Assessing the impacts of Global Changes in Arctic and Antarctic food webs

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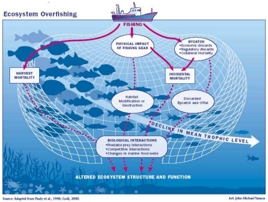
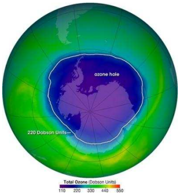
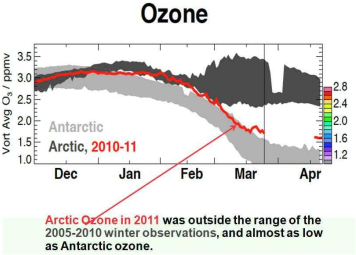
SUMMARY

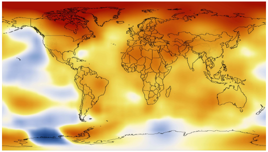
MOTIVATION

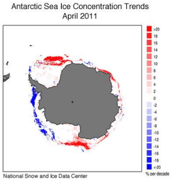
- Polar ecosystems are among the most affected by global environmental changes.

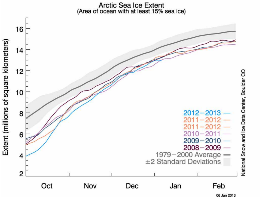






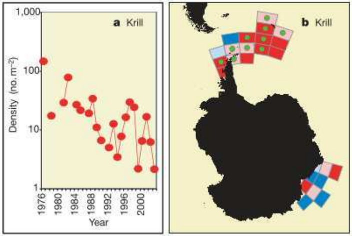


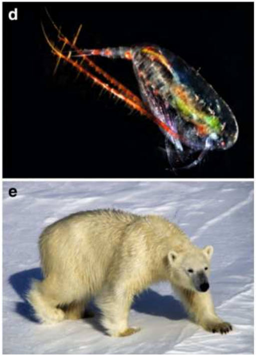


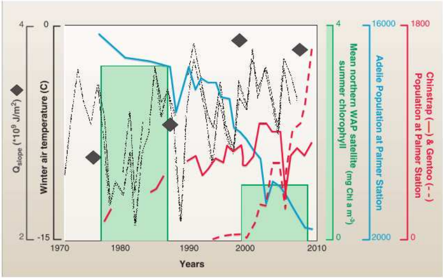


MOTIVATION

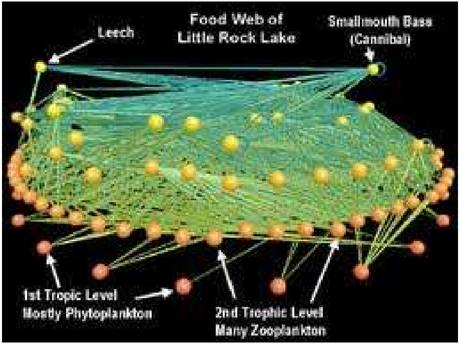
- Polar is particularly vulnerable to global changes.







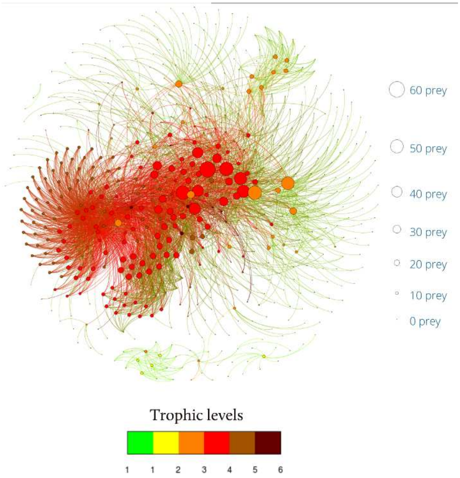
Motivation

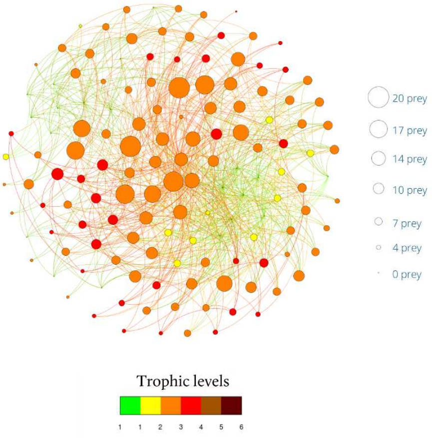

Food Web of
Little Rock Lake
Leech
Smallmouth Bass
(Cannibal)
1st Tropic Level
Mostly Phytoplankton
2nd Trophic Level
Many Zooplankton

Motivation

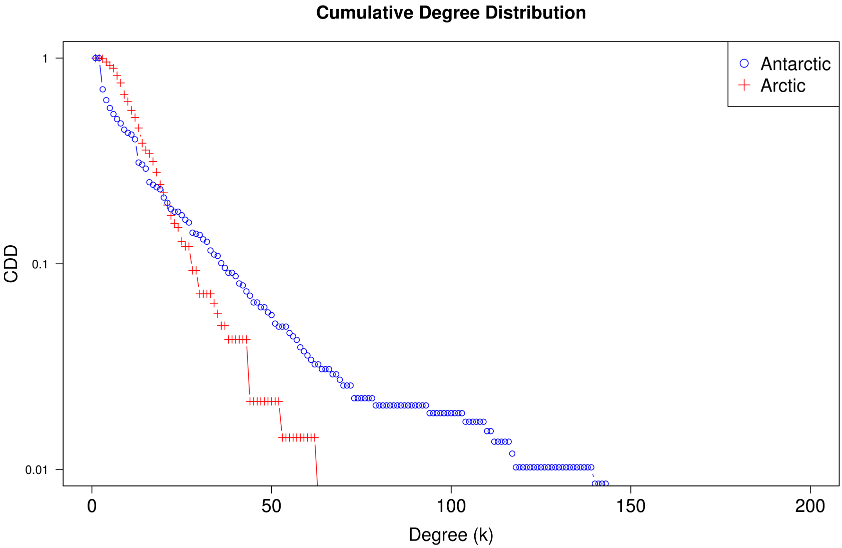
Study vulnerability of Arctic and Antarctic food webs to disturbances in order to know how these ecosystems can respond to the effects of global changes.

PREDATOR-PREY RATIO AND OMNIVORY LEVEL

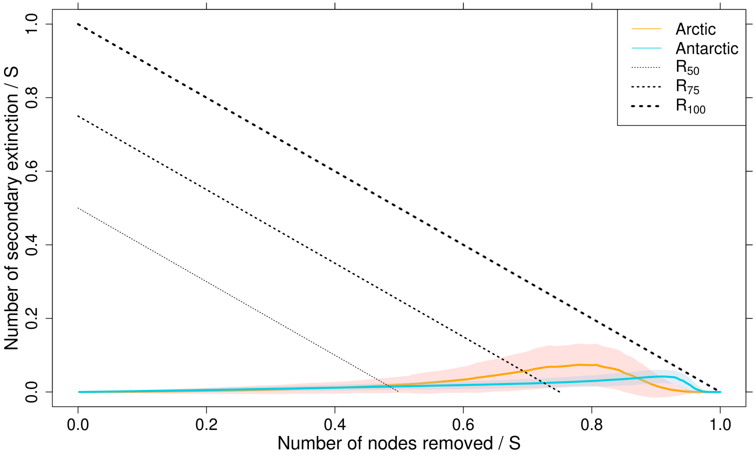




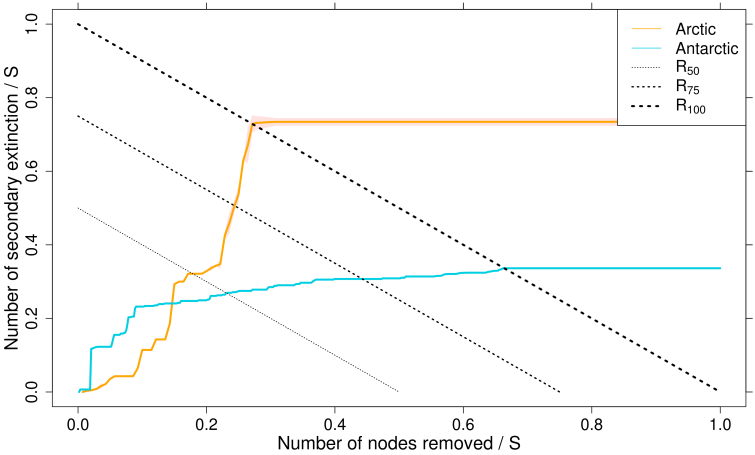
Cumulative Degree Distribution



Robustness to Random Removal



ROBUSTNESS TO PREY REMOVAL

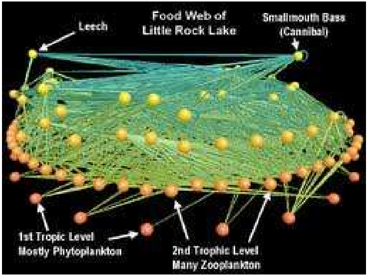


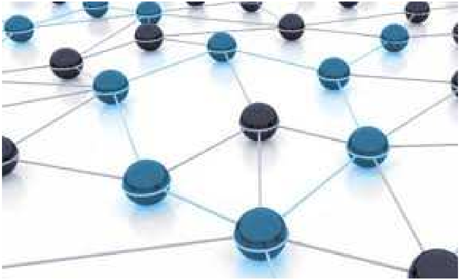
Compromised Species

Rank	Arctic			Antarctic		
	Species	***Phylum***	***Sec. ext. (mean ± sd)***	***Species***	***Phylum***	***Sec. ext. (mean ± sd)***
1	*Ciliatocardium ciliatum*	*Molluscs*	1.43 ± 3.33	*Euphausia superba*	*Arthropods*	5.07 ± 3.77
2	*Mytilus edulis*	*Molluscs*	1.37 ± 3.32	*Notocrangon antarcticus*	*Arthropods*	1.75 ± 2.76
3	*Calanus hyperboreus*	*Arthropods*	1.31 ± 3.21	*Limatula hodgsoni*	*Molluscs*	1.01 ± 2.73
4	*Calanus finmarchicus*	*Arthropods*	1.30 ± 2.75	*Nacella concinna*	*Molluscs*	1.00 ± 2.67
5	*Mallotus villosus*	*Chordata*	1.29 ± 2.71	*Clavularia frankliniana*	*Cnidarians*	1.00 ± 2.63
6	*Calanus glacialis*	*Arthropods*	1.26 ± 2.41	*Thysanoessa macrura*	*Arthropods*	0.86 ± 2.62
7	*Thysanoessa inermis*	*Arthropods*	0.90 ± 2.28	*Calanoides acutus*	*Arthropods*	0.78 ± 2.62
8	*Clupea harengus*	*Chordata*	0.86 ± 2.20	*Pseudosagitta gazellae*	*Arrow worms*	0.75 ± 2.60
9	*Metridia longa*	*Arthropods*	0.83 ± 2.04	*Euphausia crystallorophias*	*Arthropods*	0.74 ± 2.56
10	*Oithona similis*	*Arthropods*	0.83 ± 1.90	*Metridia gerlachei*	*Arthropods*	0.70 ± 2.47

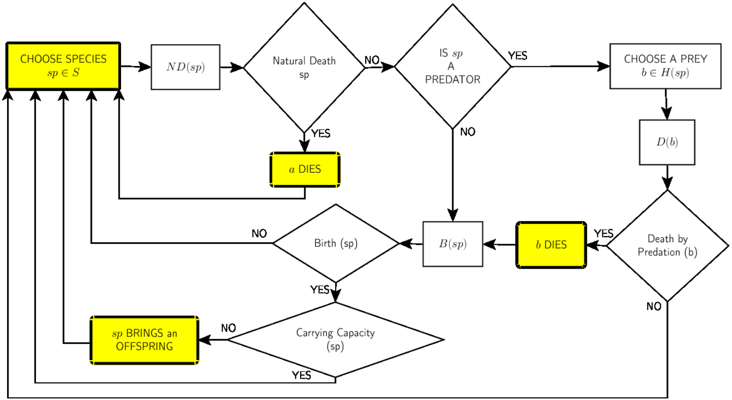
The Idea

To study food web dynamics in a landscape.





PREDATION DYNAMICS



THE EQUATIONS

- Births (Increasing number of individuals)

$$N'(sp) = N(sp) \times \left\{ [1 - NDp(sp)] \left[\sum_{b \in H(sp)} \rho(b)\, Dp(b)\right] [Bp(sp)] \right.$$

$$- \left[\sum_{c \in P(sp)} \rho(c)\,(1 - NDp(c)) \frac{\rho(sp)}{\sum_{d \in H(c)} \rho(d)} Dp(sp)\right] - [NDp($$

- Deaths (Decreasing number of individuals)

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- Deaths (Decreasing number of individuals)

The Parameters

$\rho(sp)$: Proportion of sp.

$H(sp)$: Prey Species of sp.

$P(sp)$: Predator Species of sp.

$Bp(sp)$: Birth Probability of sp.

$Dp(sp)$: Death Probability of sp.

$NDp(sp)$: Natural Death Probability of sp.

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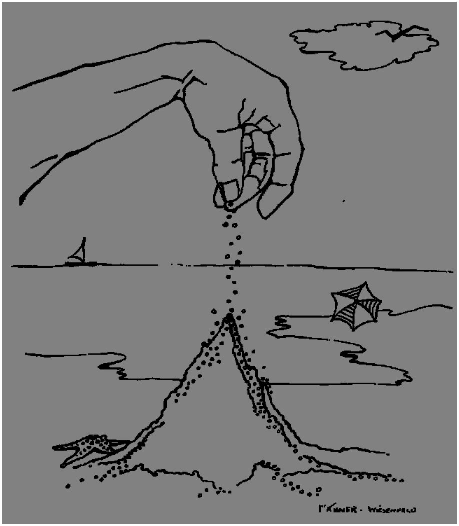
Self-Organized Parameters



SELF-ORGANIZED PARAMETERS: BIRTH

- Availability of Space

$$Bp\left(sp\right) = \left[1-\rho\left(sp\right)\right] \times \left[\sum_{b\in H(sp)}\rho\left(b\right)\left(1-\sum_{c\in P(b)}\rho\left(c\right)\right)\right] \times \left[1-\sum_{c\in P(sp)}\rho\left(c\right)\right]$$

- Safety
- Availability of Resources

Self-Organized Parameters: Birth

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- Safety
- Availability of Resources

ASSUMPTIONS

Availability of Resources of **Basal Species** is 1.0

Birth Probability of **Basal Species** depends only on **Availability of Space** and **Safety**

Assumptions

Availability of Resources of **Basal Species** is 1.0

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Self-Organized Parameters: Death

- Intraespecific Competition

$$Dp\left(sp\right) = \left[\rho\left(sp\right)\right] \times \left[\sum_{b\in H(sp)} \left(1-\rho\left(b\right)\right)\left(\sum_{c\in P(b)} \rho\left(c\right)\right)\right] \times \left[1-\sum_{c\in P(sp)} \rho\left(c\right)\right]$$

- Surprise effect
- Privation of Resources

Self-Organized Parameters: Death

- Intraespecific Competition

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ASSUMPTIONS

Death Probability of **Basal Species** is 1.0

SELF-ORGANIZED PARAMETERS: NATURAL DEATH

- Intraespecific Competition

$$NDp(sp) = [\rho(sp)] \times \left[\sum_{b \in H(sp)} (1 - \rho(b)) \left(\sum_{c \in P(b)} \rho(c)\right)\right]$$
$$\times \left[1 - \sum_{c \in P(sp)} \rho(c)\right]$$

- Absence of predators
- Privation of Resources

Self-Organized Parameters: Natural Death

- Intraespecific Competition

$$NDp(sp) = [\rho(sp)] \times \left[\sum_{b \in H(sp)} (1 - \rho(b)) \left(\sum_{c \in P(b)} \rho(c)\right)\right]$$
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Self-Organized Parameters: Natural Death

- Intraespecific Competition

$$NDp\,(sp) = \boxed{[\rho\,(sp)]} \times \boxed{\left[\sum_{b\in H(sp)} (1-\rho\,(b)) \left(\sum_{c\in P(b)} \rho\,(c)\right)\right]}$$
$$\times \boxed{\left[1 - \sum_{c\in P(sp)} \rho\,(c)\right]}$$

- Absence of predators
- Privation of Resources

Self-Organized Parameters: Carrying Capacity

- Availability of Resources

$$CC\,(sp) = \left[\sum\nolimits_{b \in H(sp)} \frac{(\rho(b))}{\left(\sum\nolimits_{c \in P(b)} \rho(c)\right)}\right]$$

Mobility Dynamics

Mobility Dynamics

- Number of individuals of species *sp* at site *i*

$$\Delta N_{sp}(i) = \sum_{j \in Neigh(i)} \left(\left(N_{sp}(j)\ M_{sp}(j,i) \ - \ N_{sp}(i)\ M_{sp}(i,j) \right) \right)$$

- Mobility of species *sp* from site *i* to *j*

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MOBILITY OF SPECIES *sp*

$$M(i,j) = \overbrace{\left[\lambda^i \frac{\Delta_{ij} f\, \Theta\left(\Delta_{ij} f\right)}{\sum_{k \in Neigh(i)} \Delta_{ik} f\, \Theta\left(\Delta_{ik} f\right)}\right]}^{Biotic} \overbrace{\left[w_{ij} \frac{\Delta_{ij} f_\eta\, \Theta\left(\Delta_{ij} f_\eta\right)}{\sum_{k \in Neigh(i)} \Delta_{ik} f_\eta\, \Theta\left(\Delta_{ik} f_\eta\right)}\right]}^{Abiotic}$$

$$\Delta_{ij} f = f^{i,j} - f^{j,i} \begin{cases} f^{i,j} = \rho_H(j) + \rho_P(i) \\ f^{j,i} = \rho_H(i) + \rho_P(j) \end{cases}$$

$$\lambda^i = \frac{1}{2}\left(1 - RE^i\right)$$

$$RE^i = \frac{New^t}{N^t}$$

Mobility of species *sp*

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$$\left\{\; w_{ij} = Connectivity\ between\ sites\ i\ and\ j\right.$$

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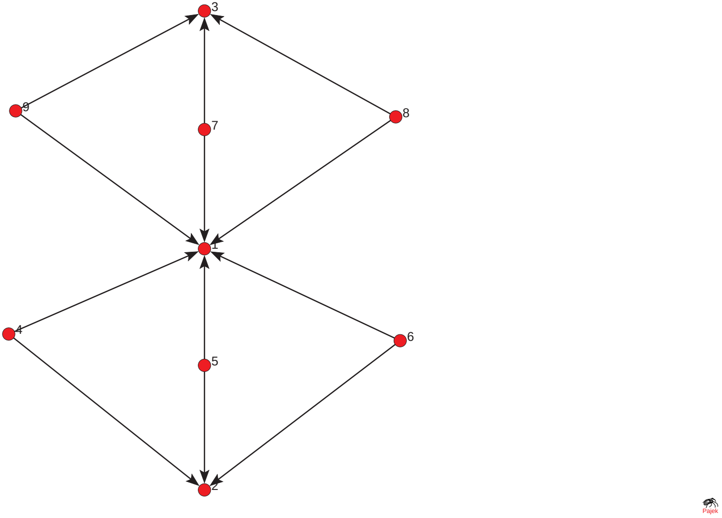
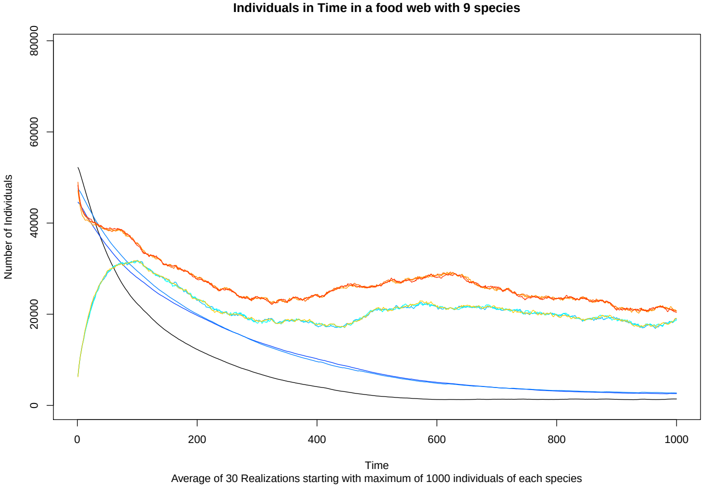
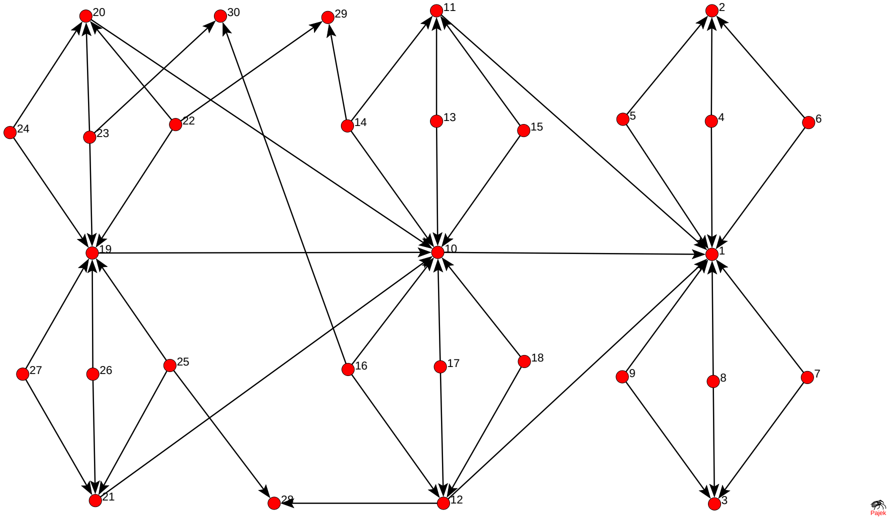
9 species food web



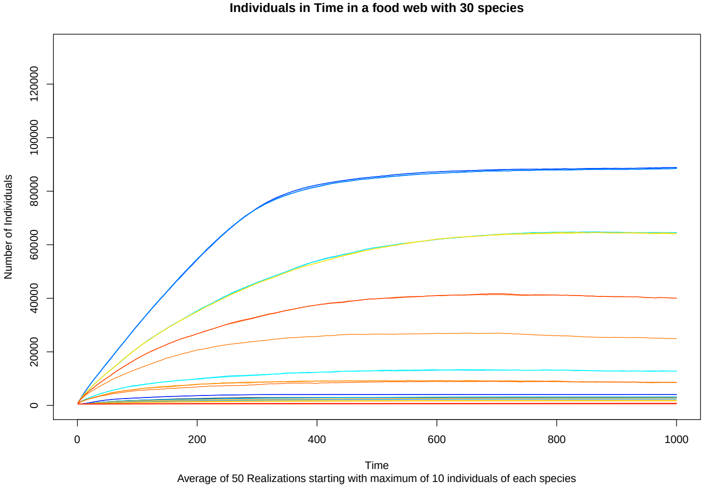
Maximum Start = 100 and 1000 Inds.



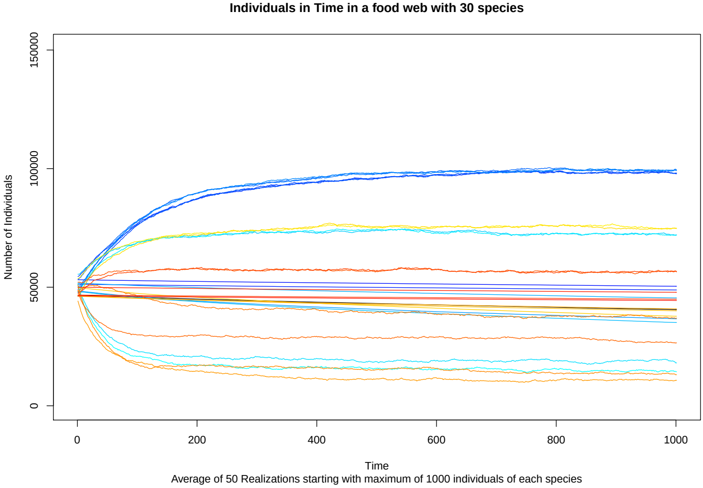
30 species food web



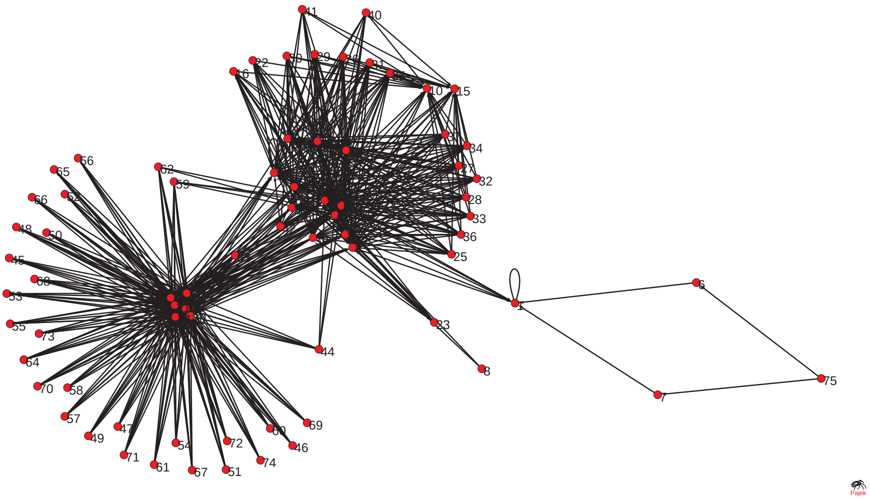
Maximum Start = 10 Inds.



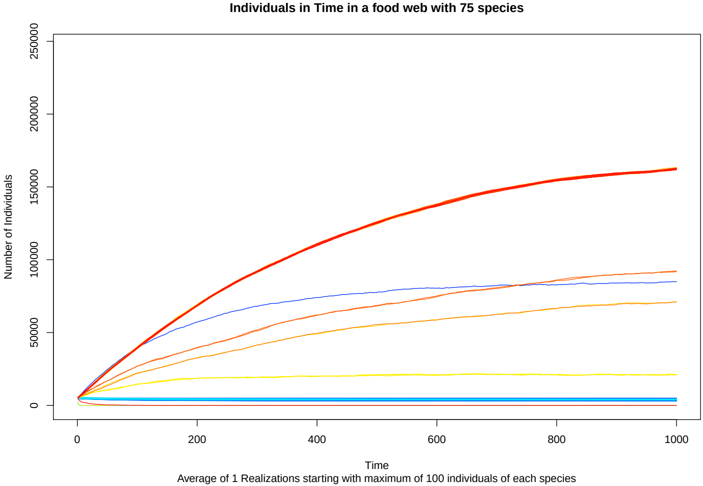
Maximum Start = 1000 Inds.



75 species food web



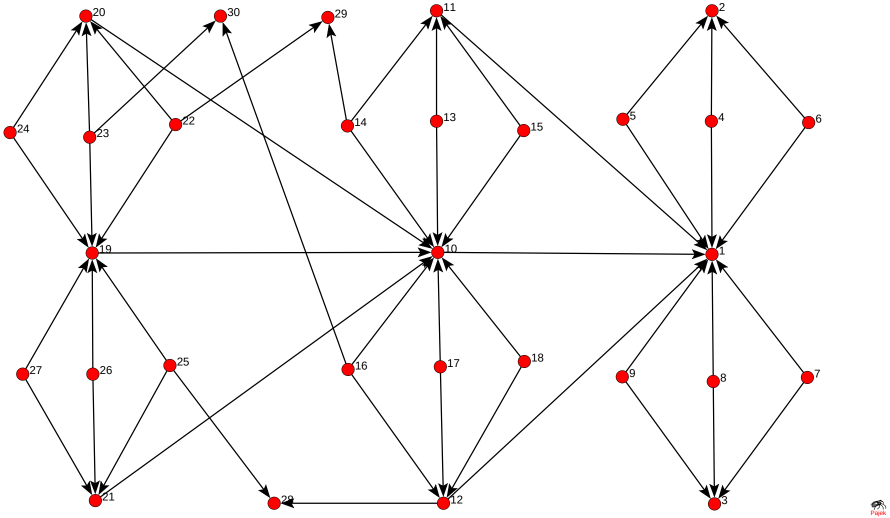
Maximum Start = 100 Inds.



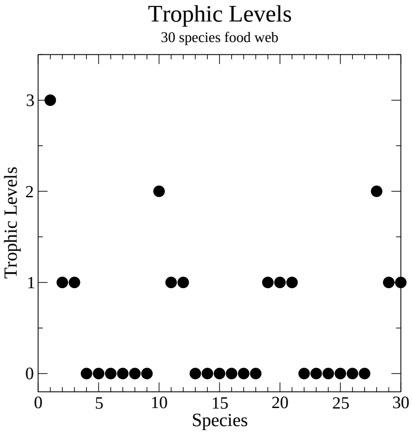
STABILITY OF THE FOOD WEBS

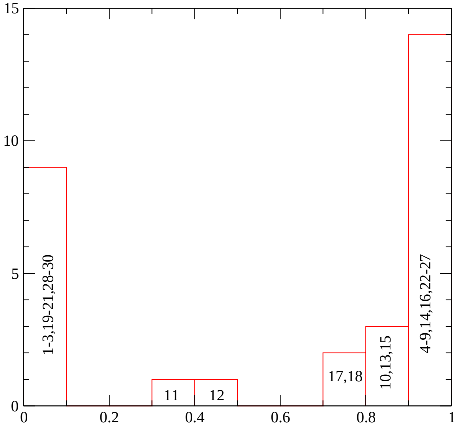
Expressing the parameters that govern the dynamics as functions of densities, aparently, we introduce correlations between Bp, Dp, NDp. As a result of that, the system **self-organizes towards steady state**, independently of the initial number of individuals.

Space of Parameters: 30 species Food Web



30 species Food Web: Space of Bp

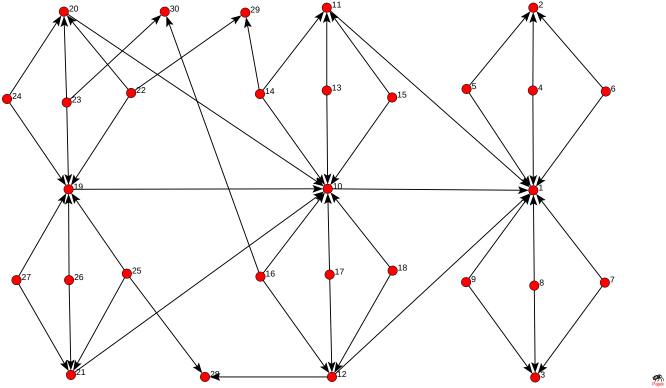




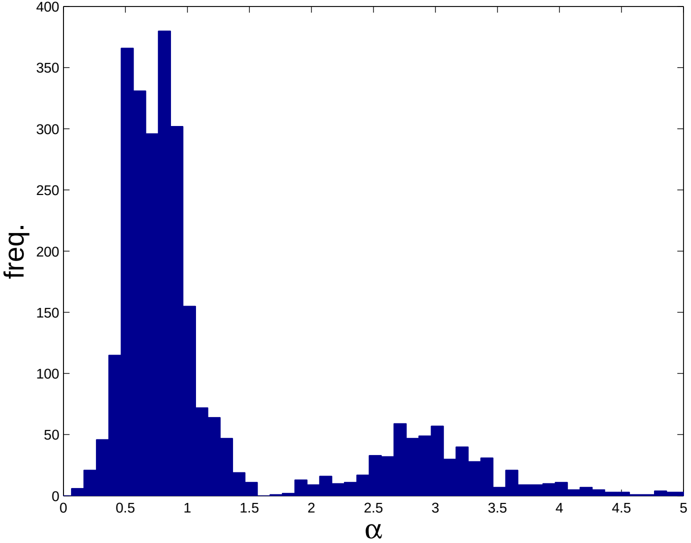
BP OF A 30 SPECIES FOOD WEB

Aparently, in a **steady site**, the lower species' **trophic level** the higher species' **birth probability**.

Metabolic Rate: For a Food Web with 30 species



Metabolic Rate: $N \sim B^{\alpha}$ (for each site)



Metabolic Theory of Ecology

- $N \sim M^{-\frac{3}{4}}$ [1]
- $B \sim M^{-\frac{1}{4}}$ [2]
- $N \sim B^3$

1 - **Brown, J. H. , Gilloly, J. F. Allen, A. P., Savage V. M., and West G. B.** (2004). Toward a metabolic theory of ecology. *Ecology*, 85:1171-1789.

2 - **West, G. B., Brown, J. H.** (2005). The origin of allometric scaling laws in biology from genomes to ecosystems: towards a quantitative unifying theory of biological structure and organization. *J Exp Biol*, 208:1575-1592.

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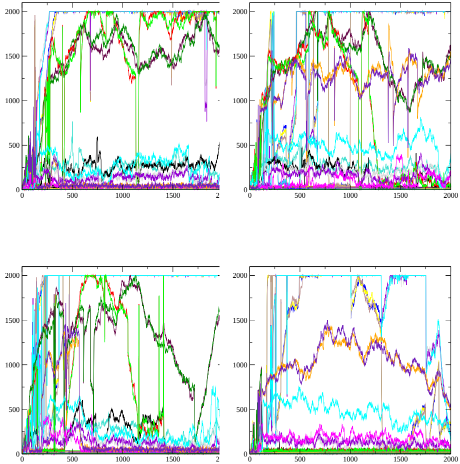
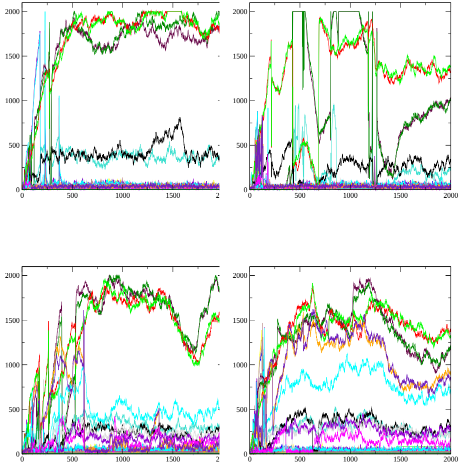
Unestable Sites: $N \sim B^1$



STEADY STATE ACHIEVED SITES: $N \sim B^3$



Methabolic Theory of Ecology

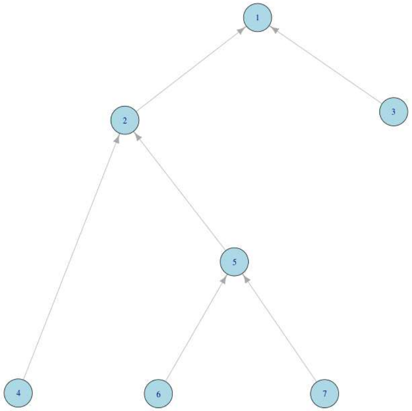
Aparently, there is a relation between a steady state achievement and the assessed α ($N \sim B^{\alpha}$) in the site.

GLOBAL CHANGES SIMULATION: DISTURBING THE SYSTEM AFTER ACHIEVING STEADY STATE

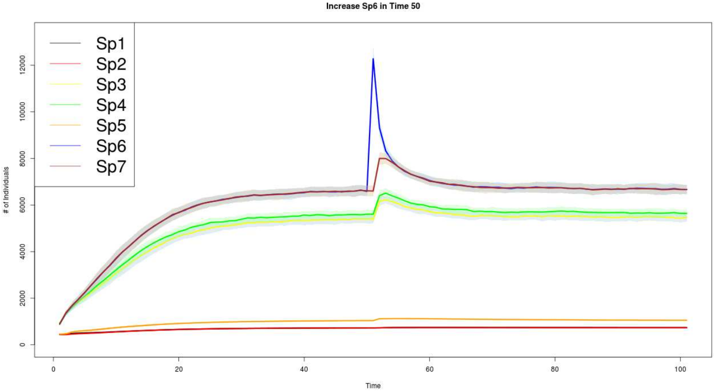
Table: **Description of the parameters to set disturbance in the system.**

Parameters	Meaning
ts	time step when the disturbance should be simulated
pt	index of patch which parameters will be changed (index starting by 0)
sp	index of the species which parameters will be changed (index starting by 0)
bp	value to be multiplied by the birth probability of species sp at patch pt
dpp	value to be multiplied by the death predator probability of species sp at patch pt
ndp	value to be multiplied by the natural death probability of species sp at patch pt
mp	value to be multiplied by the mobility probability of species sp at patch pt
cc	value to be multiplied by the carrying capacity of species sp at patch pt
nind	value to be multiplied by the number of individuals of species sp at patch pt
inv	invasion (or speciation) of the species

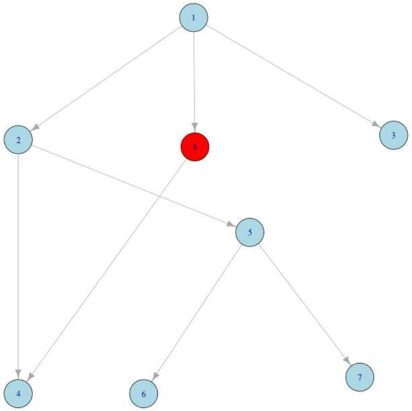
Original 7 species food web



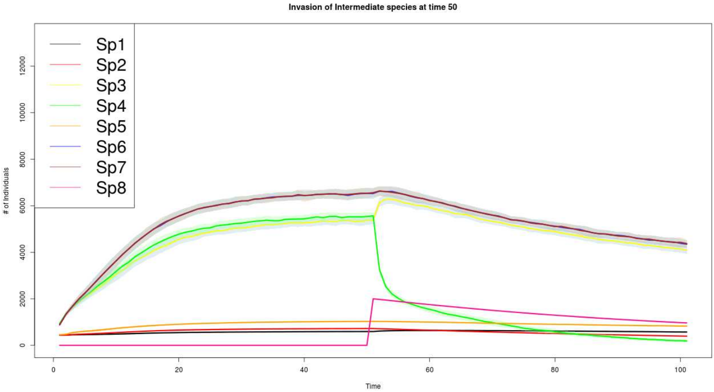
INCREASING ABUNDANCE OF BASAL SPECIES



INVASION OF AN INTERMEDIATE SPECIES



Effects of the Invasion of an intermediate species to the system at time step 50



Global Change Module

After the model achieves an steady state, we can induce some disturbances by changing the abundance of species or the values of BP, DPP, NDP, and MP.

Conclusions

Expressing the parameters that govern the dynamics as functions of densities, we introduce correlations between Bp, Dp, NDp. As a result of that, the system **self-organizes towards steady state**, independently of the initial number of individuals.

Aparently, there is a relation between a steady state achievement and the assessed α ($N \sim B^{\alpha}$) in the site.

Aparently, in a **steady site**, the lower species' **trophic level** the higher species' **birth probability**.

CONCLUSIONS

The model is general enough to allow the inclusion of biotic and abiotic iterations.

The model can be nested to niche models, and then provide a *Niche Model with Biotic Iteractions*.

The model allow the inclusion of global changes signs, by changing biotic (abundance of species, BP, NDP, etc) and abiotic parameters ($w_{i,j}$ and $\Delta^{i,j} f_\eta$).

So we can compare dynamics of the simulated systems under different global changes stress (e.g.: loss of habitat; changes in niche of species; loss of connectivity between sites; etc).

Questions

Which parameters are given to the model as an input (α, E_n, ...) and how sensible the model is to these inputs?

Could we represent the *Growing and Developing* features by forcing a predator individual to eat many prey individuals before it gives an offspring?

Is there any example of values of the *Bayesian comparison* between simulations and observations? Should we achieve an optimal ϵ?

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Could we study the patterns of intraspecific variability in ecological networks by using nested ecological networks?

Does the model mantain coexistence for all specie?

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Similarities to our work

We use *Random Encounters* (Neutral Dynamics approach) to choose individuals during the predation and migration dynamics.

Our simulations also led to a landscape with more individuals preys than predators (predators also represent just a few proportion of all the individuals)

We also define the parameters of the model as self-organized functions of the abundance of species in the landscape.

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