Quo vadis ecosystem? Insights from ecological modelling and systems ecology

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ISEM

INTERNATIONAL SOCIETY FOR ECOLOGICAL MODELLING

- Formed by Sven Jørgensen, in 1970s as companion to the journal *Ecological Modelling*.
- Over 300 members-based on conference attendance
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THEMES

- Dynamic Ecological Simulation Models
  (aquatic, terrestrial, energetics, biogeochemical, etc.)
- Ecological Modelling and Environmental Management
  (Risk assessment, Flow Analysis, Sustainability, Ecotoxicology, Monitoring and Planning)
- Modelling Coupled Natural and Social Systems
  (Socio-Ecological, Urban, Integrated Assessment)
- Modelling of Ecosystem Services
- Biodiversity and Conservation Modelling
- Ecological Landscape and Land Use Change Modelling
- Ecological Modelling for Climate Change
- Network Modelling
- Systems Ecology

ABSTRACT
SUBMISSION
DEADLINE
**16 October
2015**

EARLY
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DEADLINE
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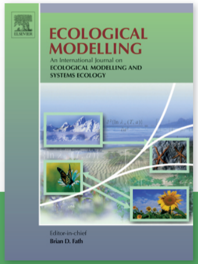

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ECOLOGICAL
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An International Journal on
ECOLOGICAL MODELLING AND
SYSTEMS ECOLOGY

Editor-in-chief
Brian D. Fath

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IIASA's
Young Scientists Summer Program (YSSP)

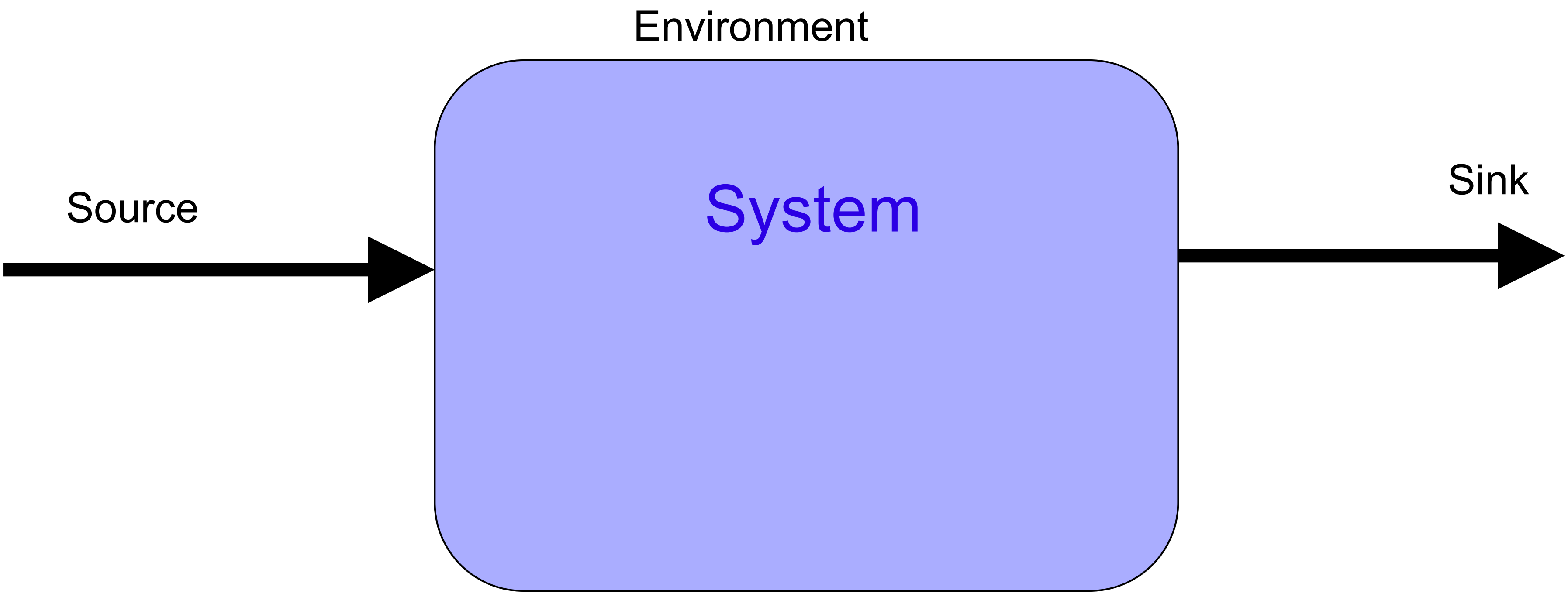
- Ph.D. students
- June 1 – August 31
- Independent Research mentored by IIASA scientists
- Funded by NMO & other sources
- January application deadline

Objectives

- Ecosystem Dynamics
  - Openness
  - Complexity
  - Ecological goal functions
  - Adaptive cycle
  - Collapse response
  - Future research

Open Systems

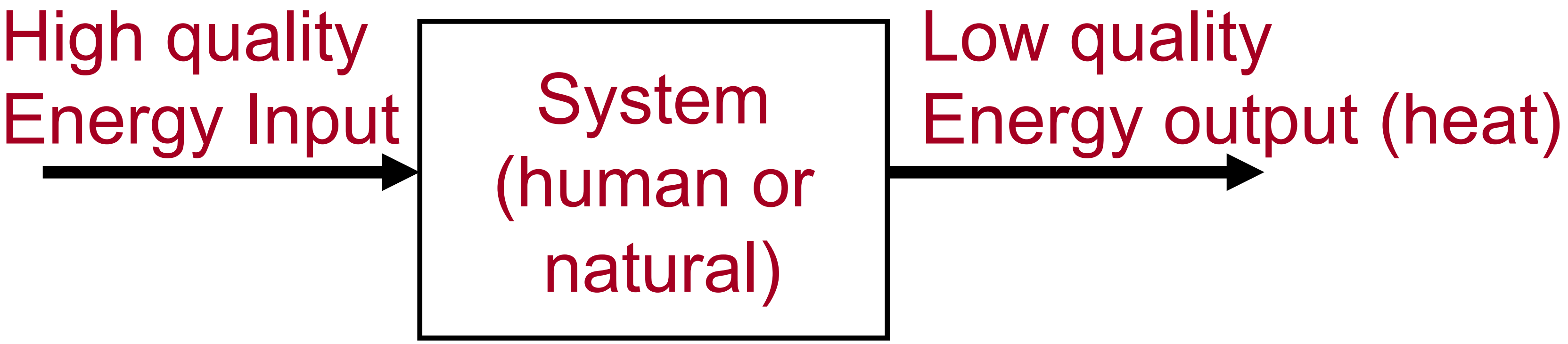
Open systems connect to their environment through both inputs and outputs



Input-State-Output

Thermodynamically, Open Systems

…build and maintain order and organization by taking in high quality energy, using it, and passing degraded energy outside of the system.



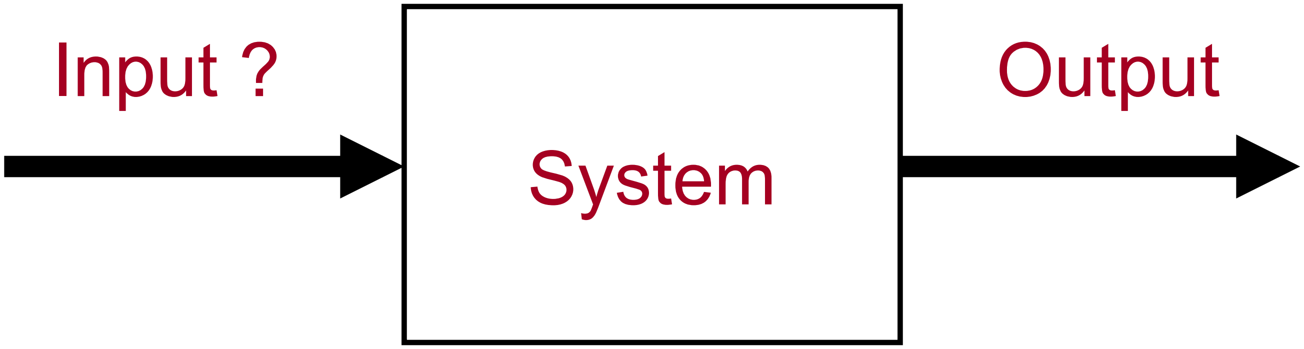
High quality
Energy Input

System
(human or
natural)

Low quality
Energy output (heat)

Ecosystem Input Constraints

- Solar radiation
- Global carbon cycle
- Rate of nutrient cycling
- Rate of hydrological cycle



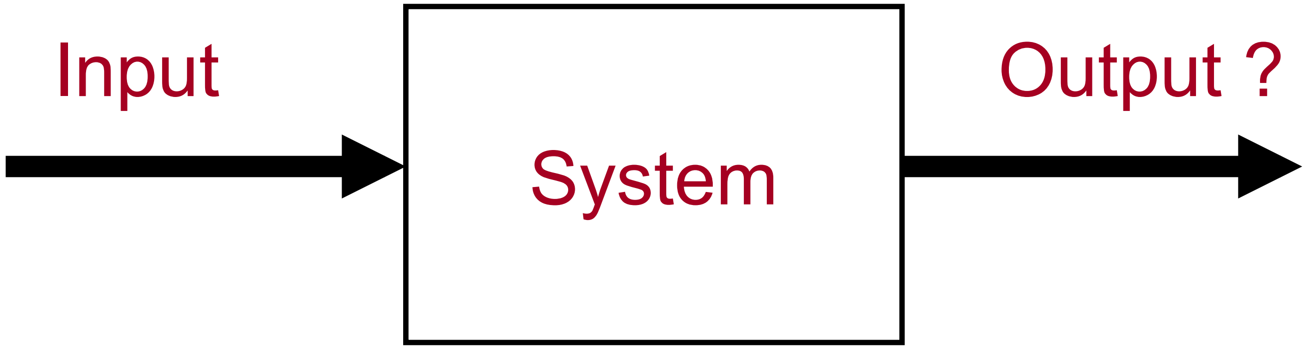
Input ?

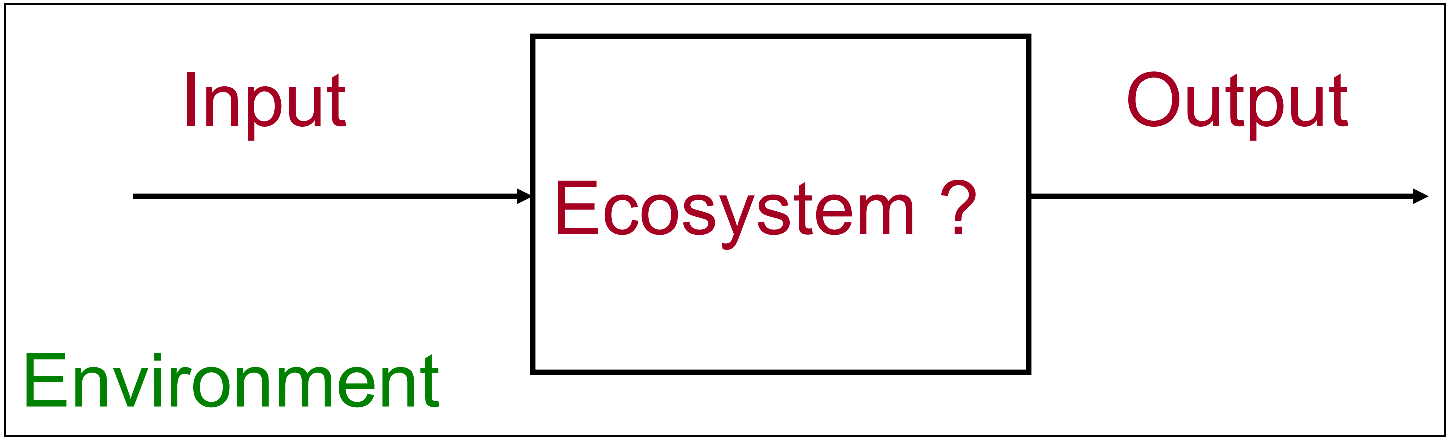
System

Output

Ecosystem Output Constraints

- Rate of decomposition
- Rate of accumulation of unwanted byproducts





Ecosystems have evolved and developed within these input-output environmental constraints.

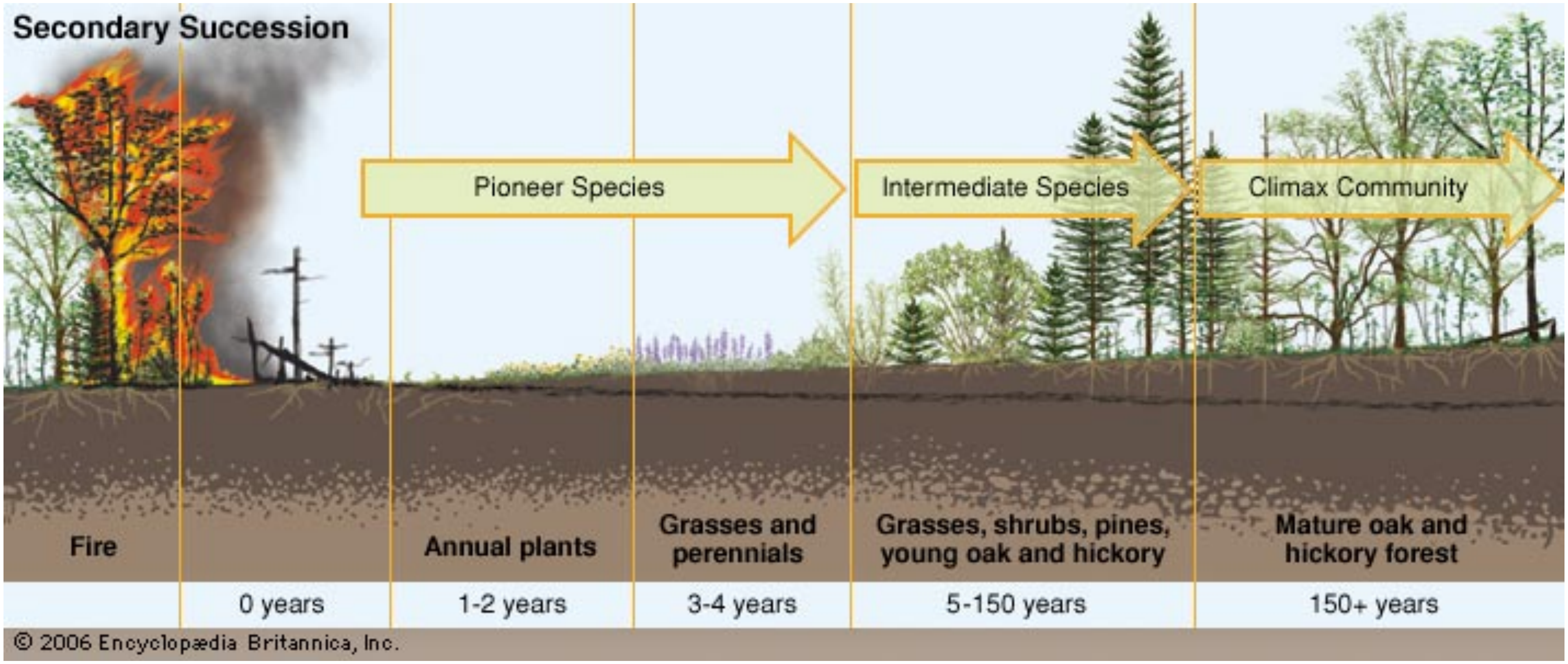
What patterns of organization and complexity arise in ecosystems?

Ecosystems are dynamic

Biological systems are characterized by a capacity for *directional change* – the cumulative manifestation of positive feedback.

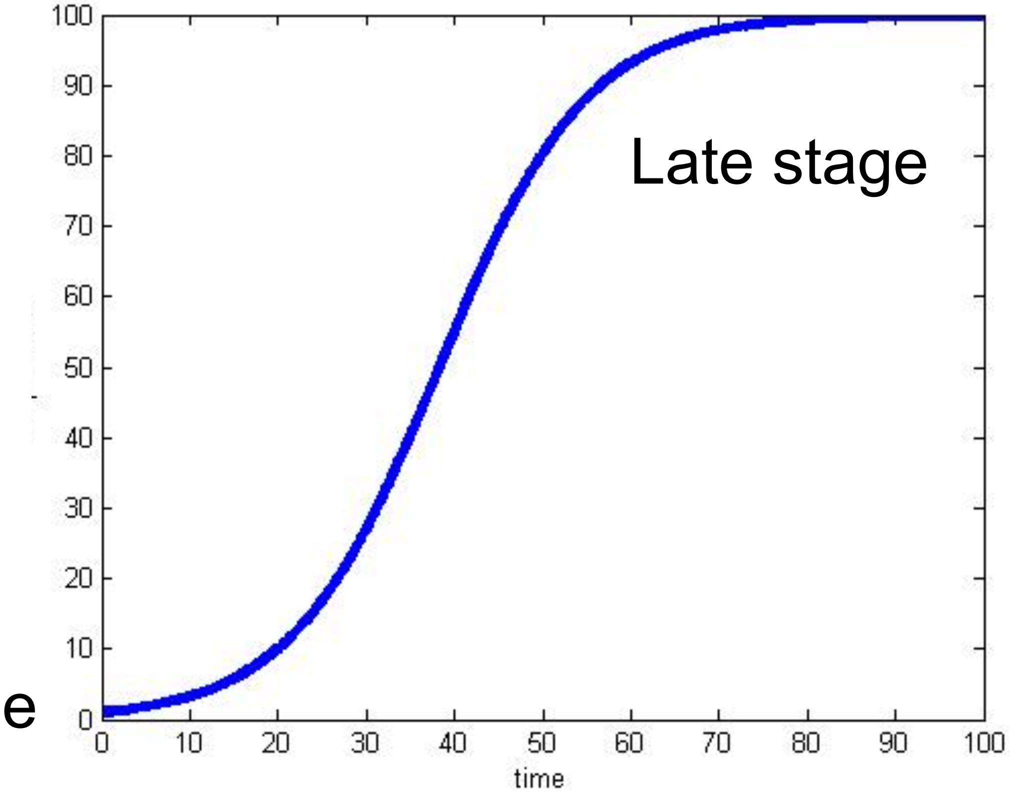
Succession – ordered pattern of growth and development

Increase in complexity and order as the result of controlled growth – decrease internal entropy



Secondary succession – reestablishment of an ecosystem from the remnants of a previous biological community following disturbance

Logistic growth from early to late successional stages



Late stage

Early stage

Extremal Concepts

- Can extremal principles contribute to better understanding and management of environmental Complex Adaptive Hierarchical Systems, and what is their potential for future research strategies?

- What are the salient extremal principles involved in ecological processes, and how are they interrelated?

Trends to be expected in ecosystem development (Odum 1969)

Ecosystem Attribute	Developmental Stage	Mature Stage
Community energetics		
Gross production/community respiration (P/R ratio)	>1	~1
Gross Production/standing crop biomass (P/B ratio)	high	low
Biomass supported/unit energy flow (B/E ratio)	low	high
Food chains	linear	weblike
Nutrient cycling		
Mineral cycles	open	closed
Nutrient exchange rate	rapid	slow
Nutrient conservation	poor	good
Overall homeostasis		
Stability (resistance to external perturbations)	poor	good
Entropy	high	low
Information	low	high

Bioenergetic model of succession

In early stages of succession, P≥R and excess is channeled into growth and accumulation of biomass.

Increase capacity and complexity of the energy storage compartments (total biomass of all species and trophic levels) as well as the complexity of energy transfer pathways.

In late stages of succession, P=R as maintenance costs increase respiration

Negative feedback maintains steady state, with little or no change in biomass (network, feedback, cycling).

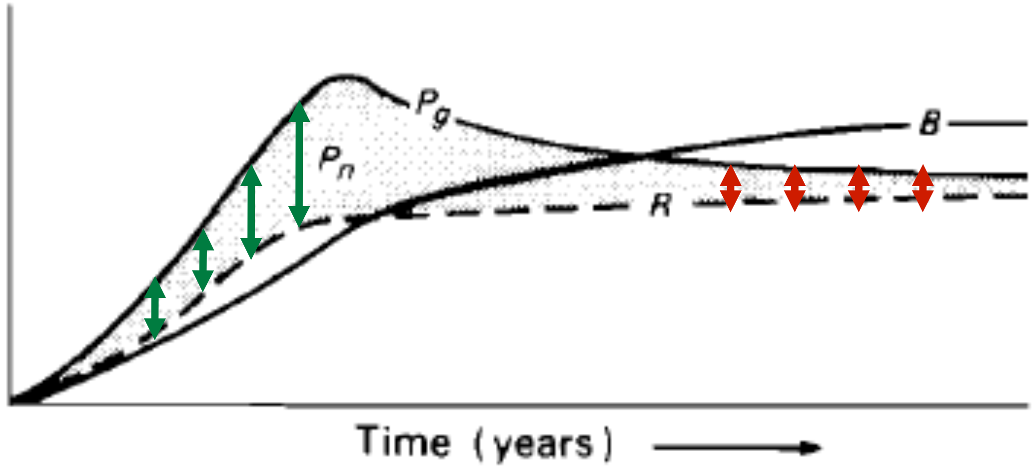


Fig. 25.17 Changes in gross (P_g) and net (P_n) production, respiration (R) and biomass (B) through succession.

Complexity

Increase in complexity and order as the result of controlled growth.

HOW CAN WE MEASURE THIS COMPLEXITY?

Environmental systems are far-from-equilibrium systems.

- How do we measure this “complexity”?
  - Extensive variable * Intensive variable
  - How much * What characteristics
  - Quantity * Quality

I=PAT

Env. Impact = Population x [Affluence x Technology]

(how much) x [(use/person) x (impact/use)]

In ecological systems

- Pioneer researchers have tried several methods
- Energy times “quality”

Extensive

  - Exergy (Jorgensen): $\sum \beta_i c_i$

Intensive

  - Emergy (HT Odum): $\sum \tau_i E_i$
  - Ascendency (Ulanowicz): $\sum T_{ij} \log\left(\frac{T_{ij} T_{..}}{T_{i.} T_{.j}}\right)$

Growth → *Quantitative* increase
Development → *Qualitative* increase

"We must realize that growth and development are two very different things. You can develop without growing and vice versa.“

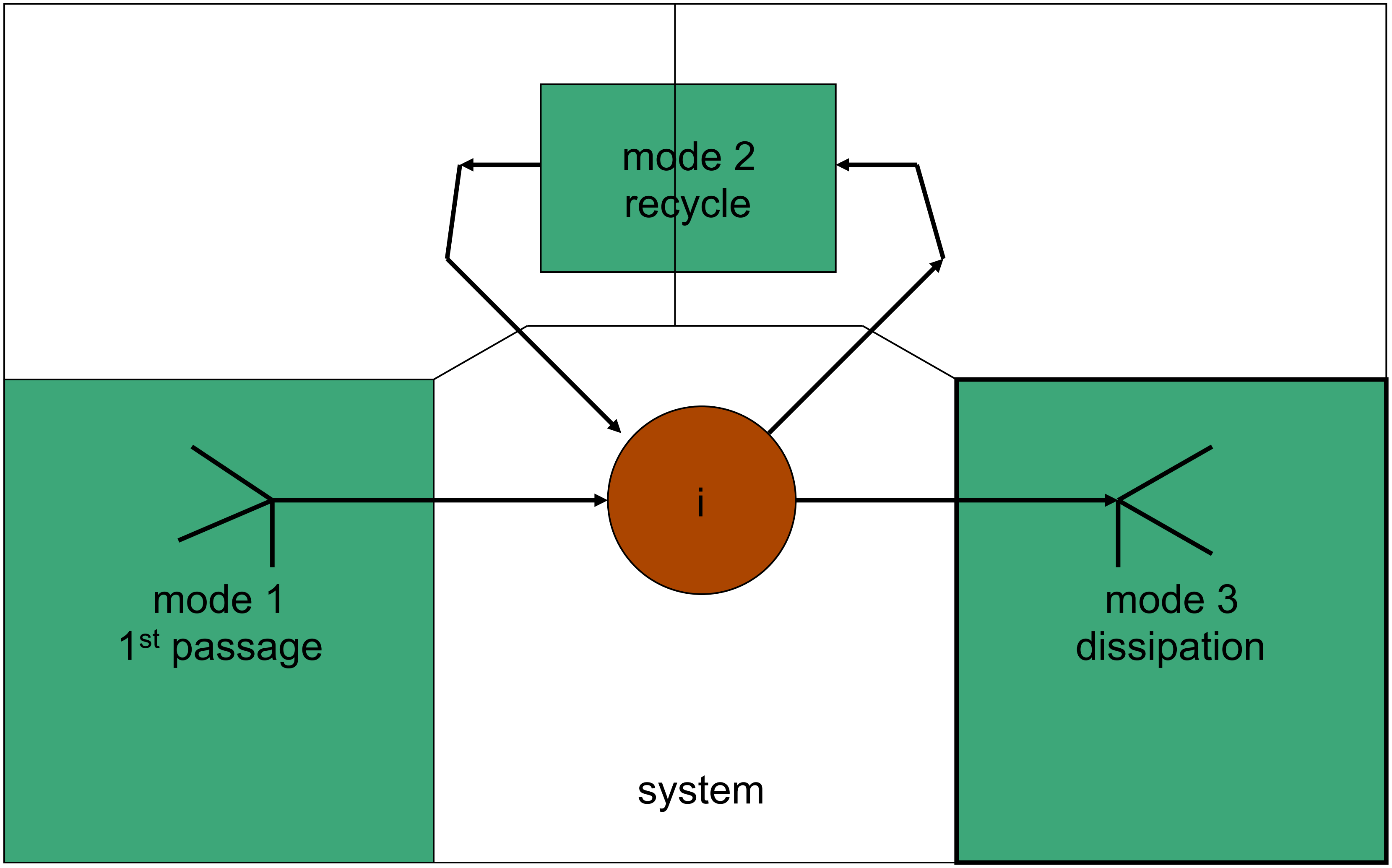
Tibor Vasko, 2009, www.solon-line.de/interview-with-tibor-vasko.html

ECOLOGICAL GOAL FUNCTIONS

1. **Maximize** **Power** (Lotka 1922, Odum and Pinkerton 1955)
   Increase in the internal energy flow: max(TST)
2. **Maximize** **Exergy Storage** (Jørgensen-Mejer 1979)
   Biomass storage and information increase: max(TSS)
3. **Maximize** **Dissipation** (Schneider-Kay 1994)
   Increase in dissipative flows: max(Total System Export)
4. **Maximize** **Cycling** (Morowitz 1968)
   Increase in cycling: max(Total System Cycling)
5. **Minimize** **Specific Dissipation** (Prigogine 1955)
   Decrease in the respiration to biomass ratio: min(TSE/TSS)
6. **Maximize** **Residence Time** (Cheslak and Lamarra 1981)
   Increase time lags to maintain the energy stores longer: max(τ)

Complementarity of Ecological Goal Functions

Flow Partitioning



Network representation of flow and storage partitioning for any (i,j) pair in the system.

	FLOW pair-wise interactions	**STORAGE** pair-wise interactions
mode 1 (first passage)	$f_{ij}^{(1)} = \left(\frac{n_{ij}}{n_{ii}} - \delta_{ij} \right) z_j$	$x_{ij}^{(1)} = \left(\frac{q_{ij}}{q_{ii}} - \delta_{ij} \right) z_j \Delta t$
mode 2 (cyclic)	$f_{ij}^{(2)} = \frac{n_{ij}}{n_{ii}} (n_{ii} - 1) z_j$	$x_{ij}^{(2)} = \frac{q_{ij}}{q_{ii}} (q_{ii} - 1) z_j \Delta t$
mode 3 (dissipative)	$f_{ij}^{(3)} = \left(\frac{n_{ij}}{n_{ii}} - \delta_{ij} \right) z_j$	$x_{ij}^{(3)} = \left(\frac{q_{ij}}{q_{ii}} - \delta_{ij} \right) z_j \Delta t$

Goal Function	Ecological Representation	Network Parameter	Network Analysis Formulation
max power	max(TST)	$TST = f^{(1)} + f^{(2)}$	$TST = \sum\sum (n_{ij})z_j$
max exergy storage	max(TSS)	$TSS = x^{(1)}+x^{(2)}$	$TSS = \sum\sum\tau_i(n_{ij})z_j$
max dissipation	max(TSE)	$TSE = f^{(3)}$	$TSE = \sum\sum (n_{ij}/n_{ii})z_j$
max cycling	max(TSC)	$TSC = f^{(2)}$	$TSC =\sum\sum (n_{ij}/n_{ii})(n_{ii}-1)z_j$
min specific dissipation	min(TSE/TSS)	$TSE/TSS = f^{(3)}/(x^{(1)}+x^{(2)})$	$TSE/TSS = \sum\sum ((n_{ij}/n_{ii})z_j)/x_{ij}$ $= \sum\sum 1/(\tau_i n_{ii})$
max residence time	max(TSRT)	$TSRT = \tau$	$TSRT = \sum\sum x_i/(n_{ij})z_j$ $= \sum\sum\tau_i$

Conclusion

Goal functions are consistent and mutually implicating

Three common properties:

1) **First passage flow**
2) **Cycling**
3) **Retention time**

Get as much as it can (maximize first passage flow);
Hold on to it for as long as it can (maximize retention time);
and
If it must let it go, then try to get it back (maximize cycling).

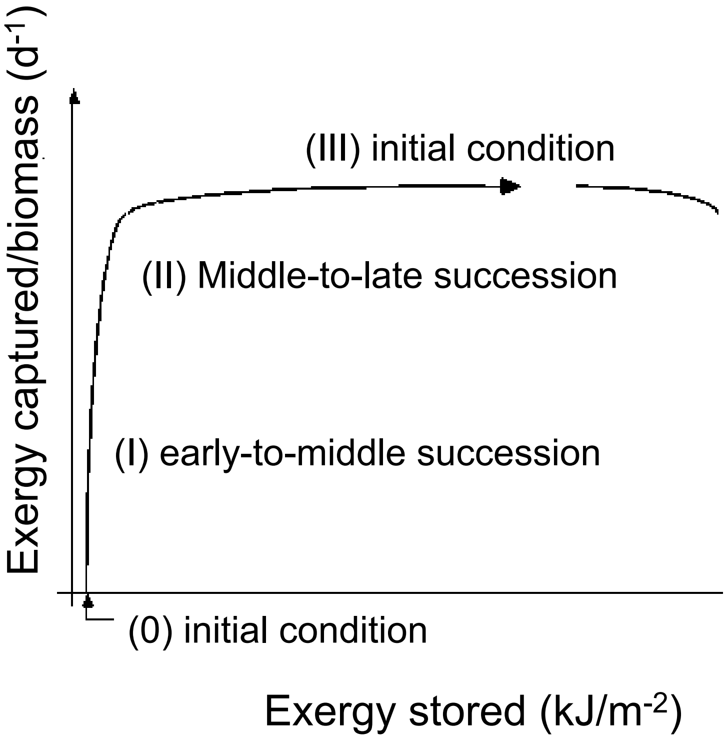
Four types of Ecosystem Growth and Development

0. *Boundary Growth:* Low-entropy energy enters the system.
I. *Structural Growth:* Increase in quantity of biomass as the number and size of components in the ecosystem increase.
II. *Network Development:* Change in system connectivity transactions, which results in more cycling.
III. *Information Development:* Qualitative change in system behavior to more energetically efficient ones.

Purpose: to investigate behavior of ecological goal functions during different growth and development stages.

Hypothesis 1: Storage and throughflow increase during all stages.

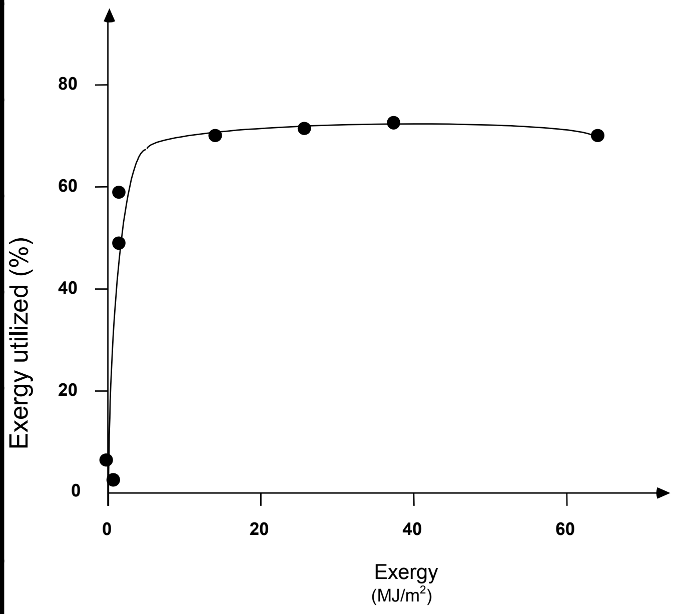
Hypothesis 2: Exergy degradation increases initially, then levels off.

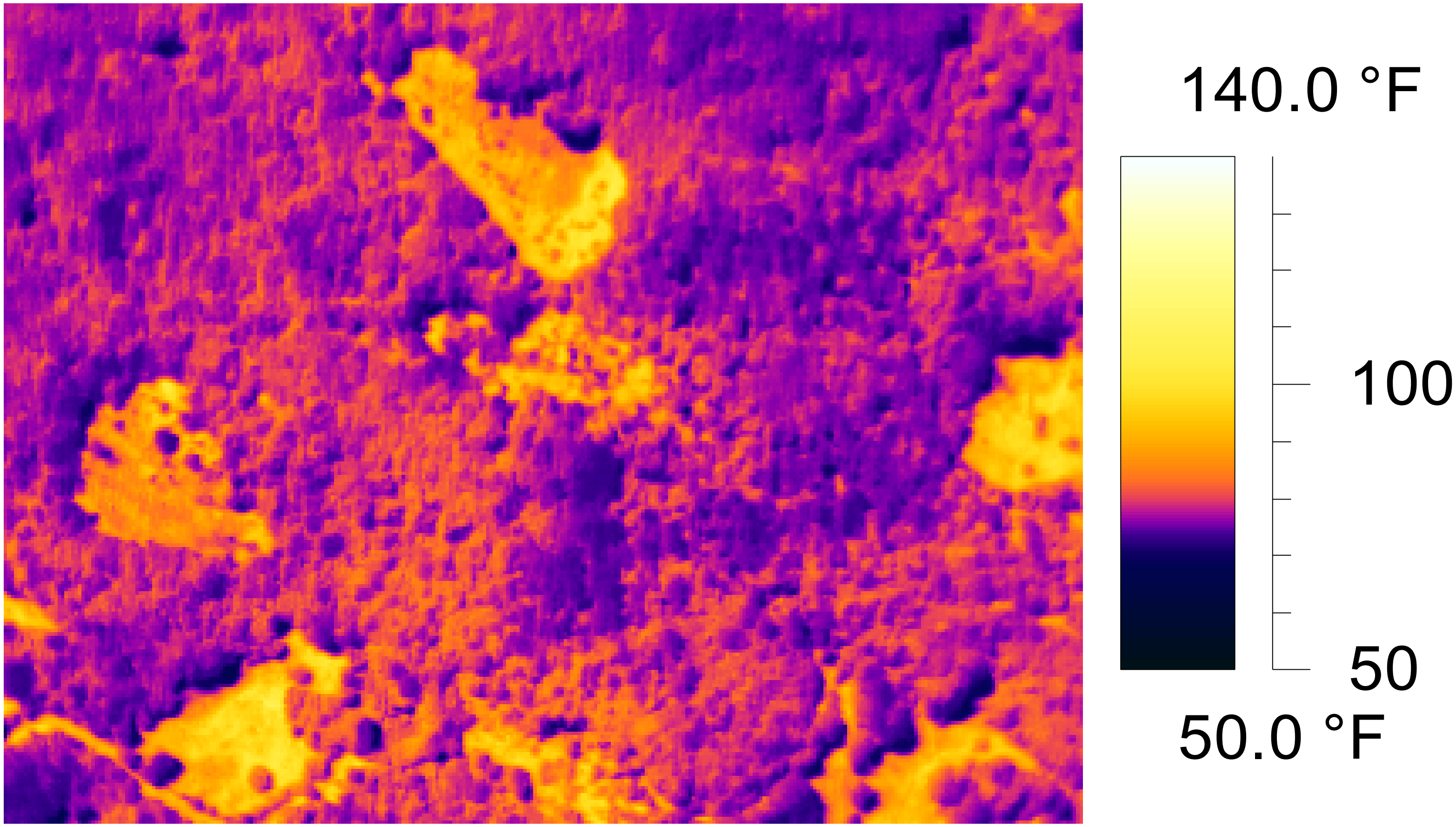


Empirical data support the theory

Ecosystem	% exergy use*	exergy storage
Quarry	6	0
Desert	2	0.07
Clear-cut	49	0.59
Grassland	59	0.94
Fir Plantation	70	12.7
Natural Forest	71	26
Old deciduous forest	72	38
Tropical rain forest	70	64

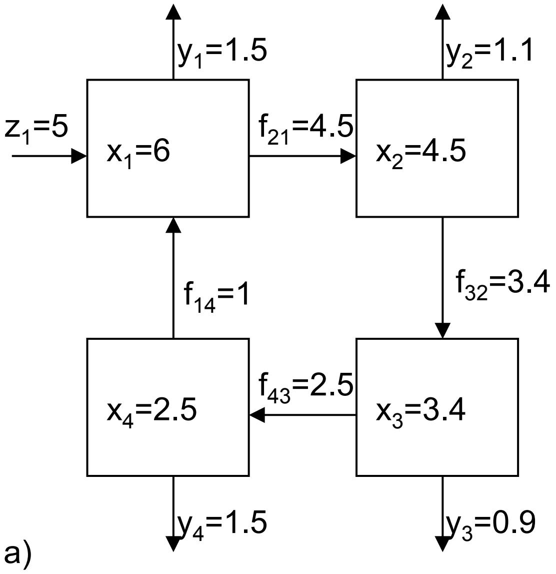
*Kay and Schneider 1992





Debeljak, 2004

Network models representing different growth & development stages

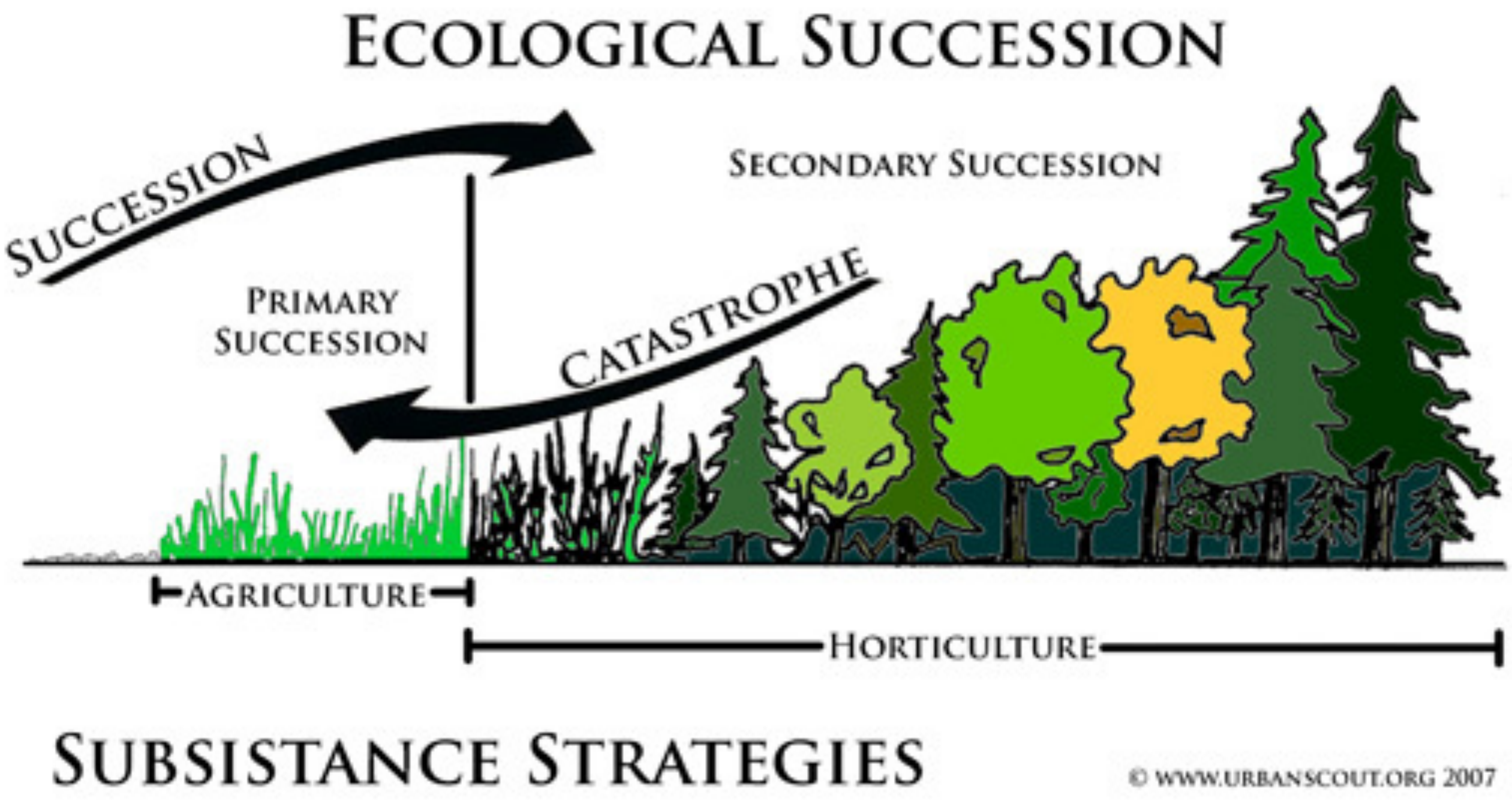


Ecosystem Development Trends

Figure Comparison	Specific entropy (output/storage)	Energy throughflow	Exergy storage (biomass)	Exergy degradation	Retention time
Fig. 7a→7b Growth form I	0.30→0.30 (unchanged)	16.4→32.8 (increased)	16.4→32.8 (increased)	5→10 (increased)	3.3→3.3 (unchanged)
Fig. 7b→7c Growth form II	0.30→0.28 (decreased)	32.8→35.8 (increased)	32.8→35.8 (increased)	10→10 (unchanged)	3.3→3.6 (increased)
Fig. 7c→7d Growth form III	0.28→0.21 (decreased)	35.8→47.1 (increased)	35.8→47.1 (increased)	10→10 (unchanged)	3.6→4.7 (increased)

	Boundary G&D	**Structural G&D**	**Network G&D**	**Information G&D**
	Biomass Throughflow	Biomass Maintenance	Cycling	Information
Specific entropy	↔	↔	↓	↓
Energy throughflow	↑	↑	↑	↑
Exergy degradation	↑	↑	↔	↔
Exergy storage	↑	↑	↑	↑
Retention Time	↔	↔	↑	↑

System moves to more conservative strategies – storage, throughflow, cycling, and retention time increase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SUCCESSION
SECONDARY SUCCESSION
PRIMARY SUCCESSION
CATASTROPHE
AGRICULTURE
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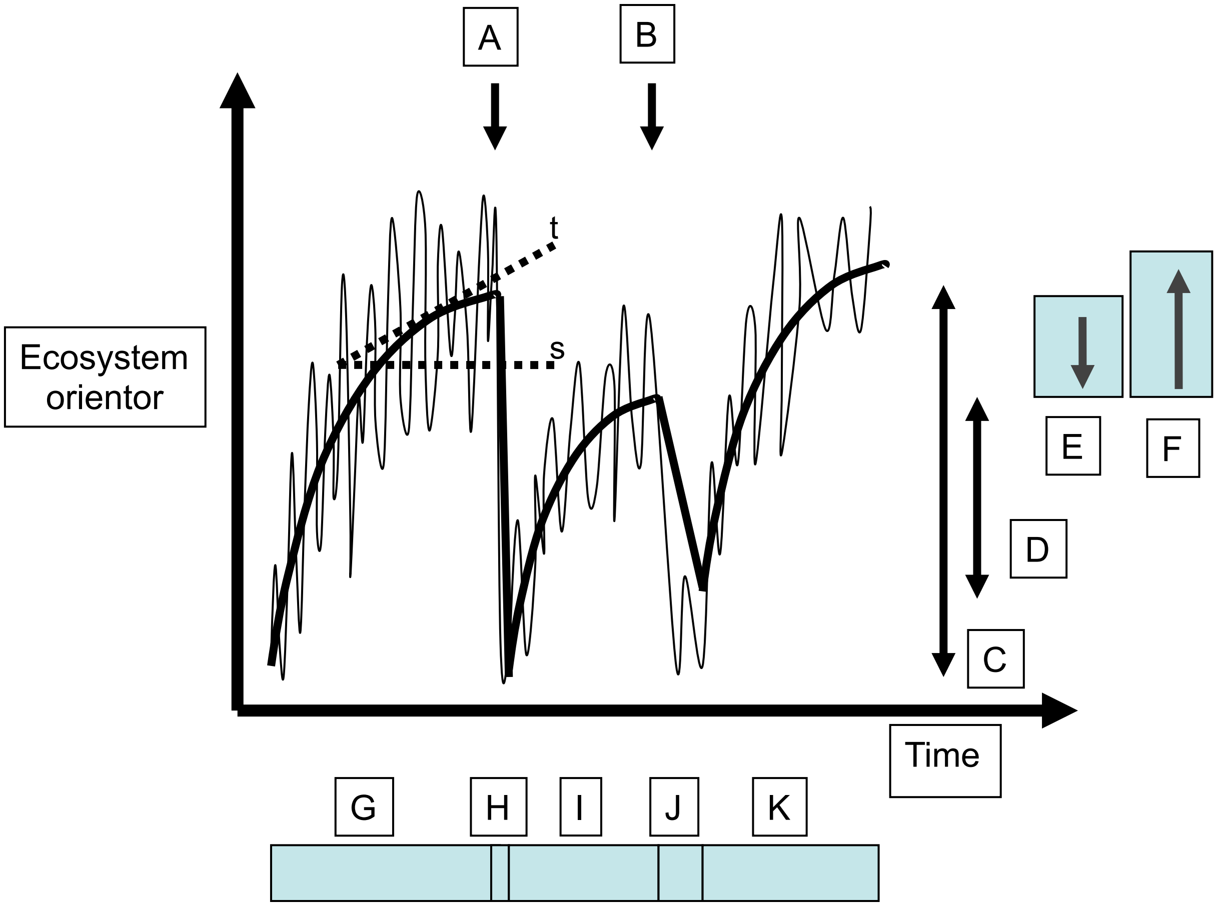
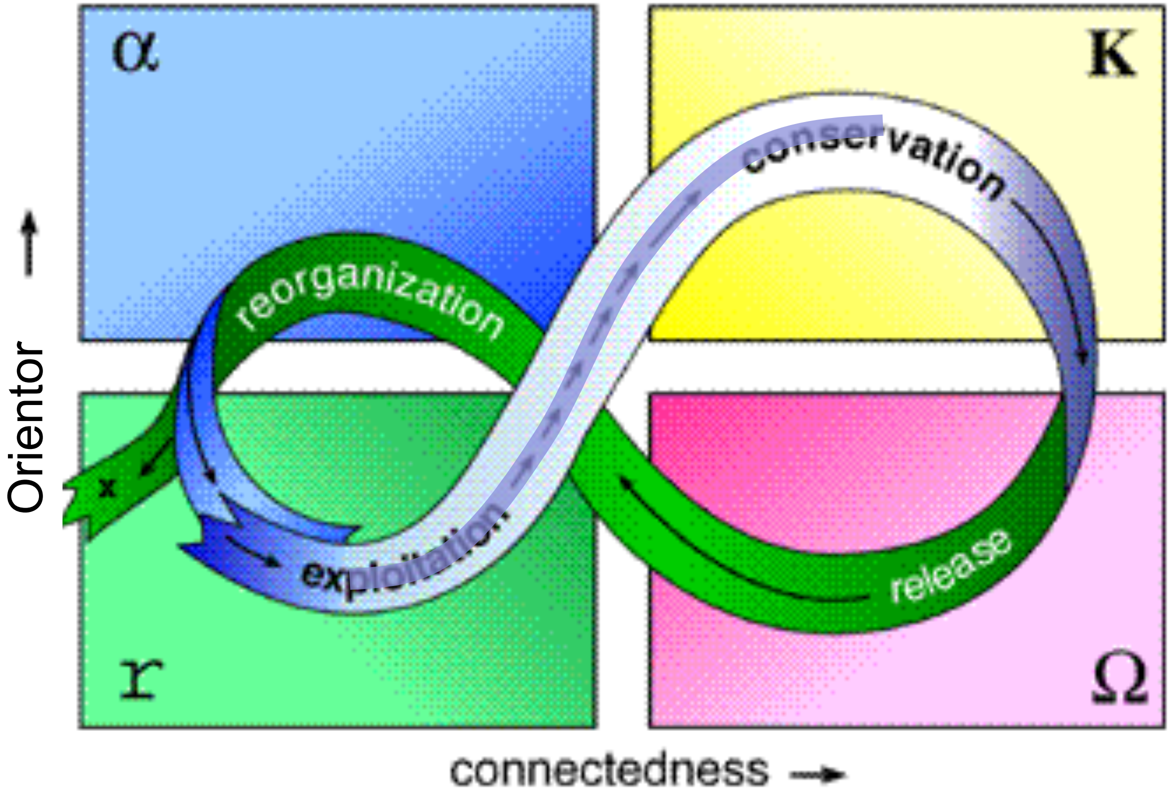


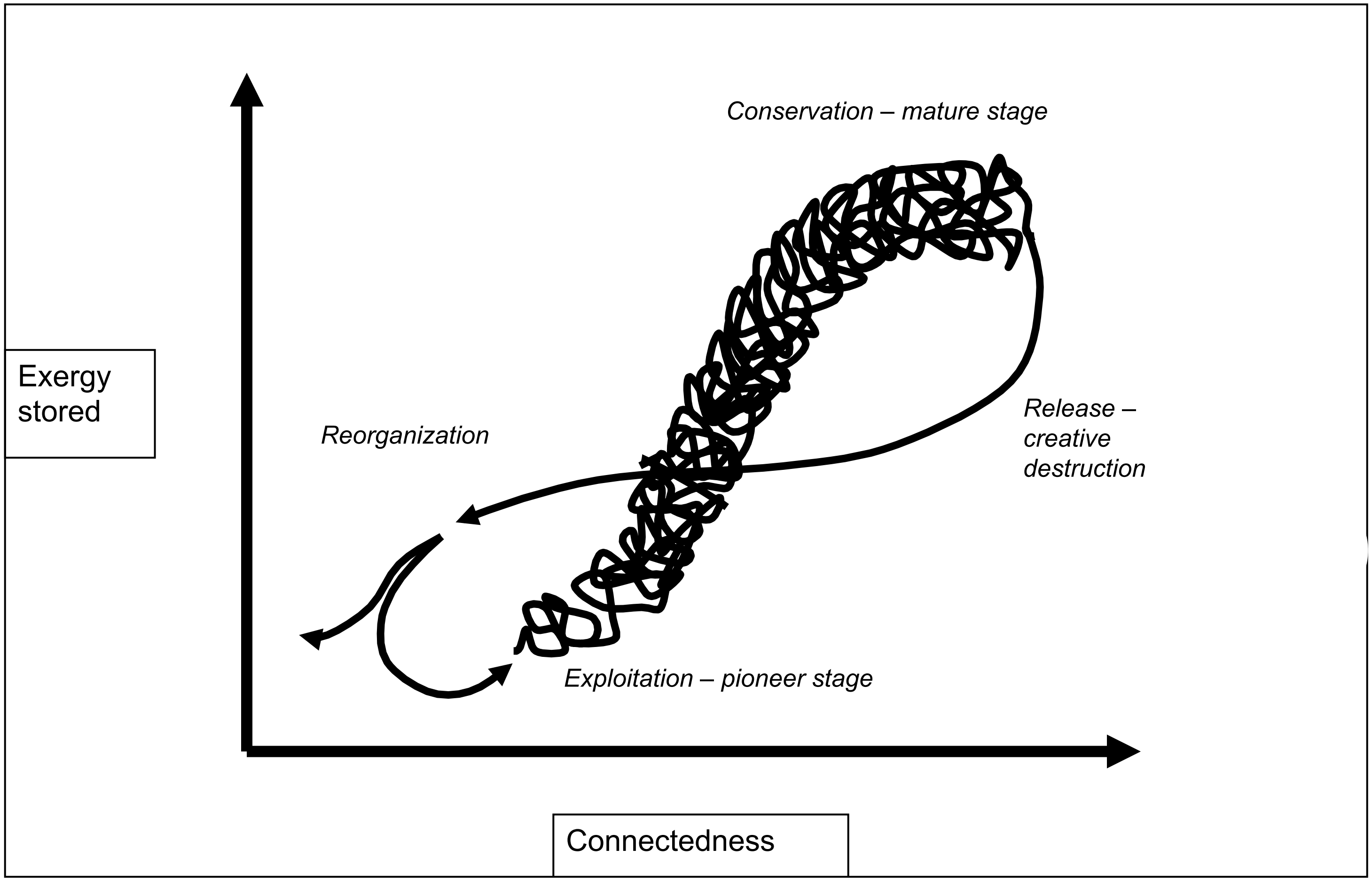
Sketch of the dynamics of ecosystem variables on two scales, both variables are influenced by the disturbances (A and B) with different magnitudes (C and D) and durations (H and J), and both variables are due to orientor dynamics during the phases G, I and K.

Adaptive Cycle: Holling's 4-stage model of ecosystem dynamics

Logistic growth only captures part of the cycle

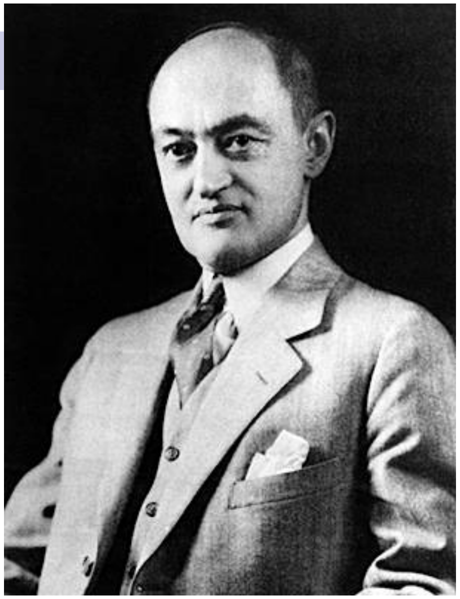


rs.resalliance.org/wp-content/uploads/2007/02/4box-adaptive-cycle.gif

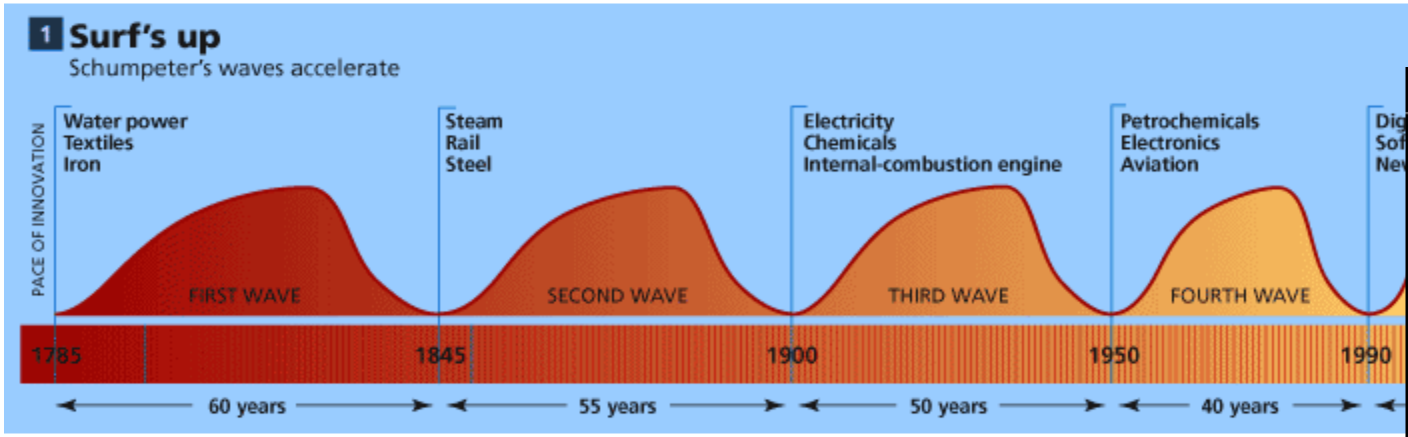


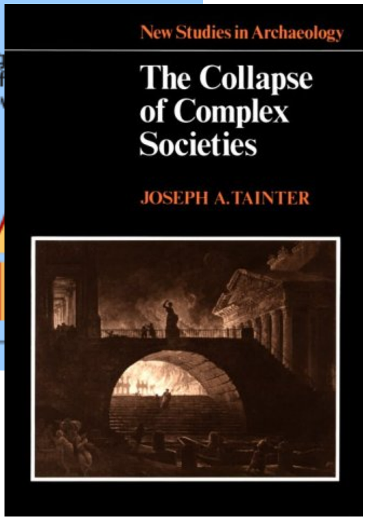
Ecosystem succession in the collapse dynamic

Benefits of collapse



- Schumpeter labeled the collapse, “creative destruction”, since it allowed for new configurations and innovation opportunities

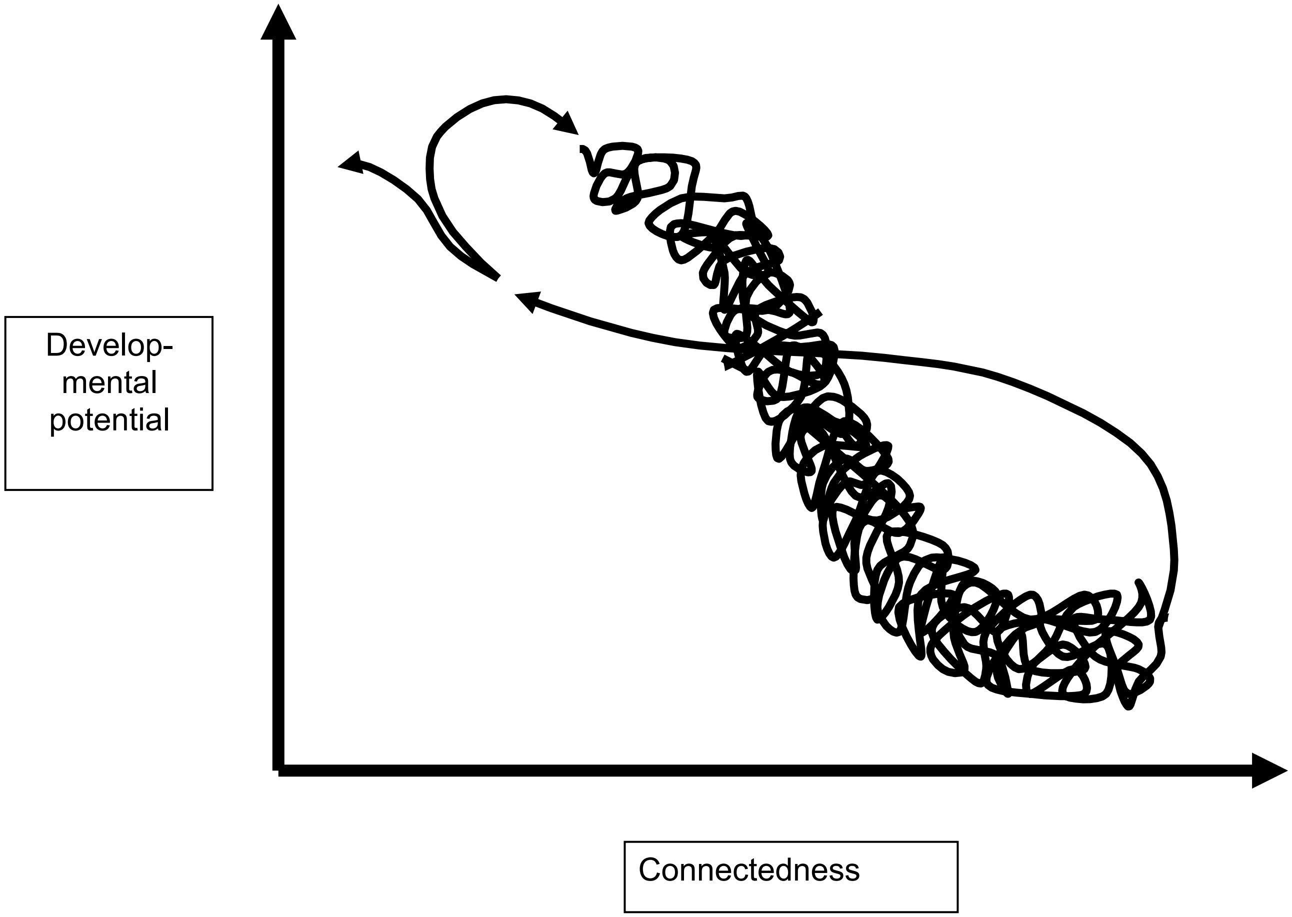




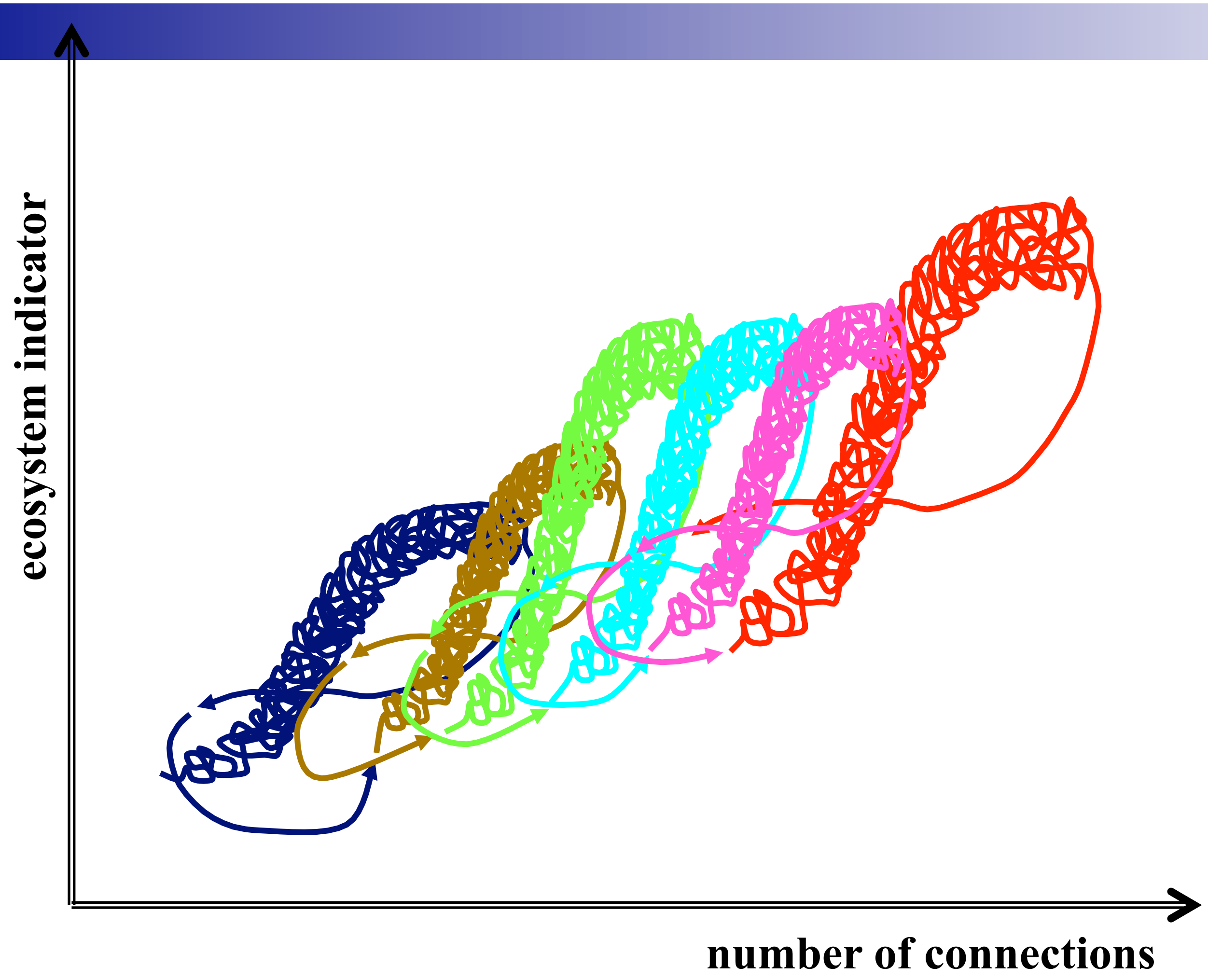
New Studies in Archaeology

The Collapse
of Complex
Societies

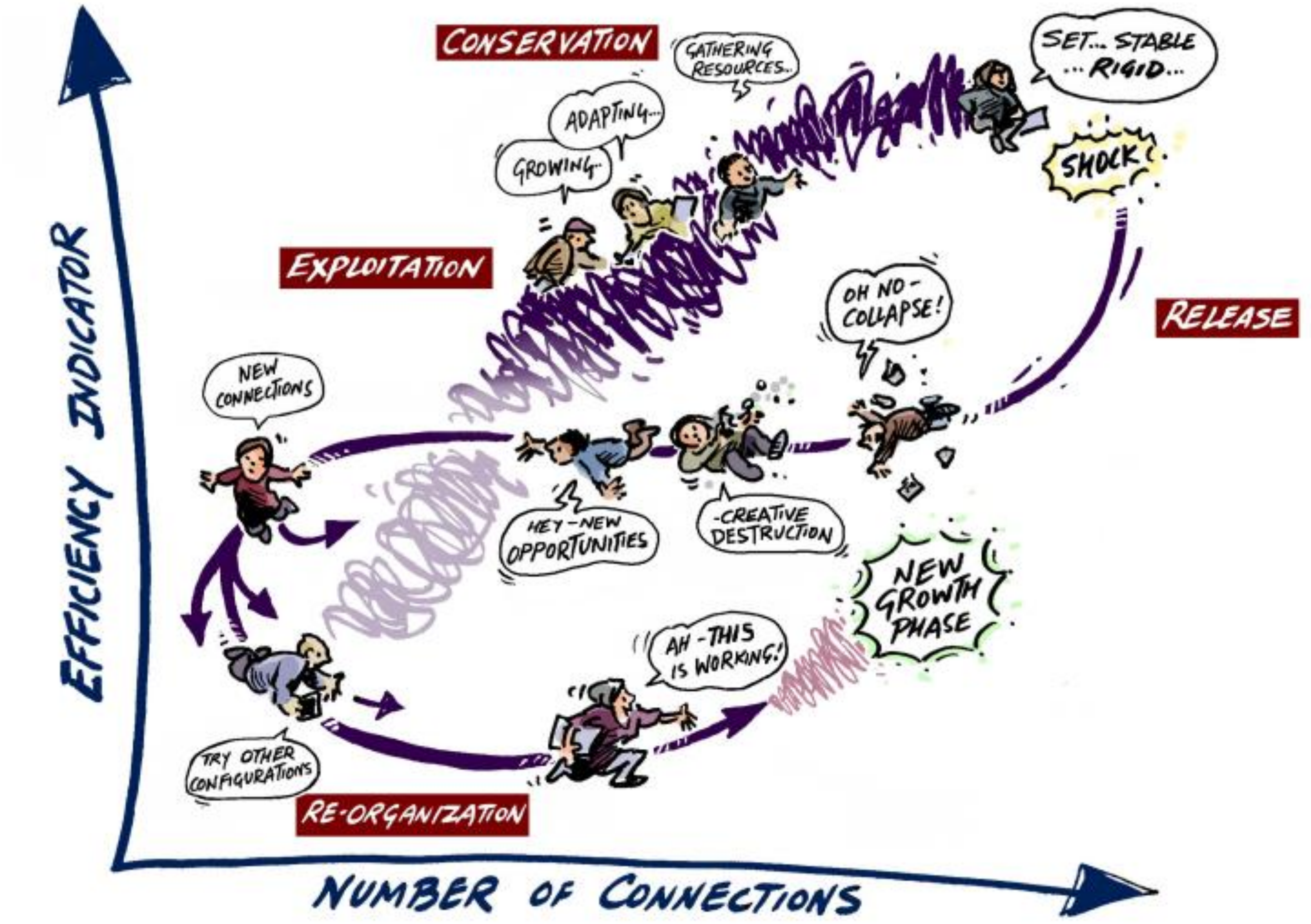
JOSEPH A. TAINTER



Developmental opportunities result from the collapse



Long-term succession of ecosystems: small-scale disturbances may support the development of the overall system.



Synthesis model

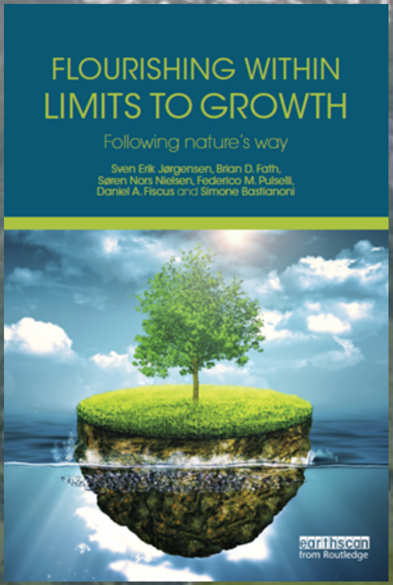
Conclusions

- Ecological systems are open systems that use resource inflows to increase complexity and move further from thermodynamic equilibrium
- Some orientors can track the dynamic development phase
- Systems go through a complex cycle of growth, development, stability, collapse and reorganization.
- Collapse is a normal response of the long term dynamic

- Understanding ecosystem dynamics, design, and function may help manage socio-economic systems

Future research in ecosystem dynamics and ecological modelling

- Individual based models
- Socio-economic-ecological models
- Spatially explicit and land use models
- Climate factors as drivers and coupled processes



FLOURISHING WITHIN LIMITS TO GROWTH

Following nature's way

Sven Erik Jørgensen, Brian D. Fath,
Søren Nors Nielsen, Federico M. Pulselli,
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earthscan
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