PARAMETRIC UNCERTAINTY IN A SIMPLE MODEL OF A SOCIAL–ECOLOGICAL NETWORK

Session ”Archaeological Networks: Uncertainty, Missing Data, and Statistical Inference”

Nicolas Gauthier

Computer Applications in Archaeology 2017

Center for Social Dynamics and Complexity
School of Human Evolution and Social Change
Arizona State University

BACKGROUND

How can we better understand the two-way interaction between ancient cities (or towns, villages, camps …) and their biophysical environments?

Lotka-Volterra style dynamical models represent the flow of energy between two populations, such as predators and prey in a trophic system or cities and resources in a social-ecological system.

$$\begin{aligned} \dot{X} &= \\ \dot{N} &= \end{aligned} \tag{1}$$

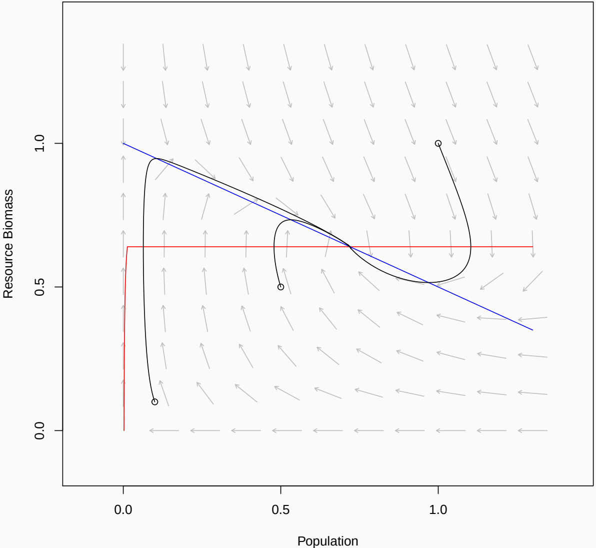
Lotka-Volterra style dynamical models represent the flow of energy between two populations, such as predators and prey in a trophic system or cities and resources in a social-ecological system.

$$\begin{aligned} \dot{X} &= \overbrace{rX\left(1 - \frac{X}{K}\right)}^{\text{logistic growth}} - \overbrace{HXN}^{\text{harvest}} \\ \dot{N} &= \end{aligned} \tag{1}$$

Lotka-Volterra style dynamical models represent the flow of energy between two populations, such as predators and prey in a trophic system or cities and resources in a social-ecological system.

$$\begin{aligned} \dot{X} &= \overbrace{rX\left(1 - \frac{X}{K}\right)}^{\text{logistic growth}} - \overbrace{HXN}^{\text{harvest}} \\ \dot{N} &= \underbrace{\frac{H}{E}XN}_{\text{growth}} - \underbrace{\frac{M}{E}N}_{\text{maintenance}} \end{aligned} \tag{1}$$

Under consumer-resource parametrization, the system will reach a stable coexistence equilibrium from any initial condition.



ELABORATING THE MODEL

Ecological Economics 77 (2012) 123–128

Contents lists available at SciVerse ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

The effect of scaling and connection on the sustainability of a socio-economic resource system

Rachata Muneepeerakul [a,b,*], Murad R. Qubbaj [a]

[a] School of Sustainability, Arizona State University, 800 S. Cady Mall, P.O. Box 875502, Tempe, AZ 85287-5502, United States
[b] Mathematical, Computational, and Modeling Sciences Center, Arizona State University, Tempe, AZ 85287-1904, United States

Bull Math Biol
DOI 10.1007/s11538-014-9949-3

Society for Mathematical Biology

ORIGINAL ARTICLE

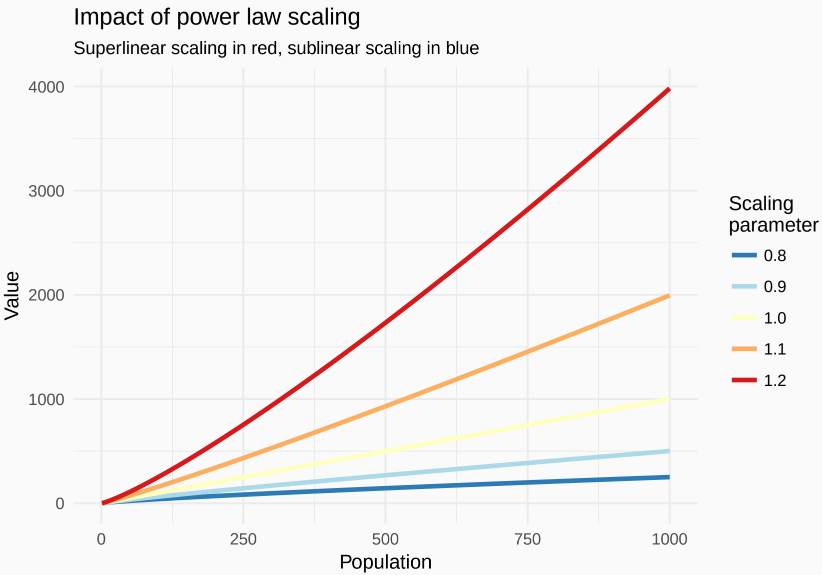
Living in a Network of Scaling Cities and Finite Resources

Murad R. Qubbaj · Shade T. Shutters · Rachata Muneepeerakul

SCALING AND CONNECTIVITY

SCALING

POWER LAW SCALING PARAMETERS



MODELING SCALING

$$
\begin{aligned}
\dot{X} &= rX\left(1 - \frac{X}{K}\right) - HXN \\
\dot{N} &= \frac{H}{E}XN \quad - \frac{M}{E}N
\end{aligned}
\tag{2}
$$

MODELING SCALING

$$\begin{aligned} \dot{X} &= rX\left(1 - \frac{X}{K}\right) - HXN^{\beta} \\ \dot{N} &= \frac{H}{E}XN^{\beta} - \frac{M}{E}N \end{aligned} \tag{2}$$

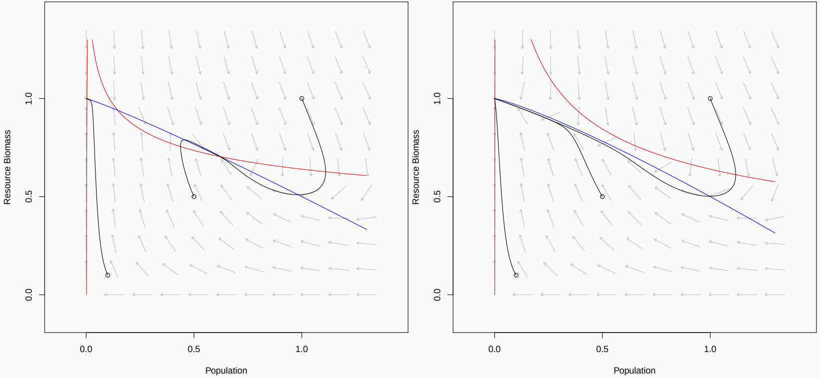
- β Superlinear scaling of harvest efficiency with population size.

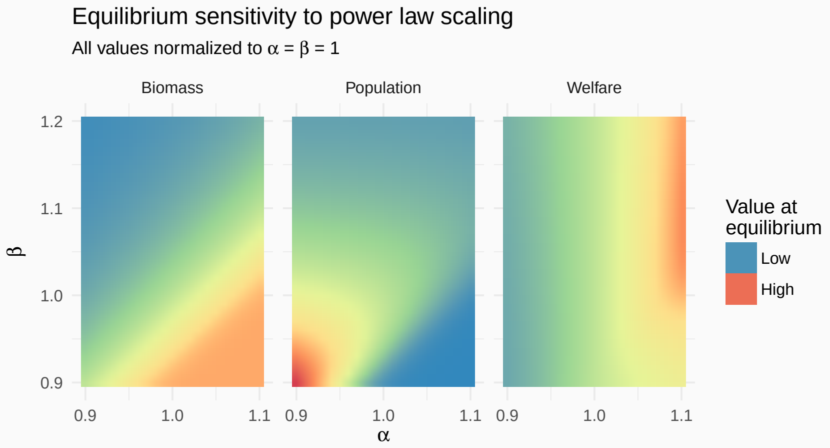
$$\begin{aligned}\dot{X} &= rX\left(1 - \frac{X}{K}\right) - HXN^{\beta} \\ \dot{N} &= \frac{H}{E}XN^{\beta} - \frac{M}{E}N^{\alpha}\end{aligned} \tag{2}$$

- β Superlinear scaling of harvest efficiency with population size.
- α Superlinear or sublinear scaling of population maintenance requirement with population size.

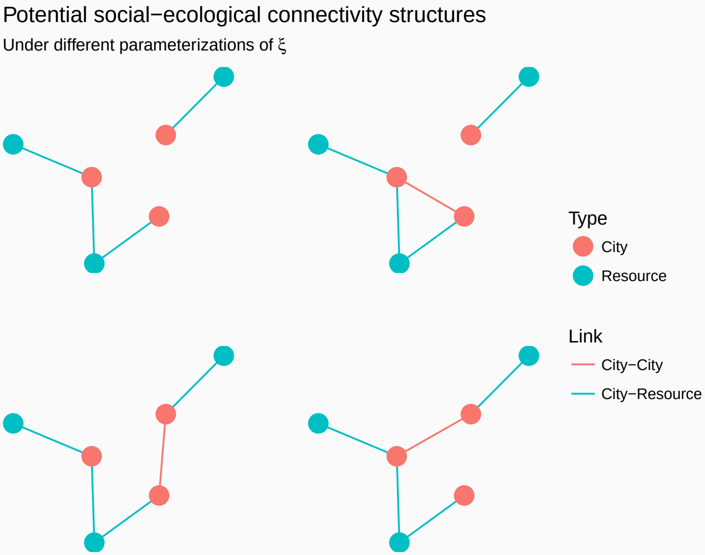
SCALING DYNAMICS

Including nonlinear scaling results in a saddle-node bifurcation. Weaker economies of scale introduce an extinction equilibrium, stronger economies of scale make extinction the only possible outcome.




Equilibrium sensitivity to power law scaling
All values normalized to α = β = 1
Biomass
Population
Welfare
1.2
1.1
1.0
0.9
β
0.9
1.0
1.1
α
Value at equilibrium
Low
High

CONNECTIVITY


Potential social−ecological connectivity structures
Under different parameterizations of ξ
Type
City
Resource
Link
City−City
City−Resource

Simulate city-resource and city-city connectivity by routing flows through adjacency matrices H and ξ.

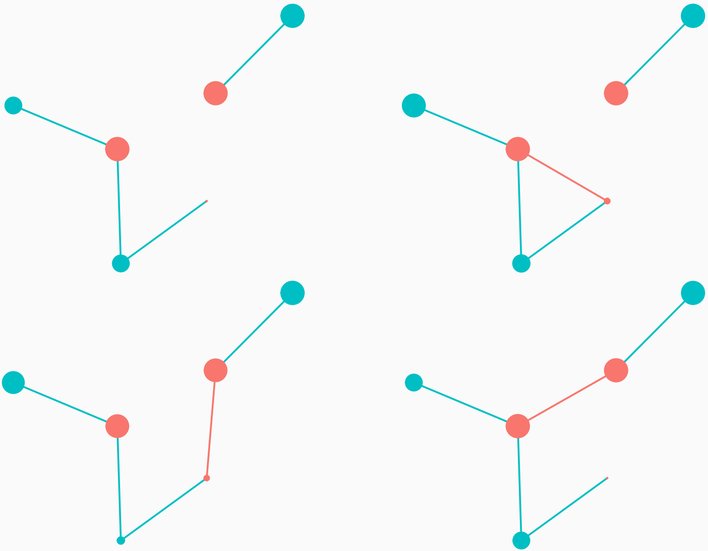
$$
\begin{aligned}
\dot{X}_i &= \\
\dot{N}_j &=
\end{aligned}
\tag{3}
$$

Simulate city-resource and city-city connectivity by routing flows through adjacency matrices $\mathbf{H}$ and ξ.

$$\begin{aligned}\dot{X}_i &= rX_i\left(1-\frac{X_i}{K}\right) - X_i\sum_j \overbrace{H_{ij}N_j^{\beta}}^{\text{resource flows to connected cities}} \\ \dot{N}_j &= \frac{N_j^{\beta}}{E}\underbrace{\sum_i H_{ij}X_i}_{\text{flows from connected resource systems}} - \frac{M}{E}N_j^{\alpha}\end{aligned} \tag{3}$$

Simulate city-resource and city-city connectivity by routing flows through adjacency matrices H and ξ.

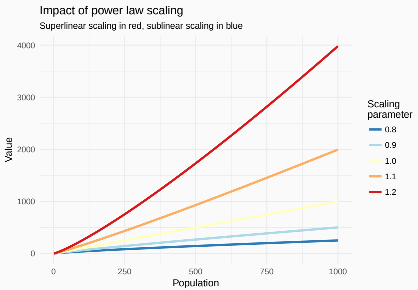
$$\begin{aligned}
\dot{X}_i &= rX_i\left(1 - \frac{X_i}{K}\right) - X_i \sum_j \overbrace{H_{ij} N_j^{\beta}}^{\text{resource flows to connected cities}} \\
\dot{N}_j &= \frac{N_j^{\beta}}{E} \underbrace{\sum_i H_{ij} X_i}_{\text{flows from connected resource systems}} - \frac{M}{E} N_j^{\alpha} - \underbrace{\nu N_j}_{\text{migration out}} + \sum_k \underbrace{\xi_{jk} \nu N_k \frac{W_j}{\sum_l \xi_{lk} W_l}}_{\text{migration in}}
\end{aligned} \tag{3}$$



ARCHAEOLOGICAL IMPLICATIONS

We need robust cross-cultural estimates of scaling parameters

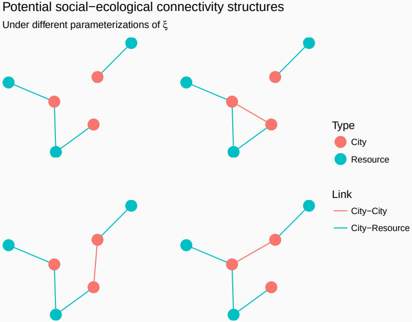
- We rarely know even if a given variable scales sublinearly or superlinearly with population size.



ARCHAEOLOGICAL IMPLICATIONS: CONNECTIVITY

Social networks and transportation networks aren't sufficient for understanding dynamics, we need to think about environmental flows as well.

- Food webs, stream networks, precipitation teleconnections, etc., can't be ignored.



- Simple models of coupled population and energy flows can provide insights into prehistoric social networks.

SUMMARY

- Simple models of coupled population and energy flows can provide insights into prehistoric social networks.
- Nonlinear scaling of socioeconomic factors with population size has a strong impact on the sustainability of ancient settlements.

SUMMARY

- Simple models of coupled population and energy flows can provide insights into prehistoric social networks.
- Nonlinear scaling of socioeconomic factors with population size has a strong impact on the sustainability of ancient settlements.
- When scaling behaviors are present, even weak social or environmental connectivity can generate considerable social-ecological complexity.

QUESTIONS?