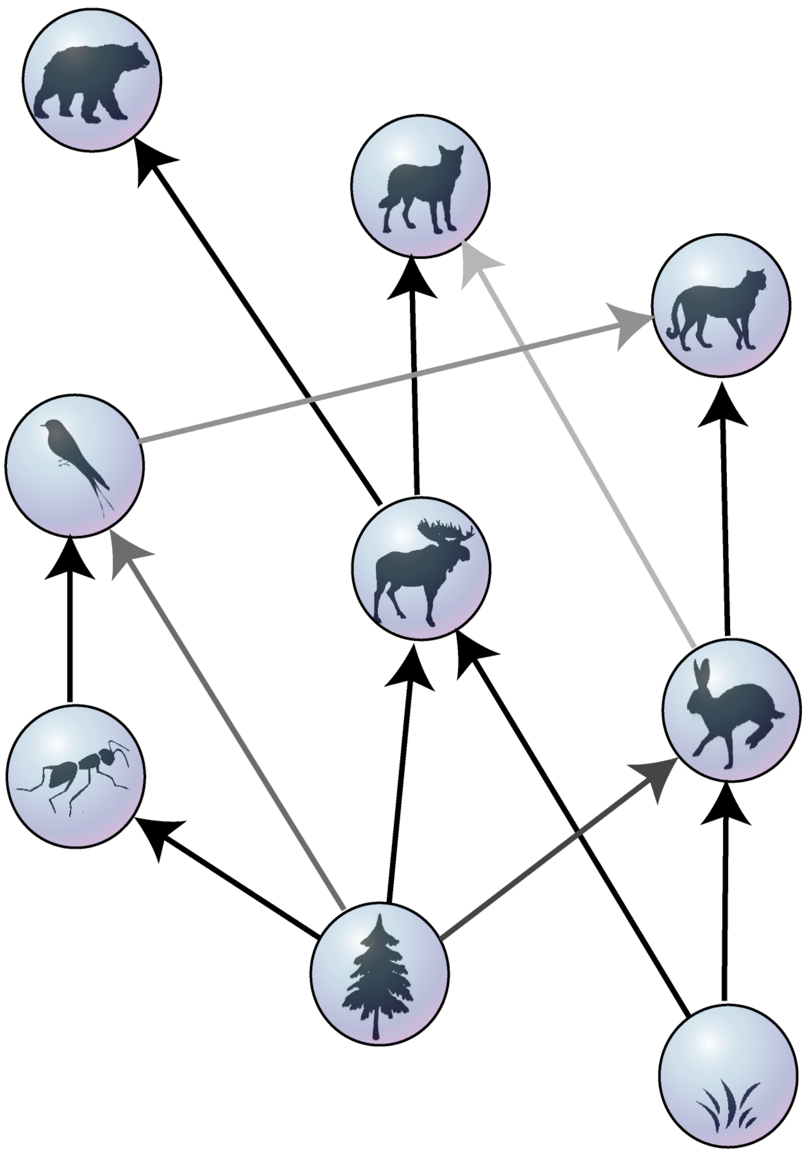
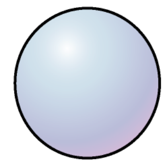
Generalized models reveal stabilizing factors in food webs.

Lars Rudolf - Dynamics of Biological Networks - University of Bristol

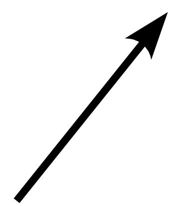
Dresden, 18.05.2012

Food webs - The Who eats Who in Ecology.



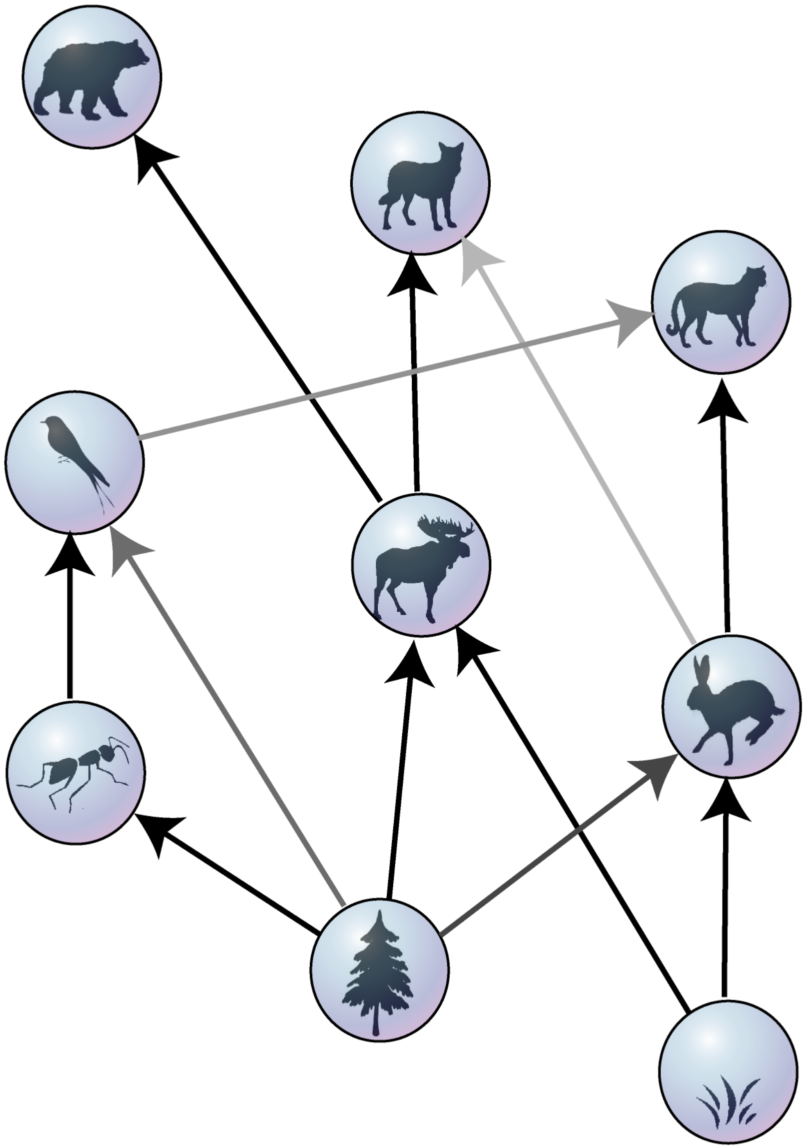


Nodes:
Species

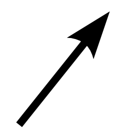


Links:
predator-prey interactions

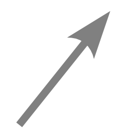
Food webs - The Who eats Who in Ecology.



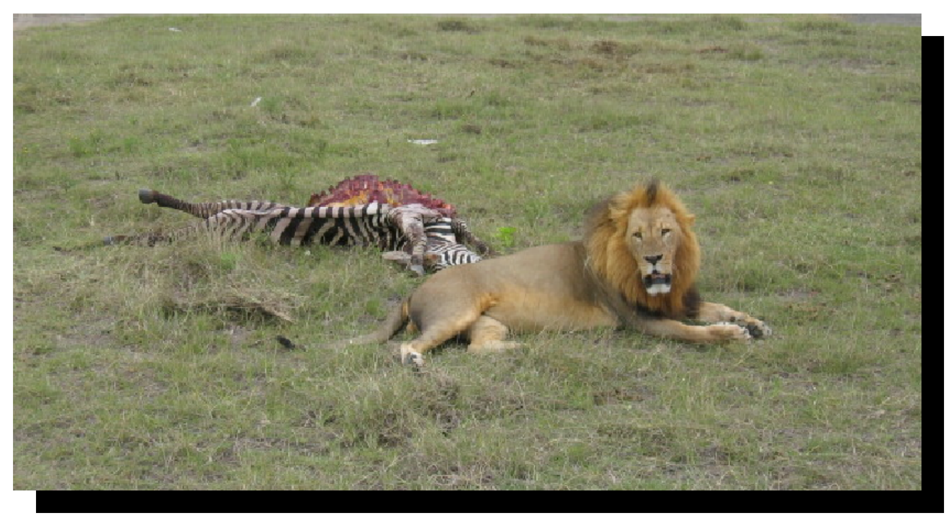
Directed biomass flows from prey to predator



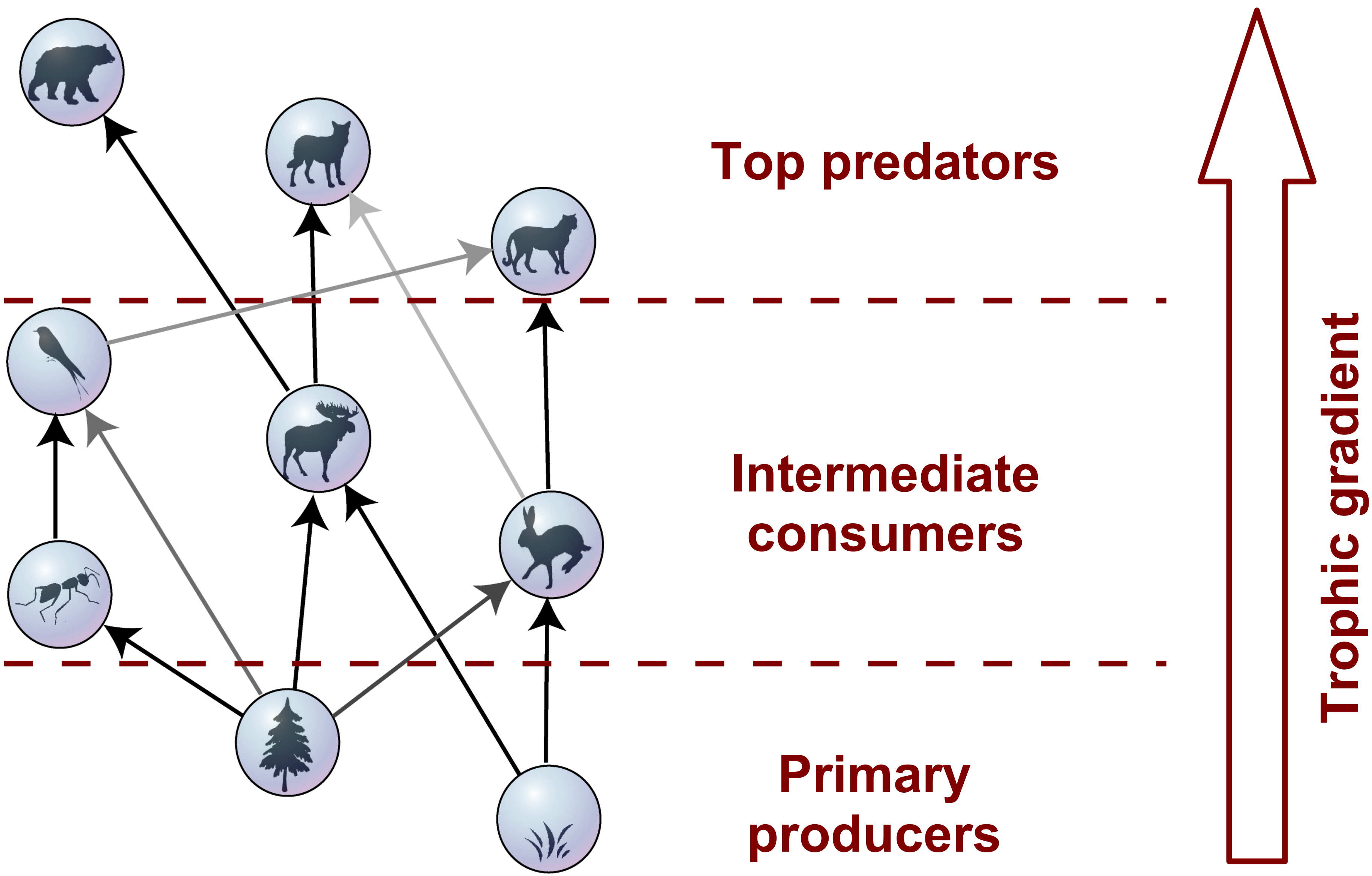
Strong links:
High biomass flow



Weak links:
Low biomass flow



Food webs - The Who eats Who in Ecology.



Complexity or stability?!

Large and complex systems are in general unlikely to be stable! *

* May R. **Will a large complex system be stable?** Nature **238** 1972

Complexity or stability?!

Large and complex systems are in general unlikely to be stable! *

The majority of natural food webs are large, complex, and stationary on population dynamical time scales.

* May R. **Will a large complex system be stable?** Nature **238** 1972

Complexity or stability?!

Large and complex systems are in general unlikely to be stable! *

The majority of natural food webs are large, complex, and stationary on population dynamical time scales.

What are the properties of food webs which give them their unusual stability?

* May R. **Will a large complex system be stable?** Nature **238** 1972

Food webs:

- large and complex networks
- many variables
- many parameters
- little informations
- strong nonlinearities
- dynamics on different time scales

Generalized Models*

* Gross T. and Feudel U.: **Generalized models as a universal approach to the analysis of nonlinear dynamical systems** PHYSICAL REVIEW E **73**, 016205 2006

GM reveal stabilizing factors in food webs.

$$\dot{X} = P(X) - L(X)$$

Conventional Modeling

- Parameterize
- Compute Steady States
- Compute Jacobian
- Investigate Dynamics

$$\dot{X} = P(X) - L(X)$$

Generalized Modeling

Conventional Modeling

Parameterize

Compute Steady States

Compute Jacobian

Investigate Dynamics

GM reveal stabilizing factors in food webs.

$$\dot{X} = P(X) - L(X)$$

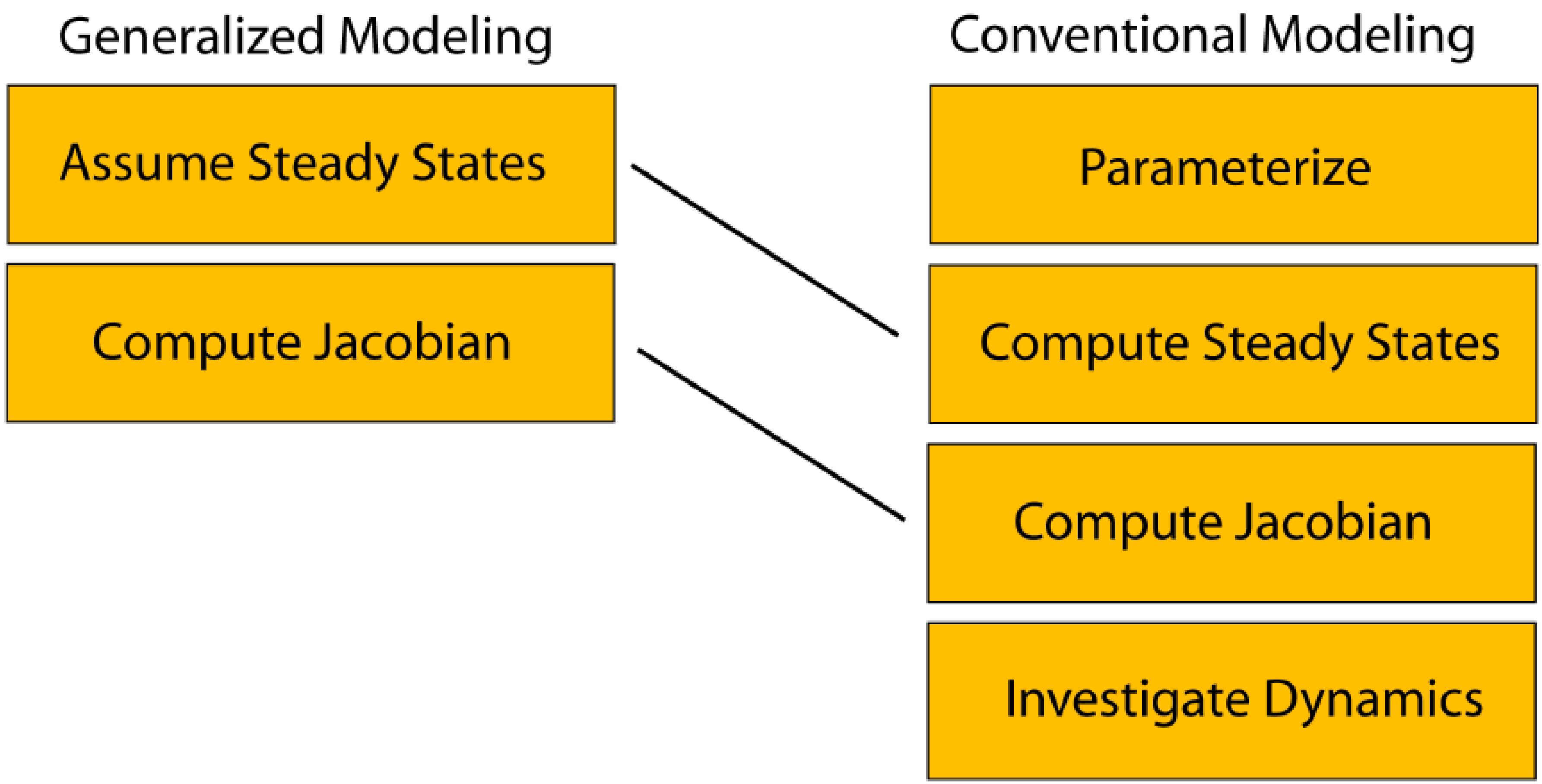
Generalized Modeling

- Assume Steady States

Conventional Modeling

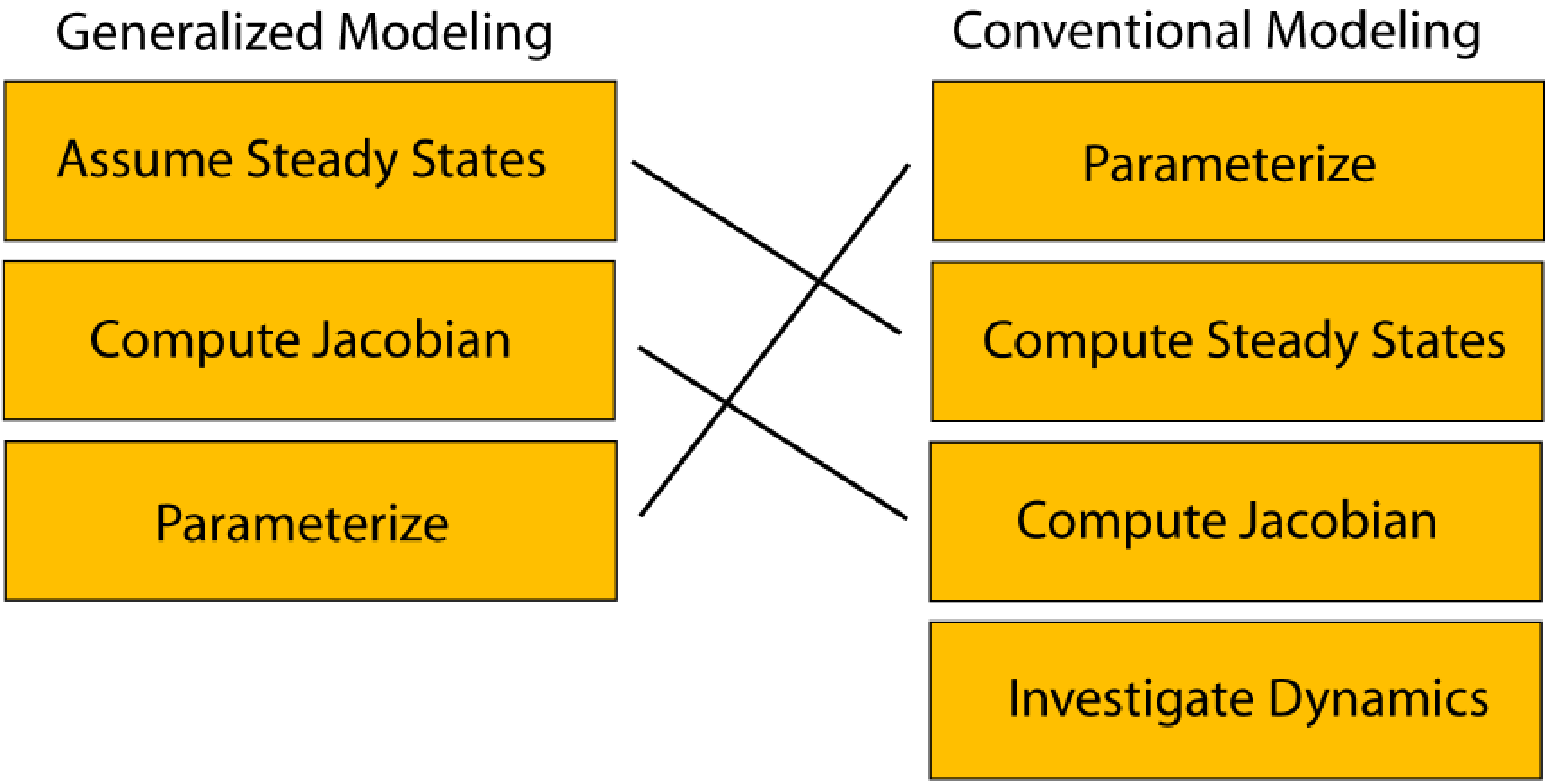
- Parameterize
- Compute Steady States
- Compute Jacobian
- Investigate Dynamics

$$\dot{X} = P(X) - L(X)$$

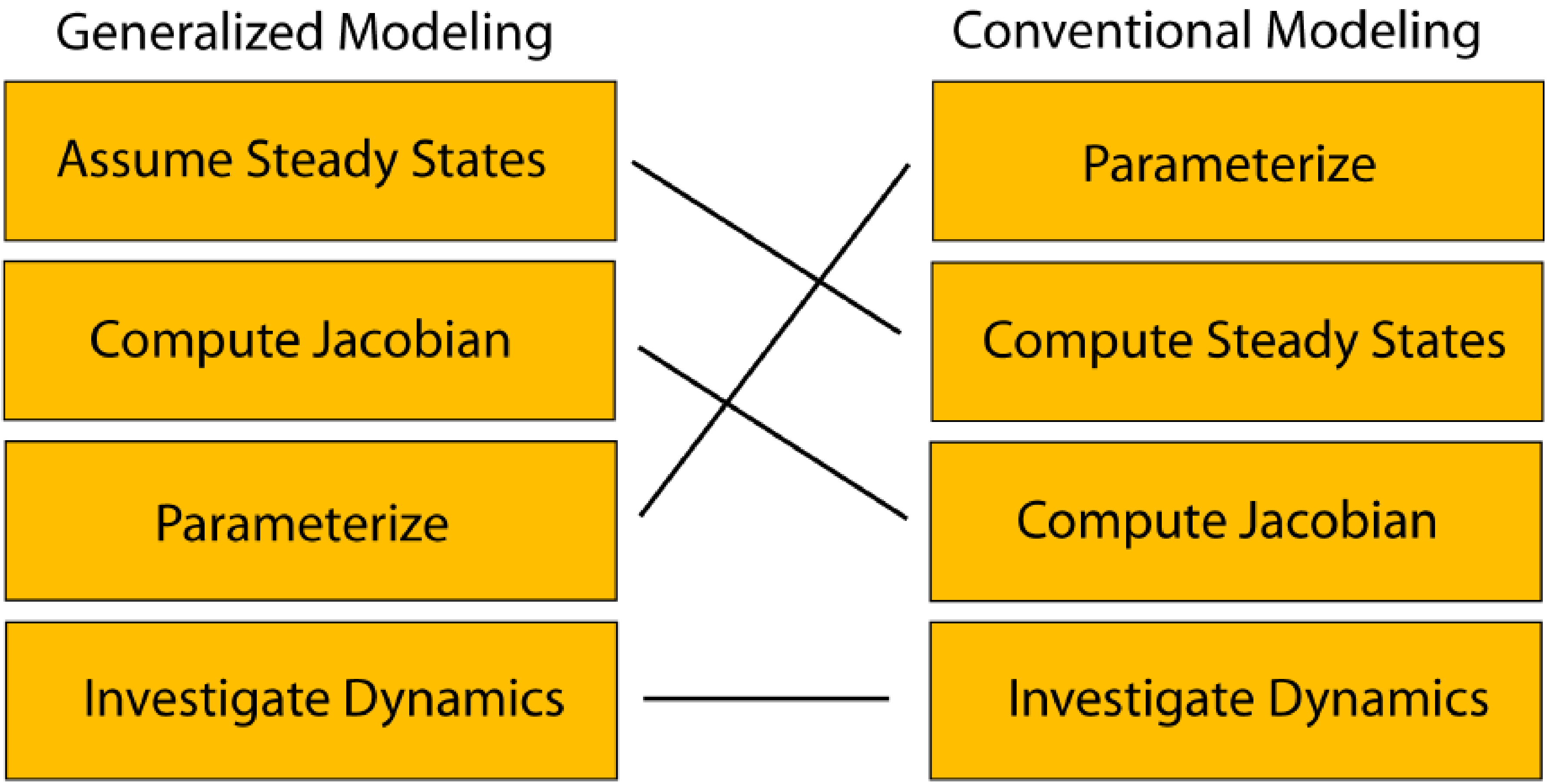

Generalized Modeling
Assume Steady States
Compute Jacobian
Conventional Modeling
Parameterize
Compute Steady States
Compute Jacobian
Investigate Dynamics

GM reveal stabilizing factors in food webs.

$$\dot{X} = P(X) - L(X)$$



$$\dot{X} = P(X) - L(X)$$



Generalized Modeling
Assume Steady States
Compute Jacobian
Parameterize
Investigate Dynamics
Conventional Modeling
Parameterize
Compute Steady States
Compute Jacobian
Investigate Dynamics

$$\dot{X} = P(X) - L(X)$$

Generalized Modeling

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

$$X^*, P^* = L^*$$

$$x = \frac{X}{X^*}, p(x) = \frac{P(X)}{P^*}, l(x) = \frac{L(X)}{L^*}$$

$$\dot{x} = \frac{P^*}{X^*}\left(p(x) - l(x)\right)$$

Generalized Modeling

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

$$X^*, P^* = L^*$$

$$x = \frac{X}{X^*}, p(x) = \frac{P(X)}{P^*}, l(x) = \frac{L(X)}{L^*}$$

GM reveal stabilizing factors in food webs.

$$\dot{x} = \frac{P^*}{X^*}(p(x) - l(x))$$

Generalized Modeling

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

Assume Steady States:

$$X^*, P^* = L^*$$

$$x = \frac{X}{X^*}, p(x) = \frac{P(X)}{P^*}, l(x) = \frac{L(X)}{L^*}$$

Compute Jacobian:

$$\mathbf{J} = \frac{P^*}{X^*}(p'(1) - l'(1))$$

$$\dot{x} = \frac{P^*}{X^*}\left(p(x) - l(x)\right)$$

Generalized Modeling

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

$$X^*, P^* = L^*$$

$$x = \frac{X}{X^*}, p(x) = \frac{P(X)}{P^*}, l(x) = \frac{L(X)}{L^*}$$

$$\mathbf{J} = \frac{P^*}{X^*}\left(p'(1) - l'(1)\right)$$

$$\alpha = \frac{P^*}{X^*} = \frac{L^*}{X^*}$$

$$\phi = p'(1)$$

$$\mu = l'(1)$$

GM reveal stabilizing factors in food webs.

$$\dot{x} = \alpha(p(x) - l(x))$$

Generalized Modeling

1. Assume Steady States
2. Compute Jacobian
3. Parameterize
4. Investigate Dynamics

Assume Steady States:

$$X^*, P^* = L^*$$

$$x = \frac{X}{X^*}, p(x) = \frac{P(X)}{P^*}, l(x) = \frac{L(X)}{L^*}$$

Compute Jacobian:

$$\mathbf{J} = \alpha(\phi - \mu)$$

Parameterize:

$$\alpha = \frac{P^*}{X^*} = \frac{L^*}{X^*}$$

$$\phi = p'(1)$$

$$\mu = l'(1)$$

GM reveal stabilizing factors in food webs.

$$\dot{x} = \alpha(p(x) - l(x))$$

Generalized Modeling

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

$$X^*, P^* = L^*$$

$$x = \frac{X}{X^*}, p(x) = \frac{P(X)}{P^*}, l(x) = \frac{L(X)}{L^*}$$

$$\mathbf{J} = \alpha(\phi - \mu)$$

$$\alpha = \frac{P^*}{X^*} = \frac{L^*}{X^*}$$

Rate of biomass turnover

$$\phi = p'(1)$$

$$\mu = l'(1)$$

Sensitivity of production or loss on species density

GM reveal stabilizing factors in food webs.

$$\dot{X}_n = S_n(X_n) + F_n(X_1, \ldots, X_N) - M_n(X_n) - \sum_{m=1}^{N} L_{mn}(X_1, \ldots, X_N)$$

Generalized Modeling

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

$$\dot{X}_n = S_n(X_n) + F_n(X_1, \ldots, X_N) - M_n(X_n) - \sum_{m=1}^{N} L_{mn}(X_1, \ldots, X_N)$$

Generalized Modeling

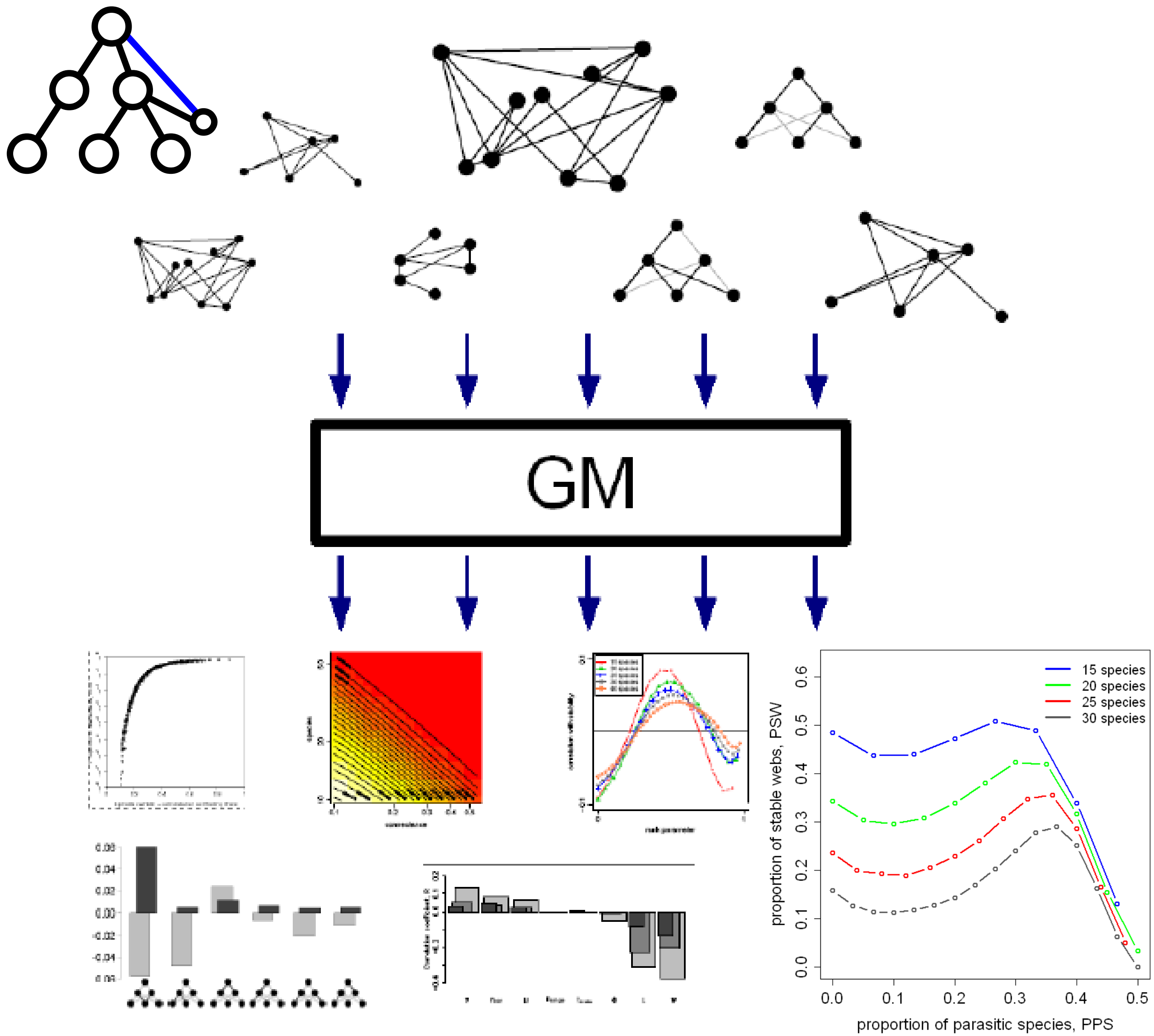
- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

Use an algorithm to create realistic topologies (**The Niche Model***) → Parameterize

* Williams R.J . & Martinez N.D. **Simple rules yield complex food webs** Nature **404** 2000

GM reveal stabilizing factors in food webs.

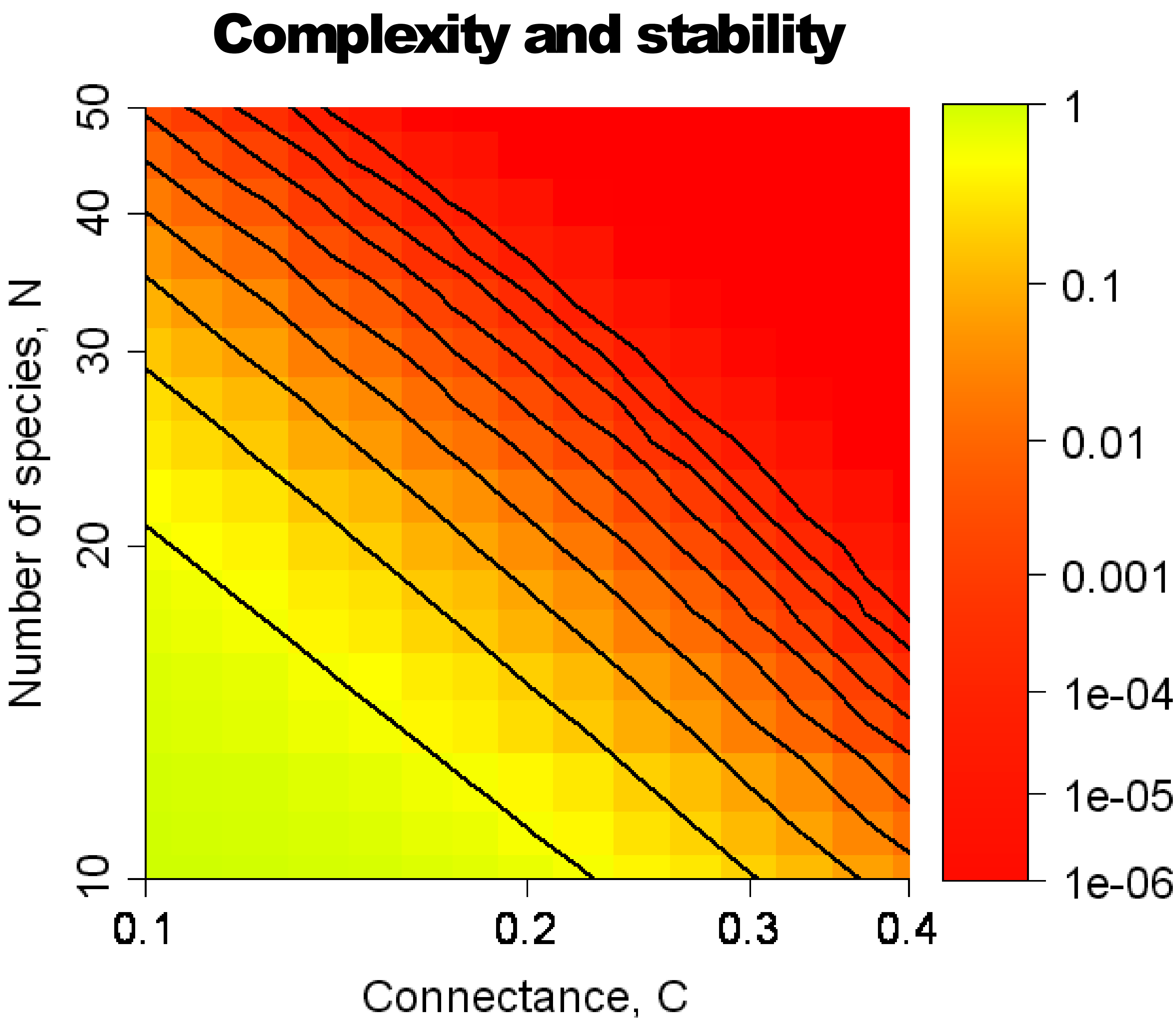
Generalized Models



Results

* Thilo Gross, Lars Rudolf, Simon A. Levin and Ulf Dieckmann:
Generalized Models Reveal Stabilizing Factors in Food Webs
Science **325**, 747 (2009)

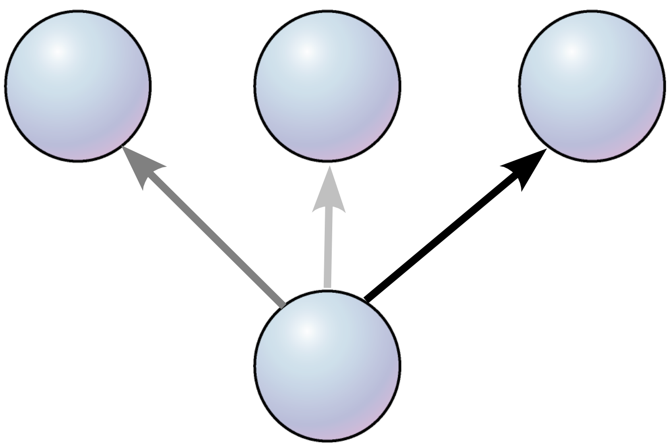
GM reveal stabilizing factors in food webs.

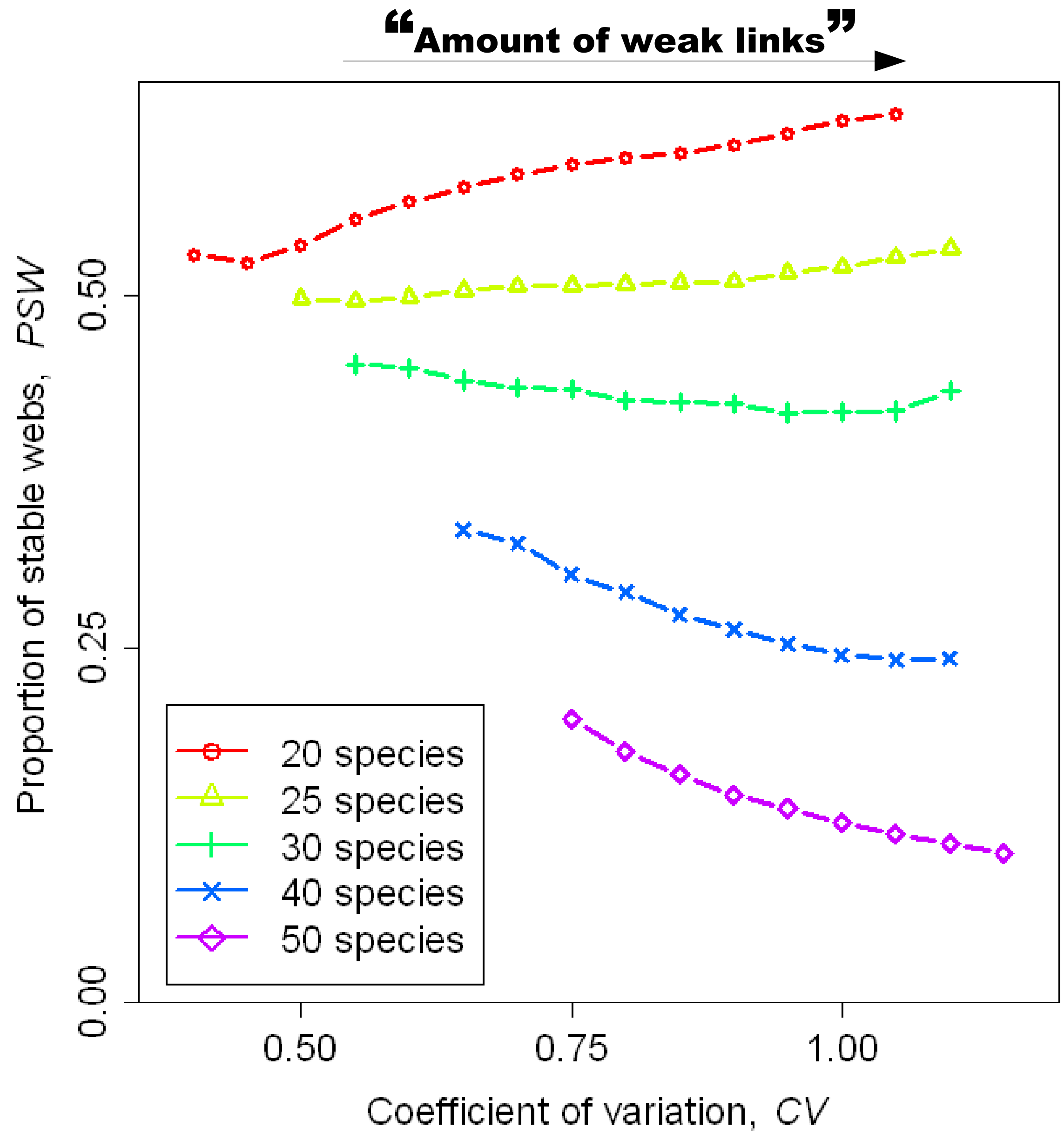


Weak links

Weak links:

- low flow interactions
- prey centric normalization



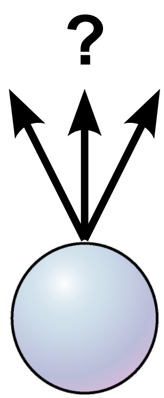


Stabilizing for small webs, but destabilizing for larger (realistic size) webs.

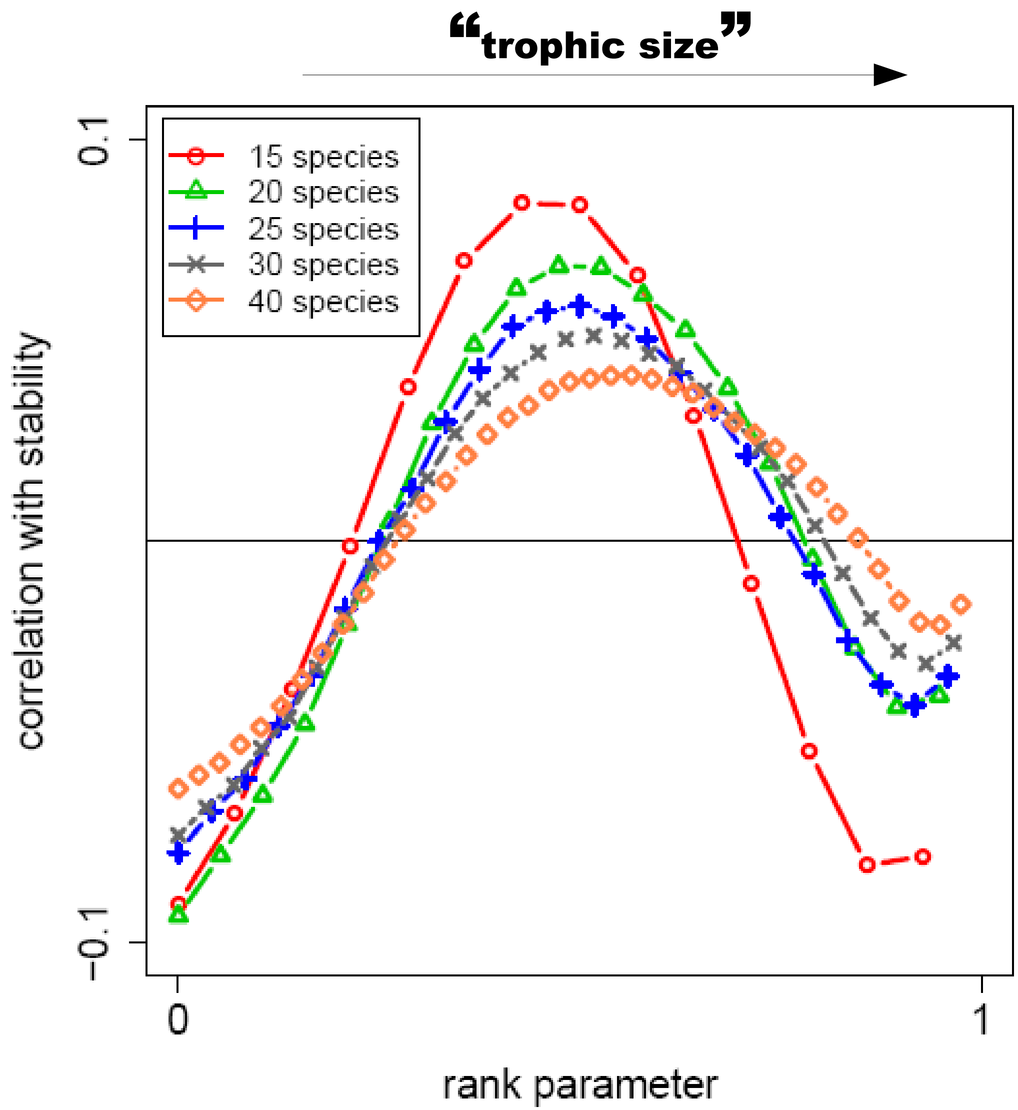
Link distribution

Link distribution:

- trophic position
- number of predators

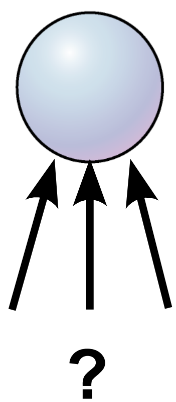


Many predators for intermediate species, but not for basal or top species.

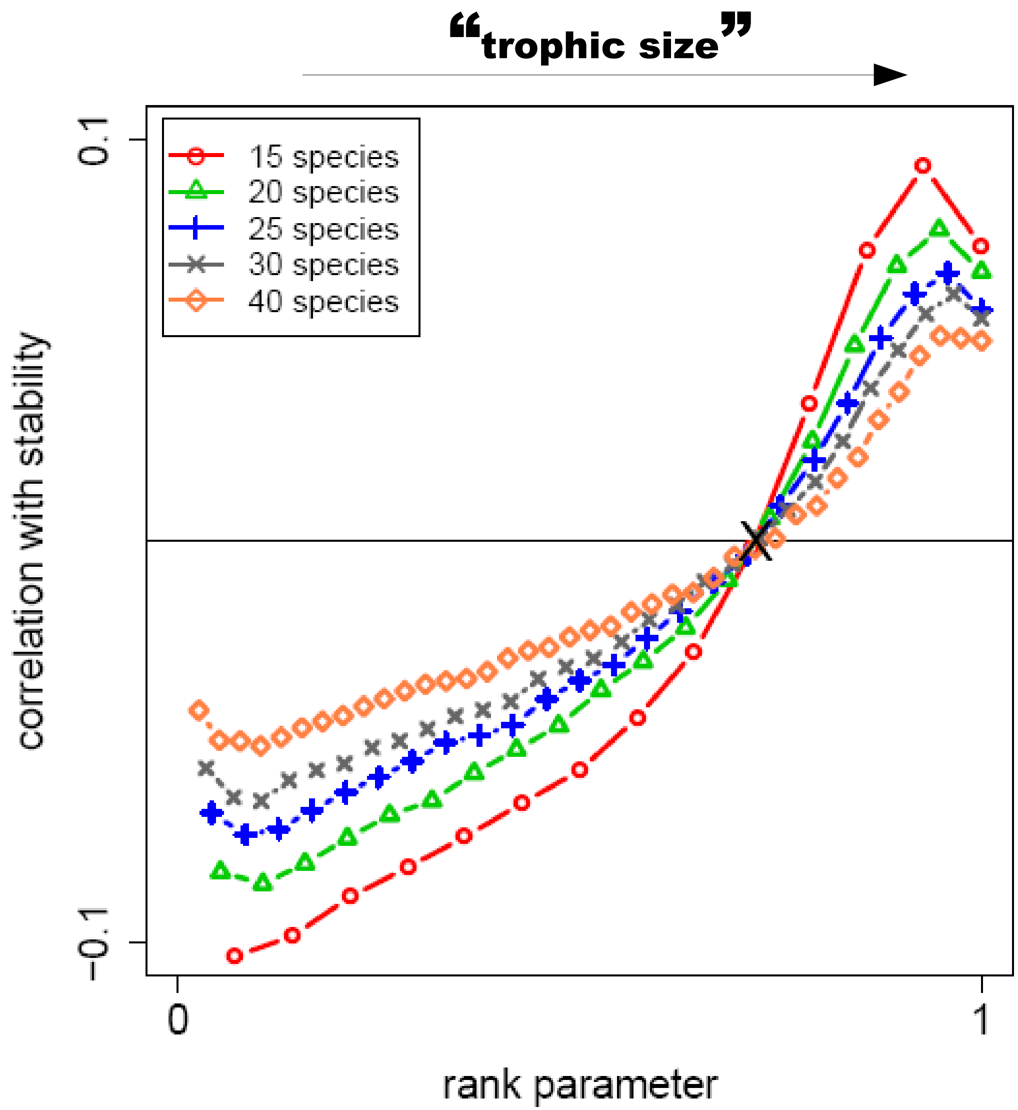


Link distribution:

- trophic position
- number of prey species



Generalist top and specialist basal species.



Conclusion

Conclusion

GM reveal stabilizing factors in food webs.

- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics

We reproduce:

New results:

New results:

GM reveal stabilizing factors in food webs.

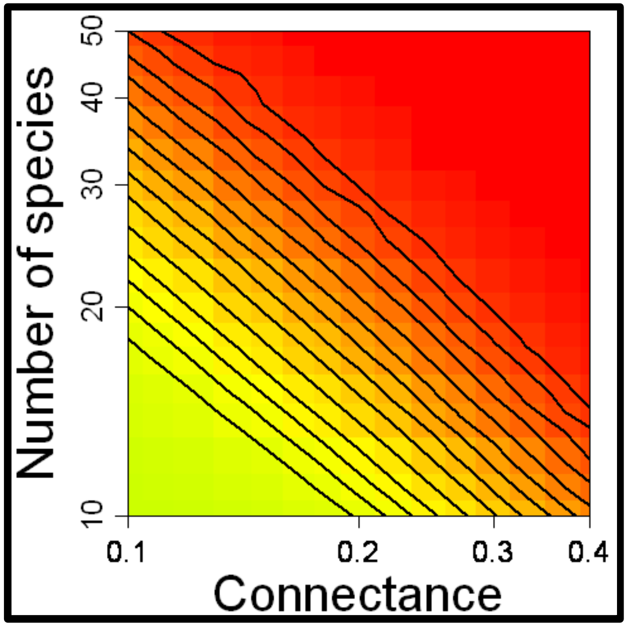
Conclusions

Assume Steady States

Compute Jacobian

Parameterize

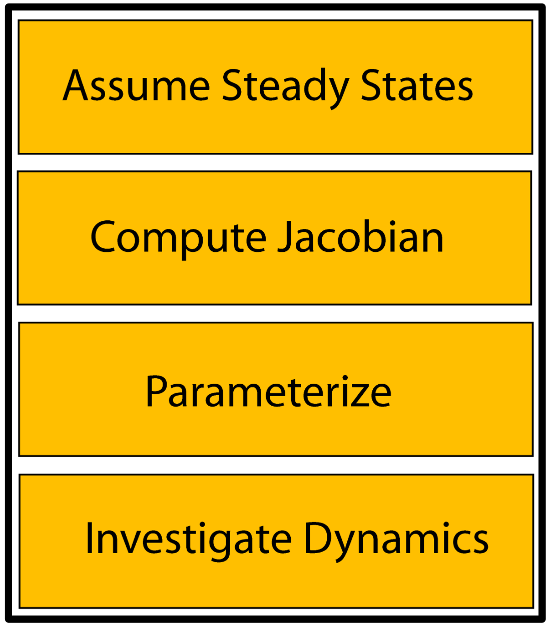
Investigate Dynamics

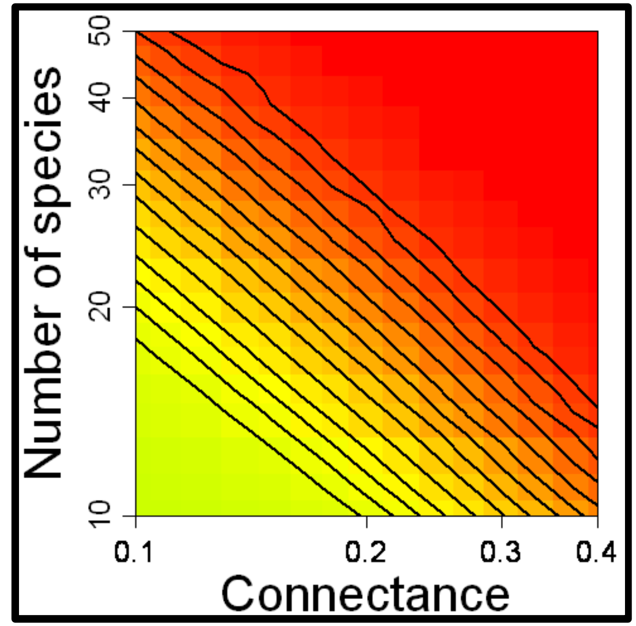


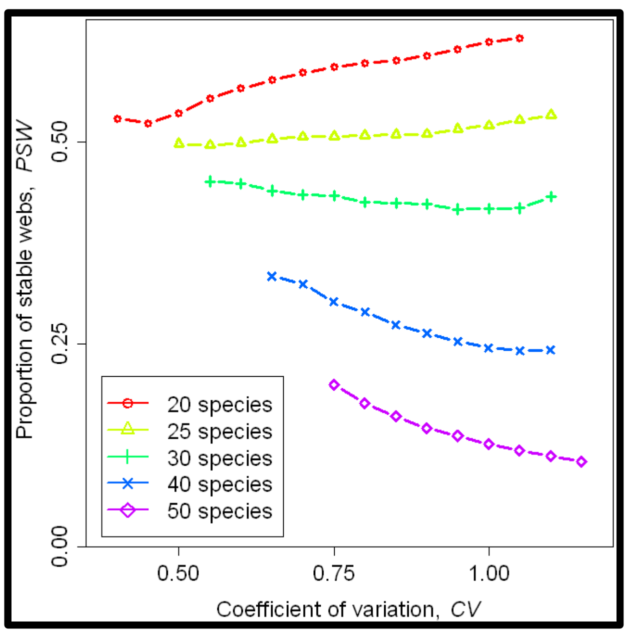
New results:

New results:

GM reveal stabilizing factors in food webs.

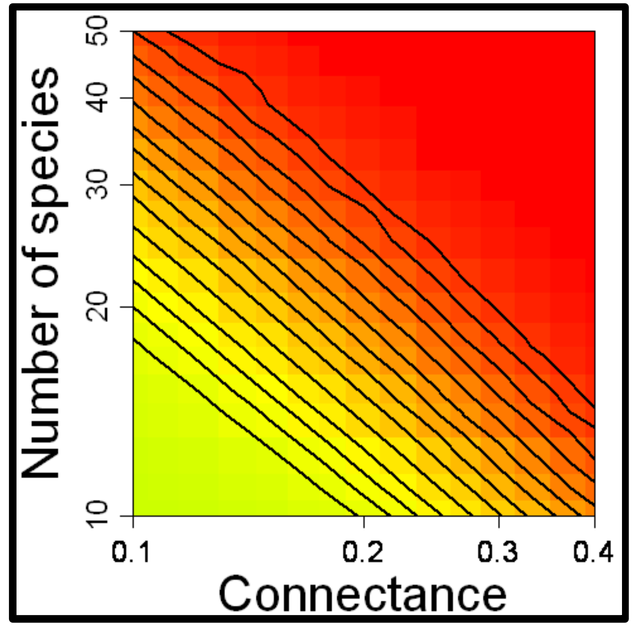


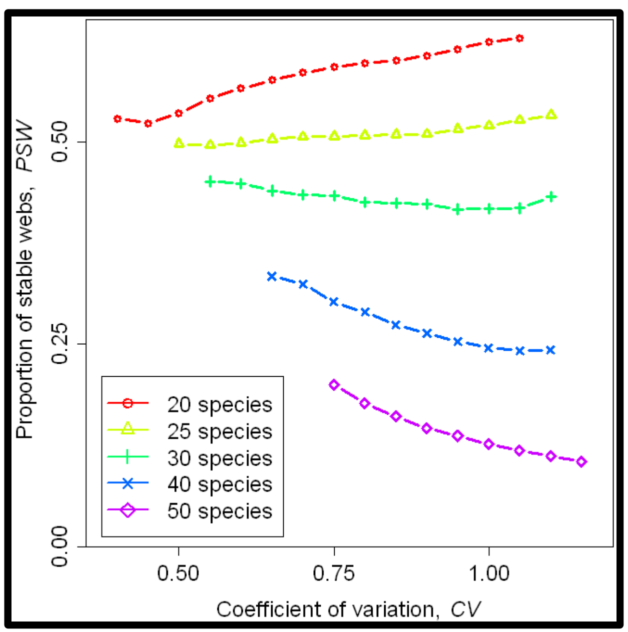


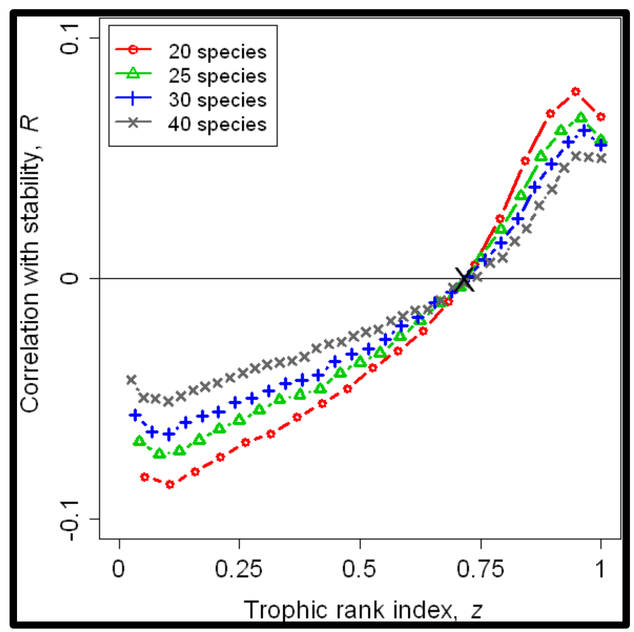


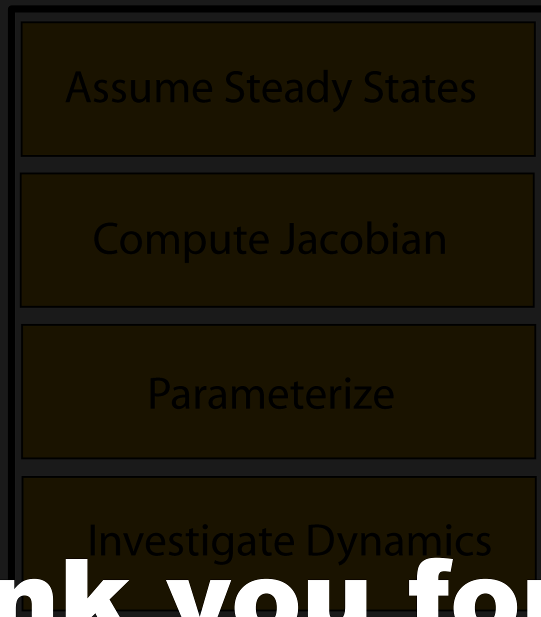
New results:

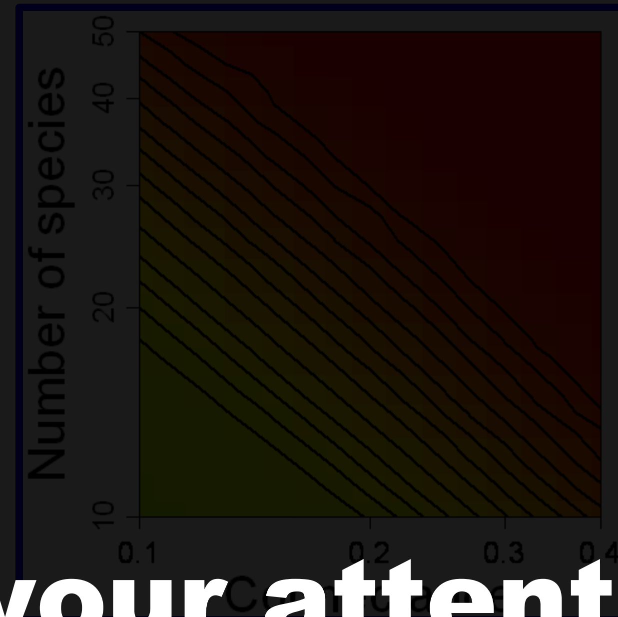
- Assume Steady States
- Compute Jacobian
- Parameterize
- Investigate Dynamics



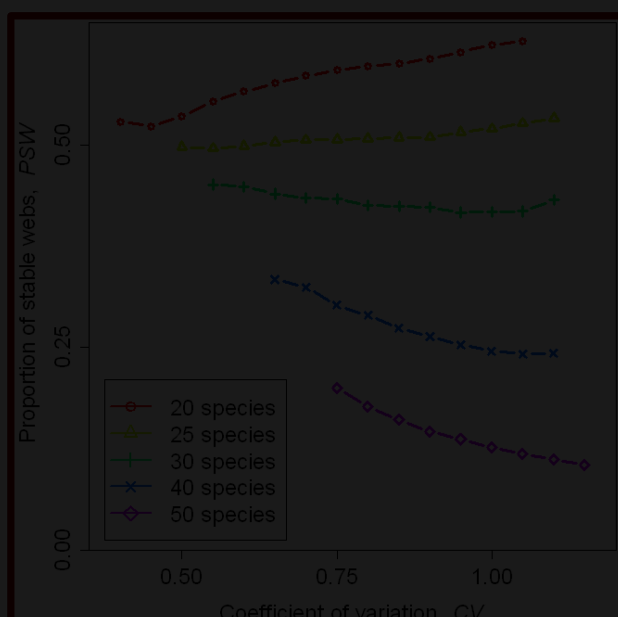


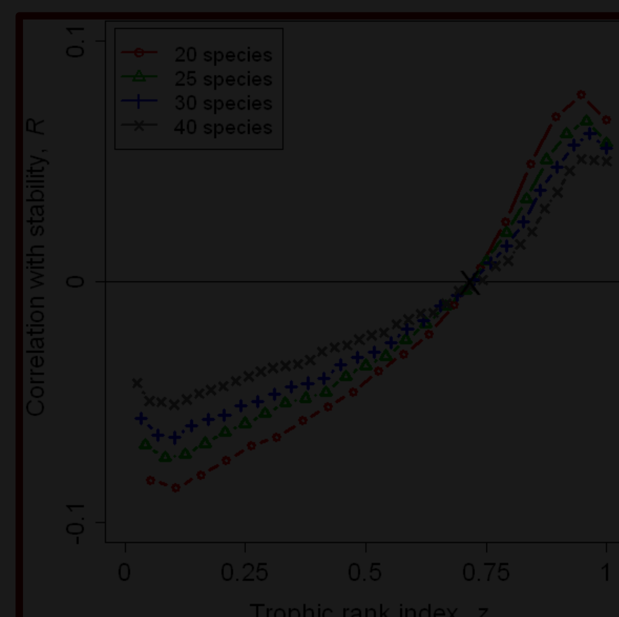






Thank you for your attention.





GM reveal stabilizing factors in food webs.