The Theoretical Foundation of Environmental Decision Support and its Application to River Management

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Environmental Decision Support

Goal of Environmental Decision Support:

Help decision makers to use the best available scientific knowledge to find management strategies that achieve societal preferences to the degree possible

Questions:

- How to represent and acquire the «best available scientific knowledge»?
- How to represent and quantify «societal preferences»?
- How to find good management strategies?
- How to synthesize this knowledge?
- How to transfer these concepts to practice?

Contents

1. Representation and Acquisition of Scientific Knowledge

The philosophy of science distinguishes two kinds of probabilities:

- **Objective probabilities** describe features of the real world that are independent of humans

- **Epistemic probabilities** are used to quantify human knowledge or beliefs

Objective probabilities:	**frequentist** (von Mises) **propensity** (Popper)
Epistemic probabilities:	**logical** (Keynes) **subjective** (Ramsey, de Finetti) **intersubjective** (Gillies)

[There are also non-probabilistic representations of (epistemic) knowledge]

1. Representation and Acquisition of Scientific Knowledge

Reasons for describing (inter-)subjective beliefs by probabilities:

•Operationalization of beliefs with indifference between lotteries and requiring **avoiding sure loss** (de Finetti)

•Requirements on **conditional beliefs** (Cox)

•Requirements on **scoring rules** (Lindley)

•**Degenerate to obj. prob.** for decreasing epistemic uncertainty

•**Consistent updating mechanism** (Bayesian inference)

Intersubjective probabilities:

•Gillies (1991, 2000) extended the argument of avoiding sure loss to groups sharing a common interest in **stating a joint probability**

•We further extend this to **probabilities aggregated from individual expert's beliefs** (experts as «measurement devices»)
[more experts allow for a more accurate determination of the state of knowledge]

1. Representation and Acquisition of Scientific Knowledge

Consideration of ambiguity by imprecision:

•Convincing arguments for ideally describing intersubjective beliefs by probabilities

•Problem of ambiguity and of acquiring such beliefs precisely

→ Use sets of probability distributions instead of a single distribution:
Use imprecise probabilities to characterize intersubjectively the state of knowledge of the scientific community

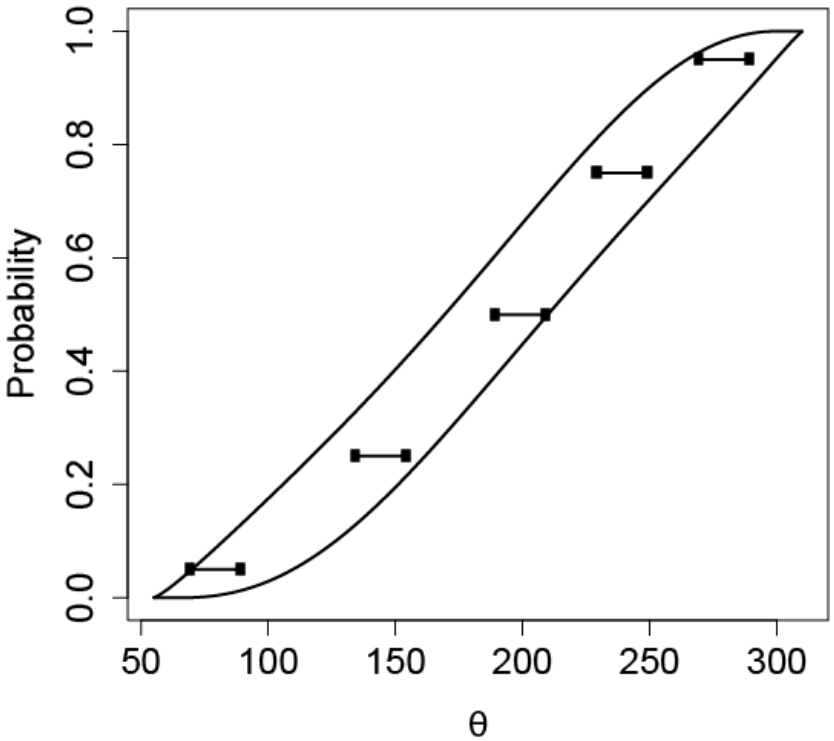
Alternative theories:

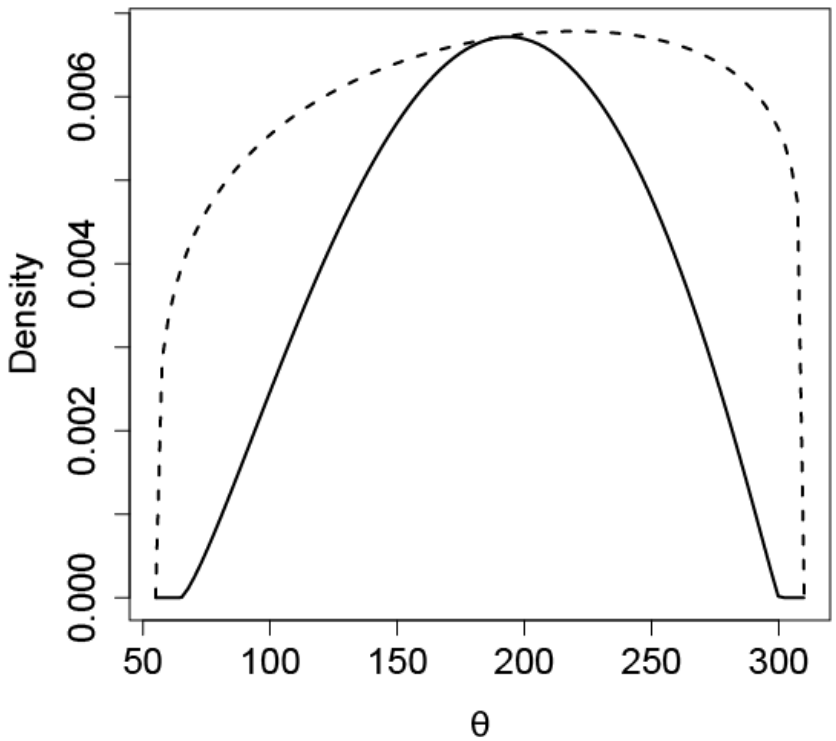
•Possibility theory and evidence theory have a weaker conceptual basis; interval analysis is too conservative

•The main point of critique of probabilities is taken into account by the extension to imprecise probabilities

1. Representation and Acquisition of Scientific Knowledge

Example of an imprecise probability defined as a density ratio class





Rinderknecht et al. 2011

1. Representation and Acquisition of Scientific Knowledge

Which knowledge to acquire?

In environmental decision support, **we need probabilistic predictions of the outcomes of all management alternatives under all scenarios** of driving forces that have to be taken into account

Two options:

a)Elicit conditional probabilities of the outcomes for all management alternatives and driving force scenarios separately

b)Elicit the structure and parameter values of a mechanistic model that predicts the outcomes based on management alternatives and scenarios as an input

The approach b) is more universal and thus more suitable for generic cases for which model development is worth doing;
a) is easier and compatible with traditional expert advice

[but we ask for predictions, not for recommendations].

2. Formulation and Elicitation of Preferences

Need for decision theories:

1.Decision support

Rules for structuring a decision process and to account for predicted outcomes and preferences in a «rational» way that can be accepted by involved persons and can **support negotiation, communication, justification of the reasons for a decision**.

2.Predictive social modelling

Predict individual, group or societal behaviour

→ We concentrate on 1. The conclusions would be different for 2.

2. Formulation and Elicitation of Preferences

Under very weak assumptions (completeness, transitivity), preferences for given outcomes can be represented by a «**value function**» that has higher value for preferred outcomes.

A «measurable value function» quantifies the degree of fulfillment of an objective on a continuous scale from 0 to 1.

Under somewhat more restrictive assumptions, risk attitudes for probabilistic outcomes can be considered by a «**utility function**» that has higher expected values for preferred outcomes.

Value and utility functions are constructed by **asking decision makers about preferences of outcomes or of lotteries of outcomes**.

Alternative theories lack a similarly good basis and lead to inconsistent results, such as rank reversals.

2. Formulation and Elicitation of Preferences

Elicitation of preferences is done in two steps:

1.a) Iteratively breaking down the overall objective into an **objective hierarchy** of increasing degree of concreteness

b) identification of (measurable) **attributes** that can be used to quantify the degree of fulfillment of the lowest level sub-objectives

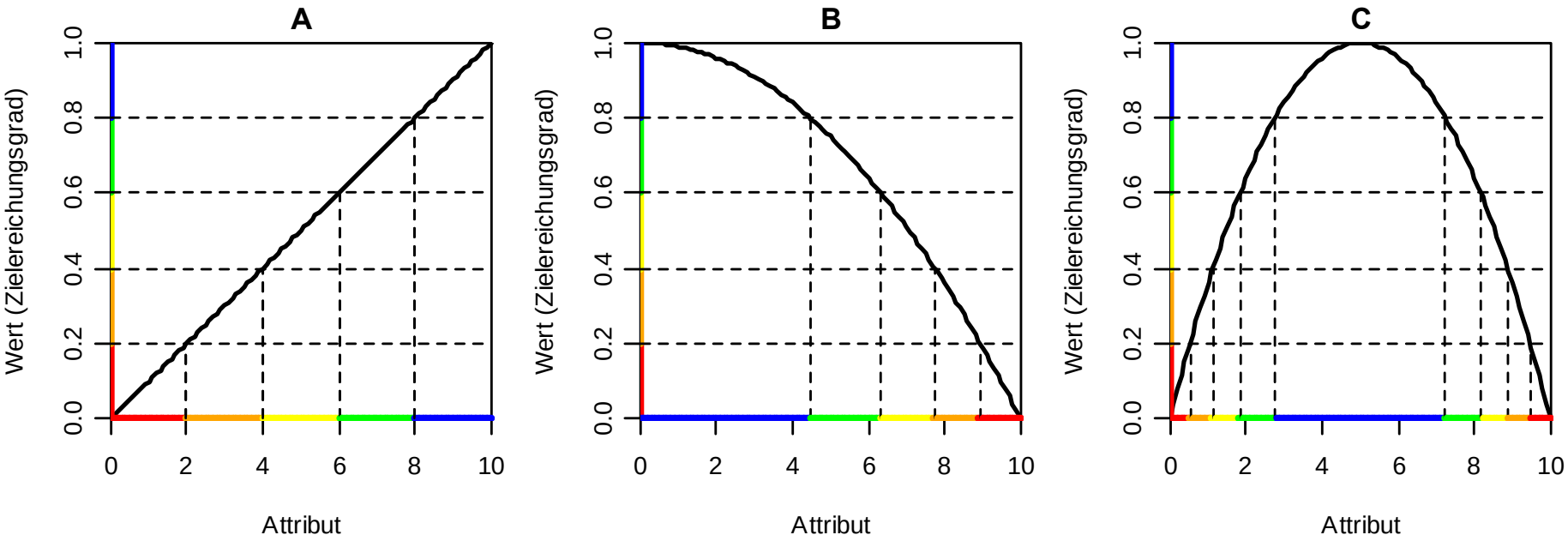
2.a) Quantifying the degree of the lowest level sub-objectives by a **value function** of the corresponding attributes;

b) aggregating these values at higher levels of the objective hierarchy;

c) transforming the overall value into a **utility** by considering the risk attitude of the decision maker (or stakeholder)

2. Formulation and Elicitation of Preferences

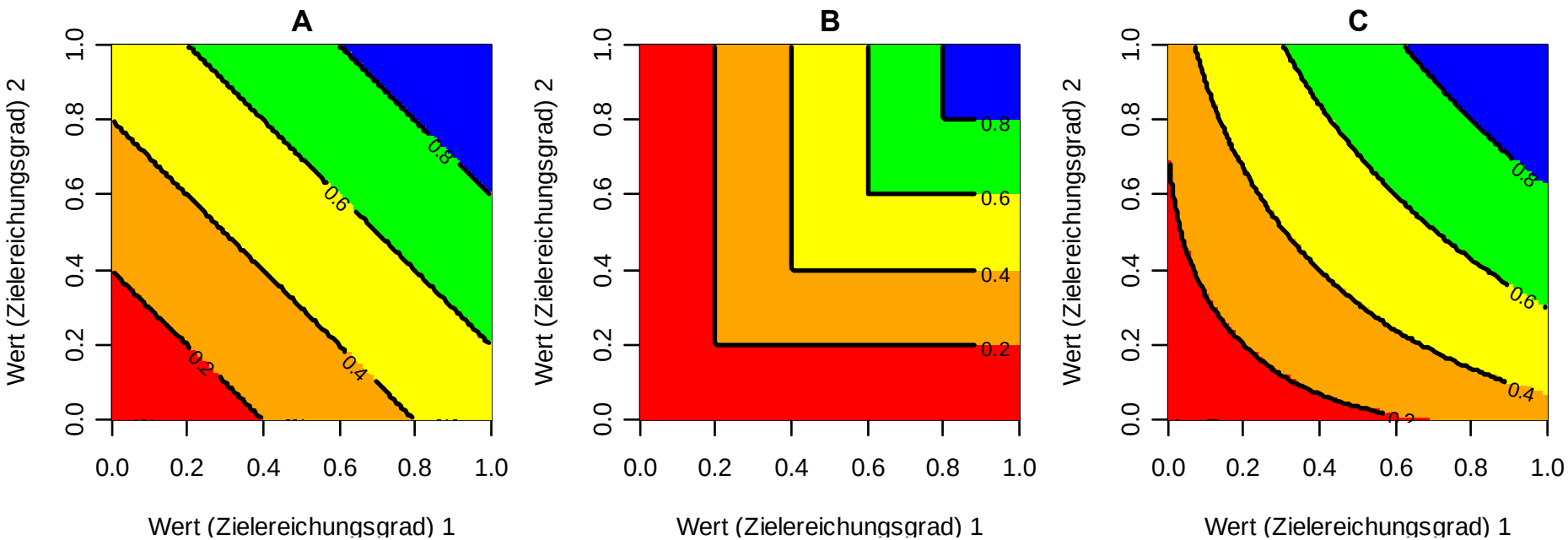
Examples of single-attribute value functions:



Reichert et al. 2011

2. Formulation and Elicitation of Preferences

Examples of value aggregation techniques:



Reichert et al. 2011

3. Finding Alternatives

Stimulating the process of creating alternatives by

- Analyzing deficits of current status
- Involving stakeholders
- Studying solutions to similar problems
- Analyzing deficiencies of alternatives

4. Synthesizing Knowledge and Preferences

Decision support is based on combining predictions with preferences

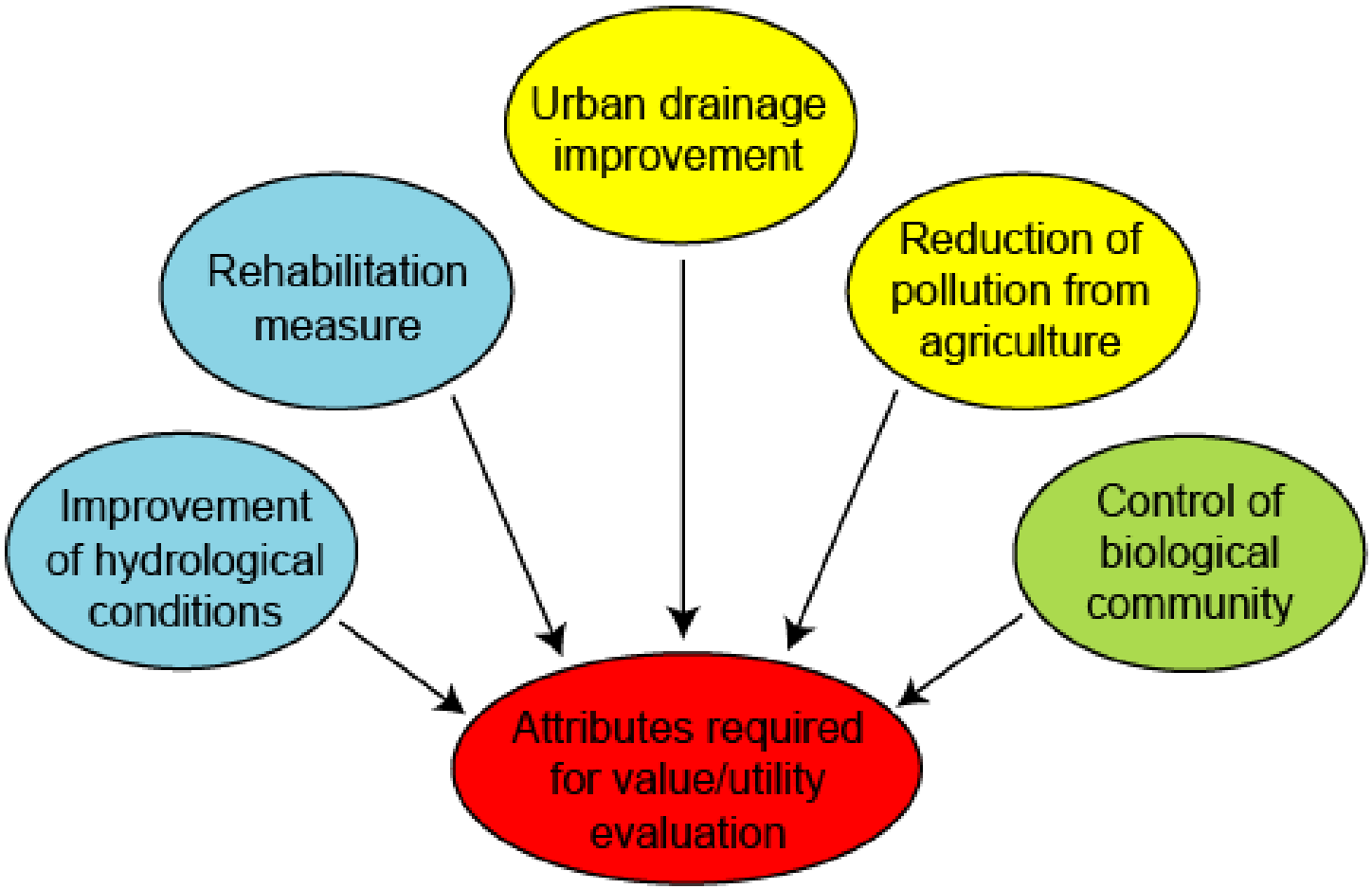
Two important tasks:

1) **Ranking alternatives** according to the **expected utility** of the predicted states for all decision alternatives gives a first overview of the desirability of different alternatives.

2) **Tracing back causes of poor assessments** of particular alternatives may **stimulate the creation of new alternatives** that have a better performance or a lower conflict potential between different stakeholder groups.

5. Application to River Management

Summarize scientific knowledge of the consequences of alternatives in the form of probabilistic, predictive models:



5. Application to River Management

Requirements:

•River **network / landscape perspective** (rather than river section)

•**Combine knowledge** from theoretical ecology, ecological stoichiometry, metabolic theory of ecology, trait data bases, …

•Emphasis on **stochastic models** to address intrinsic uncertainty (these contain deterministic models for the expected values)

•Adequate treatment of **uncertainty**:

- Stochasticity
- Structural deficiencies
- Parameter uncertainty

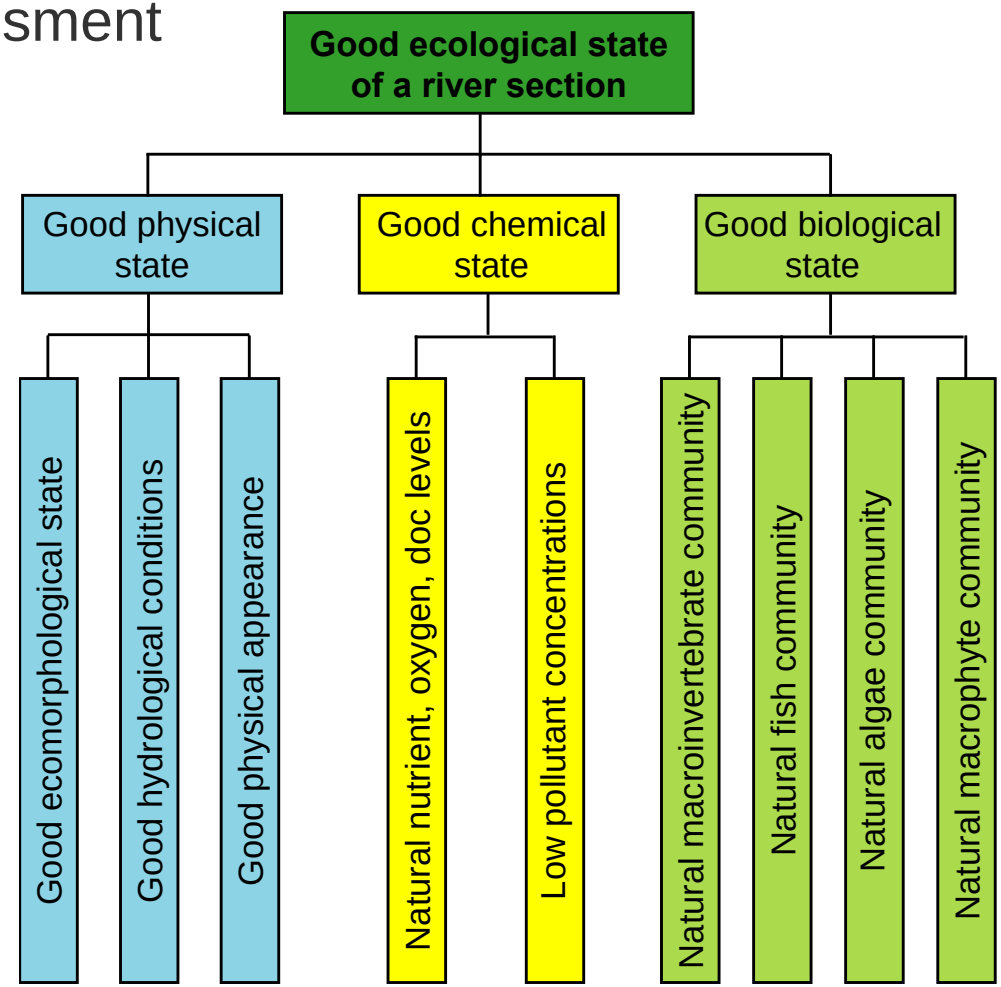
•Use adequate **inference techniques** to learn from data

- Bayesian inference
- Dealing with bias to avoid overconfidence

5. Application to River Management

Objectives hierarchy for good ecological state of a river section

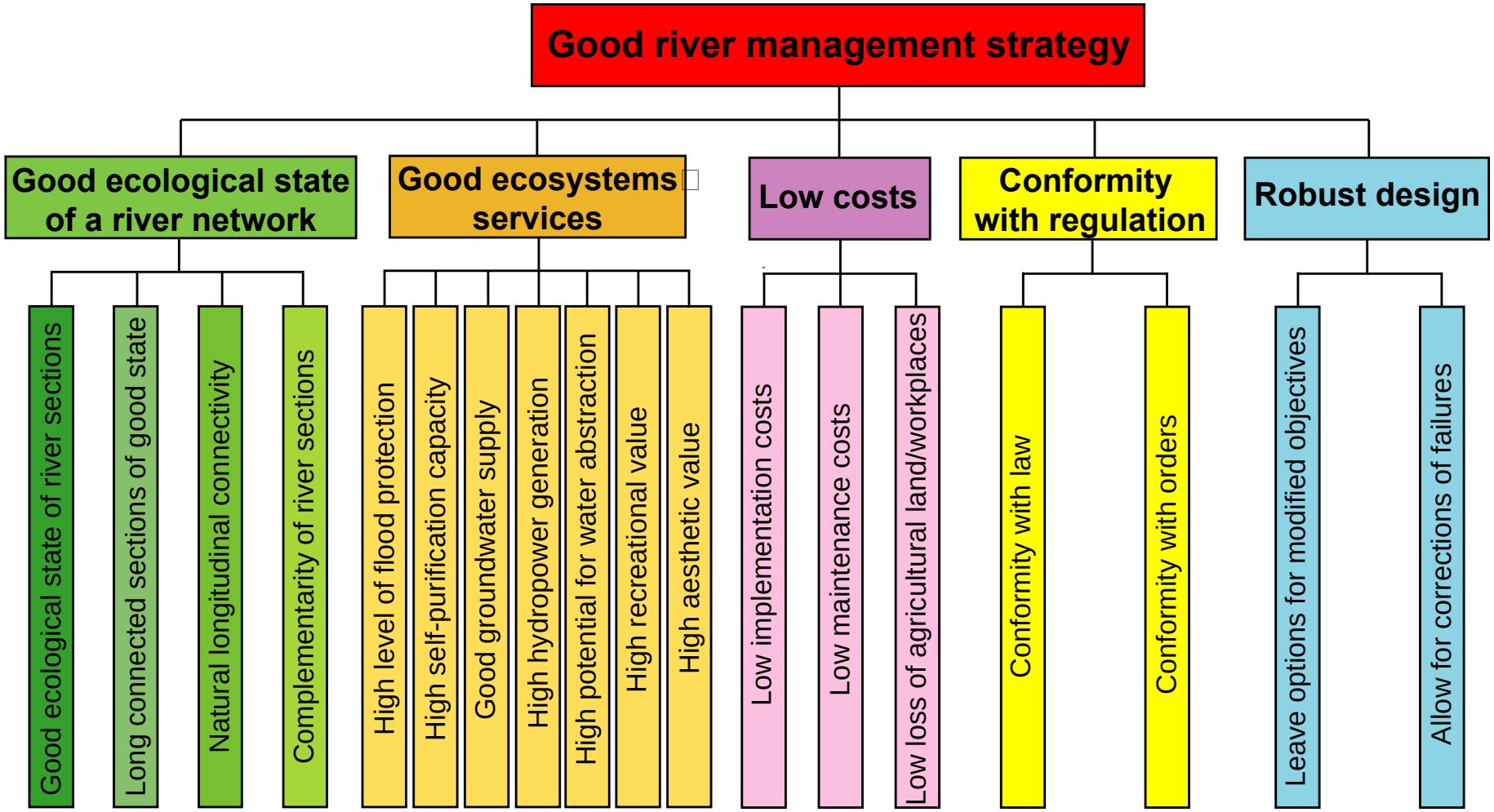
traditional assessment



5. Application to River Management

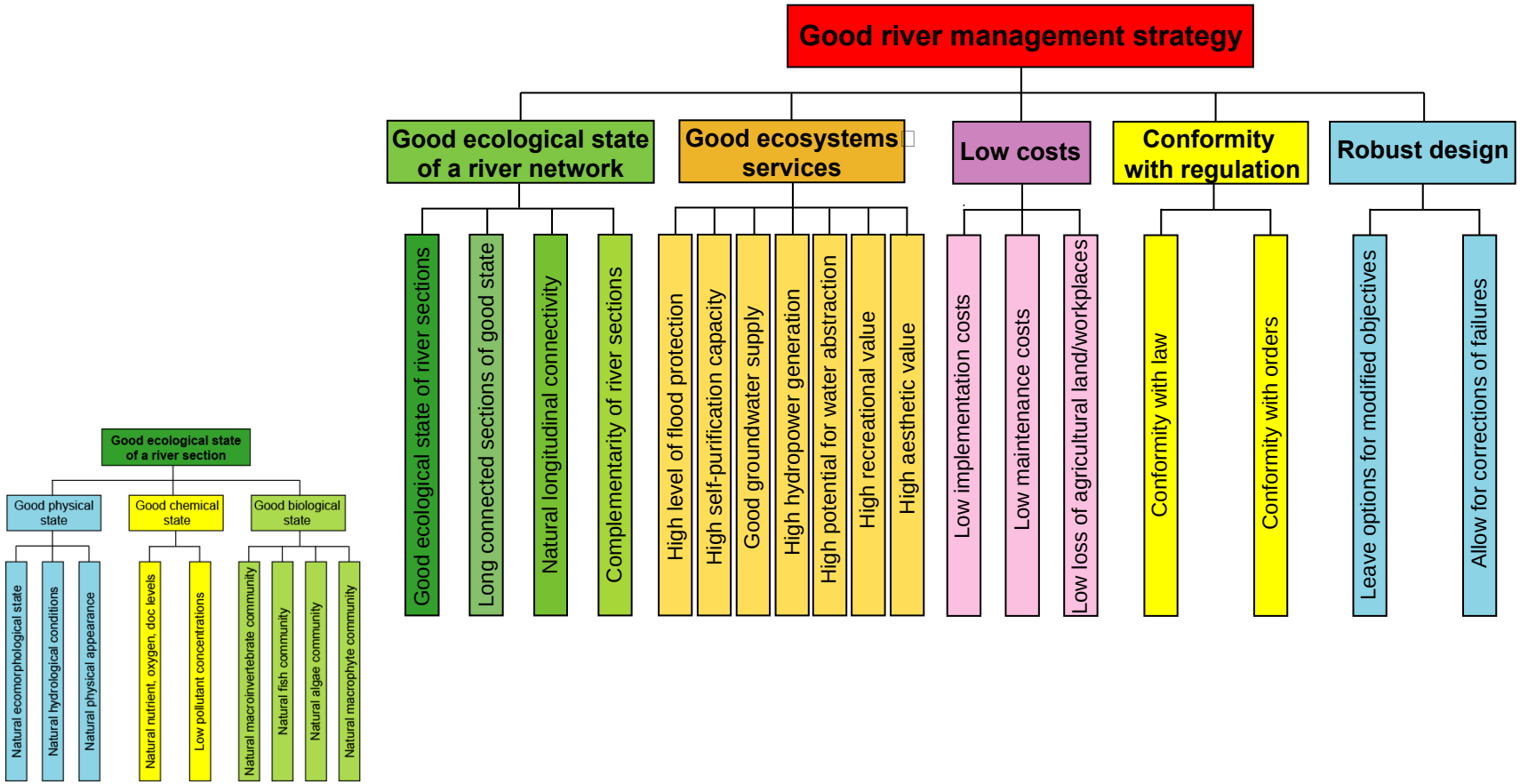
expand scope of assessment!

Objectives hierarchy for river management



5. Application to River Management

Elicitation of values:



experts (scientists, practitioners)

society (represented by stakeholder groups)

5. Application to River Management

Opportunities for Application

- **Analyzing deficits**

- **Subobjective-based prioritization**
  How to reduce chemical pollution?
  How to improve the state of the fish community?

- **Integrative, ecological prioritization**
  How to maximize the overall ecological benefit for a given budget?

- **Informal use for decision structuring / stakeholder involvement**
  Use structured decision-making process as «checklist» and for transparent communication.

- **Perform quantitative, integrative decision support**

All analyses are possible for sectoral or cross-sectoral alternatives.

Very flexible approach with a wide application area.

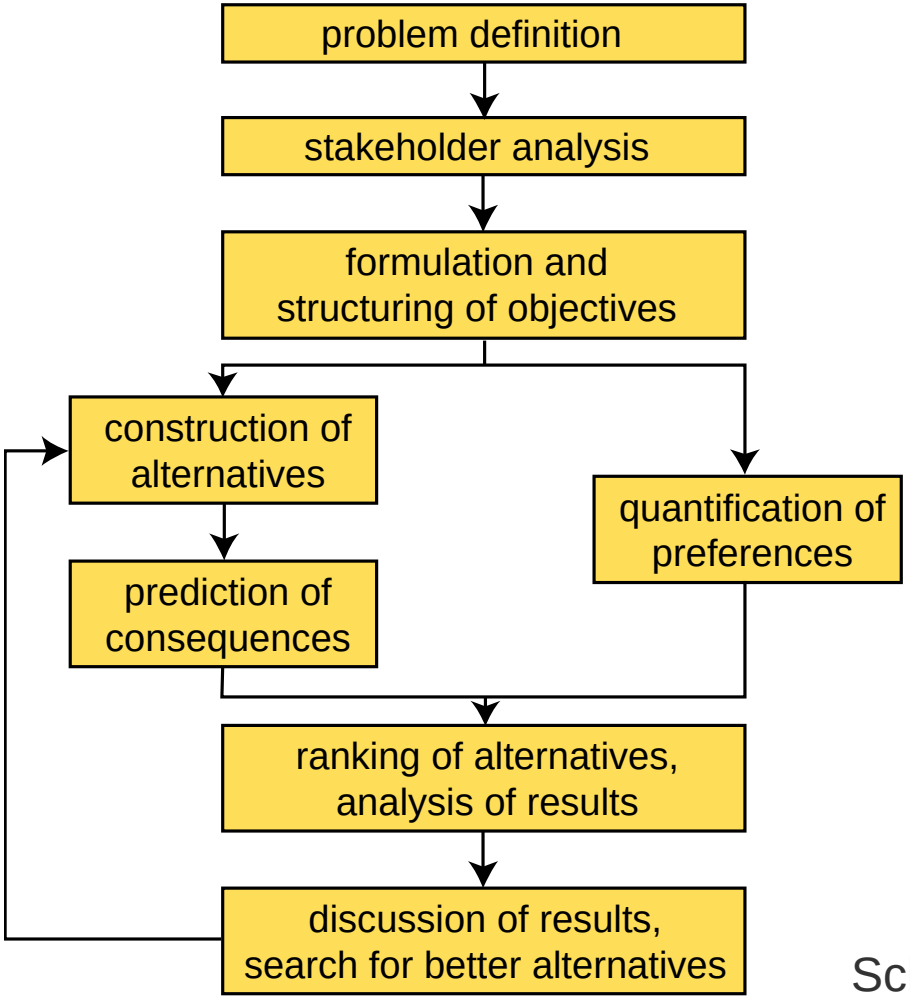
6. Making the Theory Accessible to Decision Makers

Strategy

- Visualize results wherever possible
- Present concepts in working groups with practitioners
- Publish (also) in literature read by water professionals
- Facilitate steps with small, transparent software products (not huge, intransparent DSSs)
- Listen carefully to feedback
- Demonstrate successful use of the theory: Acquire small, interconnected projects; collaborate with practitioners
- Have a vision of what to achieve but be patient with respect to implementation

6. Making the Theory Accessible to Decision Makers

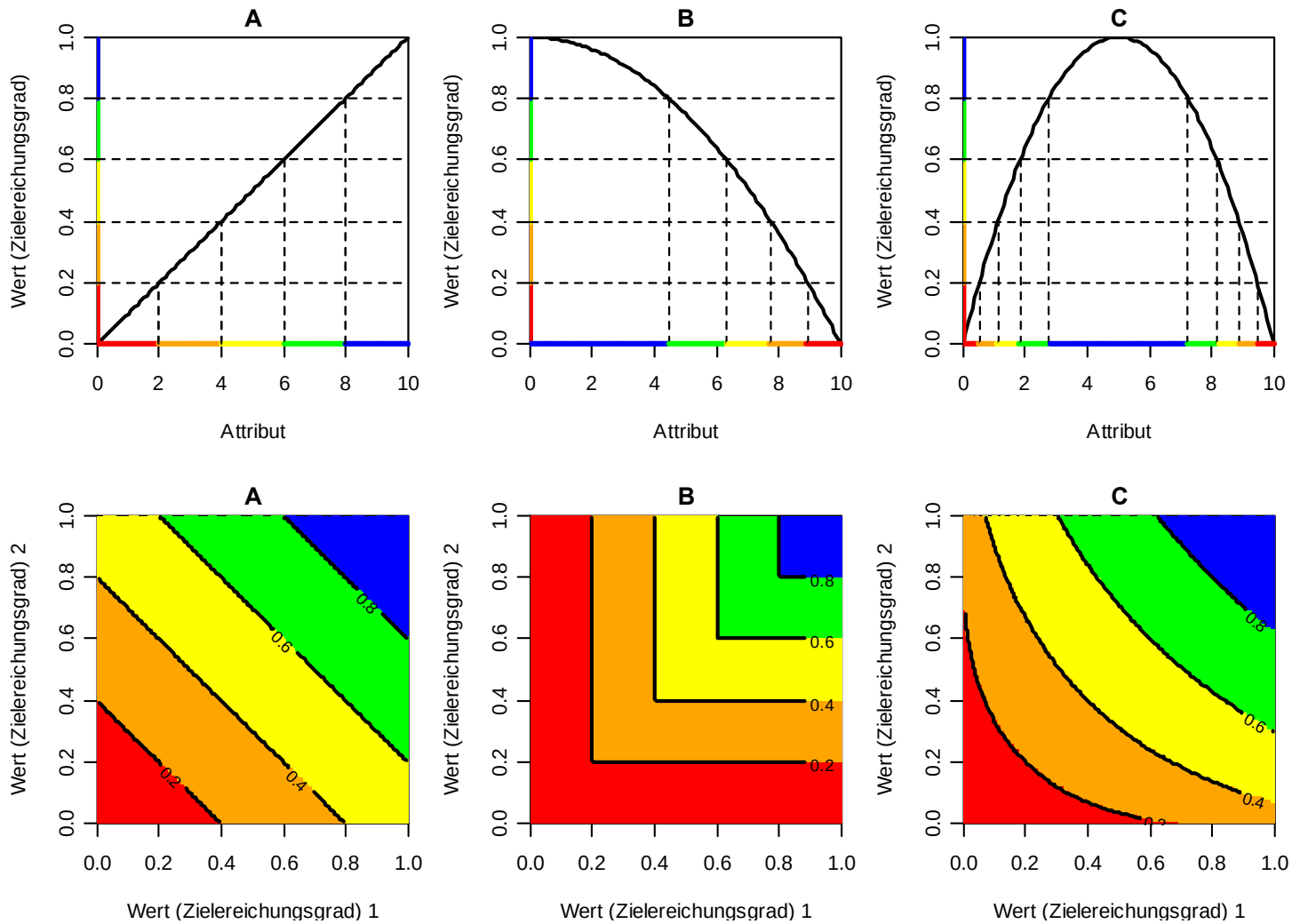
Structure the decision making process



Schuwirth et al. 2011

6. Making the Theory Accessible to Decision Makers

Visualize results wherever possible



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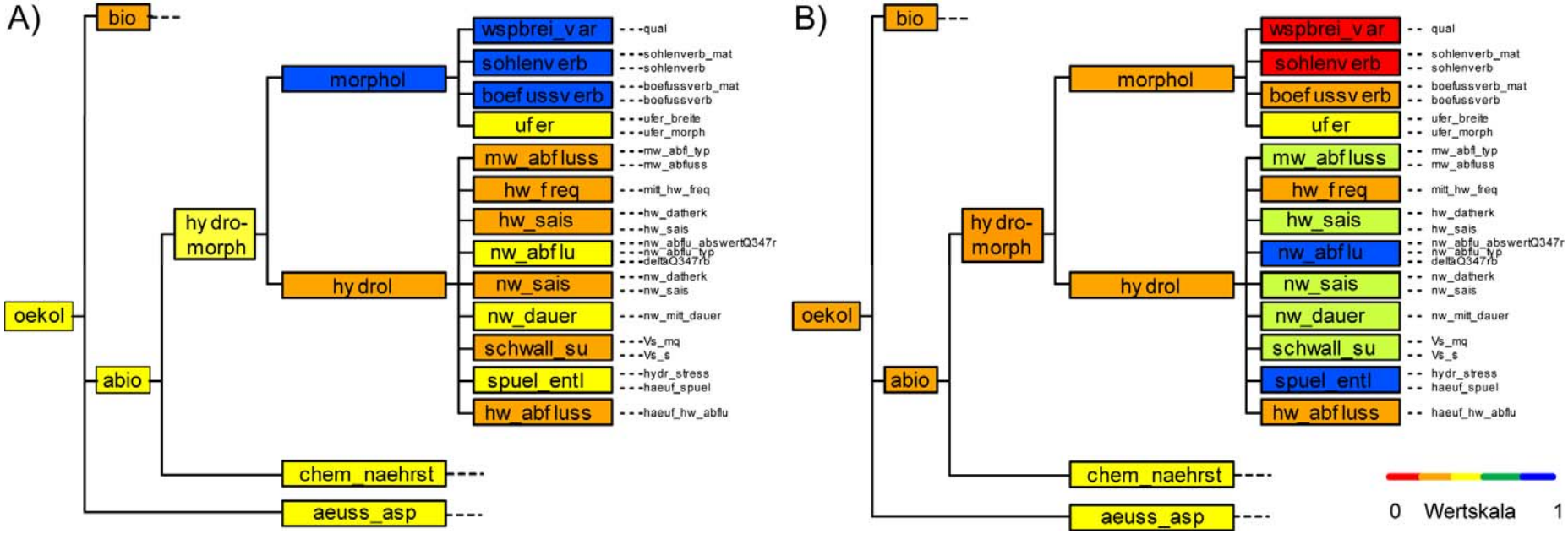
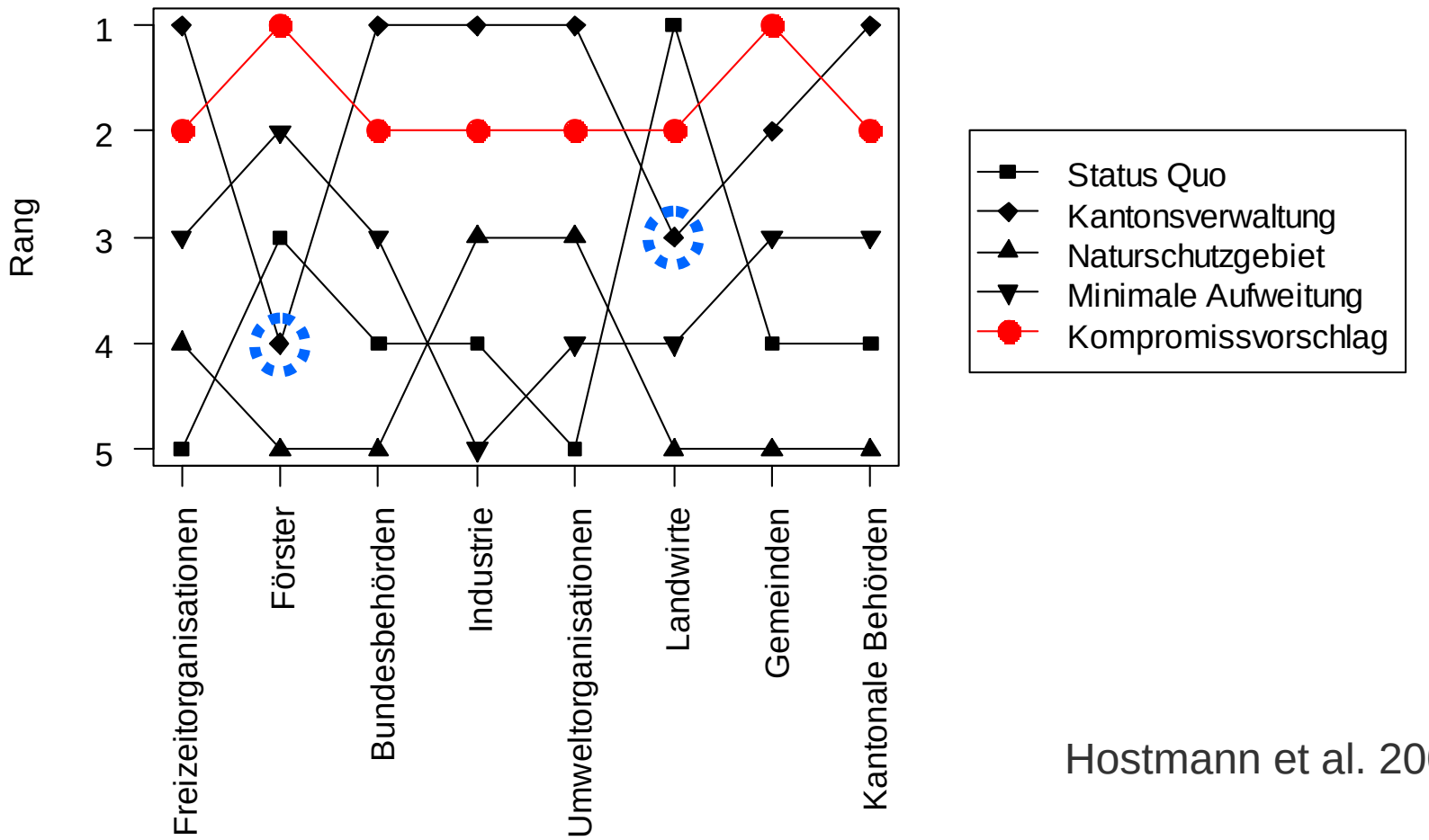


Langhans et al. 2011

6. Making the Theory Accessible to Decision Makers

Visualize results wherever possible



Hostmann et al. 2005

7. First Experiences

Scientific objectives:

•Improve prediction of ecosystem-level consequences including rigorous uncertainty analysis.

•Address methodological challenges in decision analysis

Application-oriented objectives:

•Improve documentation of scientific base of Swiss assessment procedure; increase international exchange (e.g. intercalibration)

•Clearly separate attributes from assessments

•Develop new assessment modules using value functions; reformulate existing modules using the same concept

•Replace module-specific action plans by integrative assessment

•Expand scope to river network assessment and societal values

•Extend application of assessment procedure to predictions to provide effective decision support

7. First Experiences

«Small, interconnected projects»:

•Rhone-Thur
Emphasis: first trials

•Rehabilitation prioritization (BAFU); with C. Robinson & A. Peter:
Emphasis: effects of stream morphology

•River assessment (BAFU)
Emphasis: ecological assessment procedures

•Water quality management (SNF: NRP 61); with C. Stamm et al.
Emphasis: effects of water quality, decision support

•Potential KWO hydropeaking project
Emphasis: effects of hydropeaking, test of practicability

•EU REFORM
Emphasis: international exchange

7. First Experiences

Concerns of authorities:

•Procedure is too complicated to be implemented in practice!

•We have more urgent needs for specific assessment module developments and do not need an overarching framework!

•Current procedures are satisfying – do not suggest modifications!

•Uncertainty and consideration of additional attributes may lead to changes in assessed states!

•Sectoral management works nicely – do not interfere with new concepts!

These concerns have to be taken seriously; we have to rethink our suggestions but in some cases we also have to convince authorities or stakeholders of potential benefits they may not be aware of.

7. First Experiences

Current status:

•Positive feedback from Rhone-Thur project

•Acceptance of our suggestions for new river assessment module development; discussion of our concept in several working groups

•First steps to model implementation for fish (trout) and benthos

•Constructive feedback to our «peer review» of practice-oriented publications

•Some of the concerns decreased

•Much more work to do!

8. Conclusions 1

Practical implementation aspects are often more important than sound concepts for successful application in practice

Should we care about rigorous underlying concepts?

Yes! But implementation aspects should be considered carefully

1. Responsibility of scientists / scientific institutions to **use and teach best methodologies**
2. Provide methodological **basis for scientific learning** in the presence of uncertainty
3. Optimally **transfer scientific knowledge** (including its uncertainty) into practice
4. **Stimulate integrative thinking and intercalibration** – even if sectoral management prevails
5. Long-term benefit due to **joint methodology across sectors**
6. **It is interesting** and intellectually stimulating to be / become aware what one is doing

8. Conclusions 2

Practical experiences

1. **Be patient** regarding the implementation process

2. **Implementation requires time, continuity, dialogue and trust** (to persons and institutions; transfer your contacts!)

3. Try to **be as simple as possible**, but not simpler

4. **Emphasize integrative thinking**, even if governance will remain sectoral in the intermediate future

5. Carefully **distinguish aspects that are in the research phase from those ready for implementation**

6. **Listen to feedback**; but be resistant in important conceptual aspects, such as uncertainty

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Thank you very much for your attention