Ecological Modeling and Decision Support Systems

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WS 14/15
1 The Topic

- Definition of ecology
- Concepts in ecology
- Environmental problems
- The role of IT
- The special challenges for IT
- Decision support
- The focus of the course
„Eco-Informatics“?

• Simply an application of computer science to a particular domain?
• Like bio-informatics, medicine informatics, …
• Same methods and techniques
• E.g. DB technology, simulation, image analysis, …
• Specific challenges for IT in ecology?
• → What is ecology?
• → What could be supported by IT?
Example:
Impact of Introduction of Trout in New Zealand
Example: Impact of Introduction of Trout in New Zealand

- Trout introduced to NZ rivers (1867)
- For fishing
- Compete with native fish (Galaxias)
- Both feed on invertebrates
- (sections of) rivers
  - No fish
  - Trout only
  - Galaxia only
  - Both species
- So what?
- Impact?
- Field study
**Counting Visible Invertebrates**

- **Difference**
  - hiding/visibility
  - Daytime - night

- **Different ways of locating prey**
  - Trout: visually
  - Galaxias: mechanically

**Graphs**

- Bar graph showing the number of *Nesameletus* visible in Galaxias and Trout streams during day and night.

- Bar graph showing the number of *Deleatidium* visible in different conditions: No fish, Galaxias, and Trout.
Abundance of the Fish Species

- Trout migrate upstream
- Prevented by waterfalls
- \(\rightarrow\) correlation with elevation

<table>
<thead>
<tr>
<th>SITE TYPE</th>
<th>NUMBER OF SITES</th>
<th>NUMBER OF WATERFALLS DOWNSTREAM</th>
<th>ELEVATION (m ABOVE SEA LEVEL)</th>
<th>% OF THE BED COMPOSED OF PEBBLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown trout only</td>
<td>71</td>
<td>0.42 (0.05)</td>
<td>324 (28)</td>
<td>18.9 (2.1)</td>
</tr>
<tr>
<td>Galaxias only</td>
<td>64</td>
<td>12.3 (2.05)</td>
<td>567 (29)</td>
<td>22.1 (2.8)</td>
</tr>
<tr>
<td>No fish</td>
<td>54</td>
<td>4.37 (0.64)</td>
<td>339 (31)</td>
<td>15.8 (2.3)</td>
</tr>
<tr>
<td>Trout + Galaxias</td>
<td>9</td>
<td>0.0 (0)</td>
<td>481 (53)</td>
<td>46.7 (8.5)</td>
</tr>
</tbody>
</table>
Impact on Invertebrates and Algae

- Compared to Galaxias
- Trout:
  - reduced population of invertebrates
  - Increased biomass of algae
Biomass – Production and Demand

AFDM: Ash-free Dry Mass

Production/demand (g AFDM$^{-1}$ m$^{-2}$)

- Algae
  - Production (Galaxias): 50
  - Production (Trout): 50
  - Demand (Galaxias): 50
  - Demand (Trout): 50

- Invertebrates
  - Production (Galaxias): 80
  - Production (Trout): 120
  - Demand (Galaxias): 80
  - Demand (Trout): 120

- Fish
  - Production (Galaxias): 10
  - Production (Trout): 10
  - Demand (Galaxias): 10
  - Demand (Trout): 10

Production
Demand
Further Impact?

- Potential continuation of the causal chain
- Algae feed on nitrate, ammonium, sulfate
- $\rightarrow$ Reduced concentration of nitrate, ammonium, sulfate downstream
- $\rightarrow$ … …
- Boundaries of the analysis, the model, …
Ecology: Definitions and Basic Concepts
Ecology – (One) Definition

“The scientific study of the distribution and abundance of organisms and the interactions that determine distribution and abundance” (Townsend et al. 08)

Interactions?
• at various levels
  – Individuals
  – Species
  – Physical environment
Levels of Interaction – Individual
Levels of Interaction – Population

Population

Individual
Levels of Interaction – Community

Community

Population

Individual
Levels of Interaction – Ecosystem

Ecosystem

Community

Population

Individual
Different Spatial Scales

- Global climate change
  → ocean currents
  → fish populations
- …
- Plant population in a rain forest
- …
- Inhabitants of water-filled tree holes
- …
- Bacteria in termites’ guts
## Different Temporal Scales

- Ecological succession since the Ice Age
- ...
- Migration and mating cycle of turtles
- ...
- Organisms in decomposition of sheep dung
Different Sciences and Knowledge Sources

- Biology
- Chemistry
- Physics
- Geophysics
- Hydrology
- ...

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For Instance, Trout Field Study – Aspects

- Levels to be considered?
- Spatial aspects?
- Temporal aspects?
- Disciplines involved?
Ecology: Tasks and Goals
Ecology – Goals?

“The scientific study of the distribution and abundance of organisms and the interactions that determine distribution and abundance” (Townsend et al. 08)

- Description …
- … only?
- Understanding …
- … only?
- Prediction
- … only?

Diagram:

1. Describe
2. Explain
3. Predict

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Understand in Order to Influence

Motivation:
- Limit bad impact of human activity
- Secure continued exploitation
- “Environmental problems”

Ref.: Townsend et al., Essentials of Ecology
Example:
Degradation of Mangroves in India
Optimism - „We will preserve local flora and fauna“

• „In this area the Forest Department of the Pichavaram Mangroves has started management activities in 1995 in order to preserve the local flora and fauna.“
Meanwhile, Upstream ...

Dams in Cauvery River

- Reduction of Sediments in the River
  - Less Deposition in River Delta
    - Trough-shaped Basin
      - Stagnant Water
        - Increased Salinity
          - Degradation of Mangroves
            - Reduced Shelter Against Cyclones, Tsunamis
“Side-effects” ...

- Increased Salinity
- Evaporation
- Trough-shaped Basin
- Less Deposition in River Delta
- Stagnant Water

- Degradation of Mangroves
- Cyclones
- Dams in Cauvery River
- Reduction of Sediments in the River

“Environment”

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Humans and “Environment”
“Environment”??...

- Limit bad impact of human activity
- Secure continued exploitation
- “Environmental problems”
- → Problems of human activity, economy, health, …
- Welt → Umwelt!!
- Anthropocentric perspective

“Environment”
Anthropocentric Perspective
“Side-effects” ...

- Increased Salinity
- Evaporation
- Trough-shaped Basin
- Less Deposition in River Delta
- Stagnant Water
- Reduction of Sediments in the River
- Degradation of Mangroves
- Cyclones

Dams in Cauvery River

Increased Salinity

Evaporation

Trough-shaped Basin

Less Deposition in River Delta

Stagnant Water

Reduction of Sediments in the River

Degradation of Mangroves

Cyclones

Dams in Cauvery River

Increased Salinity
Understand!

- The complex interactions of organisms and natural phenomena and systems
- **Human** activities as additional influences in this network of interactions
Causal Chains – Distant and Paradox Effects

- Building dams $\rightarrow$ more tsunami victims
- Introduce trout $\rightarrow$ more algae
- Extinguish forest fires $\rightarrow$ more trees and homes destroyed by fire
- Extinguish fires in Sequoia forest $\rightarrow$ Sequoias become extinct
- Treat cattle with Diclophenac $\rightarrow$ more diseases of people and difficult burial of dead Parsis
- …
Exercise
Design a semi-formal or diagrammatic representation that describes and explains the impact of introduction of trout in NZ

- Intuitively
- Mainly non-verbal
- May combine different forms of representation
- There is no unique solution!
- There is no “wrong” form of representation!
Challenges for IT
How Can IT Help?

Extended view
- Basis: observation, data
- Planning Experiments/Field Studies

- Observe
- Describe
- Explain
- Plan Obs.
- Manage, Control
- Predict
How Can IT Help? - 1

- Observe
- Describe
- Explain
- Manage, Control
- Predict
- Plan Obs.
IT Support: Collecting Data

- (Remote) sensing
- E.g. satellite data
- Importance of spatial aspects
- Problem: volume of spatial data
- Possible problem: covering long-time ranges
IT Support: Storing and Retrieving Data

- Data base technology
- Challenge: spatial representation
- Geographical information systems (GIS)
- Problem: Integration of different DBs
IT Support: Analyzing and Interpreting Data

- Statistical analysis
- Image processing and analysis
- E.g. vegetation coverage from satellite data
- Challenges
  - Huge volume of data
  - Grasping the meaning of data
  - Image understanding
How Can IT Help? - 3

Observe → Describe → Explain

Plan Obs. ← Predict ← Manage, Control

Describe → Predict
IT Support: Prediction

- Numerical models and simulation
- Challenges:
  - Many interactions
  - Many different aspects (→ partial models)
  - Non-numerical data, information, knowledge
  - Conceptual modeling
  - E.g. causality, explanation, causal understanding
  - Model boundaries
  - Characterize scope of a model (assumptions)
  - Support model development
  - ...

→ Modeling as Knowledge Representation
How Can IT Help? - 4

Observe -> Describe -> Explain

Plan Obs. <- Manage, Control -> Predict

Describe

Manage, Control

Observe
IT Support: Drawing Conclusions and Taking Decisions

- Environmental decision support systems
- Challenges:
  - Automated problem solving
  - Many different aspects
  - Integrating ecological knowledge with social, economic, political aspects

→ Automated Reasoning
Current Support through IT

- Mainly data processing
- Numerical simulation
- Weak for knowledge processing and problem solving
The Role of Information Technology

Environmental/Ecological System

Data Acquisition
Remote Sensing

DB, GIS

Data Analysis, Simulation

Data

Analysis Selection Interpretation Modeling Problem Solving

(Numerical) Model

Conceptual Model

Acting
The Challenge for Knowledge Representation and Reasoning

Environmental/Ecological System

Data Processing

Model-based Systems

Analysis  Selection  Interpretation  Modeling  Problem Solving

Conceptual Model

Acting
Current Support through IT

- Mainly data processing
- Numerical simulation
- Weak for knowledge processing and problem solving

- Observe
- Describe
- Explain
- Plan Obs.
- Manage, Control
- Predict
Focus of the Lecture: the Weak Parts

- (Conceptual) modeling and prediction
- Knowledge-based decision support and automated problem solving
- Areas with eco-specific challenges to IT

Diagram:

- Observe
- Describe
- Explain
- Plan Obs.
- Manage, Control
- Predict
Challenges for IT in Ecology

- Support deeper understanding
  - Support modeling process
  - Represent essential concepts
  - E.g. population, predation, migration, …
- Provide common ontology for modeling
- (Causal) explanation, education
- Automated reasoning
- Knowledge-based decision support
Example:
Decision Support for Drinking Water Treatment
An Example from the Water Treatment Domain

Metallic taste of drinking water

- The "metallic taste" is the human perception of iron in the water
- Transported by pumping and ascending in the reservoir
- Ultimately: dissolved from the sediment
- Precondition: acidic conditions

![Diagram of water treatment process](image)
Metallic taste of drinking water

- The "metallic taste" is the human perception of iron in the water
- Transported by pumping and ascending in the reservoir
- Ultimately: dissolved from the sediment
- Precondition: acidic conditions

Observation: "metallic taste"
Goal: Find Potential Remedies Automatically

Observation: "metallic taste"

Sediment

Iron

Epilimnion

Hypolimnion

Tank

Drinking Water

Oxidation

OxidationAgent

Reduce iron concentration

Iron

transport

Pump

perception

"metallic taste"

Iron

ascending

redissolving

pH = -
Benefits Expected from Use of IT
Supporting Experts

- Developing models
- Analysis, interpretation of observations
- Transfer of results
- Exchanging and reusing models
Supporting Non-Experts

- Understanding, explanations
- Analysis, interpretation of observations
- Proposal and assessment of actions
The Vision: Research and Decision Making

Decision Making

Research

Social, political, economic … models

Biological, chemical, hydrological … models
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Outline

1 The topic
2 Environmental decision-support systems
   2.1 Conceptualization
3 Modeling
2 Environmental decision-support systems
   2.2 Realization
4 Application issues and challenges
Organizational Issues

- 3 credits
  - Informatics
  - Architecture (Advanced Construction and Building Technology)
- Slides for download (pdf)
- http://mqm.in.tum.de/teaching/EMDS/Material.php
- In advance (usually …)
- Slides not self-contained!
- Basis for taking notes
- Script (after presentation)
- Don’t try exams without attendance!
- Contact: Mehdi, Gulnar <gulnar.mehdi@tum.de>
- Exams?
- Two periods: Oct. 20 – Nov.5, Jan. 14 – Jan 28