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Faculty of Forest, Geo and Hydrosciences Institute of Hydrobiology

Integrated Water Resources Management

Limnological Systems Understanding and Modelling Case Studies

Thomas Petzoldt

Outline

1. Pre-requisites
2. Multiple uses and multiple stressors
3. Management options
4. Ecological modelling
5. Case studies
6. Conclusions

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1. Pre-Requisites

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Pre-requisites

… according to the module description (MWW 16)

Grundlagen in Hydrologie, Meteorologie, Grundwasserwirtschaft, Siedlungswasserwirtschaft, Systemanalyse.

i.e.:

Hydrology, Meteorology, Groundwater management, Urban water management, Systems analysis.

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Limnology, an important fundamental of IWRM

Most of you will have fundamental knowledge in Limnology (from a course in Hydrobiology, Applied Limnology or Aquatic Ecology).

Why is this important?

- Ecological Systems are highly complex.
- We can only manage environmental systems, if we understand how they function.

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Missing pre-requisisites?

I fear that a couple of you still miss some of these required fundamentals, so please consider this lecture as a motivation, why hydrological and ecological process understanding is required and to seek for possibilities to fill the gaps.

Limnology vs. **Hydrobiology**

- Ecology of aquatic systems
  - Freshwater (lakes, reservoirs, rivers, groundwater, wetlands)
  - Marine systems (Ocean, Estuaries)
  - Technical systems (e.g. wastewater treatment plants)
- Organisms and their relationships to the environment
  - Systematics and Autecology (→ single species)
  - Systems ecology (interaction between species and between species and environment)
- Ecological functioning of aquatic systems
  - Matter turnover
  - Anthropogenic stressors
  - Bio-indication

Limnology vs. Hydrobiology

- Science (or ecology) of inland waters
  - Covers biological, chemical, physical, geological, and other attributes of all inland waters
- On one side more limited than „Hydrobiology"
  - Only inland waters (fresh and salty, rivers, lakes, ground water)
  - Less focus on the „pure biological" aspects
- On the other hand more general than „Hydrobiology"
  - Covers also geochemical, limnophysical … hydrological phenomena

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2. Multiple uses and multiple stressors

Multiple use of aquatic systems

Transportation (of water and substances)

Water supply (drinking, agriculture, industry)

Fertilization (→ flood plains)

Fishery and aqua culture

Recreation (swimming, boating, fishing … and simply enjoing nature)

Self-purification

Maintainance of bio-diversity

Flood protection

Energy conversion and storage

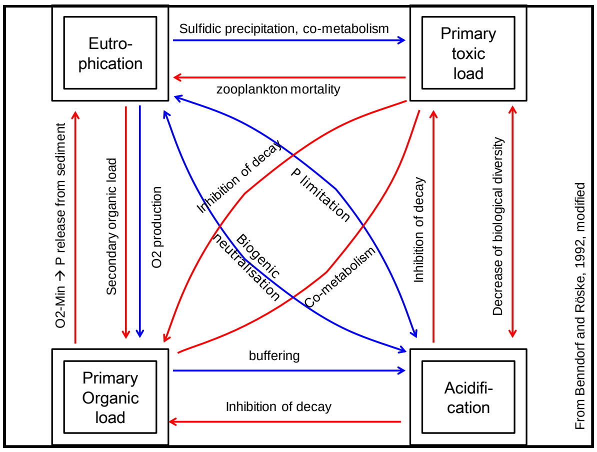
… and more

Anthropogenic Stressors for Aquatic Ecosystems

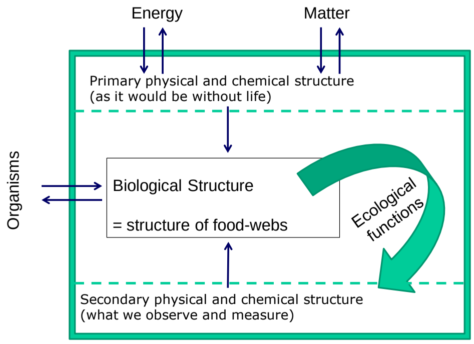
Physical
- Change of morphometric structure
- Change of hydrological regime (e.g. water withdrawal)
- Change of water temperature (e.g. powerplant cooling)
- Emission of radioactive radiation

Chemical
- Primary organic pollution (BOD)
- Eutrophication (N, P)
- Toxic substances (including pharmaceuticals)
- Acidification

Biological
- Pathogenic organisms (viruses, bacteria, protozoa, … higher animals)
- Invasive species (neobiota, neophyta, neozoa)
- Genetic information (antibiotica resistant bacteria, GMOs =genetically modified organisms)



Ecosystem functions influence system structure



From Benndorf and Röske, 1992, modified

Ecological function → structure (Examples)

Water plants change flow regime of rivers.

Beavers build dams

Algae change ogygen content of water

→ Photosynthesis, Respiration

Algae change water clarity and influence thermal stratification in lakes

… and many more

Ecosystem Response to Stressors I

Buffering
- A system is tolerant against a stressor up to a certain level

Non-linearity
- The response of the system depends non-linearly on the magnitude of a stressor.

Interaction Effects:
- antagonism, synergism
- additivity
- potentiation, inhibition

- effect of 2 or more stressors ≠ sum of their single effects

Interactions can occur between different chemicals (= mixtures) and between different types of stressors (high T + high BOD → low O_2)

Ecosystem Response to Stressors II

Time Delay
- A system reacts later, because re-structuring needs time

Timing
- The effect depends on the time of application of a stressor
  - Seasonality
    - Phosphorus has more effect in summer than in winter
  - Dependence on former state
    - Blue-green algae can develop faster and develop more intense blooms when resting stages are already available

Multiple stable states
- A system can switch between several states (with hysteresis)

Interactions (Example)

Resulting effect stronger (or weaker!) than sum of all single effects.

P-load for biomanipulation

very low:	biomanipulation useless
medium:	effective biomanipulation
above threshold (BEThP):	ineffective biomanipulation

More examples:

Nitrate can be an antagonist to internal P-loading in lowland reservoirs
→ effluent management for treatment plants?
Light absorbing substances as an antagonist to phosphorus
→ reduce P first before reducing slowly degradable DOC
Organic matrices can inhibit toxic substances
→ but be careful about transport processes
Organic matter as measure against acidification of mining lakes

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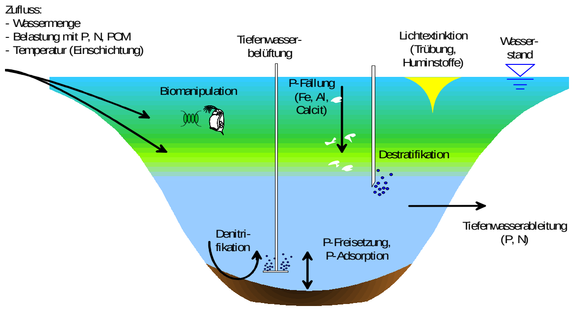
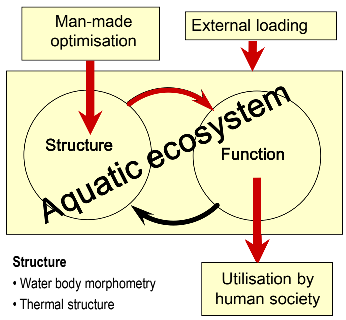
3. Management options

Lake Restoration

See also:

Merkblatt DWA-M 606
Grundlagen und Maßnahmen der Seentherapie, 2006.





Functions
- Hydraulic processes (e.g. mixing)
- Energy transformation
- Abiotic conversion of matter
- Production of organic matter
- O_2-production
- Decomposition of organic matter
- Biofiltration

Structure
- Water body morphometry
- Thermal structure
- Basic chemism of water
- Xenobiotics
- Food webs and biodiversity

Modified after Benndorf, 2008

Management Options

External Measures

➔ Eliminate stressors (or reduce their magnitude)

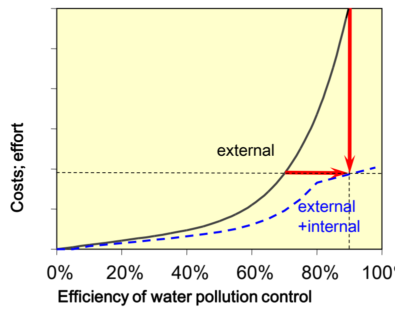
- Examples:
  - Reduce P and N emission
  - Reduce emission

Internal Measures (➔ Ecotechnology)

➔ Adapt internal structure of the system to compensate for stressors.

- Retain morphological structure of rivers:
  - Wetlands are able to elimninate N and P
  - Biomanipulation in Lakes enhances water clarity

Ecotechnology cannot compensate alone for high load, but helps to improve effectivity of external measures.



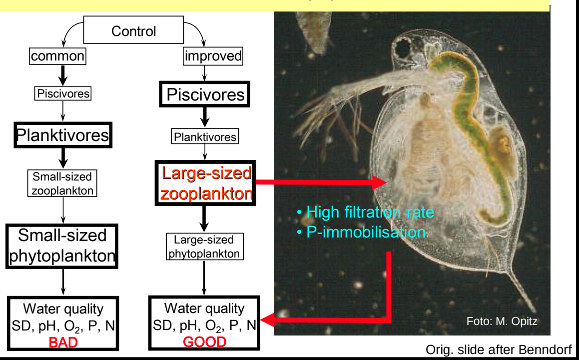
The combination of external („classical") and internal („ecotechnological") measures enables higher efficiency in water pollution control

➔ High environmental standards remain affordable

Modified after Benndorf, 2008

Ecotechnology in lakes and reservoirs: An example

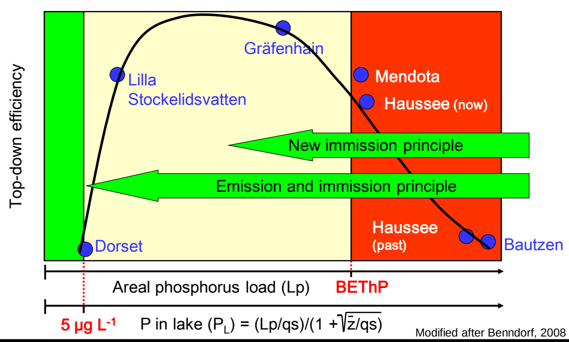
High efficiency due to top-down controlled enhancement of key species



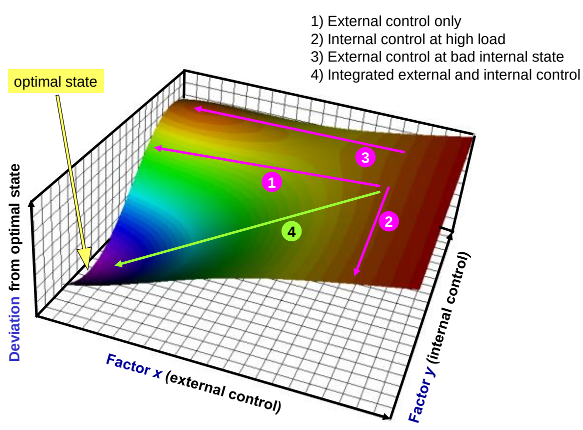
Orig. slide after Benndorf

Eutrophication Control

The Biomanipulation Example



Modified after Benndorf, 2008



Arghhh, this is sooo complex, what can I do???

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4. Ecological modelling

Why Ecological modelling (model purpose)

Systems understanding
experiment with stressors and or management alternatives without risk to real system

Budgeting
Nutrients, sources, sinks, turnover

Indirect Method
Estimation of quantitys that are difficult to measure

Interpolation and Extrapolation
What happened between the mesurements?
Spatial interpolation (→ GIS)

Forecast and projection
e.g. consequences of climate change

Processes and systems covered within ecological models

- Models for laboratory systems and „pure theory"
- Ground water, rivers, lakes, reservoirs, treatment plants, …

Matter import and transformation, ecological consequences

Requires sub-models from other disciplines:

Hydrophysics and hydrology
→flow, stratification

Chemistry
→ Decay of organic pollutants and toxic substances, redox processes and adsorption at the sediment

Biology
→ wax and wane of organisms, physiology, population dynamics, predator-prey interaction, adaption and evolution

Different levels of complexity

Predator-prey
Streeter-Phelps
River basin model
Algal growth
Fish bioenergetics
Lake model SALMO

Minimal model for an idea	Minimal model for a system (process model)	Coupled model for a system (synthetic model)
Demonstrate Hypothesis under idealised conditions	Interaction between the most important processes and state variables	Combination of results of different authors
Can often not be validated against reality	Demonstartion of consequences of assumptions	Knowledge base, Consistency check? identify knowledge gaps.
Important for theory building	Test of hypotheses	Scenarios and alternatives

In short ...

Process models | **Ecosystem models**

Why?
- Systems understanding
- Test of hypotheses

- Knowledge base
- Decision support

Examples:
- Lotka-Volterra-Model
- Sub-model N turnover

- Water quality models
- Global Change

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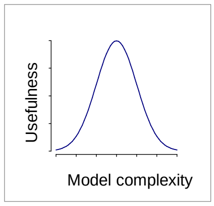
1. Maximum possible simplicity
   - Models are simplified images of reality
2. Maximum required complexity
   - How do processes interact?

Everything should be made as simple as possible, but not simpler. (A. Einstein)

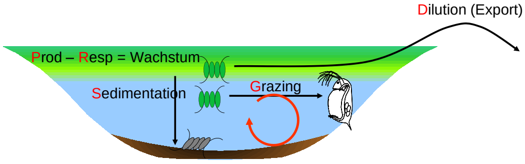
3. General validity
   - A good model should be valid for a complete class of systems
4. Proper validation
   - In the laboratory and the field
   - At the process level!!!

... and not only calibration of the outcome.

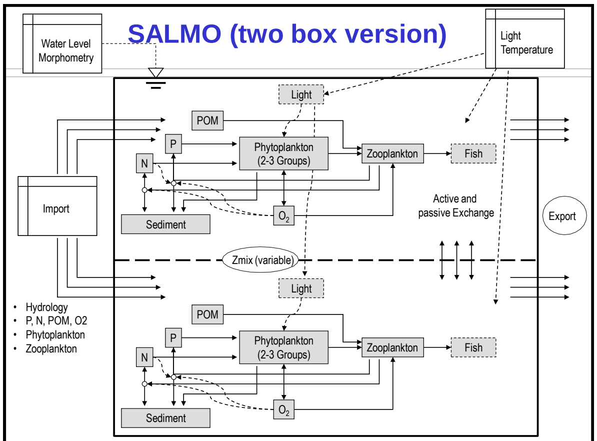


Mass balance equation of phytoplankton

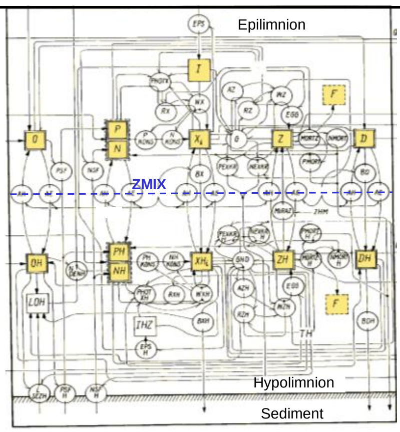
$$\frac{dX}{dt} = (P - R) - S - G - D$$



SALMO (two box version)



Modell SALMO



From: Benndorf *et al.* 1985

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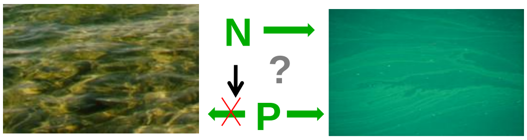
5. Case studies

Direct or indirect effect of nitrogen?



Quitzdorf Reservoir

$V = 22{,}0\ \mathrm{Mio\ m^3}$

$A = 748\ \mathrm{ha}$

$z_{max} = 8{,}1\ \mathrm{m}$

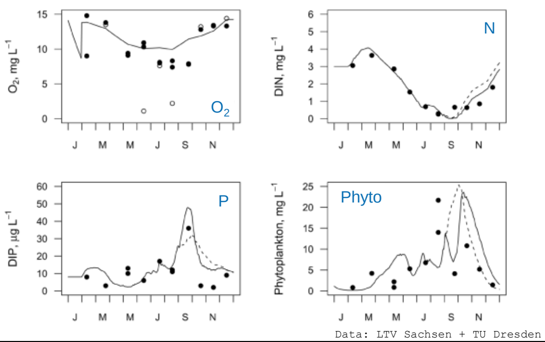
$\bar{z} = 2{,}9\ \mathrm{m}$

$\bar{t} = 190\ \mathrm{d}$

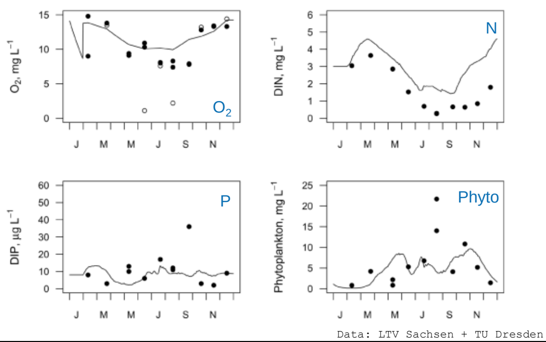
- Mostly unstratified
- Hyper-eutrophic

Case study: Petzoldt and Uhlmann (2006) Acta hydrochim. et. hydrobiol.
Data: LTV Sachsen and TU Dresden

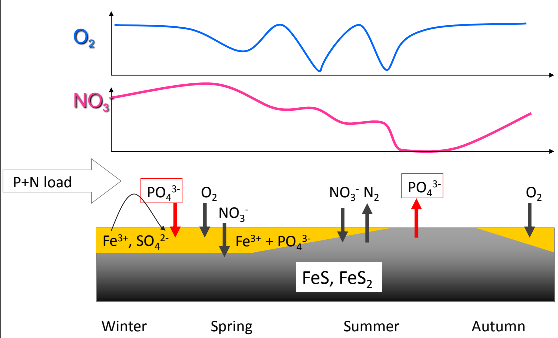
Quitzdorf reservoir: actual state



Quitzdorf reservoir: higher N load (scenario)

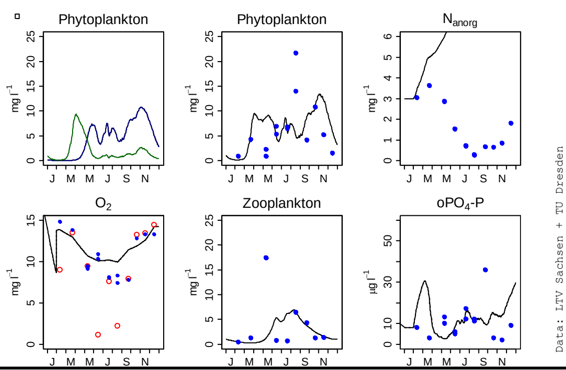


Sediments work as temporary P storage



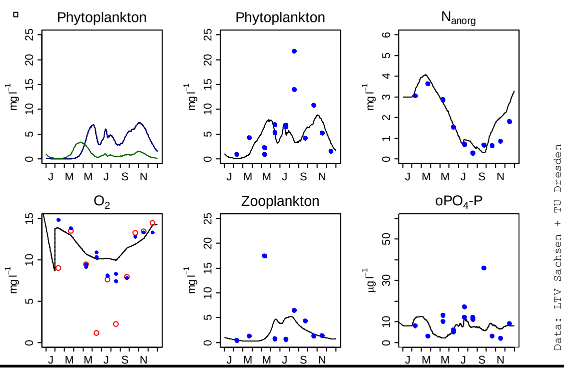
Modified after Petzoldt and Uhlmann, 2006

Standard simulation like for a „deep" reservoir



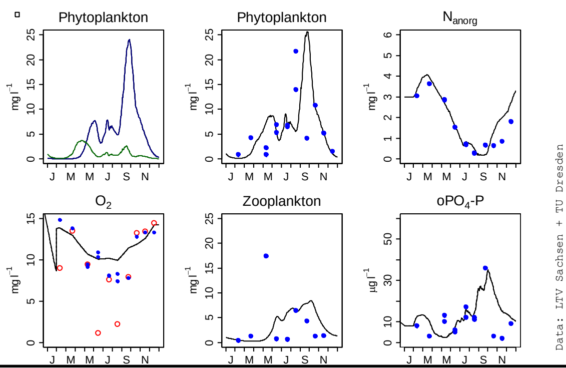
Re-parametrisation of sediment equations

Based on measurements and data → P-Adsorption, Denitrifikation



Additional sediment-related processes

Denitrifikation, N-dependend P-release in Summer



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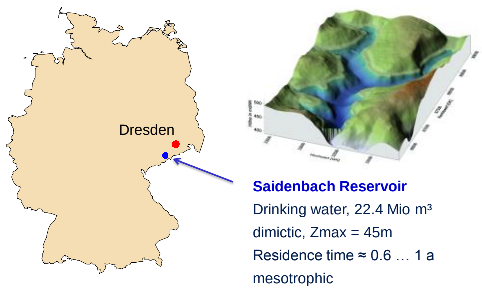
Fakultät für Forst-, Geo- und Hydrowissenschaften Institut für Hydrobiologie + Ökologische Station Neunzehnhain

Climate change and
lake ecosystems
–
can dynamic models help us
to disentangle factors?

Thomas Petzoldt

32 Years of Observation Data***

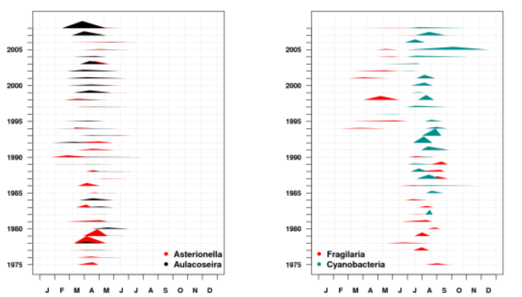


Saidenbach Reservoir
Drinking water, 22.4 Mio m³
dimictic, Zmax = 45m
Residence time ≈ 0.6 … 1 a
mesotrophic

*** Data: Ecological Station 19hain + TU Dresden + Reservoir Authority

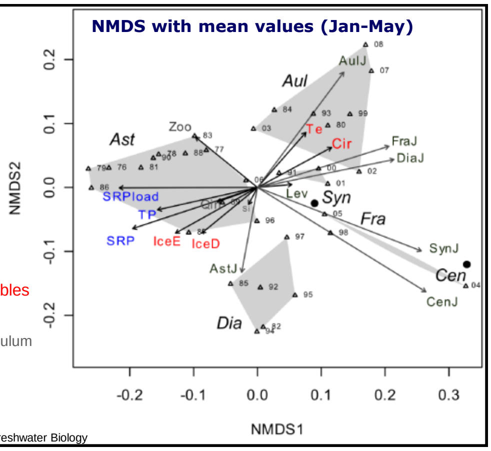
Changed dominance patterns as result of climate change?

Spring: *Asterionella* → *Aulacoseira*   Summer: *Fragilaria* → *Cyanobacteria*



Data: Horn, Horn and Paul, Ecological Station 19hain
Peak detection software: http://r-forge.r-project.org/projects/cardidates Rolinski *et al.* (2007) Oecologia

NMDS with mean values (Jan-May)



Phosphorus
Climate Variables
Other:
- January-Inoculum
- Zooplankton
- …

Horn et al. 2011, Freshwater Biology

Multivariate statistics is useful, but …

trophic state and climate variables are correlated.

statistics does not tell us how it works.

- dynamical behavior?
- causal relationships?

➔Application of a Complex Dynamic Model

The coupled model

SALMO-HR

Climate Simulation Data (IPCC-B2) (regional model REMO, MPI for Meteorology HH)

Mesoscale meteorological simulations for Saidenbach Region METRAS, MM5 (Project Partner METCON Bigalke)

Regionalized hourly data
– air temperature, global radiation,
– humidity, wind velocity & direction

Lake Morphometry and simulation parameters

Hydrology & Nutrients
– 4 tributaries, overflow spillway, bottom and raw water outlets
– P, N, POM, conductivity, temperature
– [DOM, Particles]

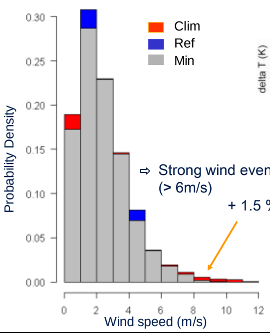
SALMO-HR

LAKE thermo-hydrodynamic model, 1D, k-e
Baumert et al, 2005

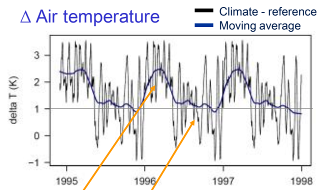
SALMO-1D >=3 phytoplankton groups, N, P, O_2, zooplankton, POM, DOM, Particles

Climate Variables in the Simulation Period

Wind speed



Δ Air temperature



Winter	Summer
2.5 K	1 K

And:
- global irradiation: +2%
- humidity + 2.4%
- empirical ice-cover model

Scenario definition

Scenario 1: Reference
- Measurements + Reanalysis data for 1995...1997

Scenario 2: Climate Change following IPCC-B2
- IPCC = Intergovernmental Panel on Climate Change (regional model REMO, MPI for Meteorology HH)
- 'most probable forecast' for 2040...2049
- on this basis:

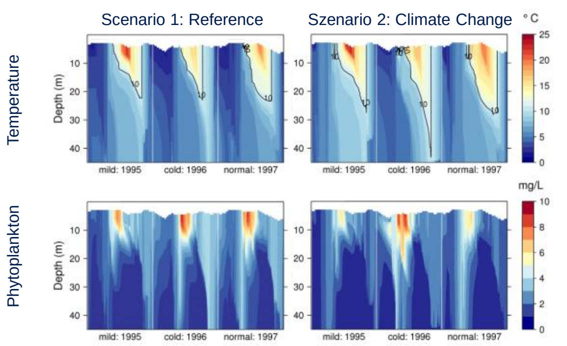
▷ temperature of tributaries +1K (assumption)
▷ mesoscale simulation for Saidenbach Reservoir region (project partner METCON, Klaus Bigalke)
air temperature, humidity, global radiation, wind field

Scenario 3: Tributaries

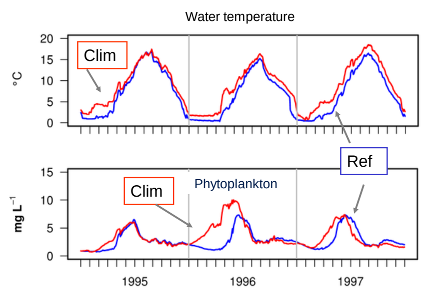
Scenario 4: Temperature
- Modification of temperature, global radiation, humidity ONLY

Scenario 5: Wind
- Modification of wind velocity and direction ONLY

Results

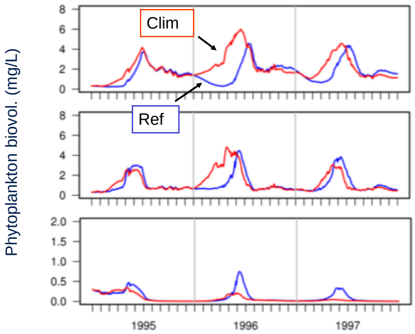


Mean Temperature and Phytoplankton in the top 10m-Layer



- 1995, warm winter (wcw) → only small change of phytoplankton
- 1996, cold winter (ccc) → increase of phytoplankton
- 1997, average winter (wcc) → time shift

Species shift in Spring



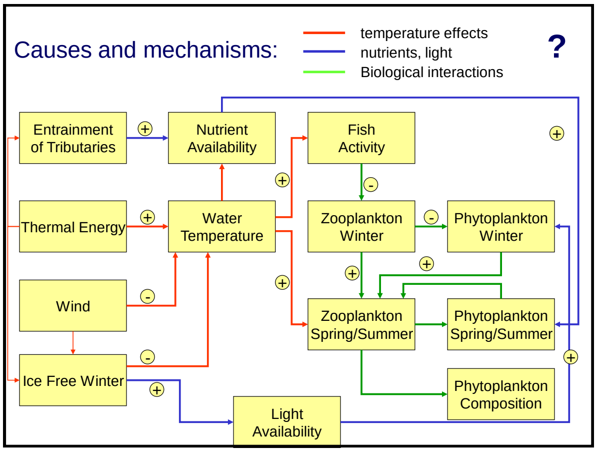
non-eadible
(e.g. Cyanobacteria)

average-size,
(e.g. Asterionella)

small
eadible
(e.g. Chlorella,
Cyclotella)

➔ Winter is sensitive period; strongest effect when heating cold years

Causes and mechanisms:



Summary: Climate change and lakes –

Dynamic models can help us to disentangle factors

If we confront model patterns with data,
reality is much more complex than simulations,
but models help:

- to increase systems understanding and
- to ask the right questions:

- Winter is sensitive phase,
- Importance of inoculum,
- Entrainment and stratification stability in summer.

Note: Several slides had to be removed from this presentation, because the underlying work is not yet published. The details will appear in the PhD thesis of René Sachse and in several international publications.

In summary:

- Cyanobacteria are more frequent in warm years.
- The most probable reason for this is increased stratification stability, i.e. less mixing of the water column.
- While diatoms are relatively heavy and settle down, cyanobacteria are able to float.

6. Conclusions

Integrated Management

Success of management depends critically
on the understanding of the internal mechanisms

Inflexible external management
ignores internal mechanisms and can be counterproductive.
(zero effect or negative side effects)

Integrated management
= external management + internal management
= joint adjustment of external and internal measures
= goal oriented (desired state of environmental systems)

Ecological models of aquatic systems

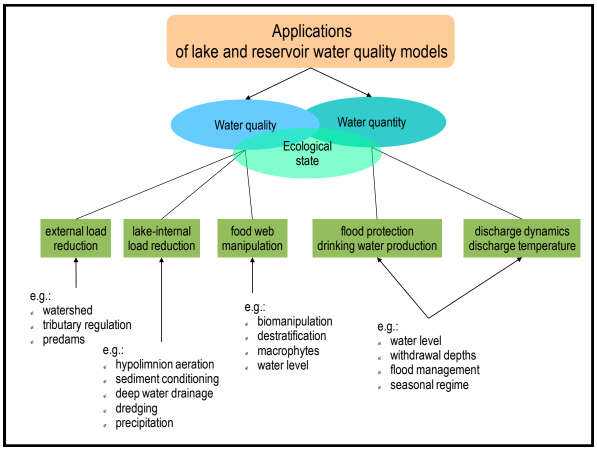
- Qualitative reproduction of patterns and „trends"
- Extremely helpful for systems understanding
- Comparison of scenarios

But (for most real systems):

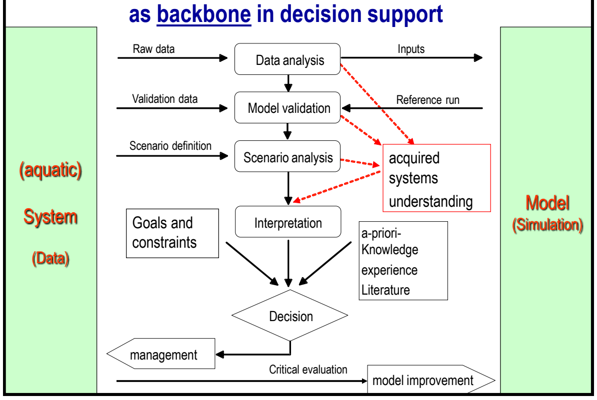
Ecological models not yet precise enough for quantitative forecasts, because of deficits in data, process knowledge and natural variability

➔ Decisions should be based on a combination of model analyses and expert judgment with sound systems understanding.

And: More research needed at the process level.



Ecological models
as backbone in decision support



Thanks to …

- PhD student: René Sachse
- Former workgroup members: Karsten Rinke, Marie König, Susanne Rolinski
- Hydrophysical model: by Helmut Baumert (IAMARIS, Hamburg)
- Data: Heidi Horn, Wolfgang Horn, Lothar Paul (Ecological Station Neunzehnhain)

- Diploma Students: Sylvia Michel, Anselm Rossi
- Projekt Partners: LTV, SAW, HYDROMOD, IAMARIS, METCON
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References

Benndorf, J. und Röske, I.: Gewässerschutz. In: Autorenkollektiv: Planung, Gestaltung und Schutz der Umwelt, Band II, S. 504-590. Eigenverlag EIPOS Dresden, 1992.

Benndorf, J. (2008): Ecotechnology and emission control: alternative or mutually promoting strategies in water resources management? International Review of Hydrobiology 93: 466-478.

Horn, H., Paul, L., Horn, W. & Petzoldt, T. (2011): Long-term trends in the diatom composition of the spring bloom of a German reservoir: is Aulacoseira subarctica favoured by warm winters? Freshwat. Biol. 56: 2483-2499.

Petzoldt, T. & Siemens, K. (2002): Nutzung eines ökologischen Simulationsmodells im Entscheidungsfindungsprozess: Anwendung des Modells SALMO auf die Talsperre Bautzen. Wasser und Boden 54(9), 42-48.

Petzoldt, T. & Uhlmann, D. (2006): Nitrogen emissions into freshwater ecosystems: Is there a need for nitrate elimination in all wastewater treatment plants? Acta Hydrochimica et Hydrobiologica 34: 305-324.