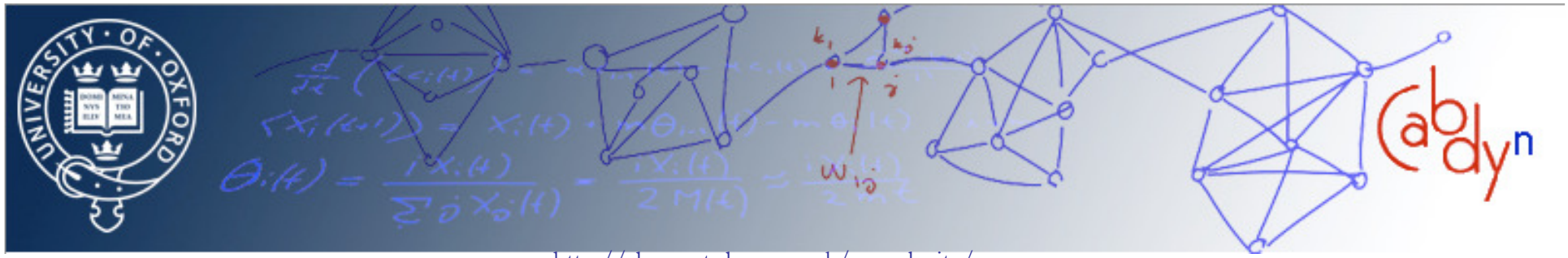


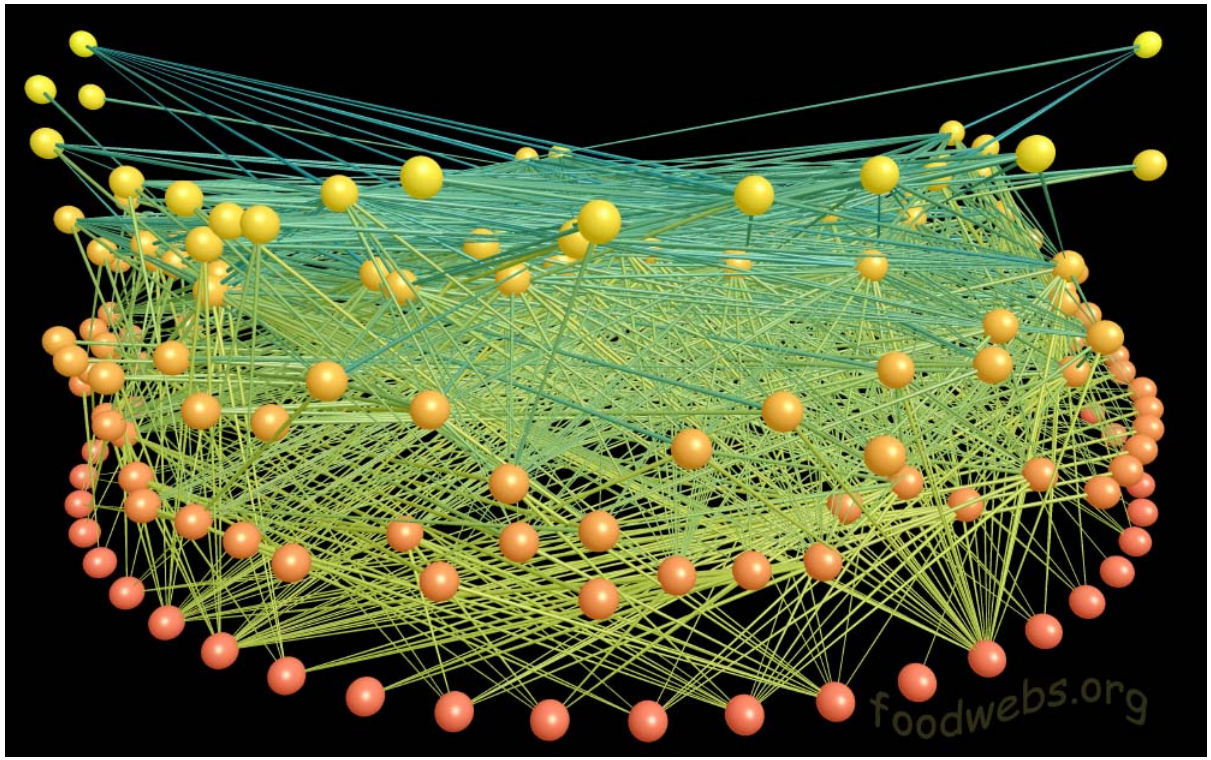
http://sbs-xnet.sbs.ox.ac.uk/complexity/

A simple model of bipartite cooperation for ecological and organisational networks

Felix Reed-Tsochas (JMI & CABDyN, Oxford)
Serguei Saavedra (Engineering & CABDyN, Oxford)
Brian Uzzi (Kellogg & NICO, Northwestern)

NetSci 2008
Norwich, 26 June 2008

Food webs



Trophic web of species from the El Verde Ranforest, Carribean National Fores, Puerto Rico.
http://www.foodwebs.org

Simple rules for food webs

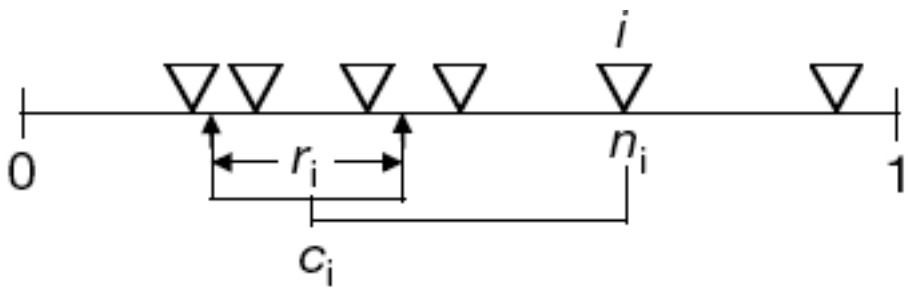
Predators consume contiguous sequence of prey in a one-dimensional trophic niche. (Williams and Martinez, *Nature* 2000)

S, L ➔ input parameters

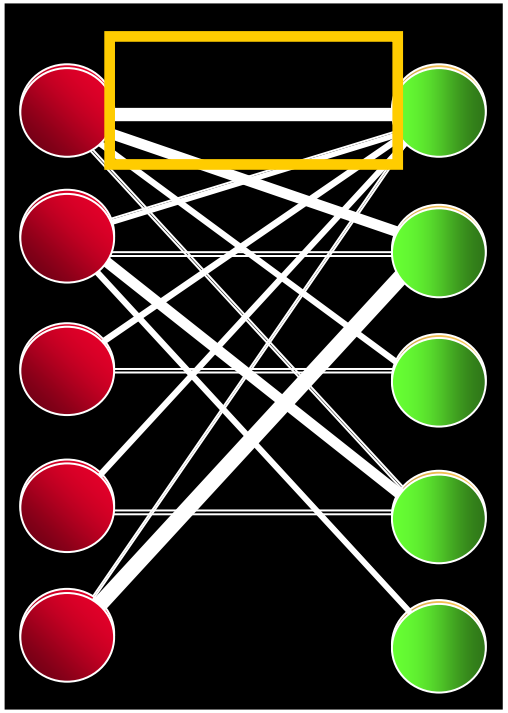
A (S × S) a_{ij}=1 if species *j* consumes species *i*

(1) species are assigned niche values that form a totally ordered set

(2) species have an exponentially decaying probability of preying on species with lower niche values

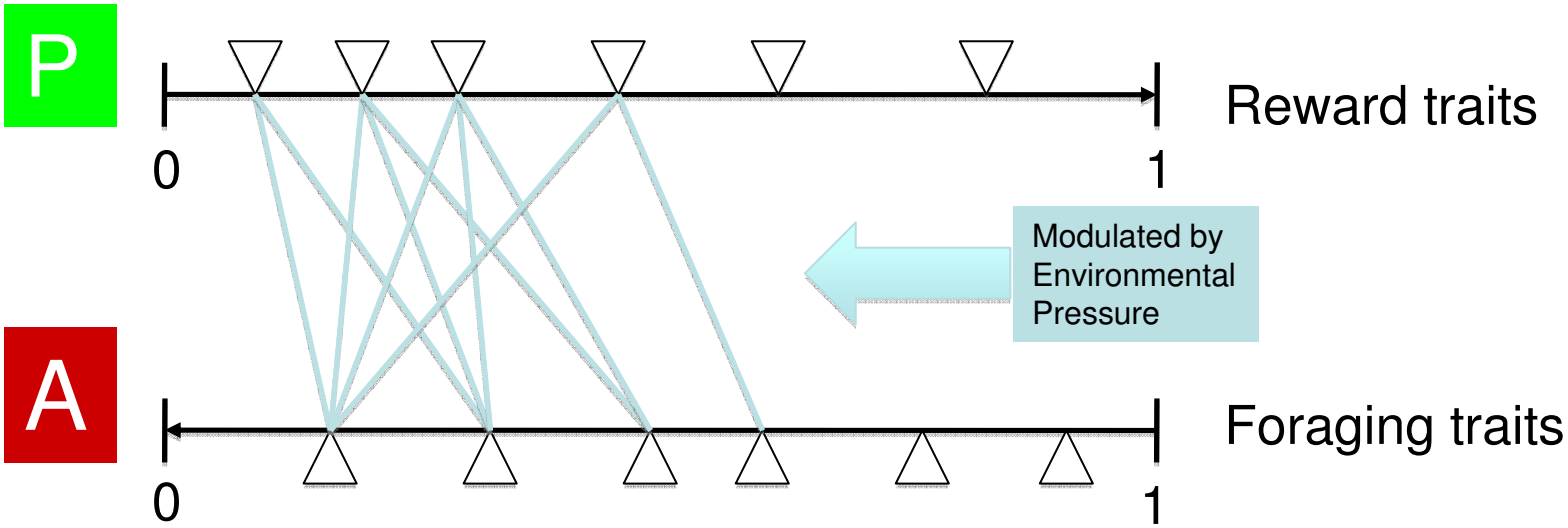


Mutualistic networks



	P_1	P_2	P_3	P_4	P_5
A_1	1	1	1	1	1
A_2	1	1	1	0	0
A_3	0	1	0	0	0
A_4	1	0	0	0	0
A_5	1	0	0	0	0

Structuring mutualistic interactions



- Trait complementarity
- Exploitation barriers
- Hierarchical phylogenetic relationships

Simple rules for bipartite cooperation

A, P, L ➔ input parameters

1. <u>Specialisation Rule</u> P

   Number of partners l_p from a∈ A that each p∈ P interacts with?

   $t_{Rp} \times \lambda_p (U, NU)$

   t_{Rp} – draw from uniform distribution [0,1] *analogous to niche value*

   λ_p – draw from beta-distribution $p(x)= \beta (1-x)^{(\beta -1)}$

2. <u>Interaction Rule</u> P ⟷ A

   Which members from a∈ A cooperate with each member of p∈ P?

   Determined by complementarity between t_{Rp} and t_{Fa}

   $t_{Fa} \times \lambda_{lp} (U, NU)$

   t_{Fa} – draw from uniform distribution [0,1]

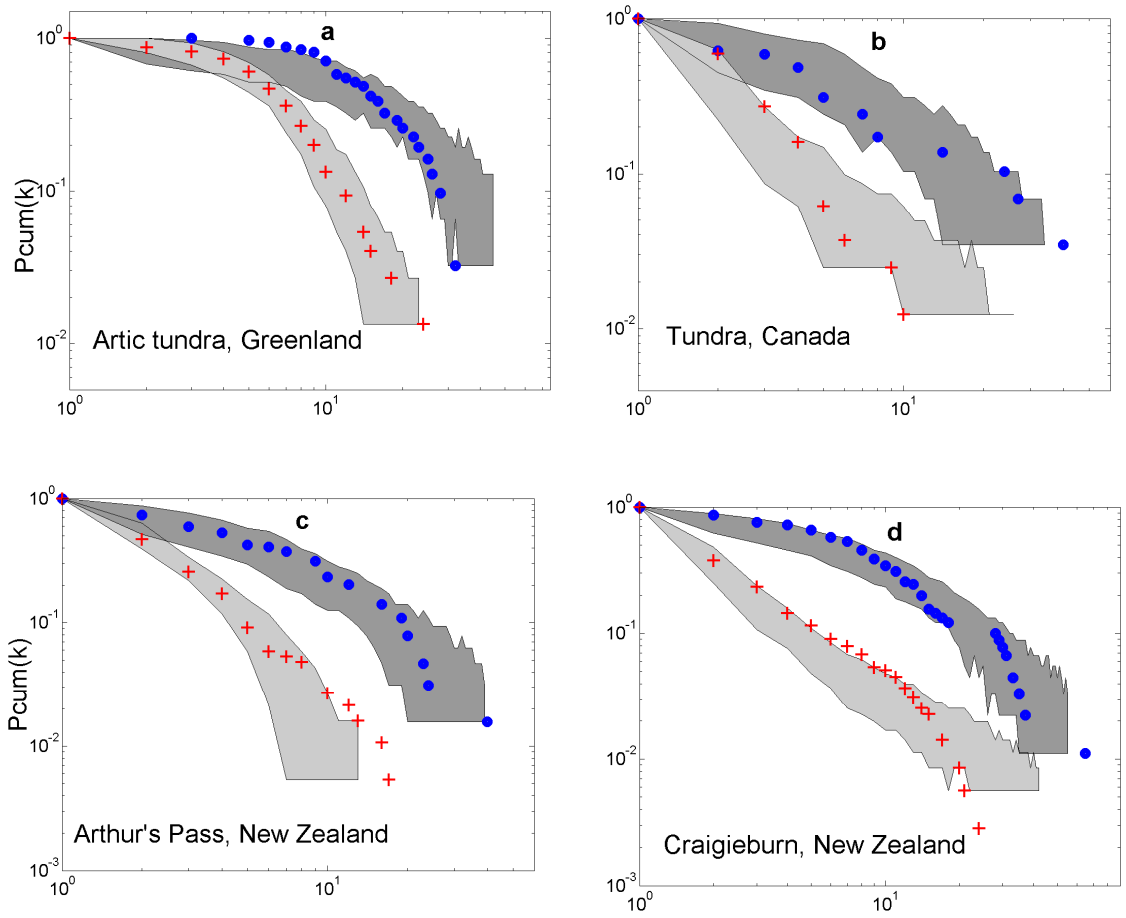
   λ_{lp} – draw from beta-distribution

Model vs. empirical data

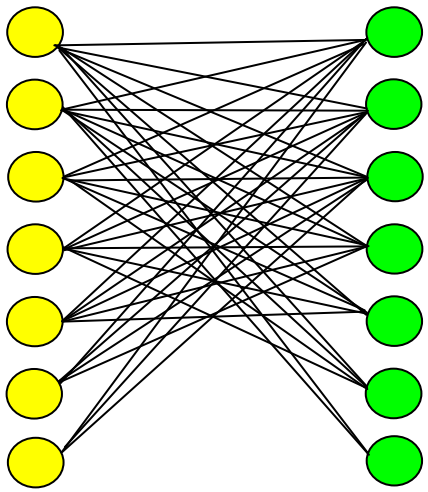
Dataset – Environment	L	P	A	$Beta(P_P$--$P_A)$	N	Q
Marsh, Japan	430	64	187	NU(0.79††--0.99††)	0.95†(0.94)	0.55††(0.56)
Grassland, Cass, New Zealand	374	41	139	NU(0.29†--0.77††)	0.92††(0.91)	0.47††(0.47)
Subalpine forest/meadow, Japan	865	90	354	U(0.45††--0.10†)	0.97†(0.96)	0.54†(0.53)
Subalpine, Arthur's, New Zealand	120	18	60	NU(0.10†--0.90††)	0.72*(0.87)	0.55†(0.54)
Subalpine, Craigieburn, New Zealand	346	49	118	U(0.03**--0.92††)	0.94††(0.94)	0.48††(0.47)
Tundra, Canada	179	29	81	NU(0.73††--0.74††)	0.94†(0.90)	nm
Scrub/snow gum forest, Australia	252	36	81	U(0.03**--0.95††)	0.90††(0.92)	nm
Deciduous forest, USA	65	7	33	NU(0.91††--0.64††)	0.86††(0.84)	nm
Artic tundra, Greenland	453	31	75	U(0.02**--0.41††)	0.74*(0.85)	nm
Subarctic rock slope, Sweden	242	24	118	U(0.22†--0.53††)	0.86†(0.90)	nm

For each pollination dataset, the table presents its environment/location; total number of links L., P and A are the number of nodes in class P and class A respectively. Note that all networks have ratios $P/A<0.5$ and $L/(P\cdot A)<0.3$. For the degree distributions, $Beta(P_P$-$P_A)$ shows the environmental condition, uniform (U) or non-uniform (NU) that best reproduces the observed network properties, along with the combined P-statistic using the two-group equivalence KS test between the empirical and model-generated distributions of class P and class A respectively. N and Q correspond to the observed nestedness and mean modularity values respectively, along with the normalized errors (z-scores) for the comparison between the empirical and model-generated values. The model-generated mean values for N and Q are shown inside the parentheses. Note that five observed pollination networks have already been found to be non-modular (nm)[8]. All comparisons are based on 1000 model simulations.

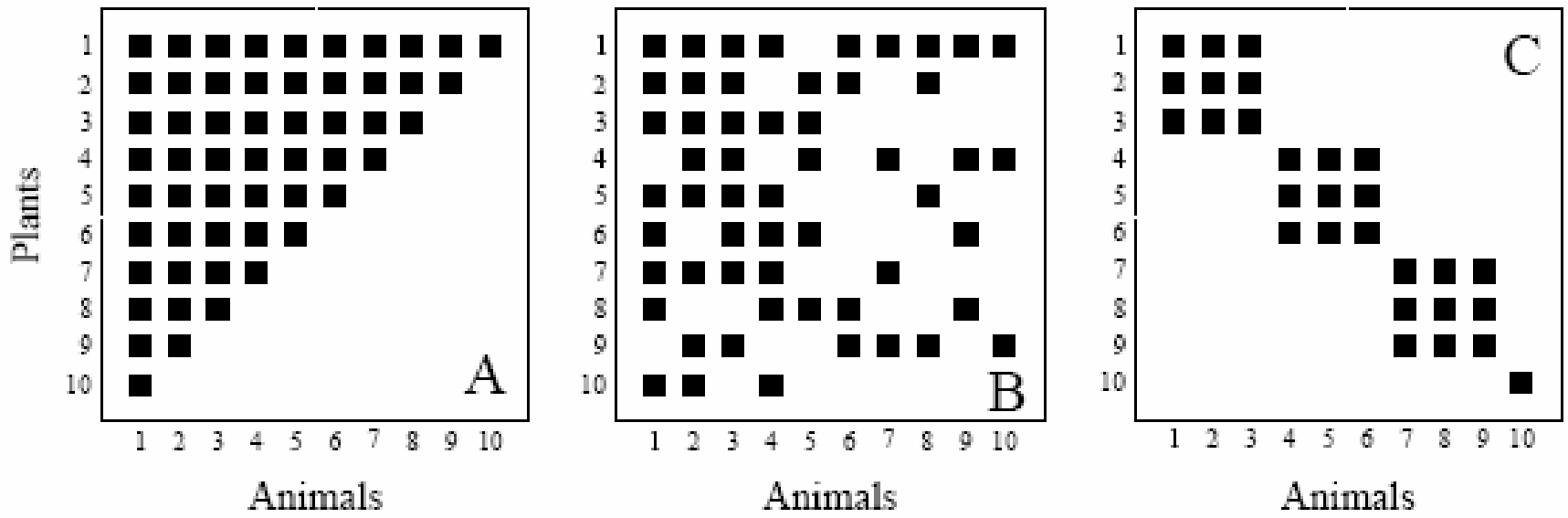
Directed degree distribution



Cumulative degree distributions. This is the distribution of animals per plant and vice versa. For this, we used the cumulative degree distribution, $P_{cum}(k)$, a widely used statistical metric that measures the probability that a node has up to k network connections. The distributions are plotted on a log-log scale. The blue dots represent the cumulative distribution for plants, the red crosses represent the cumulative distribution for animals. The grey region corresponds to the 95% confidence over 1000 simulations using the model-generated degree distributions.

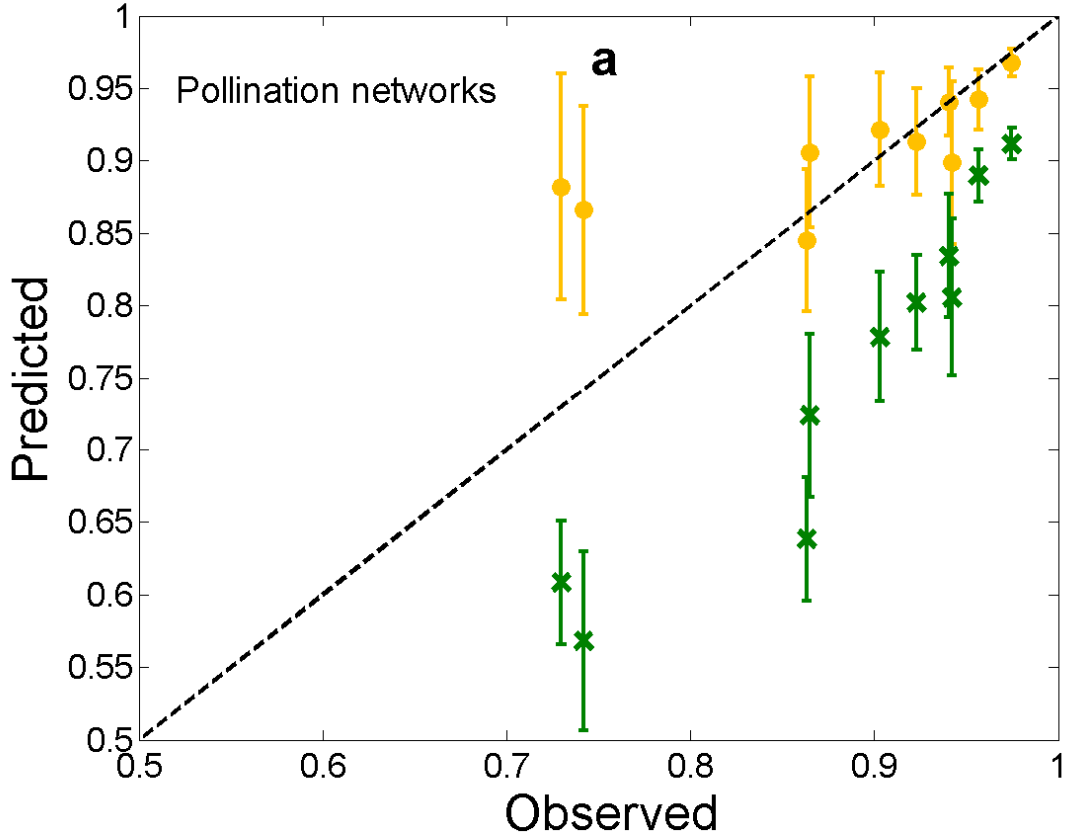


Nestedness



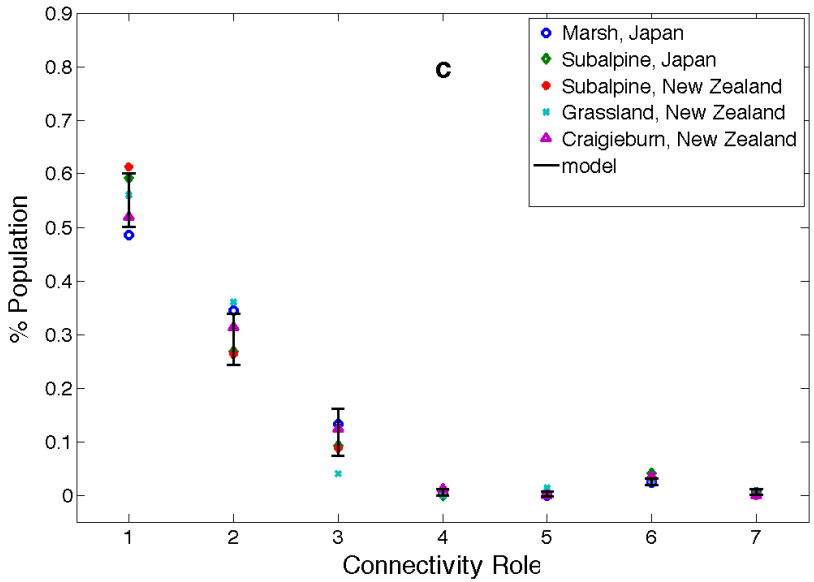
Bascompte et al. *PNAS* **100** (2003)

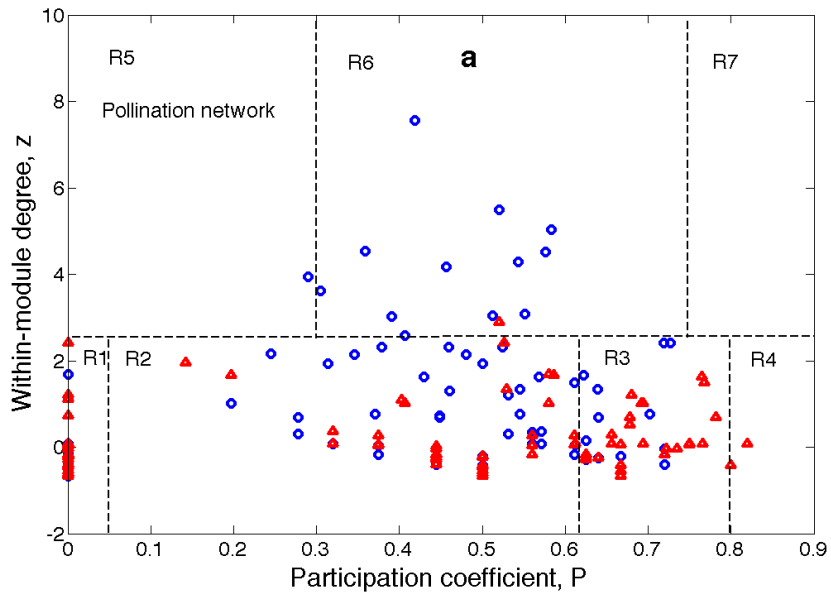
Measuring Nestedness



The observed nestedness values (dashed line), and the average plus two standard deviations values generated by the model (yellow dots) and the random assemblages (green crosses) following Bascompte's et al.[25] null model. Here, a nestedness of 0 means a perfectly nested matrix. Note that the two standard deviation bars account for -2<Z-score<2 as defined by Z=(observed-average predicted)/st. dev. predicted. This analysis was carried out over 1000 simulations.

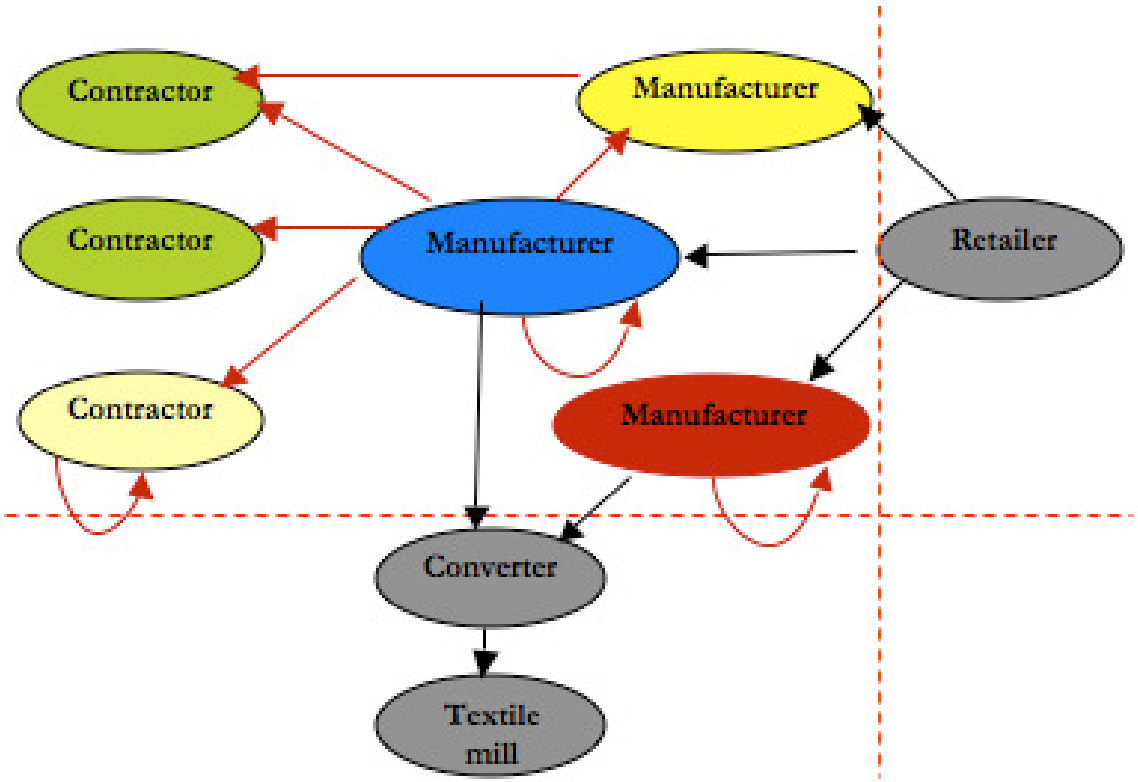
Communities & connectivity roles





Connectivity roles. The figure shows the percentage of population for the observed connectivity roles (colors), and the values (avg±stdv) generated by the model (black bars). We followed Guimera's et.al.[26] classification for nodes, where roles 1-4 are classified as non-hubs and roles 5-7 as hubs.

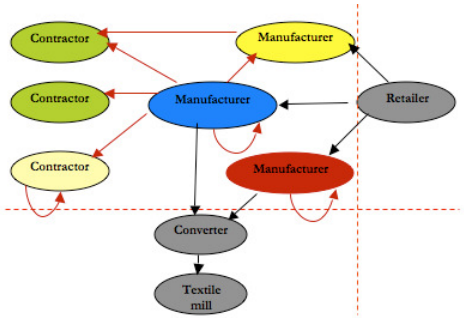
The New York City Garment Industry



Data collected by UNITE

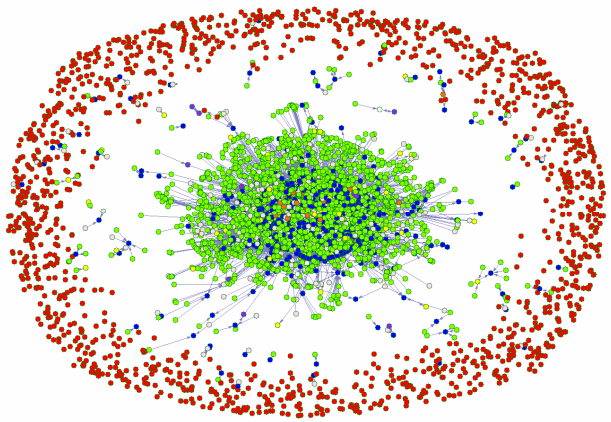
- Extensive data set of ~700,000 customer-supplier transactions in the NY garment industry from 1985-2003 collected by UNITE.

	paidbyfi	paidforf	periodfr	periodto	adjgr	gross	net
1	00109332	00109332	010185	013185	2881.23	2881.33	605.8
2	00109332	00109332	100185	103085	189.63	189.65	41.77
3	00109332	01000019	010185	013185	706.66	706.68	148.58
4	00109332	00106409	010185	053185	6049.93	6049.96	953.55
5	00109332	00107128	090185	093085	4356.48	4356.5	719.53
6	00109332	00205734	040185	053185	-1440.02	-1439.99	-226.96
7	00109332	00109332	010185	063085	1338.38	1338.36	281.39

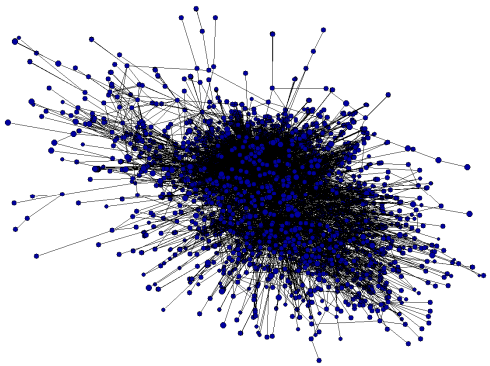


The NYGI Network Structure

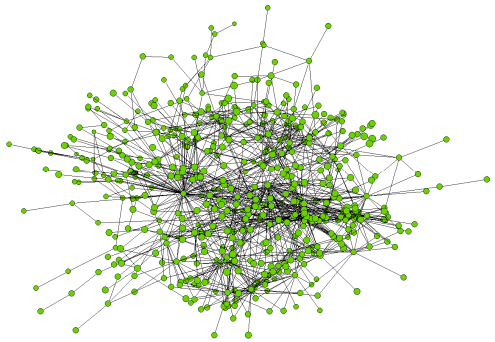
	paidbyfi	paidforf	periodfr	periodto	adjgr	gross	net
1	00109332	00109332	010185	013185	2881.23	2881.33	605.8
2	00109332	00109332	100185	103085	189.63	189.65	41.77
3	00109332	01000019	010185	013185	706.66	706.68	148.58
4	00109332	00106409	010185	053185	6049.93	6049.96	953.55
5	00109332	00107128	090185	093085	4356.48	4356.5	719.53
6	00109332	00205734	040185	053185	-1440.02	-1439.99	-226.96
7	00109332	00109332	010185	063085	1338.38	1338.36	281.39



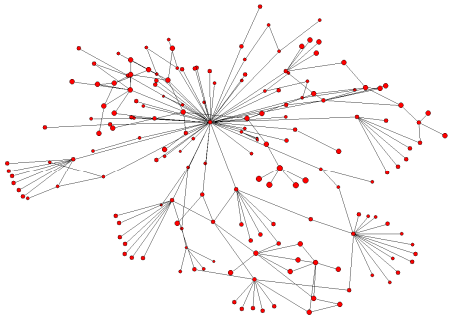
Contracting behaviour



1985: 3249 firms

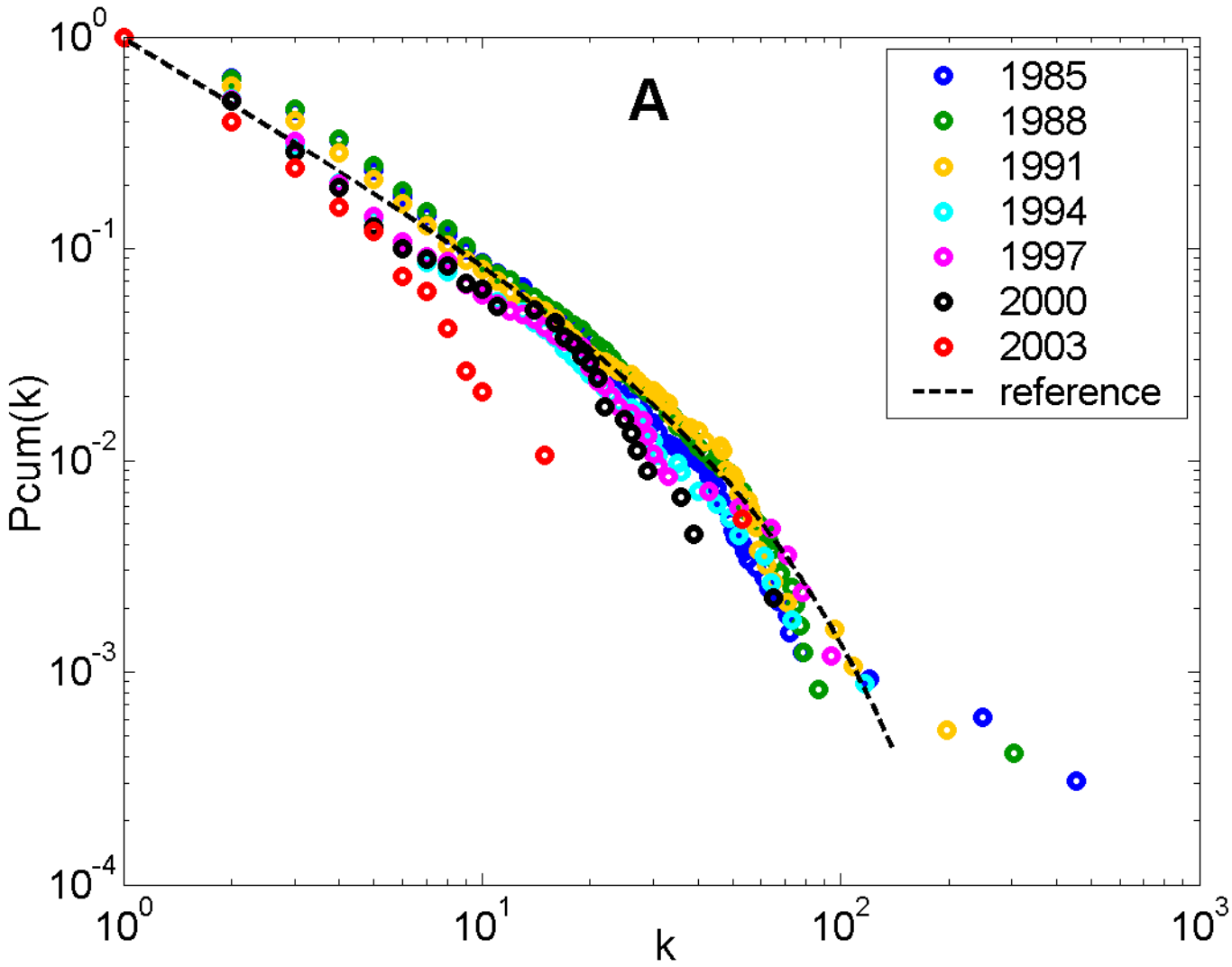


1995: 1046 firms

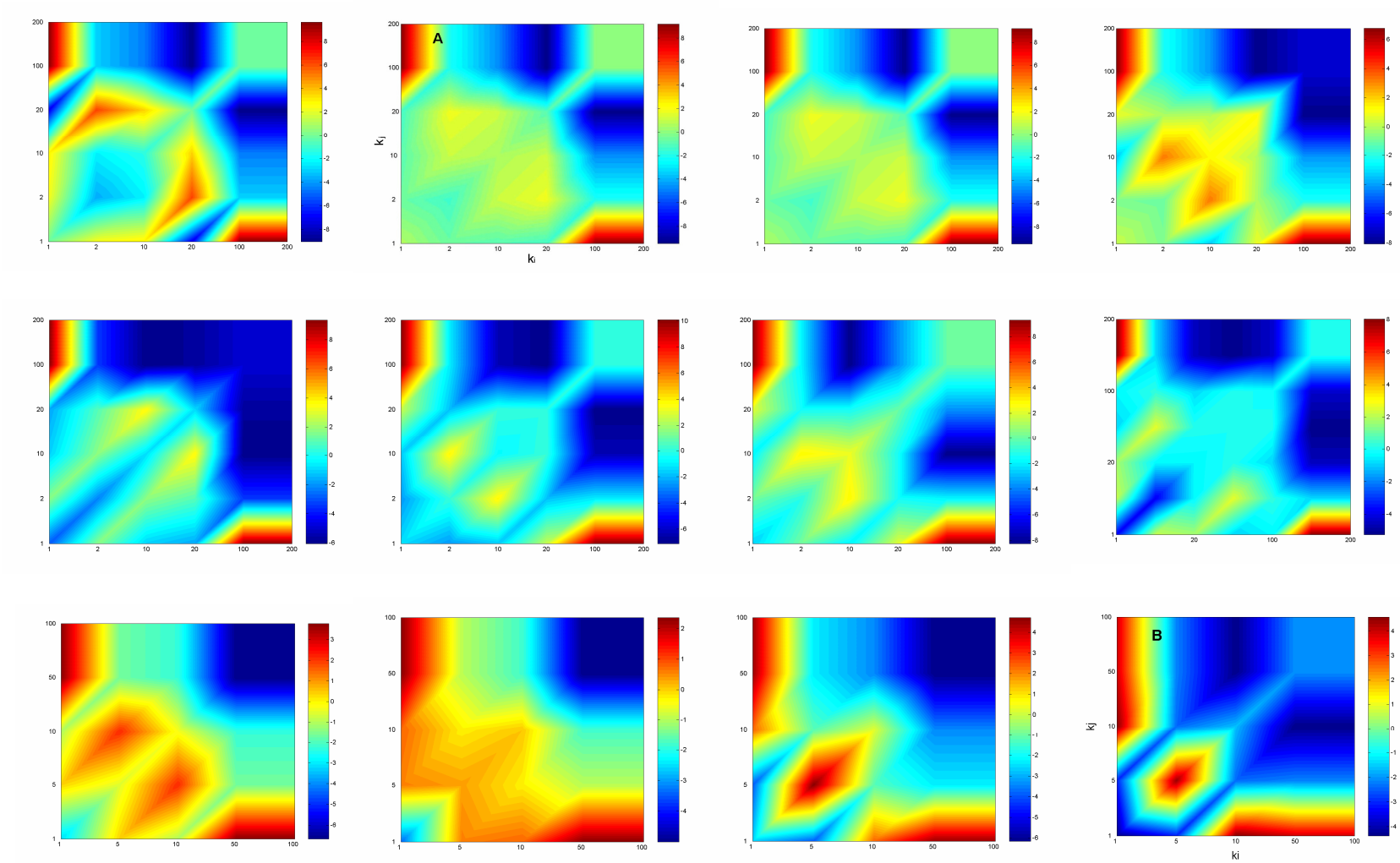


2003: 190 firms

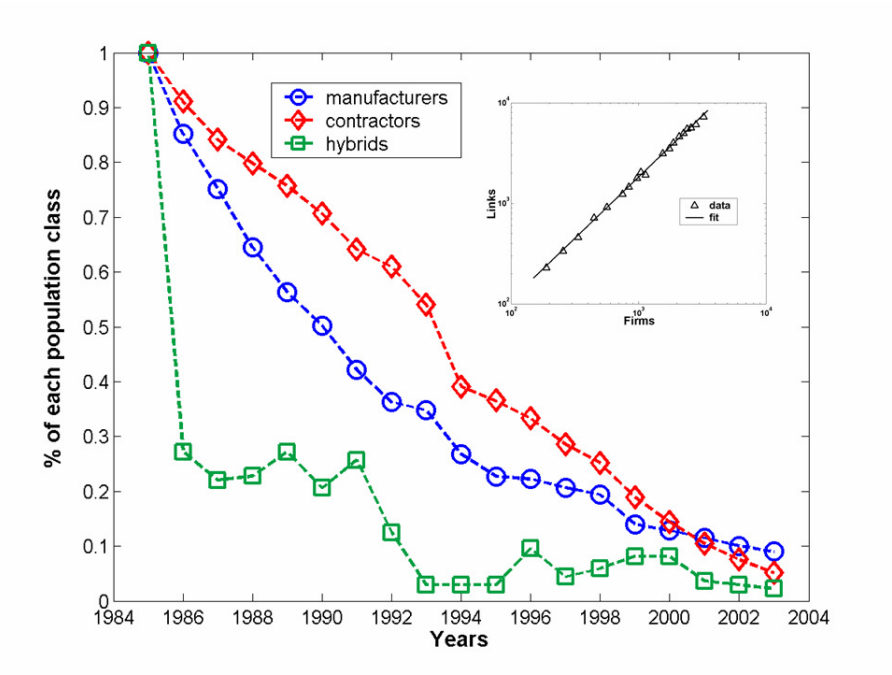
Stationary Degree Distribution

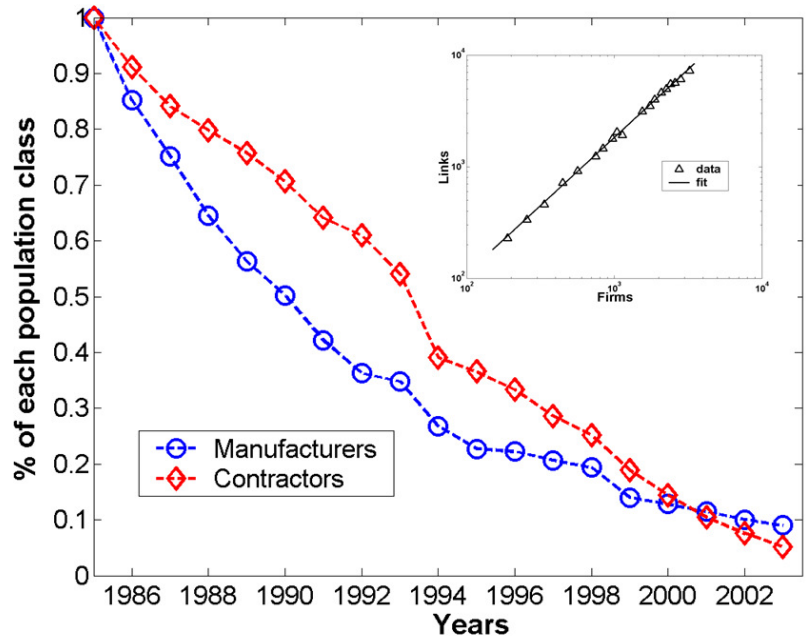


Evolution of Disassortativity



Population dynamics





Declining trajectories over the years for manufacturers (blue circles), contractors (red diamonds), and hybrids (green squares). The number of firms is normalized to its corresponding value in 1985. The inset shows the relationship in a log-log scale between the total number of firms and links in the network. The solid line is the fit to the data defined by $\gamma = 1.22 \pm 0.01$(s.e), r2=0.99.

Organisational and ecological data

Dataset – Environment	L	P	A	$Beta(P_P--P_A)$	N	Q
Marsh, Japan	430	64	187	NU(0.79††--0.99††)	0.95†(0.94)	0.55††(0.56)
Grassland, Cass, New Zealand	374	41	139	NU(0.29†--0.77††)	0.92††(0.91)	0.47††(0.47)
Subalpine forest/meadow, Japan	865	90	354	U(0.45††--0.10†)	0.97†(0.96)	0.54†(0.53)
Subalpine, Arthur's, New Zealand	120	18	60	NU(0.10†--0.90††)	0.72*(0.87)	0.55†(0.54)
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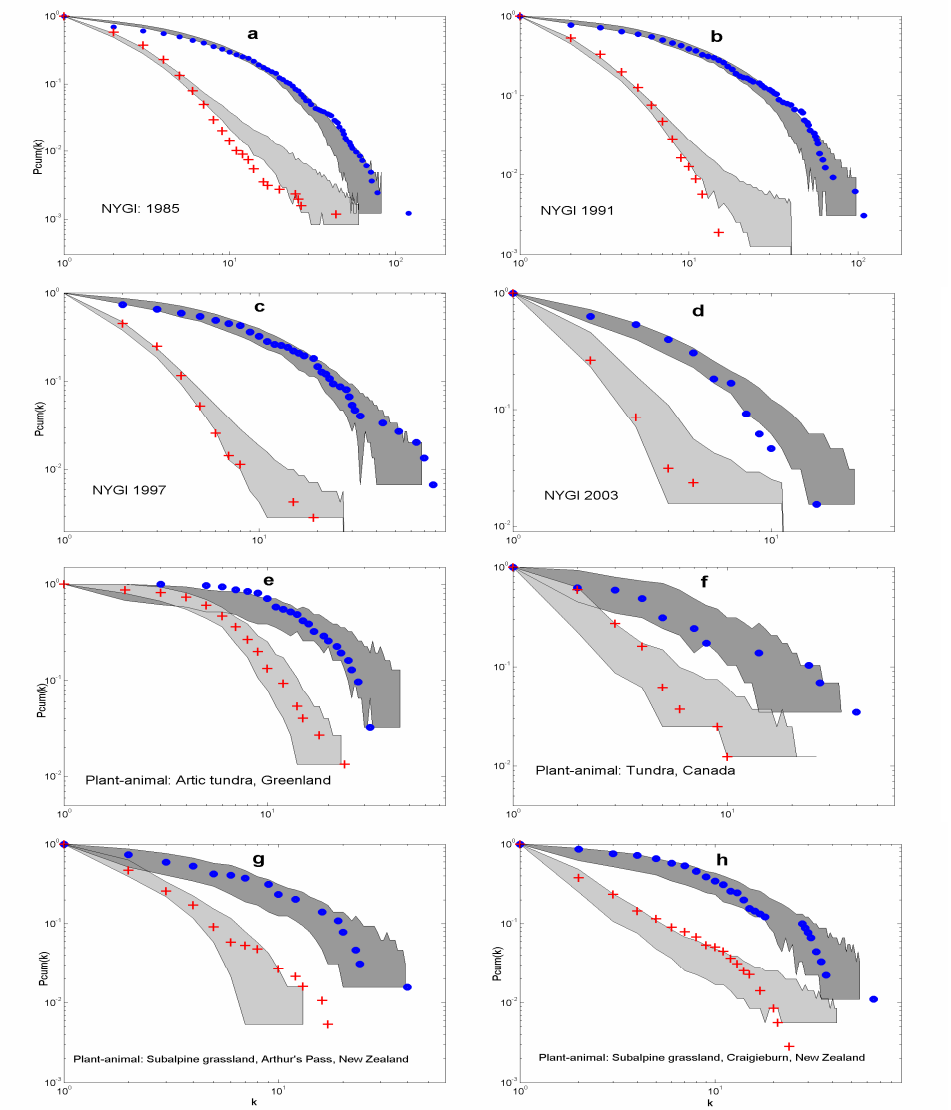
Tundra, Canada	179	29	81	NU(0.73††--0.74††)	0.94†(0.90)	nm
Scrub/snow gum forest, Australia	252	36	81	U(0.03**--0.95††)	0.90††(0.92)	nm
Deciduous forest, USA	65	7	33	NU(0.91††--0.64††)	0.86††(0.84)	nm
Artic tundra, Greenland	453	31	75	U(0.02**--0.41††)	0.74*(0.85)	nm
Subarctic rock slope, Sweden	242	24	118	U(0.22†--0.53††)	0.86†(0.90)	nm
NYGI 1985	7250	823	2562	NU(0.89††--0.10†)	0.99†(0.99)	0.60*(0.50)
NYGI 1991	3981	325	1590	NU(0.91††--0.12†)	0.98†(0.98)	0.62*(0.52)
NYGI 1997	1450	148	700	NU(0.96††--0.18†)	0.97†(0.96)	0.66**(0.62)
NYGI 2003	228	62	128	U(0.93††--0.32††)	0.96††(0.95)	0.72††(0.71)

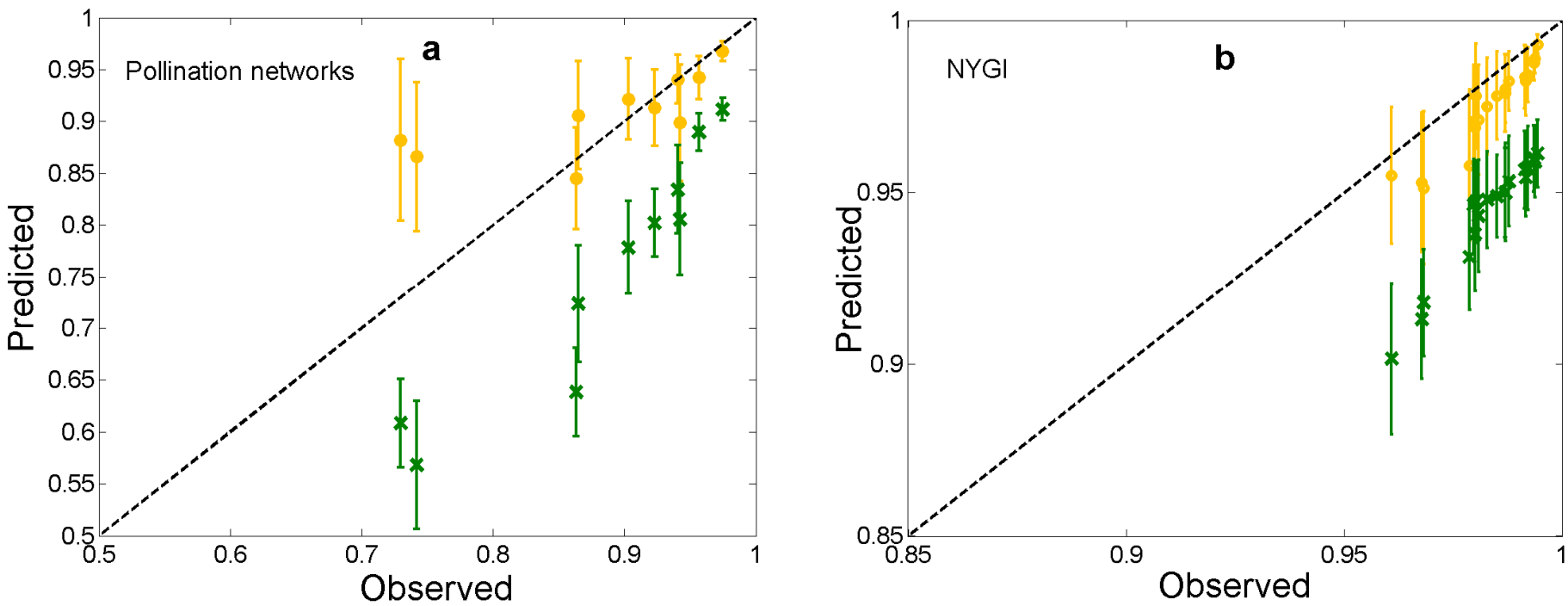
For each pollination dataset and the four organizational networks, the table presents its environment/location; total number of links L., P and A are the number of nodes in class P and class A respectively. Note that all networks have ratios $P/A<0.5$ and $L/(P\cdot A)<0.3$. For the degree distributions, $Beta(P_P\text{-}P_A)$ shows the environmental condition, uniform (U) or non-uniform (NU) that best reproduces the observed network properties, along with the combined P-statistic using the two-group equivalence KS test between the empirical and model-generated distributions of class P and class A respectively. N and Q correspond to the observed nestedness and mean modularity values respectively, along with the normalized errors (z-scores) for the comparison between the empirical and model-generated values. The model-generated mean values for N and Q are shown inside the parentheses. Note that five observed pollination networks have already been found to be non-modular (nm)[8]. All comparisons are based on 1000 model simulations.

Directed degree distribution

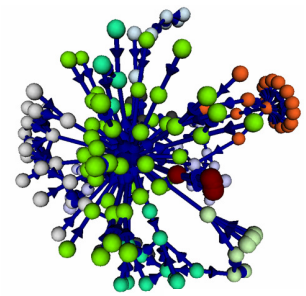


Cumulative degree distributions. This is the distribution of contractors per manufacturer, or animals per plant, and vice versa. For this, we used the cumulative degree distribution, $P_{cum}(k)$, a widely used statistical metric that measures the probability that a node has up to k network connections. The distributions are plotted on a log-log scale. The blue dots represent the cumulative distribution for manufacturers or plants, the red crosses represent the cumulative distribution for contractors or animals. The grey region corresponds to the 95% confidence over 1000 simulations using the model-generated degree distributions.

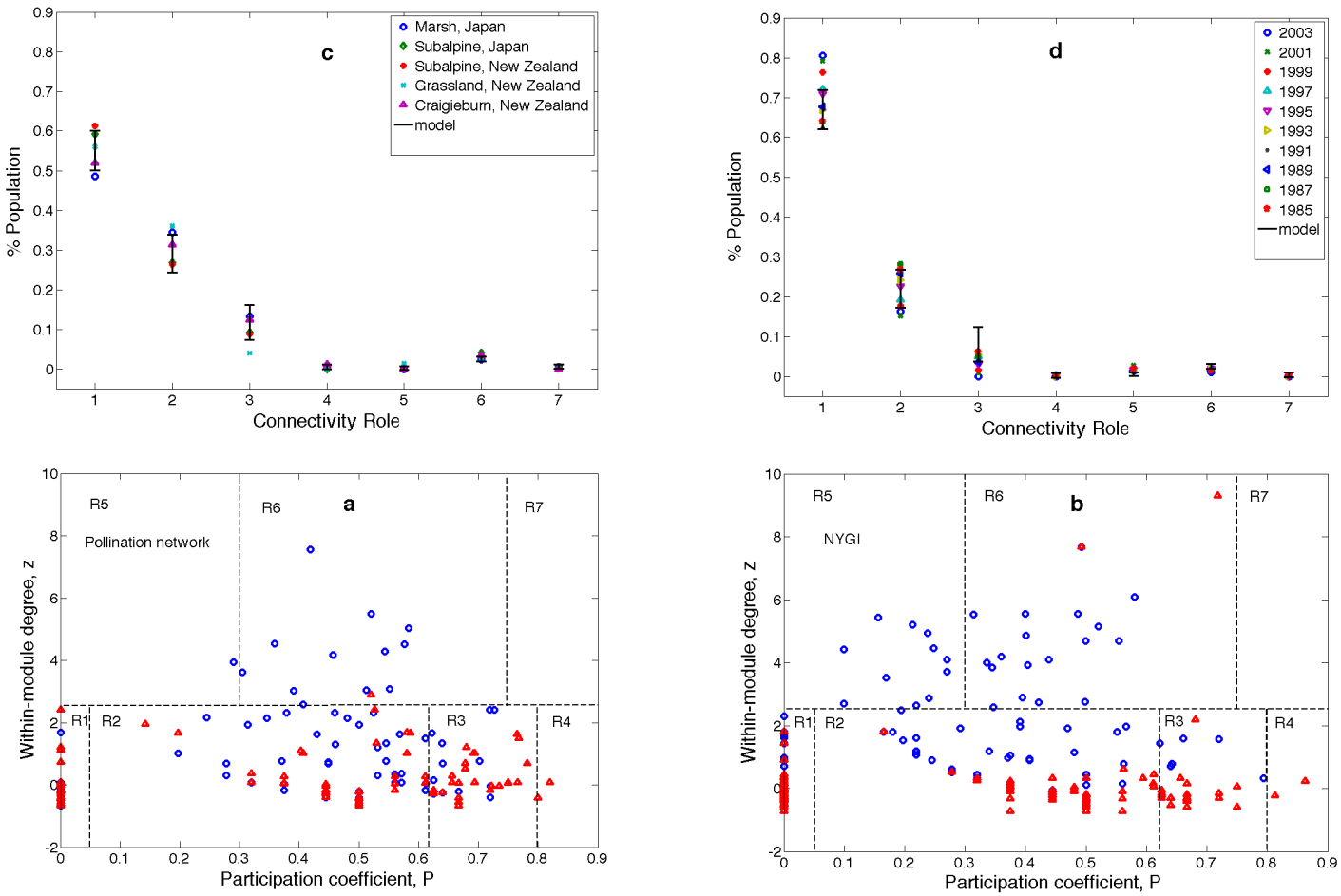
Nestedness



Nestedness. **a** and **b** show for the NYGI (1985-2003) and the pollination networks respectively, the observed nestedness values (dashed line), and the average plus two standard deviations values generated by the model (yellow dots) and the random assemblages (green crosses) following Bascompte's et al.[25] null model. Here, a nestedness of 0 means a perfectly nested matrix. Note that the two standard deviation bars account for -2<*Z*-score<2 as defined by *Z*=(observed-average predicted)/st. dev. predicted. This analysis was carried out over 1000 simulations.



Communities & connectivity roles



Connectivity roles. **a** and **b** show for the NYGI (1985-2003) and the modular pollination networks respectively, the percentage of population for the observed connectivity roles (colors), and the values (avg$\pm$stdv) generated by the model (black bars). We followed Guimera's et.al.[26] classification for nodes, where roles 1-4 are classified as non-hubs and roles 5-7 as hubs.

Observations and Questions

- Simple stochastic model which generates many of the structural features of mutualistic networks
- Unexpected correspondence between:

  Ecological Networks ↔ *Organisational networks*
- To what extent is this generative model for cooperative structures more general (or even generic)?
- Require a more systematic understanding of how environmental conditions modulate specialization and interaction constraints.

Thank you!