Course 2.1.1: Basics of Ecosystem Analysis

May 24, 2006 Ecosystem Protection Concepts

A

Ecosystem Protection II. → W. Windhorst
- Ecosystem Integrity, the Concept → Pres. Timo
- Ecosystem Integrity, Applications → Pres. Timo

The UNCBD Ecosystem Approach – Case Studies → W. Windhorst
- Forest Ecosystems → Pres. Pawel

B

Ecosystem Theory. → F. Müller
- Network Theory → Pres. Kamil
- Thermodynamics → Pres. Aiko
- Hierarchy Theory → Pres. Pawel
- Gradient Principles → Pres. Lech

Organizing Salzau
- Web pages
- Transfer
- Working plans
- Problems
August Macke: Felsige Landschaft, 1914, Aquarell, 24 × 20 cm, Land: Deutschland, Stil: Expressionismus.
What are theories?
Popper: "Theory is the fishing net that scientists cast to catch the world, to explain it and to control it."

Theories are empirically or deductively based, aggregating and integrating representations of the proved knowledge of a scientific disciplin.

Abstract description, explanation and organization of a scientific disciplin.

- sets of hypotheses
- non-evaluative
- capable of being falsified
- prognostic
- applicable to single cases
- directing the development, orientation, and structure of the disciplin

What are theories?
Which theories are relevant for ecosystem comprehension?
Farina: "Theories are interpreting the complexity and heterogeneity of the environment (landscape)."

Naveh & Liebermann: "The organization of complexity in landscape structure and function has become a central issue in contemporary landscape ecology."

Landscape Theories

Approaches:
- Hierarchy Theory
- Fractal Geometry
- Chaos Theory
- Catastrophe Theory
- Self-Organization
- Information Theory
- Thermodynamics
- Theory of Dissipative Structures
- Percolation Theory
- Metapopulation Theory
- Systems Source-Sink
- Spatial Pattern Analysis

Which theories are relevant for ecosystem comprehension?
Which theories are relevant for ecosystem comprehension?
Which theories are relevant for ecosystem comprehension?

Ecosystem Theories

Information Theory
- Improbability of the Occurrence of an Event
- Syntactic, Semantic, Pragmatic Information

Hierarchy Theory
- Analysis of Subsystems with Asymmetric Interactions
- Scales, Holons, Constraints and Filters

Measures of Diversity
- Measures of Complexity
  - Ascendancy
    - Total Throughflow
    - Flow Articulation

Principles and Methods of Scale Distinction
- Fundamentals for the Existence of Emergence

A = I * T
Hierarchies and the problems of scale

Holon Level (+1)

Spatial Extent: High
Frequencies: Low

Minor Interactions
Multiple Interactions
Filter
Constraints

Holon Level (0)

Spatial Extent: Small
Frequencies: High

Holon Level (-1)
Which theories are relevant for ecosystem comprehension?
Ecosystem Dynamics
(Voluntary) Homework:
Find examples for...

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<thead>
<tr>
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<th>terrestrial</th>
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Holling’s conceptual model incorporates both Clementsian linear succession and Gleasonian independent, species-level disordered behaviour, which are integrated into a complexity based framework with insights gleaned from catastrophe theory, chaos theory and self-organization theory.

 Stored exergy

Figure from G. Zurlini
What is a succession?

.... an ordered process of community development including regular changes of the species compositions

.... changes occurring due to variations of the species interactions

.... changes occurring due to internal processes within the community

.... changes in community structure effecting changes in the physical ecosystem functions
  - energy
  - water
  - nutrients
  - which direction?
Types of successions:

- autogeneouss successions
  ---> consequences of internal processes

- allogeneouss succession
  ---> consequences of external influences

- primary succession
  ---> „natural“ development

- secondary succession
  ---> following primary successions which have developed under man‘s disturbing influences
Types of successions:

- progressive successions
  ---> complexification

- retrogressive succession
  ---> consequences of disturbances
  ---> simplification
Climax:

- final and „stable“ community of a developmental sequence

- climatic climax
  theoretical community which is the typical result of successions within a certain (climatic) area

- edaphic climax
  result of succession, effecting modifications of the climatic climax community due to physical modifications of the sites
Three examples for ecosystem development from ODUM

a. Microorganisms in a hay solution
Three examples for ecosystem development from ODUM

a. Microorganisms in a hay solution

b. Plant successions after fire and in dune systems
Three examples for ecosystem development from ODUM

a. Microorganisms in a hay solution

b. Plant successions after fire and in dune systems

c. Primary production and respiration throughout successions

Why do ecosystems develop where?

A mutual hypothesis from Weber et al. (1989)
Integration of new elements (species) into an autocatalytic system will take place, if loss is decreased, internal cycling is optimized, and dampening capacity increases (Weber et al. 1989)

Efficiency of the whole as a parameter of selection
Maximum Size due to the Constraints, Provided by the Site Conditions

"Resulting State"
"Goal"
"Attractor"

State Variable / Orientor / Indicator

Time / Maturity / Stage of Development
Maximum Size due to the Constraints, Provided by the Site Conditions

Dynamics of a potential higher hierarchical level

Dynamics of a potential lower hierarchical level
Ecophysiological and functional orientors

- loss reduction
- storages
- biomass
- biomass/production ratio
- harvest/throughput ratio
- transpiration
- respiration
- respiration/biomass ratio
- resource utilization
- utility
- intraorganismic storages
- metabolic quotients

System dynamical orientors

- buffer capacity?
- stability?
- (meat)stability?
- resilience?
- resistance?
- signal filtering?

System organizational orientors

- complexity
- hierarchical levels
- semi autonomy
- feedback control
- holistic determination
- criticality
- connectedness
- overconnectedness
- redundancy
Do ecosystems always follow the orientors?
Do ecosystems always follow the orientors?

No.
Renewal
- Accessible Carbon,
  - Nutrients and Energy

Conservation
- k-Strategy
  - Climax
  - Consolidation

Exploitation
- r-Strategy
  - Pioneers
  - Opportunists

Creative Destruction
- Fire
  - Storm
  - Pest
  - Senescence

Organization
Connectedness

Stored Capital (Storage)
(Mineralisation)
(Juvenile Stage)

Accessible Carbon,
Nutrients and Energy

Consolidation
(Adult Stage)

Fire
Storm
Pest
Senescence

Disturbance Incorporation

SLOWLY
RADILIY

4box1.pre

SLOWLY
RADILIY
The only stable component of nature is change!
Catalogue of questions

• What is a succession and how can we distinguish succession types?
• Find examples for progressive and retrogressive successions.
• Which are the typical developmental phases of lake communities
  • on an annual basis?
  • within 10 years?
  • within 1000 years?
• What is an orientor?
• Which are the differences between the concepts of stability, resilience, elasticity, and buffer capacity?
• Which are the components of the 'adaptive cycle' referring to
  • a bacteria population
  • the dune system of the island of Sylt?
  • the man-environmental system of Schleswig-Holstein during the past 250 years?
What does all this mean from a systems scientific viewpoint?
Structurized Systems State with Concentration Gradients
Structurized Systems State with Concentration Gradients

Diffusion, Dispersion, Dissipation

Thermodynamic Equilibrium (no Gradients)
Structurized Systems State with Concentration Gradients

Diffusion, Dispersion, Dissipation

Thermodynamic Equilibrium (no Gradients)

Dissipative Self-Organisation

Structurized Systems State with New Gradients
Self-Organization:

Spontaneous Creation of Macroskopic Structures from Microskopic Disorder

Gradient Formation
Principles of Self-Organization:
Principles of Self-Organization:

- Exergy Import
- Exergy Degradation
- Entropy Export
Principles of Self-Organization:

Exergy Import
- Convertible Energy
  - e.g. Radiation
  - CO₂-Input

Exergy Degradation
- Energy Transformation
  - e.g. Physiological Processes
  - Growth
  - Respiration

Entropy Export
- Energy Output
  - e.g. Heat
  - CO₂-Output
**Principles of Self- Organization:**

- **Exergy Import**
  - Convertible Energy
    - e.g. Radiation
    - CO₂-Input

- **Exergy Degradation**
  - Energy Transformation
    - e.g. Physiological Processes
    - Growth
    - Respiration

- **Entropy Export**
  - Energy Output
    - e.g. Heat
    - CO₂-Output

- **Gradient Formation**
Principles of Self-Organization:

- Exergy Import
- Systems State Far from Equilibrium
- Internal Control / Regulation
- Symmetry Breaking Organization
- Cooperativity of Subsystems
- Thermodynamic Openness of System
- Constraints in Hierarchies
- Meta Stability after Small Impulses
- Fluctuations in Phase Transitions
- Historicity and Irreversibility

- Exergy Degradation
- Gradient Formation

- Entropy Export

Criteria after Ebeling (1989)
System in a Normal State
System in a Normal State

System in an Excited State
Exergy Gradient
Energy Potentially Captured
Utilizable Energy
Input
Case A: Isolated System

Available Energy cannot be Captured

Utilizable Energy

Exergy Gradient

Energy Potentially Captured

Entropy Produced

Energy Emitted

Non-Utilizable Energy

Input

Output
Exergy Degrading Network

Case B: Integrated System

Available Energy can be Captured and Utilized

Utilizable Energy

Input

Output
Gradients and Non-Equilibrium

SCHNEIDER & KAY (1994):
"If a system is moved away from thermodynamic equilibrium, by the application of a flow of exergy, it will utilize all avenues available, that is build up as much dissipative structure as possible, to reduce the effects of the applied exergy gradient."

Living systems are degrading and utilizing applied gradients by the self-organized formation of a hierarchy of nested internal gradients.

Self-Organization in Principle Leads to Complexifying Dynamics with an Increasing Number of Interrelated Gradients
S.E. Joergensen:
If a systems receives a through-flow of exergy, the system will utilise this exergy to move away from thermodynamic equilibrium.
If the system is offered more than one pathway to move away from thermodynamic equilibrium, the one yielding most stored exergy, i.e. with the most ordered structure or the longest distance from equilibrium by the prevailing conditions, will have a propensity to be selected.

----> optimisation of exergy storage

- biomass
- organic matter
- structure and information
Maturity: Optimum defined by the site’s constraints

GRAD  = Diversity of gradients
EX (T) = Total amount of exergy captured
EX (S) = Exergy invested into the creation of the gradient structure (storage)
EX (M) = Exergy necessary for the maintenance of the gradient structure (degradation)
Maximum Size due to the Constraints, Provided by the Site Conditions

"Resulting State"
"Goal"
"Attractor"
Maximum Size due to the Constraints, Provided by the Site Conditions

- natural external inputs (e.g. fire, storm, pests)
- human external inputs (e.g. clear cut, pollution,...)
- senescence of a system (e.g. one-aged forests)
- dominance of species (e.g. mosses in fens, pests)
- internal feedback loops (e.g. soc accumulation)
Maximum Size due to the Constraints, Provided by the Site Conditions

Disturbance

System A

System B

Time / Maturity / Stage of Development
Maximum Size due to the Constraints, Provided by the Site Conditions

Dynamics of a potential higher hierarchical level

Dynamics of a potential lower hierarchical level

Time / Maturity / Stage of Development

State Variable / Orientor / Indicator
Information theoretical orientors
- information
- heterogeneity
- species richness
- Shannon index
- ascendency
- system throughput
- system overhead
- connectivity

Structural and community orientors
- development of symbioses
- life span
- body size
- r/k selection
- fecundity
- biomass
- niche diversity
- specialization
- prey specificity

Network theoretical orientors
- indirect effects
- cycling index
- complexity of cycles
- chain length
- average trophic levels
- residence times
- network homogenization
- network amplification
- network synergism
- utility
- trophic efficiencies
**Thermodynamic orientors: exergy**
- exergy capture
- exergy flows
- exergy consumption
- exergy degradation
- exergy storage
- specific exergy
- structural exergy

**Thermodynamic orientors: entropy**
- entropy
- minimum excess entropy
- total entropy production
- specific entropy production
- dissipation

**Thermodynamic orientors: emery and power**
- emergy
- power
- flow activity
- flux density

**Thermodynamic orientors: gradients**
- gradient emergence
- gradient degradation

**Thermodynamic orientors: distance from equilibrium**
- structure
- information
- heterogeneity
- complexity
Catalogue of questions:

- Are ecosystems dissipative systems?
- Are ecosystems self-organized systems? Try to check the principles of self-organization after Ebeling (1989)

Try to find good definitions of three thermodynamic variables:
- What is the exergy of a system/an ecosystem?
- What is the entropy production of a system/an ecosystem?
- What is emergy and where can you find it in ecosystems?

Try to apply the thermodynamic principles by comparison of the energy budgets of (a) a desert and (b) a tropical rain forest with reference to
- exergy capture
- exergy storage
- exergy degradation
- entropy production