$ **Hierarchy reduces destabilising feedback!**

This work has been published!

https://doi.org/10.1038/s42003-023-05060-1

https://doi.org/10.1101/2024.01.25.577181

Our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?
- How do these networks respond to **external stressors and disturbances**?
- How do these networks **emerge** from an eco-evolutionary perspective?

Project 2: Livestock management promotes **bush encroachment** in savanna systems

Healthy savanna system
(Tanzania, East Africa)

Project 2: Livestock management promotes **bush encroachment** in savanna systems

Healthy savanna system
(Tanzania, East Africa)

Encroached land
(Waterberg Plateau in Namibia)

Project 2: Livestock management promotes **bush encroachment** in savanna systems

Self-reinforcing feedback

Healthy savanna system
(Tanzania, East Africa)

Encroached land
(Waterberg Plateau in Namibia)

Talking about bush encroachment with...

Katja Tielbörger
Plant ecologist
Universität Tübingen

Britta Tietjen
Theoretical ecologist
Freie Universität Berlin

Korinna T. Allhoff
Theoretical ecologist
Universität Hohenheim

Franziska Koch
MSc student
Universität Tübingen

Herbivory as a key driver of bush encroachment

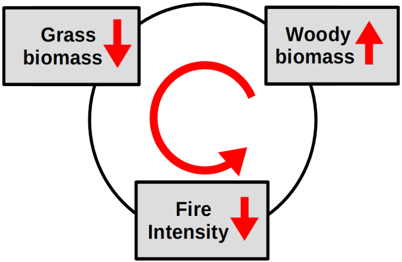


Figure inspired by Langevelde et al. *Ecology* (2003).
For a synthetic review see D'Odorico et al. *Ecohydrology* (2012).

Herbivory as a key driver of bush encroachment

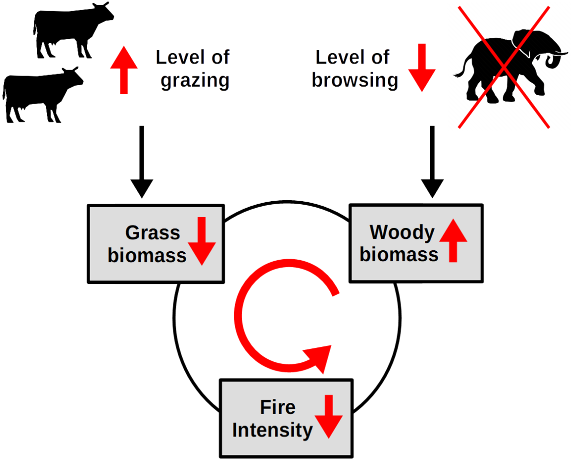


Figure inspired by Langevelde et al. *Ecology* (2003).
For a synthetic review see D'Odorico et al. *Ecohydrology* (2012).

Herbivory as a key driver of bush encroachment

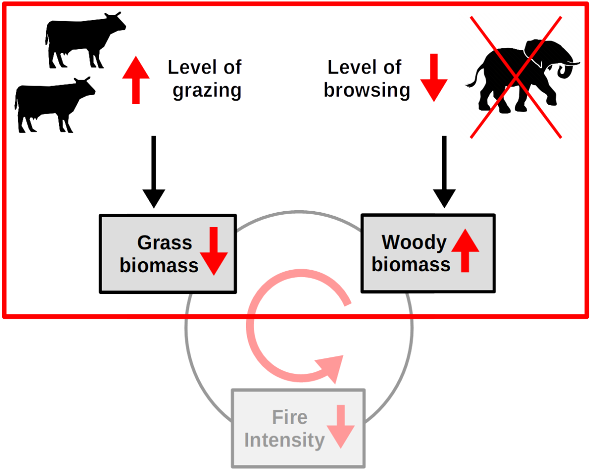
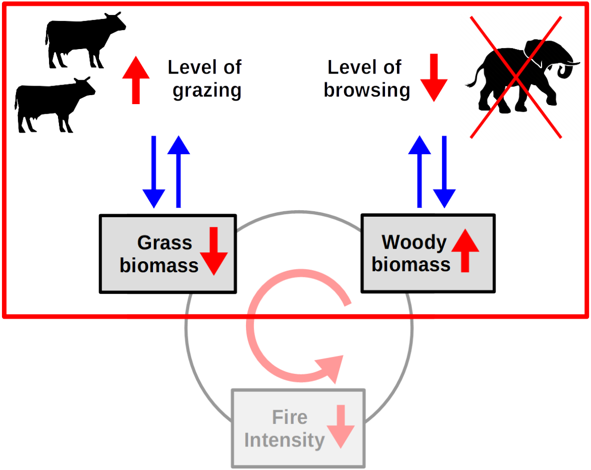


Figure inspired by Langevelde et al. *Ecology* (2003).
For a synthetic review see D'Odorico et al. *Ecohydrology* (2012).

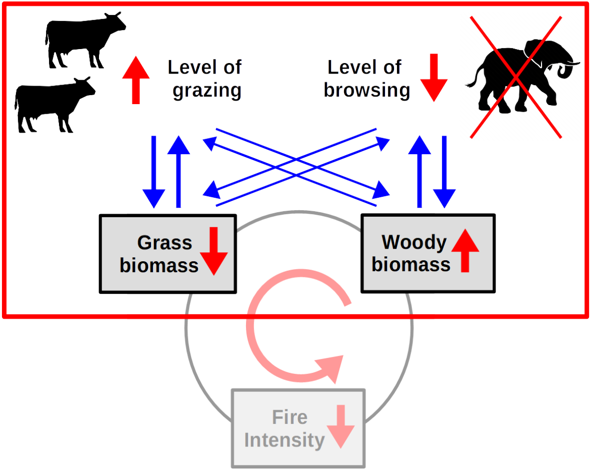
Herbivory as a key driver of bush encroachment



What about **dynamic feedback** between herbivores and vegetation?

Figure inspired by Langevelde et al. *Ecology* (2003).
For a synthetic review see D'Odorico et al. *Ecohydrology* (2012).

Herbivory as a key driver of bush encroachment



What about
dynamic feedback
between herbivores
and vegetation?

What about
crossfeeding
of mixed feeders?

How do these processes
affect **system stability**?

Figure inspired by Langevelde et al. *Ecology* (2003).
For a synthetic review see D'Odorico et al. *Ecohydrology* (2012).

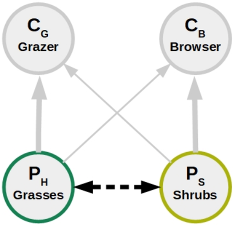
Specific model assumptions 1/3

grasses: $$\frac{dP_H}{dt} = r_H P_H \left(1 - \frac{P_H + cP_S}{K_H}\right) - F_{HB} C_B - F_{HG} C_G$$

shrubs: $$\frac{dP_S}{dt} = r_S P_S \left(1 - \frac{P_S + cP_H}{K_S}\right) - F_{SB} C_B - F_{SG} C_G$$

browsers: $$\frac{dC_B}{dt} = e(F_{HB} + F_{SB}) C_B - m_b C_B - m_d C_B^2$$

grazers: $$\frac{dC_G}{dt} = e(F_{HG} + F_{SG}) C_G - m_b(1 - f_b) C_G - m_d(1 - f_d) C_G^2$$



- Without herbivores, grasses and shrubs follow **LV-competition**.

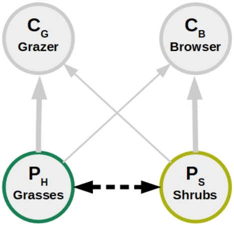
Specific model assumptions 1/3

grasses:
$$\frac{dP_H}{dt} = r_H P_H \left(1 - \frac{P_H + cP_S}{K_H}\right) - F_{HB} C_B - F_{HG} C_G$$

shrubs:
$$\frac{dP_S}{dt} = r_S P_S \left(1 - \frac{P_S + cP_H}{K_S}\right) - F_{SB} C_B - F_{SG} C_G$$

browsers:
$$\frac{dC_B}{dt} = e(F_{HB} + F_{SB}) C_B - m_b C_B - m_d C_B^2$$

grazers:
$$\frac{dC_G}{dt} = e(F_{HG} + F_{SG}) C_G - m_b(1 - f_b) C_G - m_d(1 - f_d) C_G^2$$



- Without herbivores, grasses and shrubs follow **LV-competition**.
- Grasses grow faster ($r_H > r_S$) but shrubs have a higher carrying capacity ($K_S > K_H$).

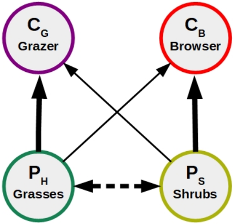
Specific model assumptions 2/3

grasses:
$$\frac{dP_H}{dt} = r_H P_H \left(1 - \frac{P_H + cP_S}{K_H}\right) - \mathbf{F_{HB}} C_B - \mathbf{F_{HG}} C_G$$

shrubs:
$$\frac{dP_S}{dt} = r_S P_S \left(1 - \frac{P_S + cP_H}{K_S}\right) - \mathbf{F_{SB}} C_B - \mathbf{F_{SG}} C_G$$

browsers:
$$\frac{dC_B}{dt} = e(\mathbf{F_{HB}} + \mathbf{F_{SB}}) C_B - m_b C_B - m_d C_B^2$$

grazers:
$$\frac{dC_G}{dt} = e(\mathbf{F_{HG}} + \mathbf{F_{SG}}) C_G - m_b(1 - f_b) C_G - m_d(1 - f_d) C_G^2$$



- F_{ij} represent feeding interactions.

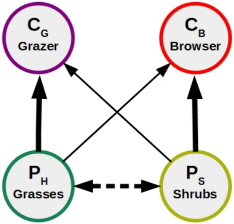
Specific model assumptions 2/3

grasses: $$\frac{dP_H}{dt} = r_H P_H \left(1 - \frac{P_H + cP_S}{K_H}\right) - \mathbf{F_{HB}} C_B - \mathbf{F_{HG}} C_G$$

shrubs: $$\frac{dP_S}{dt} = r_S P_S \left(1 - \frac{P_S + cP_H}{K_S}\right) - \mathbf{F_{SB}} C_B - \mathbf{F_{SG}} C_G$$

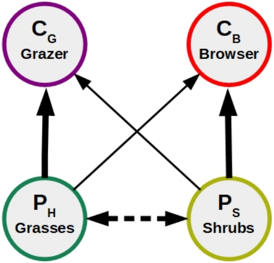
browsers: $$\frac{dC_B}{dt} = e(\mathbf{F_{HB}} + \mathbf{F_{SB}}) C_B - m_b C_B - m_d C_B^2$$

grazers: $$\frac{dC_G}{dt} = e(\mathbf{F_{HG}} + \mathbf{F_{SG}}) C_G - m_b(1 - f_b) C_G - m_d(1 - f_d) C_G^2$$

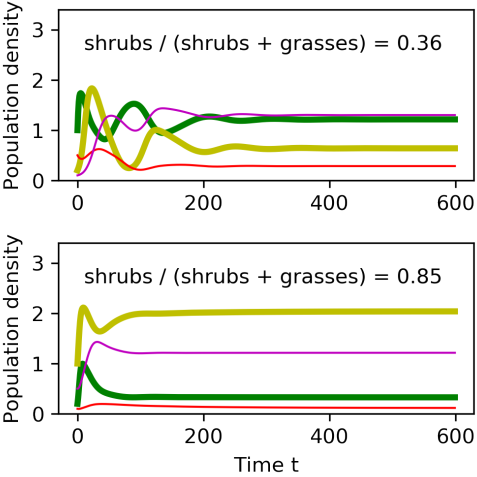


- F_{ij} represent feeding interactions.
- Grazers prefer grasses ($\mathbf{F_{SG}} < \mathbf{F_{HG}}$).
- Browsers prefer shrubs ($\mathbf{F_{HB}} < \mathbf{F_{SB}}$).

Alternative Stable States



Koch et al. *Oikos* (2023)



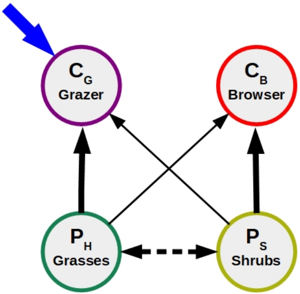
Specific model assumptions 3/3

grasses: $$\frac{dP_H}{dt} = r_H P_H\left(1 - \frac{P_H + cP_S}{K_H}\right) - F_{HB} C_B - F_{HG} C_G$$

shrubs: $$\frac{dP_S}{dt} = r_S P_S\left(1 - \frac{P_S + cP_H}{K_S}\right) - F_{SB} C_B - F_{SG} C_G$$

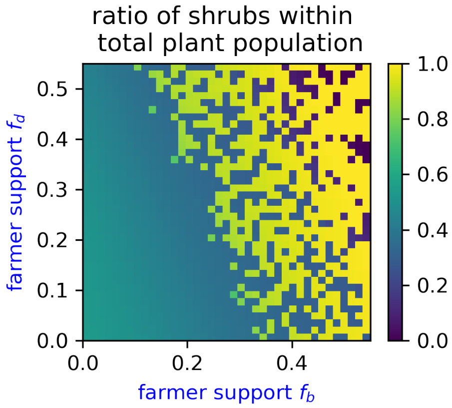
browsers: $$\frac{dC_B}{dt} = e(F_{HB} + F_{SB}) C_B - \mathbf{m_b} C_B - \mathbf{m_d} C_B^2$$

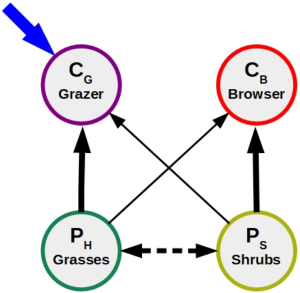
grazers: $$\frac{dC_G}{dt} = e(F_{HG} + F_{SG}) C_G - \mathbf{m_b(1 - f_b)} C_G - \mathbf{m_d(1 - f_d)} C_G^2$$



- Farmers support their livestock ⇒ **reduced grazer loss rates**.

Increasing levels of farmer support enable bistability

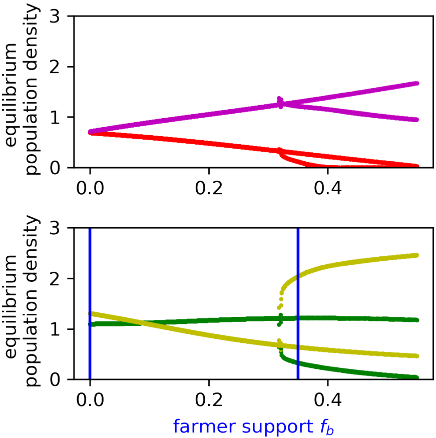


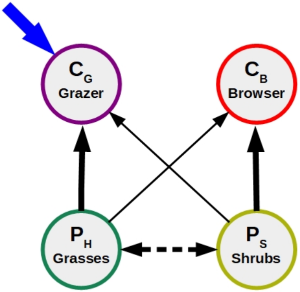


- Farmers support their livestock ⇒ **reduced grazer loss rates**.

Koch et al. *Oikos* (2023)

Increasing levels of farmer support trigger bistability

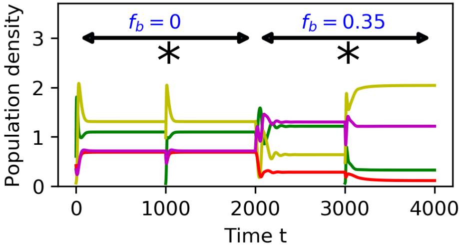




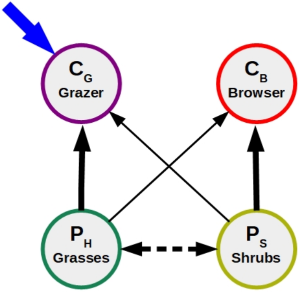
- Farmers support their livestock ⇒ **reduced grazer loss rates**.

Koch et al. *Oikos* (2023)

External disturbances (e.g. $* =$ drought) can force the system to "tip over"

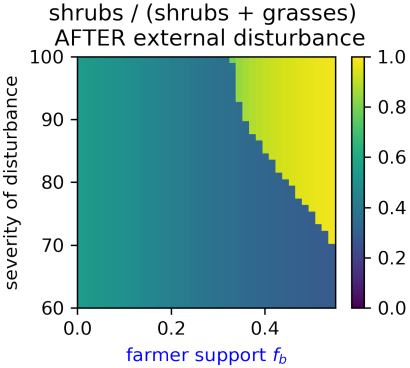


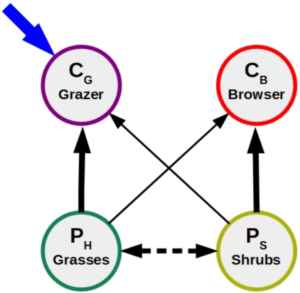
Koch et al. *Oikos* (2023)



- Farmers support their livestock $\Rightarrow$ **reduced grazer loss rates**.

Resistance to disturbances declines for increasing levels of farmer support

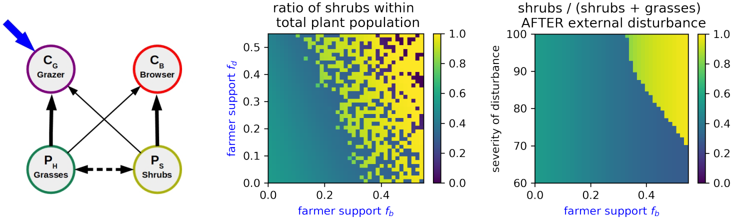




- Farmers support their livestock ⇒ **reduced grazer loss rates**.

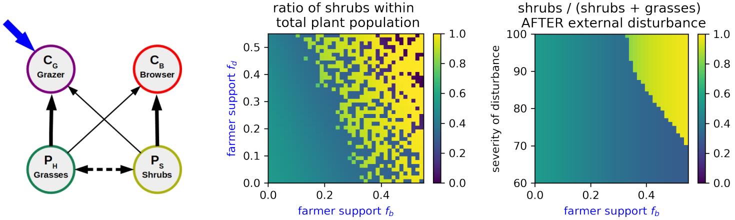
Koch et al. *Oikos* (2023)

Summary



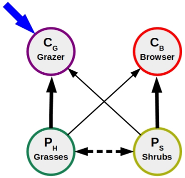
- Increasing levels of farmer support trigger bistability.

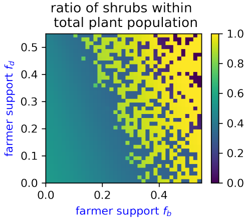
Summary

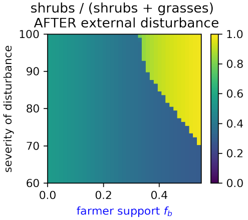


- Increasing levels of farmer support trigger bistability.
- The system might "tip over" in response to external disturbances, such as drought events.

Summary







- Increasing levels of farmer support trigger bistability.
- The system might "tip over" in response to external disturbances, such as drought events.
- Resistance to disturbances declines for increasing levels of farmer support.

This work has also been published!

OIKOS

Research article

Livestock management promotes bush encroachment in savanna systems by altering plant–herbivore feedback

Franziska Koch[1,2], Britta Tietjen[3,4], Katja Tielbörger[1] and Korinna T. Allhoff[1,2]

[1]Inst. of Evolution and Ecology, Eberhard Karls Univ. Tübingen, Tubingen, Germany
[2]Inst. of Biology, Univ. of Hohenheim, Hohenheim, Germany
[3]Freie Univ. Berlin, Theoretical Ecology, Berlin, Germany
[4]Berlin-Brandenburg Inst. of Advanced Biodiversity Research (BBIB), Berlin, Germany

Corresponding author: Korinna T Allhoff Email korinna.allhoff@uni-hohenheim.de

Oikos
2023: e09462
doi: 10.1111/oik.09462

Subject Editor: James Bullock
Editor-in-Chief: Vigdis Vandvik
Accepted 26 September 2022

Savannas are characterized by the coexistence of two contrasting plant life-forms: woody and herbaceous vegetation. During the last decades, there has been a global trend of an increase in woody cover and the spread of shrubs and trees into areas that were previously dominated by grasses. This process, termed bush encroachment, is associated with severe losses of ecosystem functions and typically difficult to reverse. It is assumed to be an example of a critical transition between two alternative stable states. Overgrazing due to unsustainable rangeland management has been identified as one of the main causes of this transition, as it can trigger several self-reinforcing feedback loops. However, the dynamic role of grazing within such feedback loops has received less attention. We used a set of coupled differential equations to describe the competition between shrubs and grasses, as well as plant biomass consumption via grazing and browsing. Grazers were assumed to receive a certain level of care from farmers, so that grazer densities emerge dynamically from the combined effect of vegetation abundance and farmer support. We quantified all self-reinforcing and self-dampening feedback loops at play and analyzed their relative importance in shaping system (in-)stability. Bistability, the presence of a grass dominated and a shrub dominated state, emerges for intermediate levels of farmer support due to positive feedback that arises from competition between shrubs and grasses and from herbivory. We furthermore demonstrate that disturbances, such as drought events, trigger abrupt transitions from the grass dominated to the shrub dominated state and that the system becomes more susceptible to disturbances with increasing farmer support. Our results thus highlight the potential of interaction networks in combinations with feedback loop analysis for improving our understanding of critical transitions in general, and bush encroachment in particular.

https://doi.org/10.1111/oik.09462

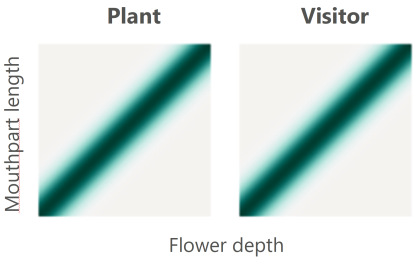
Our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?
- How do these networks respond to **external stressors and disturbances**?
- How do these networks **emerge** from an eco-evolutionary perspective?

Project 3: The role of **FLINT**s for eco-evolutionary dynamics of biodiversity and interaction networks

DFG funded package proposal "FLINT"
with one theoretical and three empirical subprojects,
5 PhD students and 12 PIs in total, started in 2024

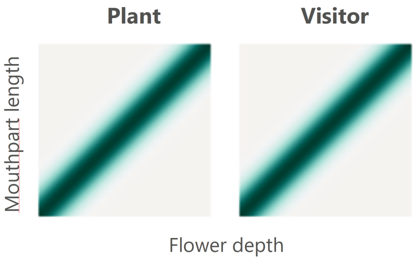
What is a FLINT?



FLINT = **F**itness effect **L**andscape of biotic **INT**eractions

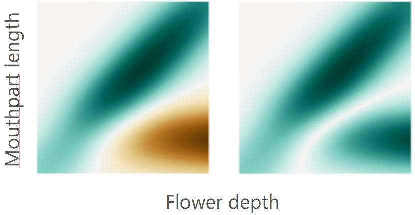
Simple example: trait matching!

What is a FLINT?



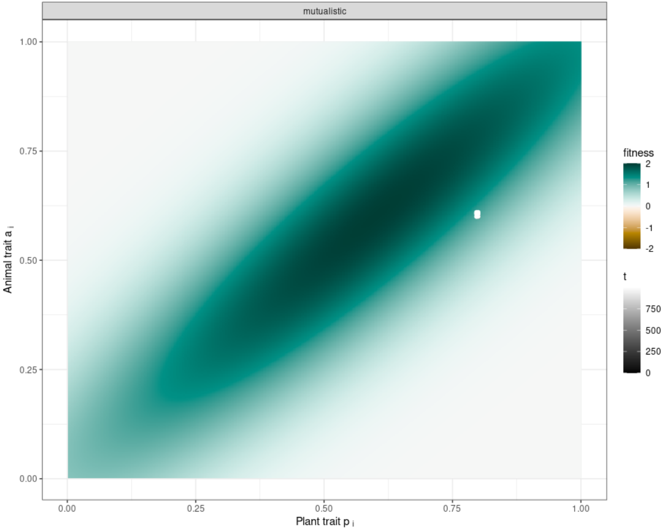
FLINT = **F**itness effect **L**andscape of biotic **INT**eractions

Simple example: trait matching!

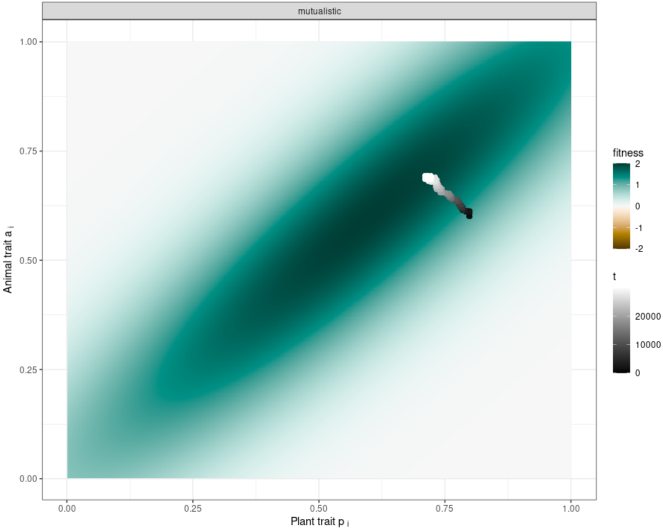


Slightly more complex example: nectar robbing!

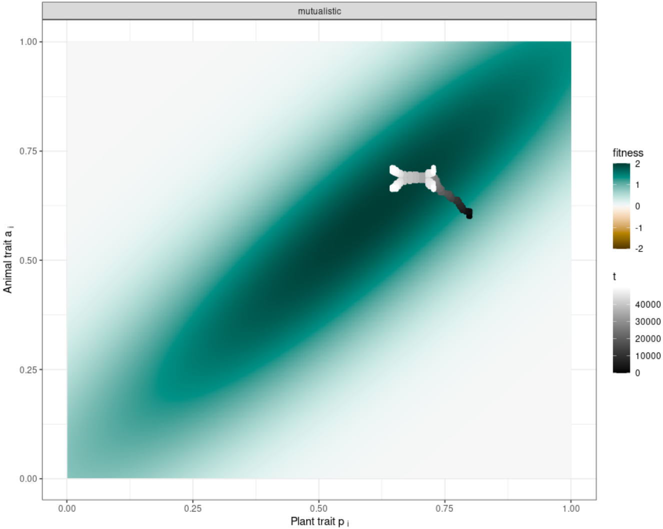
Simulating diversification using a trait matching FLINT



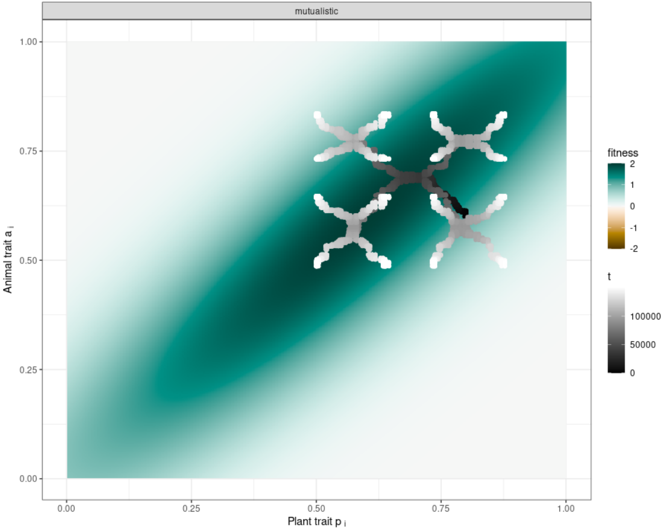
Simulating diversification using a trait matching FLINT



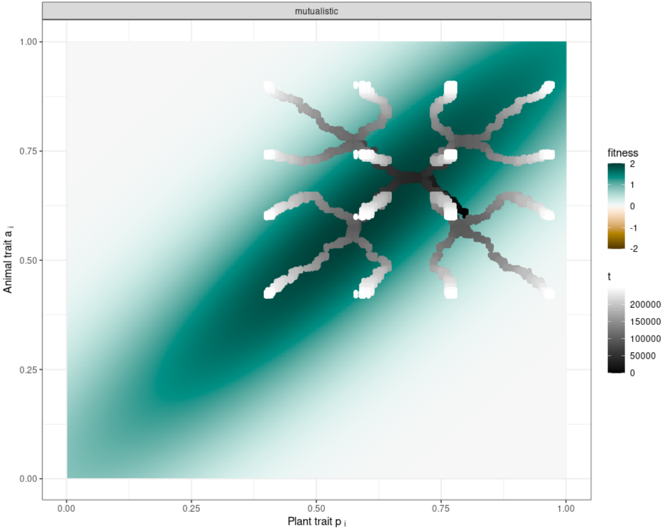
Simulating diversification using a trait matching FLINT



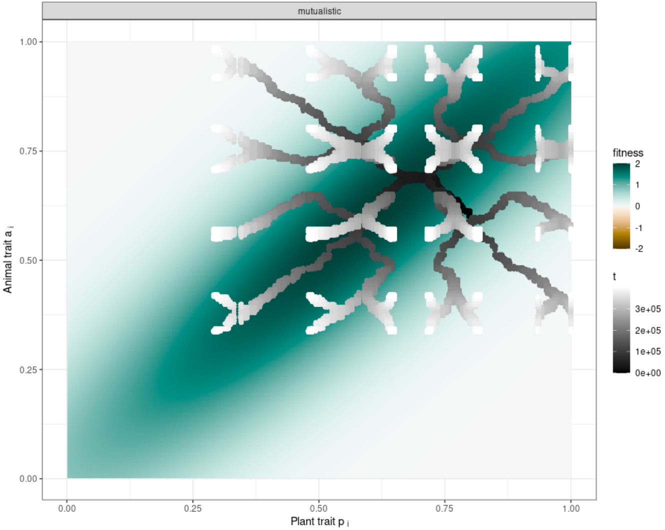
Simulating diversification using a trait matching FLINT



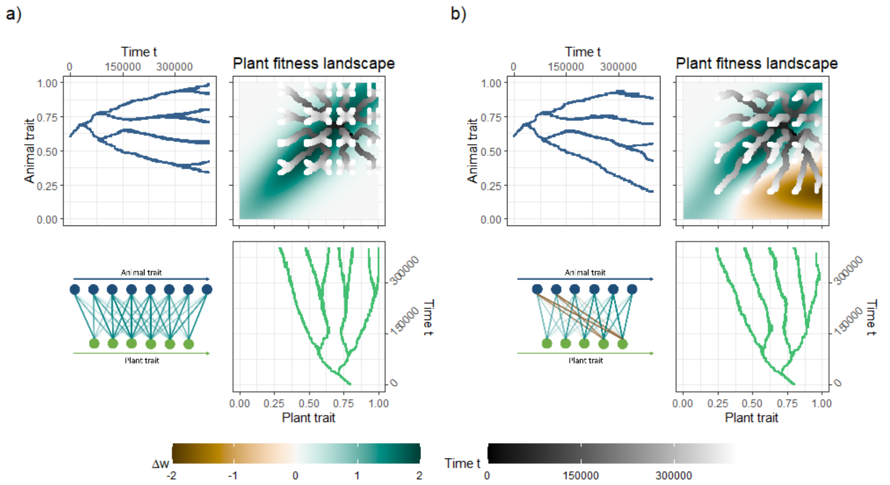
Simulating diversification using a trait matching FLINT



Simulating diversification using a trait matching FLINT



Landscape topology matters for biodiversity dynamics!



Open questions for the theoretical subproject

- How does landscape topography affect initial diversification?
- Which landscape topographies maximise initial diversification rates?

Open questions for the theoretical subproject

- How does landscape topography affect initial diversification?
- Which landscape topographies maximise initial diversification rates?

- How does landscape topography affect the structure of emergent interaction networks?
- Which landscapes topographies lead to realistic network structures?

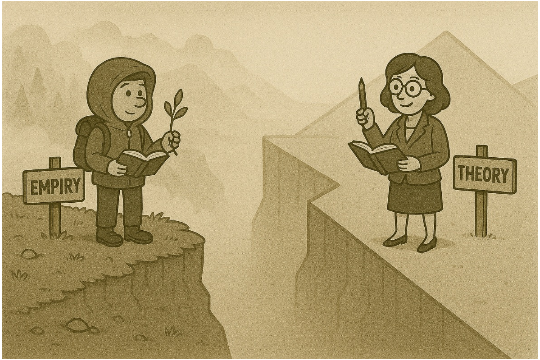
Open questions for the theoretical subproject

- How does landscape topography affect initial diversification?
- Which landscape topographies maximise initial diversification rates?

- How does landscape topography affect the structure of emergent interaction networks?
- Which landscapes topographies lead to realistic network structures?

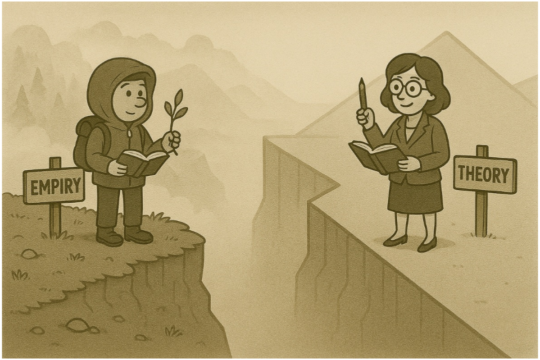
Work in progress

Overarching goal of the FLINT project:
theory-based synthesis across empirical study systems and interaction types



Work in progress

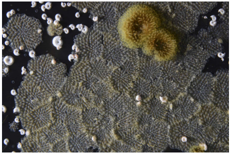
Overarching goal of the FLINT project:
theory-based synthesis across empirical study systems and interaction types



https://ecology.uni-hohenheim.de/en/flint

Back to our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?

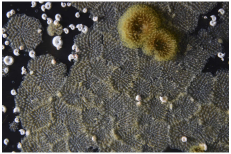


Credit: Gail Ashton

bryozoans (-/-)

Back to our favourite research questions

- Do such networks have a specific **structure**? If yes, how does their structure affect network **stability**?



Credit: Gail Ashton

bryozoans (-/-)

Credit: Bismark Ofosu-Bamfo

tree-liana (-/+)

Back to our favourite research questions

- How do these networks respond to **external stressors and disturbances**?

Credit: Korinna Allhoff

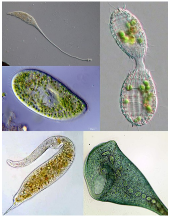
herbivory (-/+)

Back to our favourite research questions

- How do these networks respond to **external stressors and disturbances**?

Credit: Korinna Allhoff

herbivory (-/+)



https://en.wikipedia.org/wiki/Ciliate

freshwater ciliates (-/-)

Back to our favourite research questions

- How do these networks **emerge** from an eco-evolutionary perspective?

https://en.wikipedia.org/wiki/Entomophily

pollination (+/+)

https://en.wikipedia.org/wiki/Nectar_robbing

nectar robbering (-/+)

Do you want to learn more?

Then please get in touch!