Ecosystems: Questions, Concepts, Theories and Indicators
Outline

• Questions referring to the ecosystem approach
  - Operational guidance
  - Malawi principles

• Concepts to link theory and practice
  - Orientor theory
  - Ecosystem indicators
  - Ecosystems as parts of human-environmental systems

→ Applications will be shown by W. Windhorst
Operational guidance 1-5

- Focus on relationships and processes within ecosystems, e.g. stores and flows of energy, water, nutrients)
  - Ecosystem resilience
  - Causes of biodiversity loss
  - Determinants for management decisions

- Enhance benefit-sharing
  - Environmental security
  - Sustainability
  - Valuation of ecosystem goods and services

How to quantify?
How to treat irreversible processes?
How to conceive? How to apply?
How to quantify?
How to link to ecosystem processes?
Operational guidance 1-5

• Use adaptive management practices
  - Managing uncertainties
  - Management as a learning process
  - Flexible ecosystem management
  - Long-term orientation

• Select the appropriate scale and improve decentralization

• Ensure intersectoral cooperation

Ecosystem Approach, Salzau 2006
Guidelines and questions
The objectives of management of land, water and living resources are a matter of societal choice

- How to investigate the relevant societal preferences?
- How to realize participative approaches?
- How to translate scientific concepts into every-days-language and how to educate stakeholders?

→ Many questions for social scientists and environmental planners
Management should be decentralized to the lowest appropriate level

• How to reduce the influence of centralized and hierarchical institutional settings?
• How is this assumption correlated with the scale approach in other principles?
• How will high-level constraints be implemented?

→ Apply hierarchy theory in environmental management
Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems

- How to implement risk analysis concepts which indeed take into account indirect and de-localized effects?
- How to couple ecosystem processes with landscape dynamics?
- How to convince managers to use systems analysis approaches?

→ Link ecosystem science with landscape ecology
Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context

• How to quantify (existing and potential) ecosystem goods and services?
• How to compare environmental values with economic values?

→ Investigate the structures and functions in human-environmental systems
→ Look for innovative ecosystem based evaluation systems

Ecosystem Approach, Salzau 2006
Principle 4
Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context.
Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

- How to measure ecosystem functioning?
- How are structures and functions interrelated?
- How to evaluate ecosystem organizations of future states?
- How to indicate ecosystem services?

→ Do research on linkages between structures and functions (ecosystem organization, ecosystem theory)
→ Derive ecosystem indicators
→ Investigate ecosystem services

Ecosystem Approach, Salzau 2006
Principle 5
Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
Ecosystems must be managed within the limits of their functioning.

• Which functions have to be taken into account?
• How to quantify those limits?
• How to cope with adaptation and constraints' dynamics?

→ Search good ecosystem indicators
→ Apply those indicators and link them with functioning ecosystem models
→ Use and develop scenario techniques
Ecosystems must be managed within the limits of their functioning.

<table>
<thead>
<tr>
<th>Measured variables</th>
<th>Modelled variables</th>
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<tbody>
<tr>
<td>Precipitation</td>
<td>Interception</td>
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<td>Infiltration (m)</td>
<td>Seepage</td>
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<td>Water balance</td>
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<td>Meteorologically dominated energy flows: foodwebs</td>
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</table>

**Ecosystem Approach, Salzau 2006**

**Principle 6**
The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

- How do different scales interact?
- How to find the appropriate scales?
- How to correlate spatial and temporal features?

→ Intensify research on hierarchies and scale interactions
The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.
Recognizing the varying temporal scales and lag-effects of ecosystem processes, objectives for ecosystem management should be set for the long term.

- How to foresee the outcome of long-term processes?

→ Intensify long-term ecological research
Recognizing the varying temporal scales and lag-effects of ecosystem processes, objectives for ecosystem management should be set for the long term.
Management must recognize that change is inevitable.

• How to convince managers that stability is not the primary target any more?
• Where do we want ecosystem to develop towards?

→ Find quantitative examples for Holling's adaptive cycle
→ Improve models to cope with structural changes
Management must recognize that change is inevitable.
The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biodiversity.

- How to derive and compare ecosystem services?
- How to integrate conservation and land use (outside of preserved areas)?

→ Intensify research on ecosystem services
→ Investigate human-environmental systems
The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biodiversity.

Reindeer herding:
Recommendations for sustainable land use
RENMAN

Ecosystem Approach, Salzau 2006
Principle 10
The ecosystem approach should consider all forms of relevant information, including scientific, indigenous and local knowledge, innovations and practices.

- How to make all these forms of knowledge available?

→ Build up comprehensive information systems
The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

- How to realize this demand, e.g. in national administration?
- How to organize such a complex attempt?

→ Strengthen interdisciplinary cooperation
→ Build up interdisciplinary structures in environmental administration

Ecosystem Approach, Salzau 2006
Principle 12
• **Items to be observed:**
  Ecosystem structures - functions - organizations

• **Spatial levels to be integrated:**
  Ecosystems - ecotones - landscapes - watersheds

• **Hierarchies to be involved:**
  Scale interactions (short-long, small-large)

• **Destruction and decay to be included:**
  Management of change - ecosystem dynamics

• **Humans to be integrated:**
  Conservation - land use - services

• **Conventions to be realized:**
  Sustainability - risk - health - integrity - security

• **Strategies to be followed:**
  Interdisciplinary cooperation and participation

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Ecosystem Approach, Salzau 2006
Interim balance
What is ecosystem integrity?

Applying ecosystem concepts – a (first) case study
What is ecosystem integrity?

Political Target:
Sustainable Development
An alternative formulation for the ecological component of sustainable development:

...“Meet the needs of future generations”....

= 

Keep available the functions of nature (ecosystem services)

intergenerational (long-term)

intrigenerational (global)
Production Functions

Carrier Functions

Information Functions

Processual Provision of Services

Regulation Functions

Provision of Services

Processual Provision of Services
- Protection cosmic influences
- Regulation energy balance
- Regulation chemistry atmosphere
- Regulation chemistry ocean
- Regulation climate
- Regulation runoff & flood prevention
- Regulation groundater recharge
- Regulation waterbalance catchments
- Regulation erosion and sedimentation
- Regulation soil fertility
- Regulation biomass production
- Regulation organic matter
- Regulation nutrient budgets
- Regulation waste storage
- Regulation biological control
- Regulation habitat maintenance
- Regulation diversity maintenance
- Protection cosmic influences
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The „functions of nature“ build up the framework for the ecological focus of sustainable development.

Providing the functions of nature results in an appropriate performance of the regulation functions.
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To maintain the "functions of nature" the ability for future self-organization of ecosystems must be supported.
The "functions of nature" provide the framework for the ecological focus of sustainable development.

Providing the functions of nature results in an appropriate performance of the regulation functions.

The "functions of nature" are based upon self-organizing processes.

To maintain the "functions of nature" the ability for future self-organization of ecosystems must be supported.

Eco-target "ecological integrity": preservation against non-specific ecological risks.

Barkmann et al. 2001
How to indicate integrity?
Normative Arguments

Risk Minimization and Ecological Integrity

System-analytical Arguments

Thermodynamics, Gradient Principle and Orientor Theory
Indicators of the Capacity for Self-Organization

Normative Arguments: Risk Minimization and Ecological Integrity

System-analytical Arguments: Thermodynamics, Gradient Principle and Orientor Theory

Indicators as Orientors as Indicators

- Major Ecological Risk
- Minor Ecological Risk
- Landuse-Intensity
- Maturity
- Pioneer Stage

Natural (primary) Succession
Structural Gradients

Functional Gradients
<table>
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Structural Gradients

- Abiotic Gradients
- Biotic Gradients

Functional Gradients

- Hydrological Gradients
- Energetic Gradients
- Nutrient Gradients

- Inputs
- Outputs
- Efficiencies
- Storages
<table>
<thead>
<tr>
<th>Structural Gradients</th>
<th>Proposed Indicators:</th>
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<td>• Abiotic Gradients</td>
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<td>• Biotic Water Flows</td>
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<td>• Nutrient Gradients</td>
<td>• Entropy Export</td>
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<td>• Storage Capacity</td>
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Location of the Bornhöved Lakes District
Case study
ecosystem comparison

Examples from Barkmann et al. (2001): GAIA 10/2 and Müller (2005): Ecological Indicators 5/4
Proposed Indicators:

- Biotop Heterogeneity
- Species Abundances
- Biotic Water Flows
- Exergy Capture
- Entropy Export
- Metabolic Efficiency
- Nutrient Loss
- Storage Capacity

Baumann (2001), Barkmann et al. (2001)
Exergy Capture

Biodiversity

Abiotic Heterogeneity

Storage

Nutrient Loss $^{-1}$

Biotic Water Flows

Metabolic Efficiency $^{-1}$

Entropy Export

Capacity for Self-Organisation

Baumann et al. 2001
Exergy Capture

Entropy Export

Biodiversity

Abiotic Heterogeneity

Metabolic Efficiency $^{-1}$

Biotic Water Flows

Nutrient Loss $^{-1}$

Storage

Capacity for Self-Organisation

Maize

Field

Beech Forest

50 %

100 %

150 %
Case study
land use scenarios

Examples from Schrautzer et al. (i.p.): Ecological Studies and Müller et al. (2006): Ecological Indicators 6/1
Ecosystem types and modelled landscape units
<table>
<thead>
<tr>
<th>Indicandum</th>
<th>Indicator(s)</th>
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<tbody>
<tr>
<td>- biotic structures</td>
<td>- number of plant species</td>
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<td></td>
<td>- plant strategy types</td>
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<tr>
<td>- energy budgets</td>
<td>- net primary production (NPP)</td>
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<td>→ exergy capture</td>
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<td>- microbial soil respiration (MSR)</td>
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<td>→ entropy production</td>
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<tr>
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<td>- NPP/soil respiration</td>
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<td>- hydrological budgets</td>
<td>- evapotranspiration / transpiration</td>
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<td>→ nutrient loss</td>
<td>- nitrate leaching</td>
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<td>- denitrification</td>
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<td>- chemical budgets</td>
<td>- nitrogen balance</td>
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<td>→ storage capacity</td>
<td>- carbon balance</td>
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States of development

- Wet alder carrs, mesotrophic
  - Drained alder carrs, mesotrophic
    - Wet grasslands, weakly drained, mesotrophic
      - Wet grasslands, weakly drained, eutrophic
        - Wet grasslands, moderately drained
          - Wet grassland, intensively drained

Disturbances:
- DE: deforestation
- DR: drainage
- EU: eutrophication
- GR: grazing
- MO: mowing
- PI: ploughing

Retrogressional sequence on histosols
Ecosystem Indicators for Wet Grassland Ecosystems
(Intensively Drained Ecosystems = 100%)

- Net Primary Production
- No. of Plant Species
- Evapotranspiration / Transpiration
- NPP / Soil Respiration
- N Net Mineralization
- N Leaching
- Denitrification
- Microbial Soil Respiration
- Carbon Balance
- Nitrogen Balance
- NPP / Soil Respiration

Legend:
- Intensively Drained (ID)
- Moderately Drained (MD)
- Weakly Drained, Eutrophic (WDEU)
- Weakly Drained, Mesotrophic (WDME)
Ecosystem Indicators for Wet Grassland Ecosystems
(Intensively Drained Ecosystems = 100%)

- Net Primary Production
- No. of Plant Species
- Evapotranspiration / Transpiration
- NPP / Soil Respiration
- Nitrogen Balance
- Carbon Balance
- N Net Mineralization
- N Leaching
- Denitrification
- Microbial Soil Respiration

Legend:
- ID
- MD
- WDEU
- WDME

Hem 2, Hem 3, Hem 4

Weakly Drained, Mesotrophic
Weakly Drained, Eutrophic
Moderately Drained
Intensively Drained
Conclusions

- Ecosystem states can be indicated on a holistic level
- Ecosystem development can be depicted on the base of complex models
- Ecosystem science is ready for further applications
- Ecosystem principles provoke many questions to science and practice