Einführung in die Systemtheorie (gekoppelter Mensch-Umweltsysteme)

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Überblick

1. Der Begriff des Systems
2. Probleme
3. Beispiele systemtheoretischer Ansätze
4. Begriff des Modells
5. Beispiele für die Anwendung systemtheoretischer Ansätze

Der Begriff des “Systems”

(u.a. Karl Ludwig von Bertalanffy 1901-1972)

Als **System** (griechisch σύστημα, s*ýstema)* wird eine Gesamtheit von Elementen verstanden, die auf- und miteinander wechselwirken, so dass man sie als eine aufgaben, sinn- oder zweckbezogene Einheit auffassen kann und das sich in diesem Sinn von der Umwelt abgrenzt.

Ein System erhält und organisiert sich durch Strukturen; Struktur ist ein Muster der Systemelemente und ihrer Beziehungsgeflechte

Einige Eigenschaften

- Komplexität
- Lernend
- Dynamik
- Autonom
- Adaptiv
- Wechselwirkung
- ……

Eineine heitliche Systemtheorie existiert nicht:

Regelungstechnik/Kybernetik (McCulloch, Wiener, Rosenblatt)
Soziologie (Luhmann)
Physik (Shannon, Zeeman,Mandelbrot)
Umweltsystemanalyse

Aufbau und Funktionsweise hängt vom Standpunkt des Betrachters ab!

At each level of organisation novelties occur in both properties and logic (Jacob 1974)!

System thinking is distinct from analytical thinking, [but both is] essential for understanding complexity (Boardman 1995)!

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Warum das alles?

Interdisziplinäres Erkenntnismodell, d.h. der **Modellbegriff** spielt eine zentrale Rolle!

Die Analyse von Strukturen, Mechanismen und Funktionen soll Vorhersagen über das System ermöglichen

Modell: Gegenstand wissenschaftlicher Methodik die eine zu untersuchende Realität durch Erklärungsgrößen abbildet

Mathematisches Modell (Prognose, Erklärung, Entscheidung)
Prosa Modell (semantisch, Struktur)

Beispiele systemtheoretische Ansätze I “soziale Systeme” (Luhmann)

Typen sozialer Systeme: Interaktionssysteme, Organisationssysteme und Gesellschaftssysteme.

Gesellschaft: System höherer Ordnung, ein System „anderen Typs“, umfasst die anderen Systeme

Unterschied zu anderen Systemverständnissen: Handlungsstruktur also nicht definiert über Beziehungen sondern durch Kommunikations- und Handlungssystem, daher ist es eher ein operatives Modell (eher zeitliche statt räumliche Prägung)

Literatur:

Niklas Luhmann, Dirk Baecker, Einführung in die Systemtheorie, 2004
Niklas Luhmann, *Soziale Systeme. Grundriß einer allgemeinen Theorie*, 2001

Beispiele systemtheoretische Ansätze II “biologische Systemlehre” (Bertalanffy)

Abgrenzung zu Physik: Kritik deduktiver Verfahren (isolierte Betrachtung von Einzelphänomene), nicht adäquat für die Biologie

Prägte den Begriff der “organisierten Komplexität” und des “Fliessgleichgewichtes”

Zentral ist der Begriff des offenen Systems, das durch Aufnahme von Energie zu einem höheren Organisationsgrad entwickeln. Die interne Variabilität ermöglicht es einem solchen System sich über Austauschprozesse in einem dynamischen Umfeld zu stabilisieren (Selbstorganisation)

Vergl.: 2. Hauptsatz (Wärmetod): abgeschlossenes System im Gleichgewicht ein höchstmögliches Maß an Entropie.

Literatur:

Bertalanffy: *The Theory of Open Systems in Physics and Biology*; Science 111,23-9 (1950)

Beispiele systemtheoretische Ansätze III "Komplexe Systemtheorie"

(Zeemann, Feigenbaum, Bak, Haken,….)

Physikalische Beschreibung komplexer Phänomene: Chaos, Emergenz, self-organised criticality, strange attractors

Chaos: sensible Anhängigkeit von den Anfangsbedingungen
Emergenz: das ganze ist mehr als die Summe der Einzelteile
so-crititicality: Selbststabilisierung von Systemen
(**strange) attractors:** unter Dynamik des Systems nicht mehr zu verlassende Teilstruktur des Phasenraums

Literatur:

Richter/Rost:*Komplexe Systeme, Teubner, 2003*
Haken*: Synergetics: Introduction and Advanced Topics*, Springer 2004

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Woraus besteht ein mathematisches Modell?

Wachstum der Weltbevölkerung

$$dN/dt = a\, N^{1+1/k}$$

Zustandsvariable: N, t Modellparameter: a, k	beschreiben den Zustandsraum müssen aus Daten bestimmt, oder geschätzt werden
$N(t) = N(t_0)\ (t^* - t_0 / t^* - t)^k$	Lösung

Beispiele

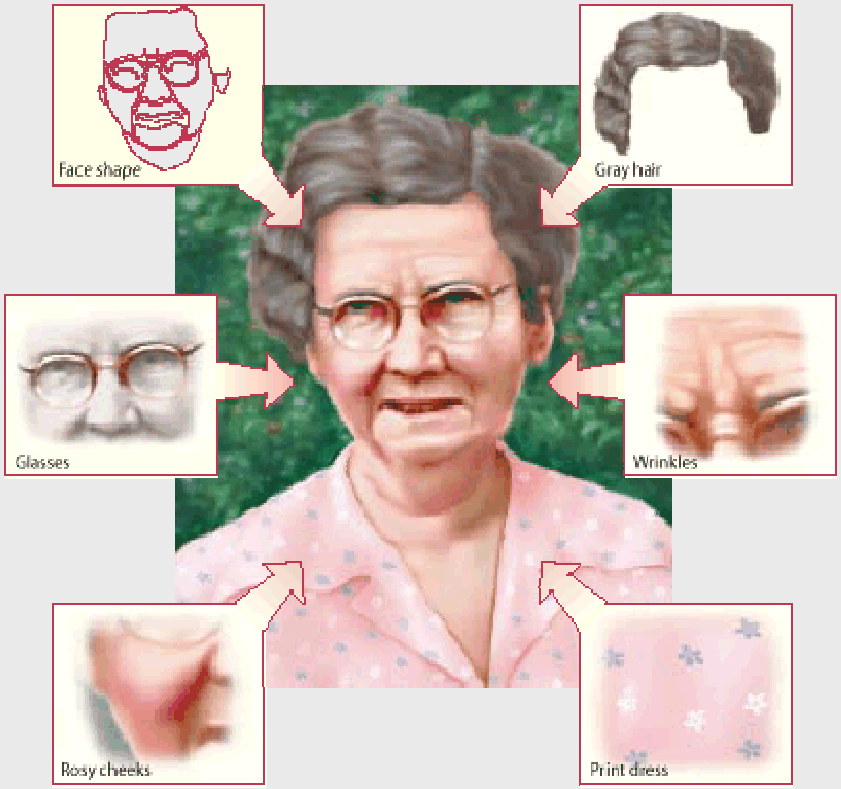
Das Musterkonzept

Integrated Systems Analysis

Coding

– 10101110001011001101010001101110000…

Extremely simple pattern screening leads to grandmother's identification



An Expert System of Global Change Syndrome Concept

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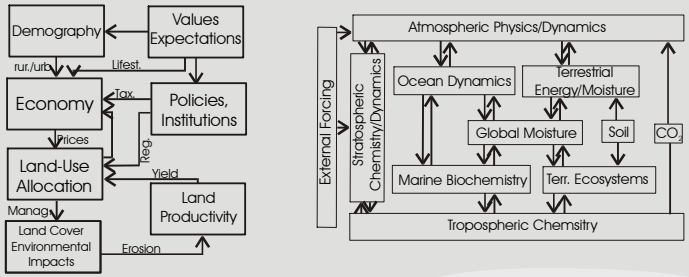
Syndrome Concept: Indicator & Story Based (symbol systems hypothesis; Newell 1976)

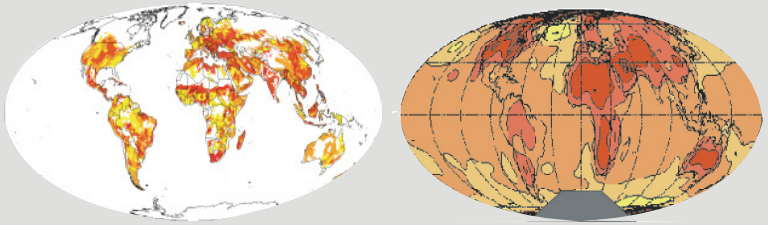
Integrated Systems Analysis

An Intermediate Complexity Analysis of Global Change

General Systems Knowledge

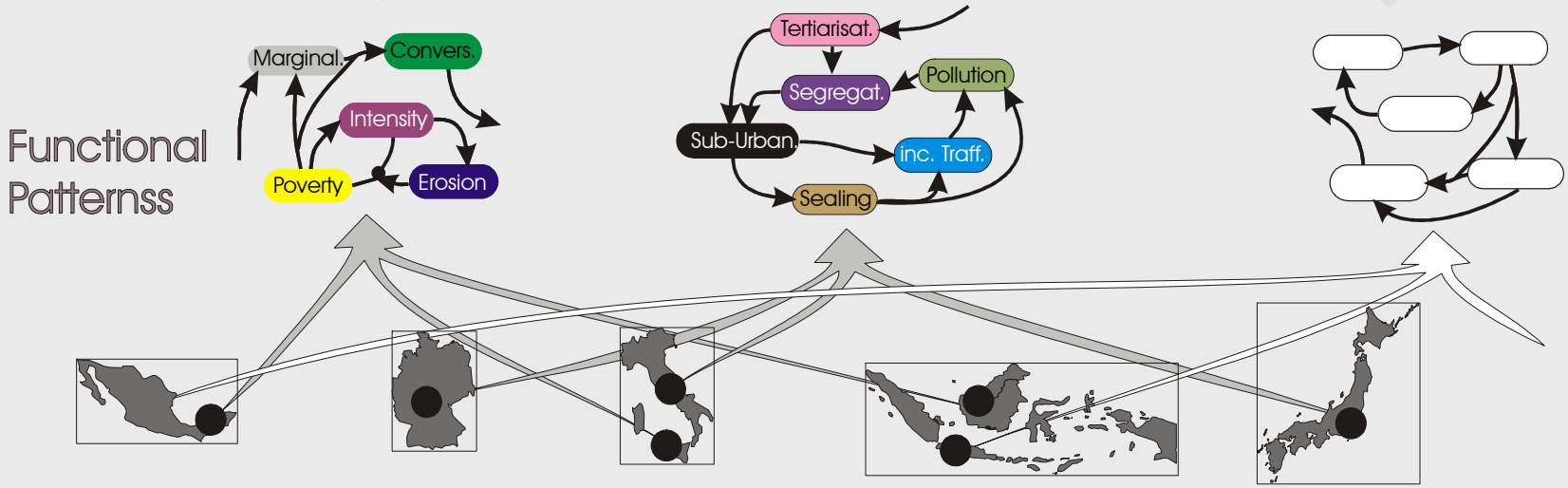


Global Core Problems



SOIL DEGRADATION GLOBAL WARMING

Functional Patternss



Detailed Local and Regional Case Studies

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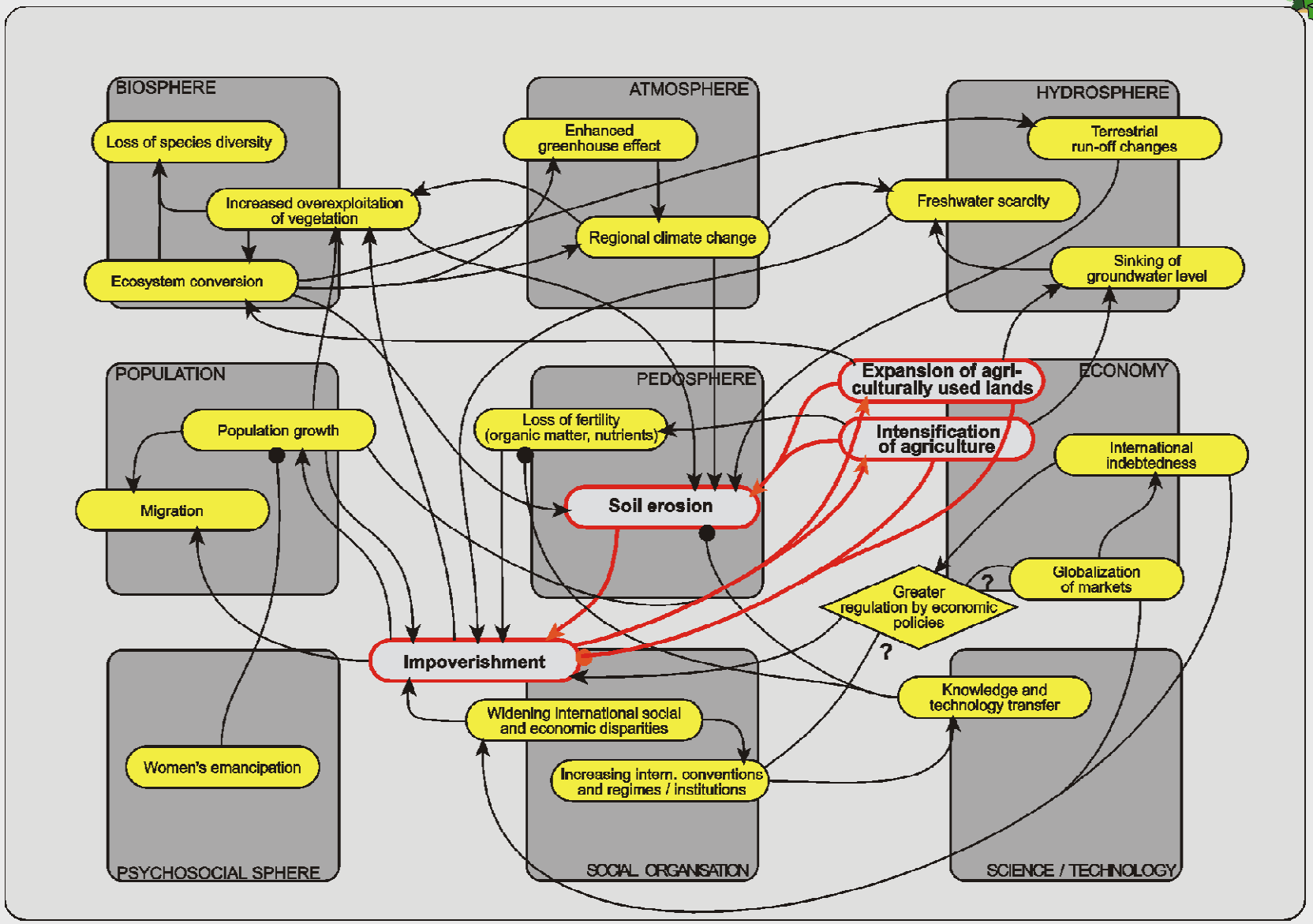
Network of Interrelations: Sahel Syndrome



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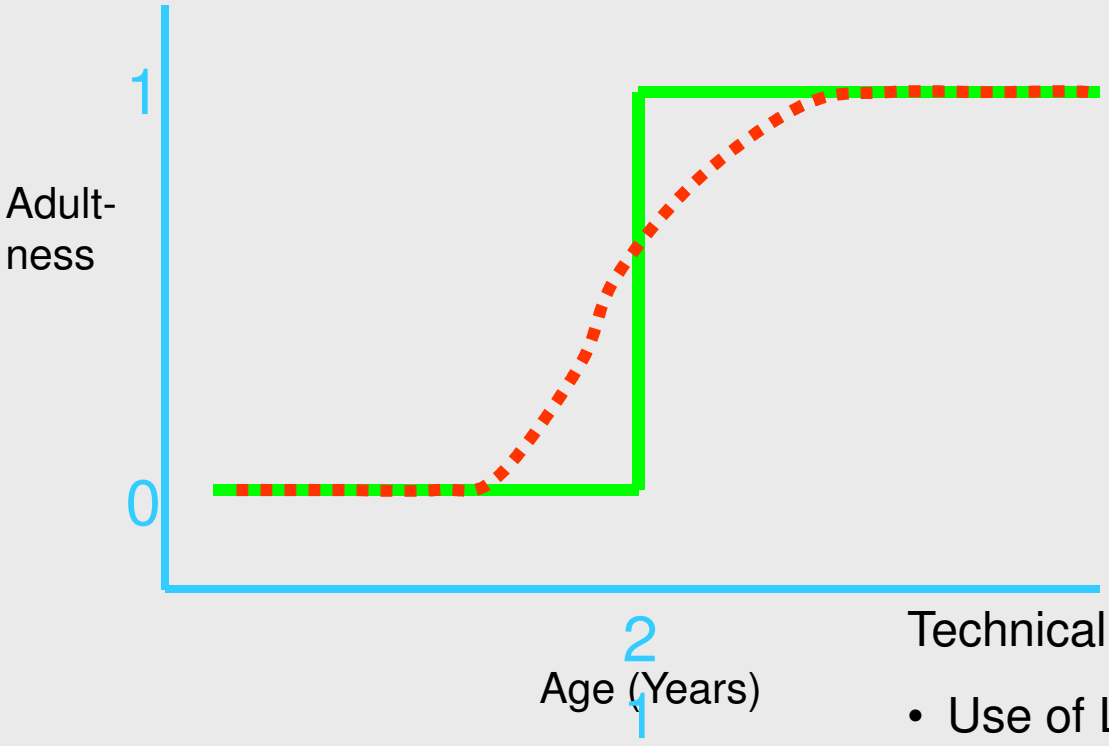
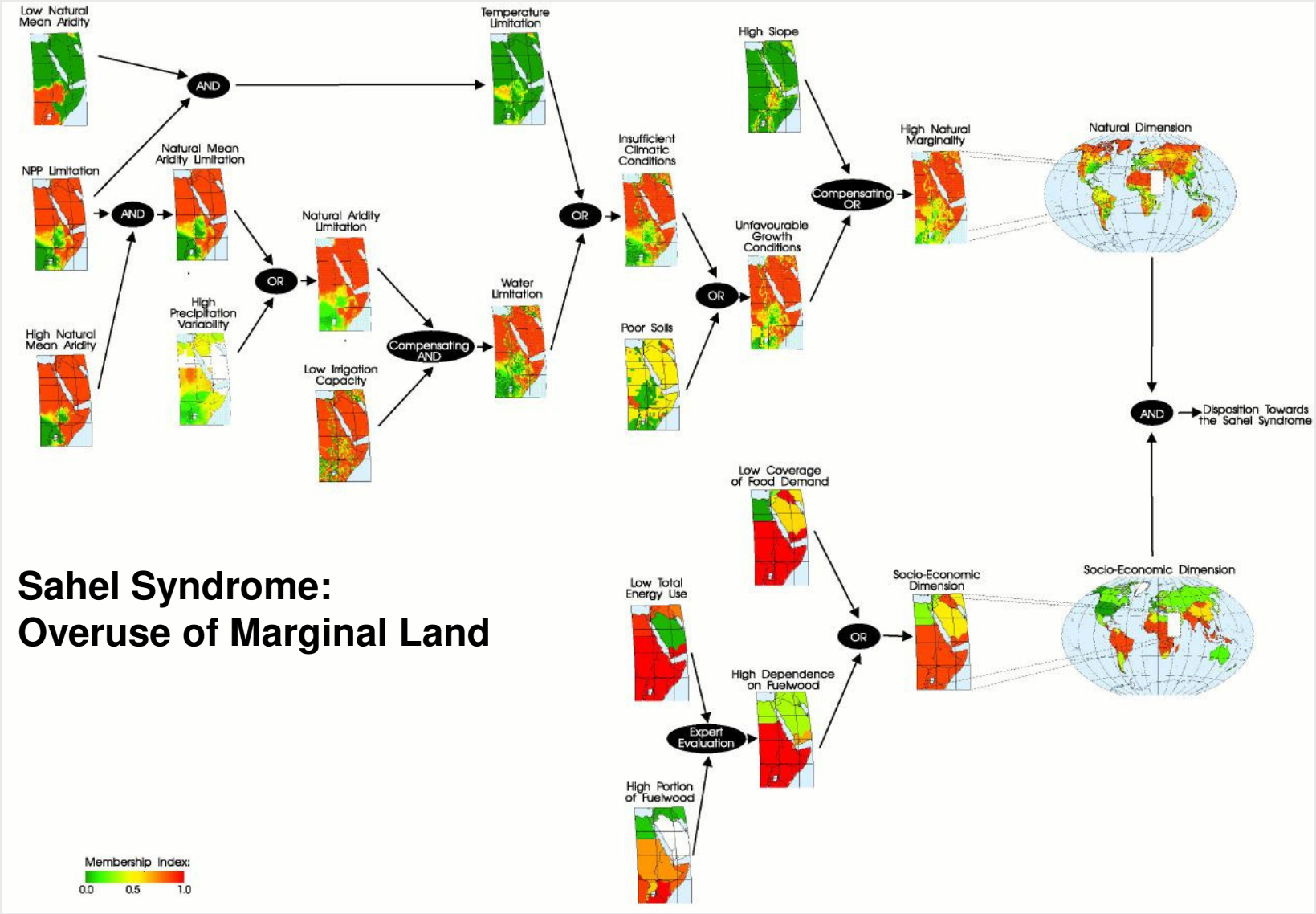
The Fuzzy Logic Concept



Technical Issues:

- Use of Linguistic Variables
- Incorporation of Risk and Uncertainty
- Copes with Missing Data
- Degree of Membership (DM) *is not* Probability

Diagnosis of Hazardous Patterns: Sahel Disposition



Sahel Syndrome:
Overuse of Marginal Land

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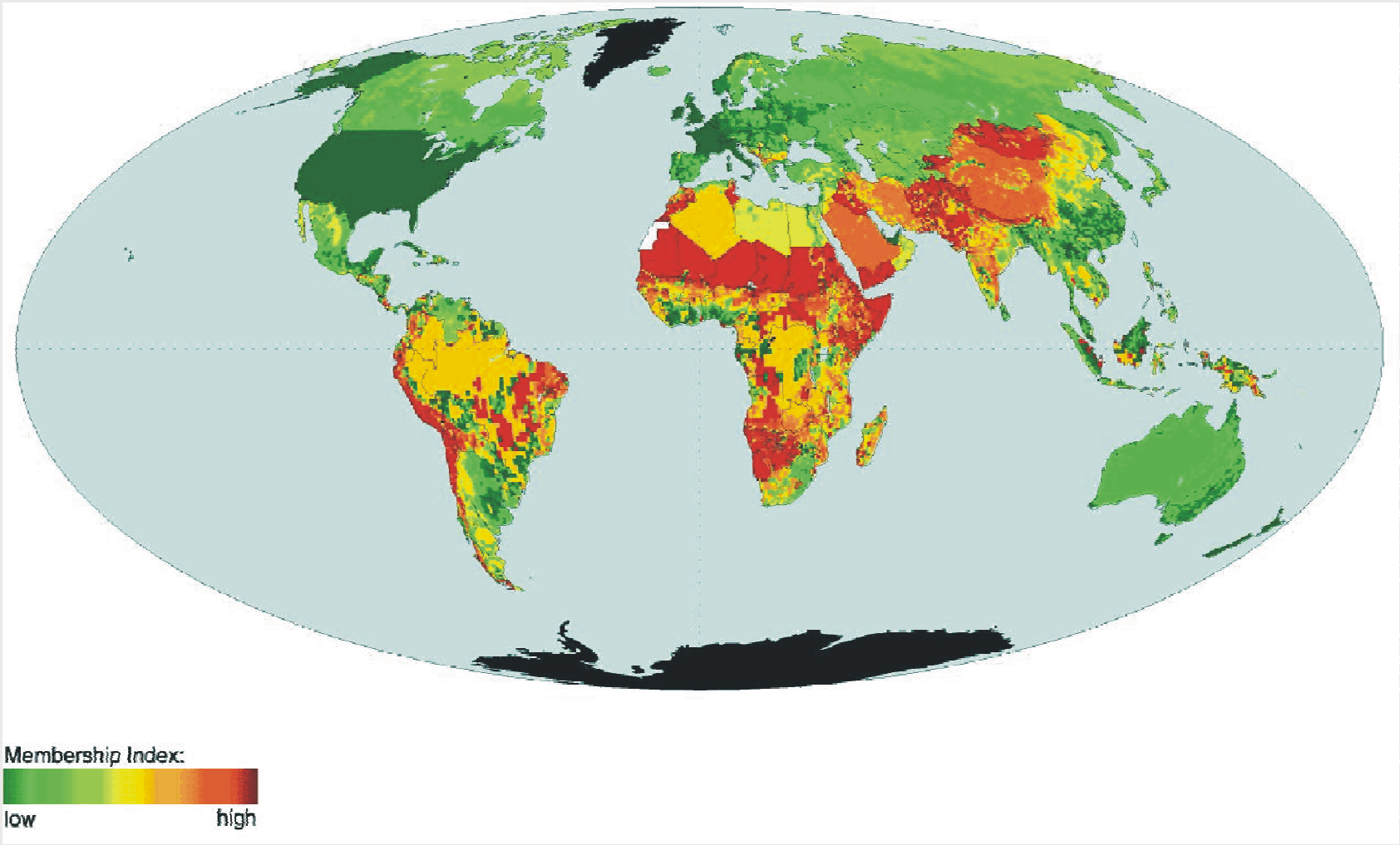
Overall Sahel Disposition



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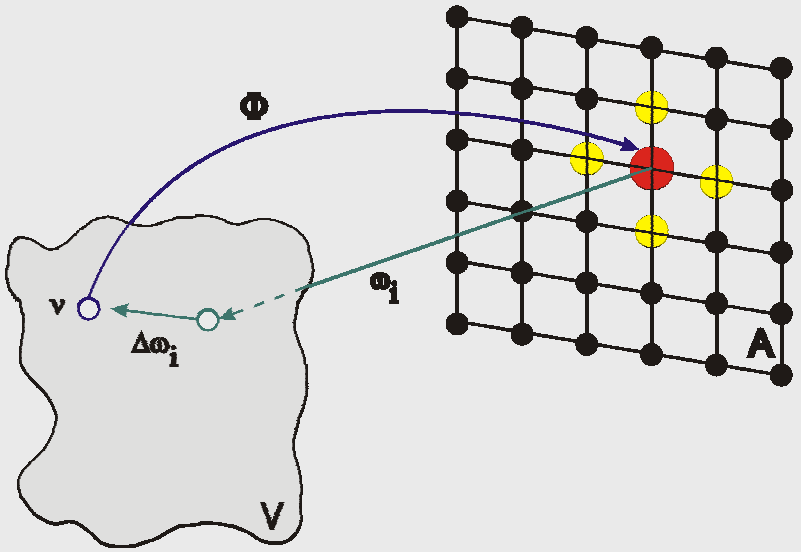
Selbstorganisierende Netzwerke

Self-Organizing Neural Networks



Challenge:

- **Eliminate redundant information**
- **Avoid topological distortions**
- **Estimate embedding dimension**
- **Find a suitable classification**

Provides a ‚nonlinear' classification

Algorithm:

1. Initialisation of reference vektors ω_i.
2. Choose input (stochastically) ν.
3. Network response: localisation of the winner neuron

$$\| \nu - \omega_i \| \leq \min_{\forall i' \in A} \| \nu - \omega_{i'} \|$$

4. Adaptation of synaptic strength of the winner ω_i and its next neighbours

$$w_{i'j}(t+1) = w_{i'j}(t) + \varepsilon(t)\ h_{ii'}(t)\ \left[v_j - w_{i'j}(t) \right].$$

$h_{ii'}$ represents a Gaussian neighbourhood function

$$h_{ii'}(t) = \exp\left(-\frac{\| i - i' \|}{2 \cdot \sigma(t)^2} \right),$$

with ε, σ as:

$$\varepsilon(t) = \exp\left(-\frac{t}{\varepsilon_0} \right) \quad \text{and} \quad \sigma(t) = \exp\left(-\frac{t}{\sigma_0} \right)$$

5. Back to Step 2. or termination if the SOM converges.

after Kohonen 2001

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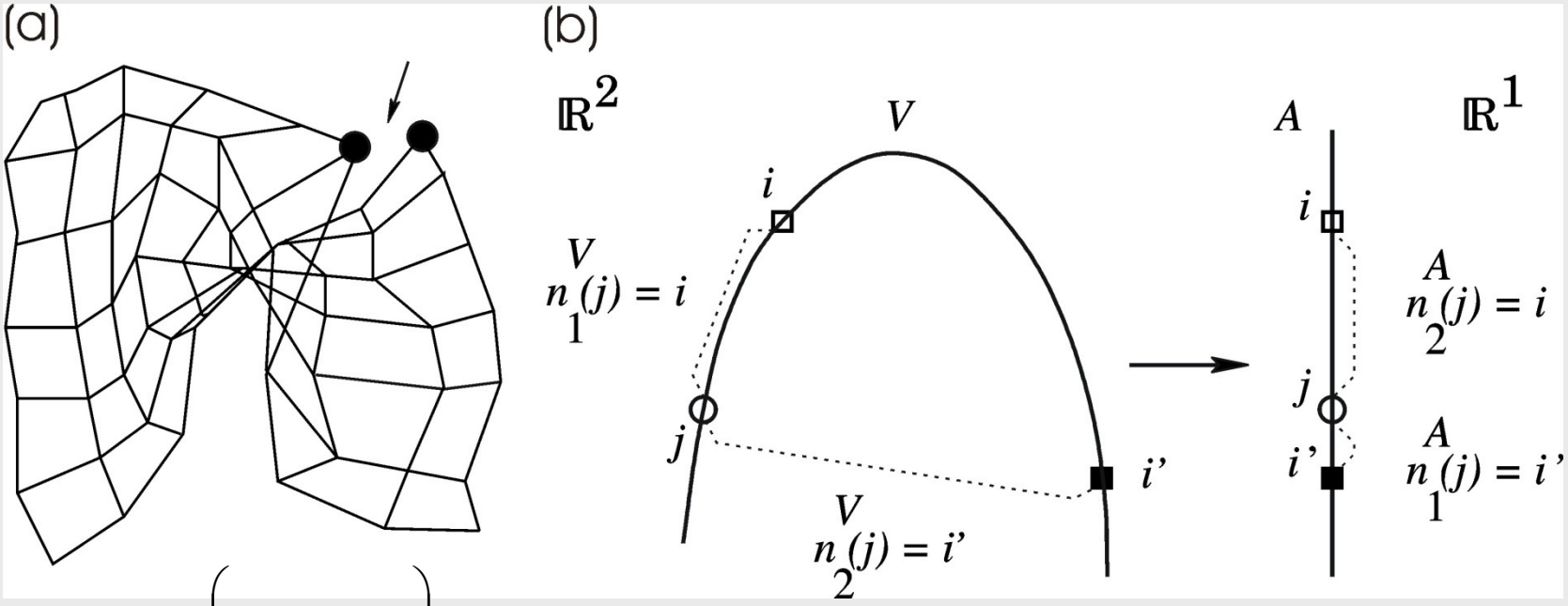
Topographisches Produkt



$$Q_1(j,k) = \frac{D^V\left(w_j, w_{n_k^A(j)}\right)}{D^V\left(w_j, w_{n_k^V(j)}\right)}$$

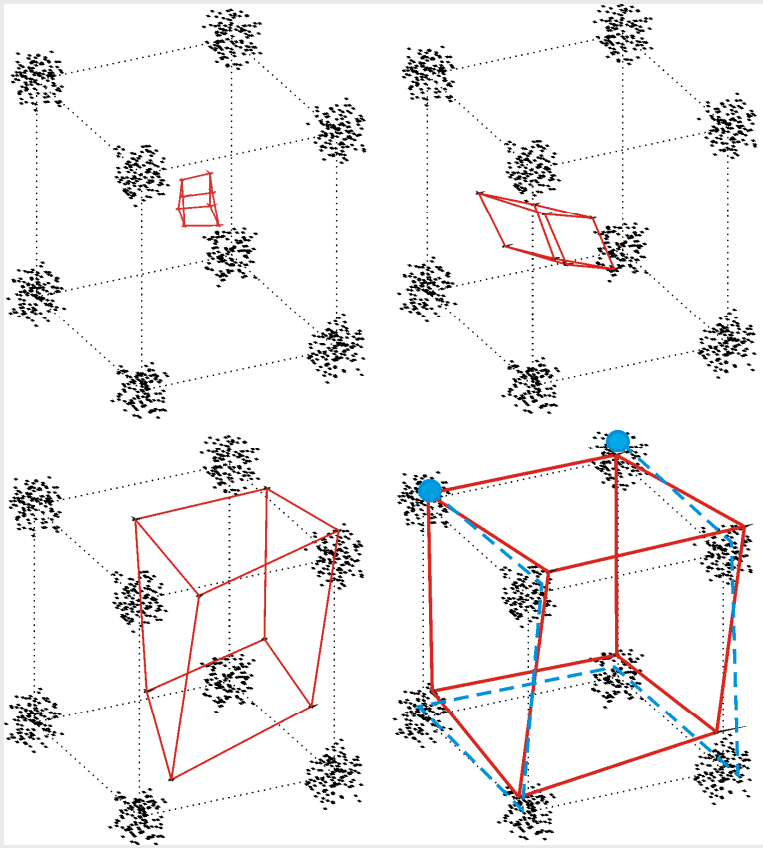
$$Q_2(j,k) = \frac{D^A\left(j, n_k^A(j)\right)}{D^A\left(j, n_k^V(j)\right)}$$

Für $Q_1(j,1) > 1$, weil $D^V(j,i') > D^V(j,i)$.
Für $Q_2(j,1) < 1$, nur falls $Q_1 = Q_2 = 1$ sind abgebildete Punkte deckungsgleich!

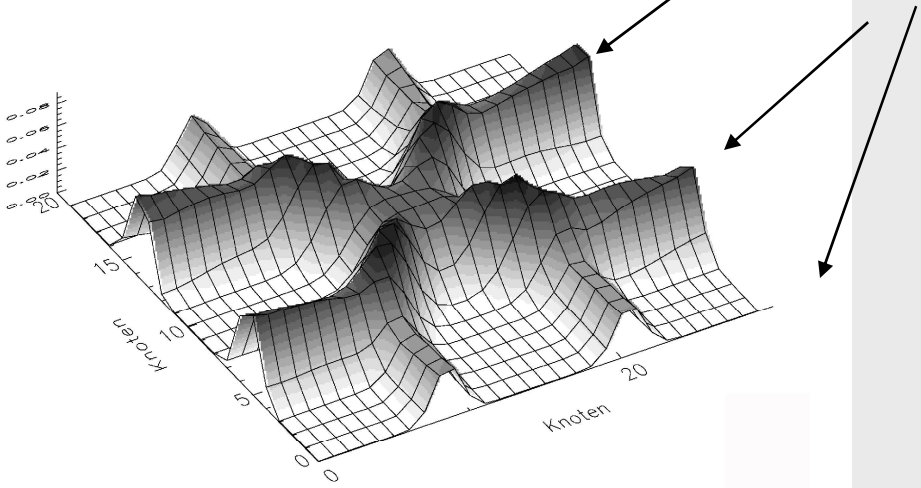
$n_k^V(j)$ und $n_k^A(j)$ nächste Nachbarn der Ordnung k des Punktes j

Optimale Klassifizierung unter topologischen Gesichtspunkten

Integrated Systems Analysis



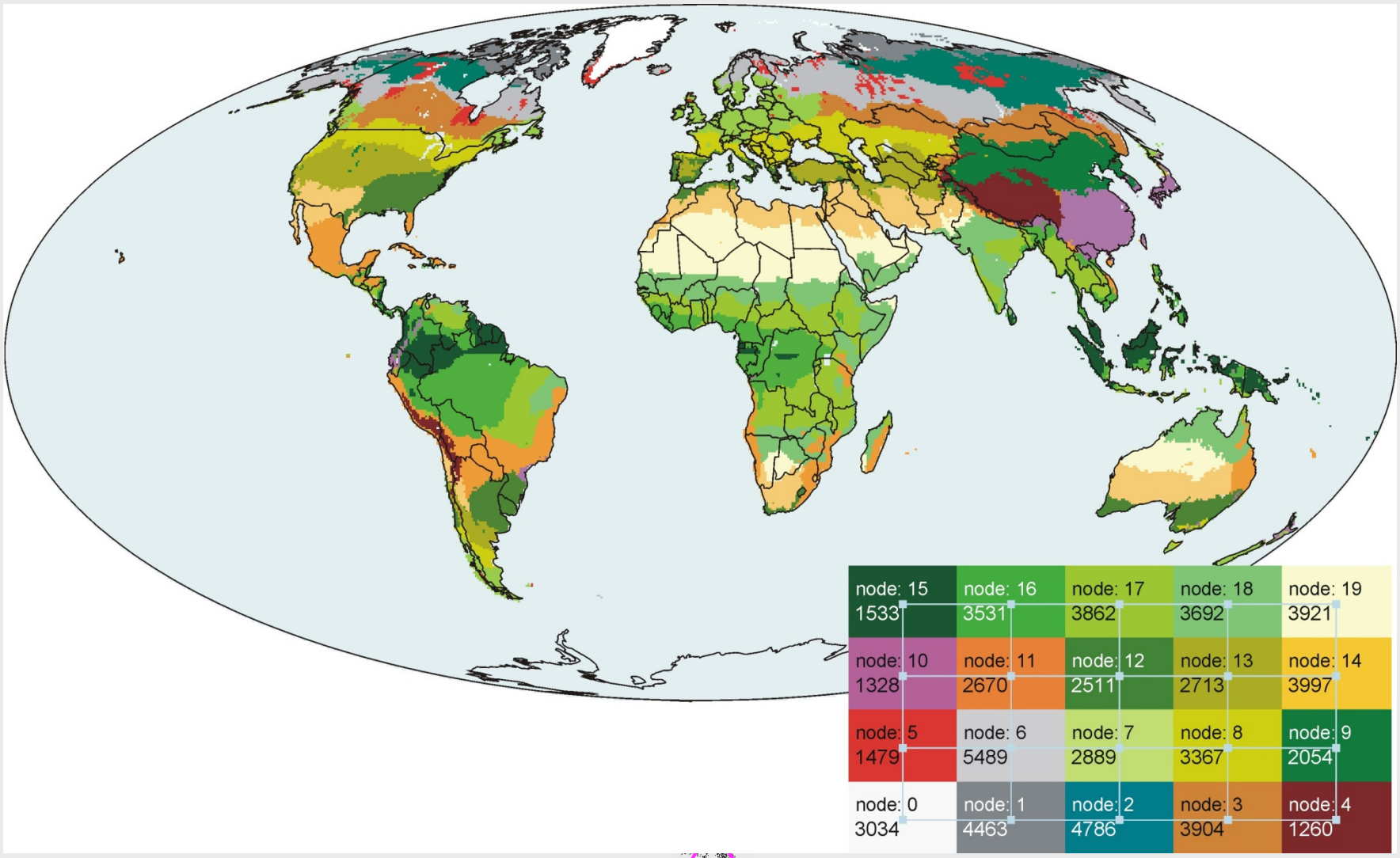
Klassenteilung



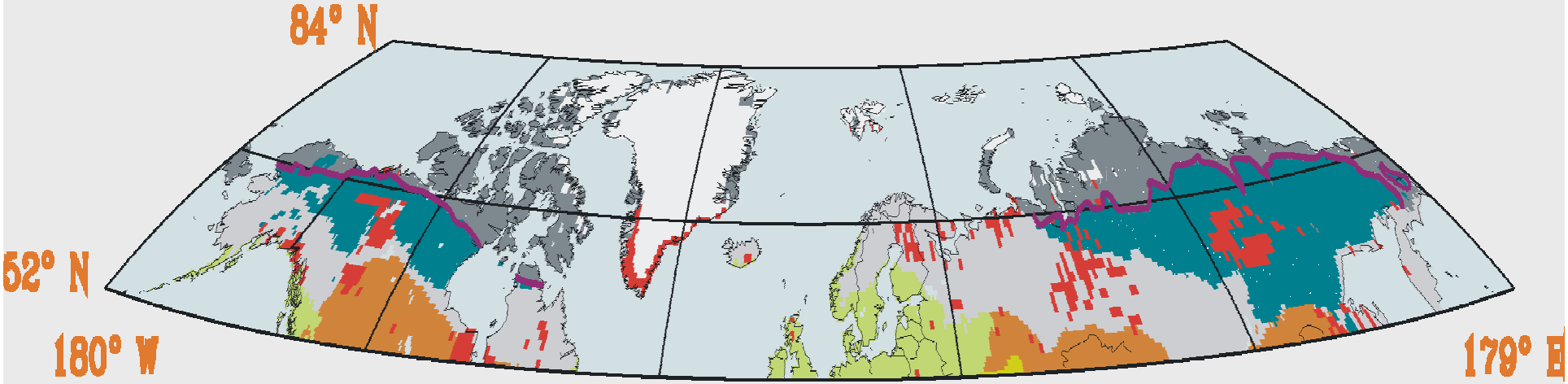
	dim	geometry	Topographical product	# iterations
	1	8	-0.076945 ± 0.009546	15 120 ± 29
	2	4x2	-0.038619 ± 0.009297	9 280 ± 13
√	3	2x2x2	0.001960 ± 0.000298	17 890 ± 34
	4	2x2x2x2	0.128865 ± 0.069812	13 264 ± 298

Algorithm, cf. Bauer & Pawelzik 1992, IEEE Trans. Neur. Networks

Globale „Klima-“ oder „Vegetationsklassifzierung“ ?



Ecosystem View, Data Driven!
Changes of Ecosystem Complexes
(IS92a scenario: 2xCO2)



Tundra/Taiga Border (magenta line)
July isotherm: 10°C (Walter & Breckle 1991)
Annual precipitation < 250-300 mm (O'Hare 1996)

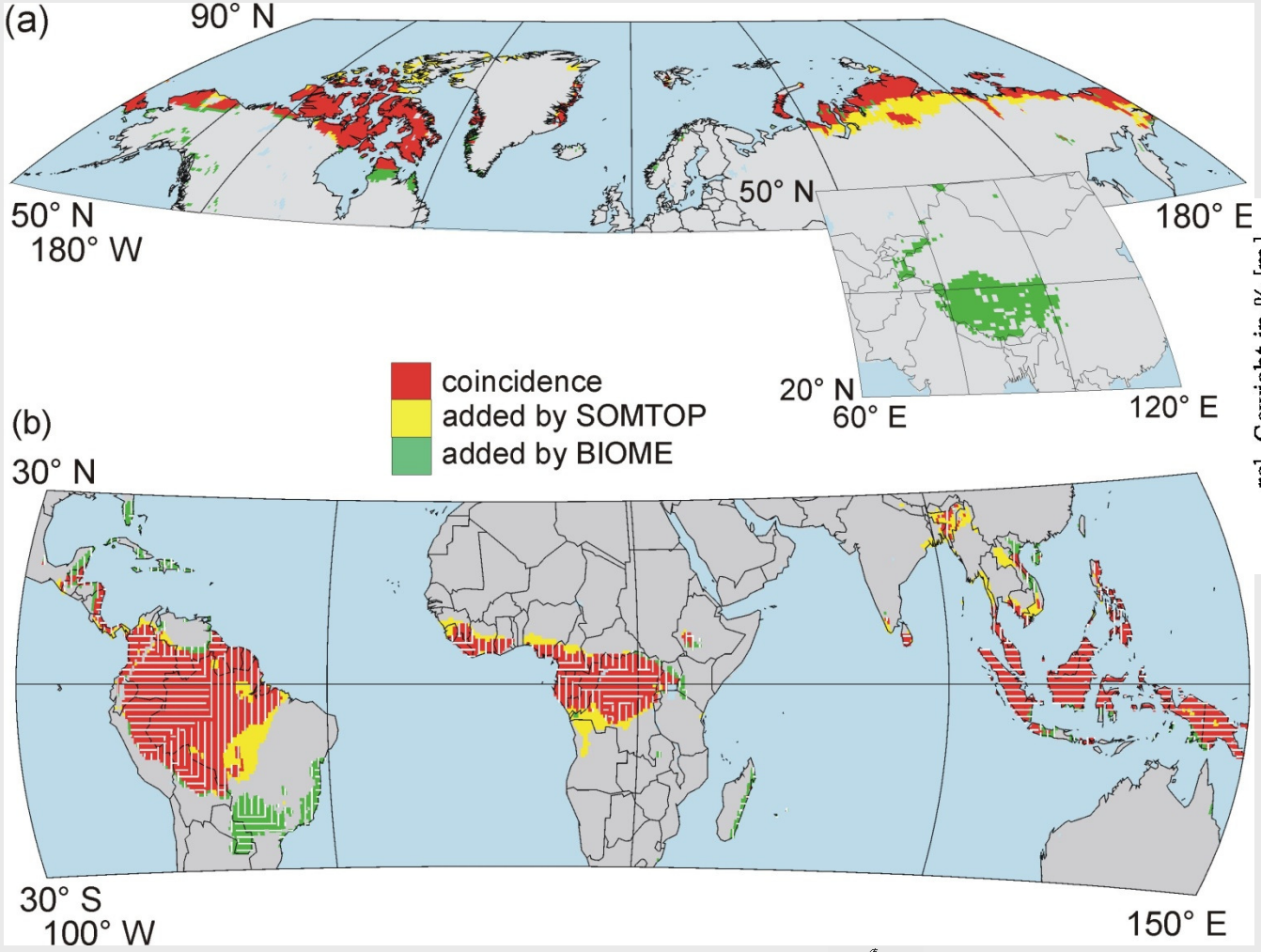
SOM: 9.7 +/- 1.6 °C (July temperature)
233 +/- 56 mm (precipitation)

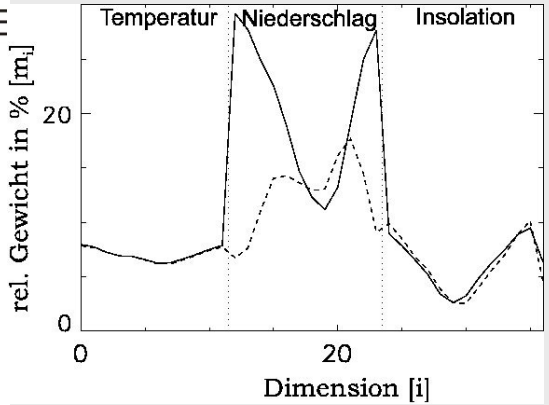
Changes in the circumpolar regions:
Upright hatched: northward shift of southern tundra border

Upper right to lower left corner hatching: northward shift of southern taiga border

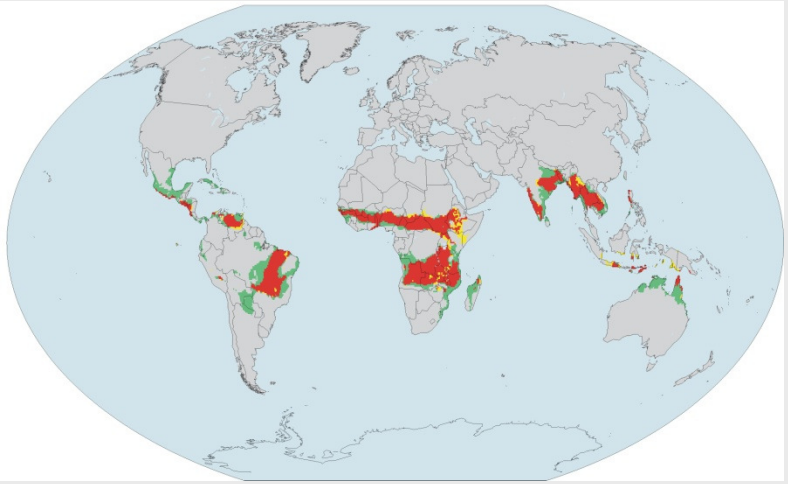
Kropp & Schellnhuber 2008, Kropp et al. 2005b

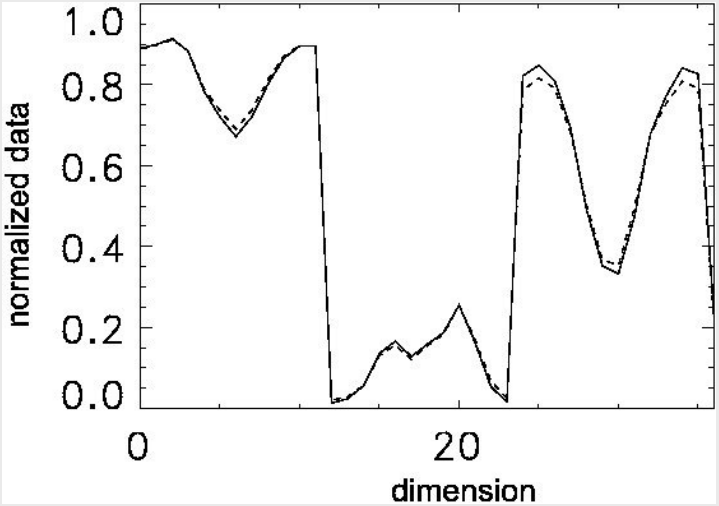
Vergleich Biome Modell/SOMTOP





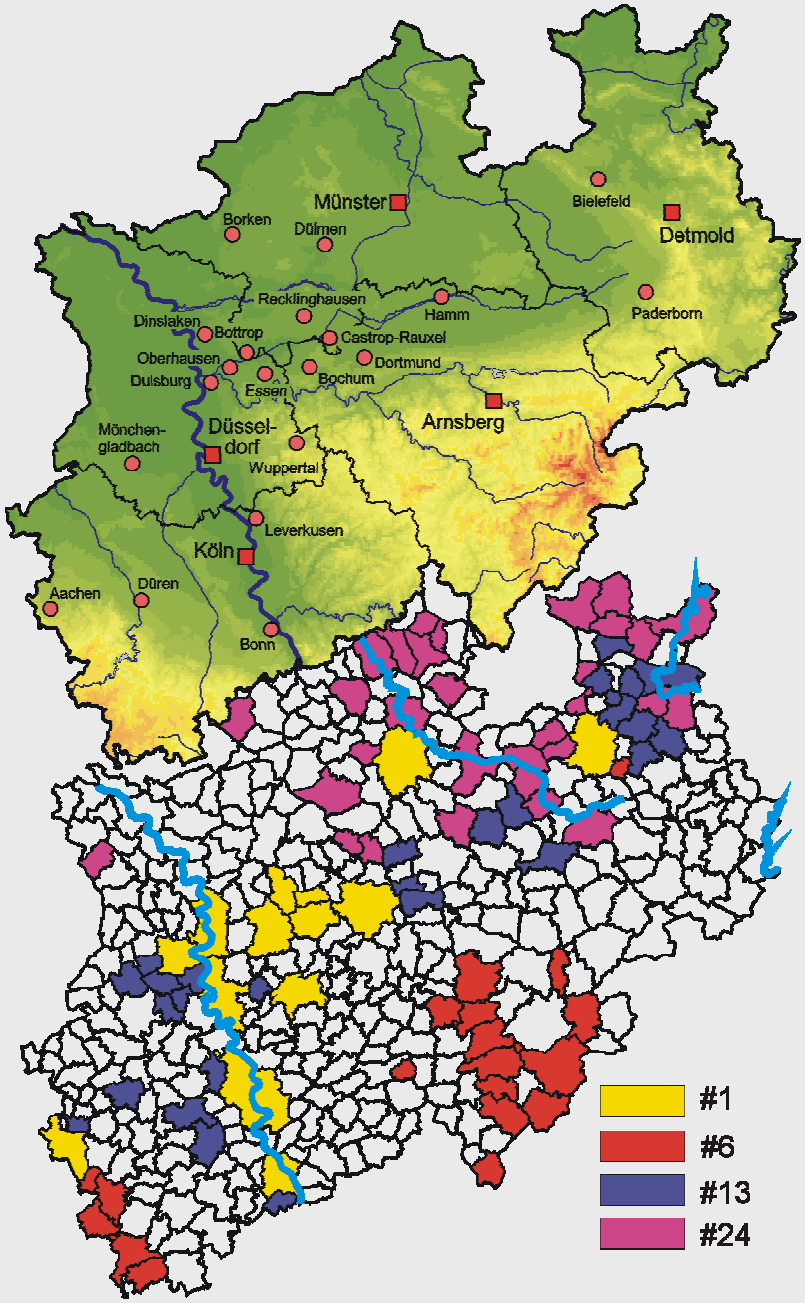
Leistung der SOM





Fast identisch, aber Minimierung der Varianz (> 25%)

Regional Distribution of Vulnerability Classes



#1: Industrial Centres (mainly Rhine-Ruhr basin)

#2: Recreation Regions

#13: Suburbs and Low Diversified Cities

#24: Rural Communities

Kropp et al. 2006

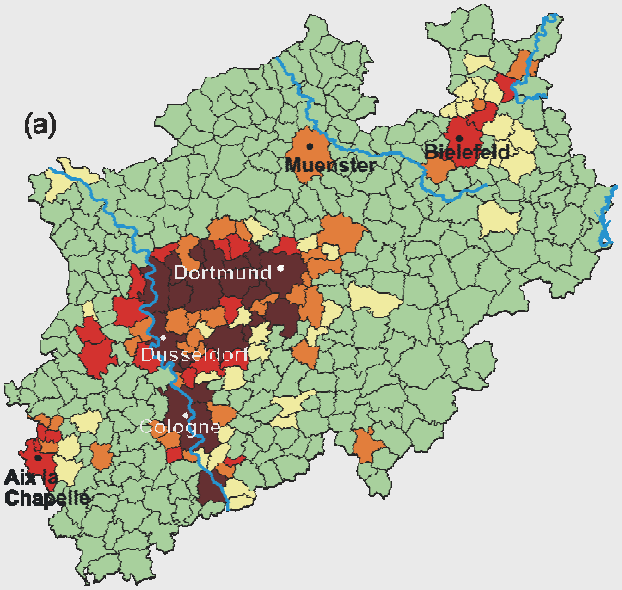
Sektorale Suszeptibilität

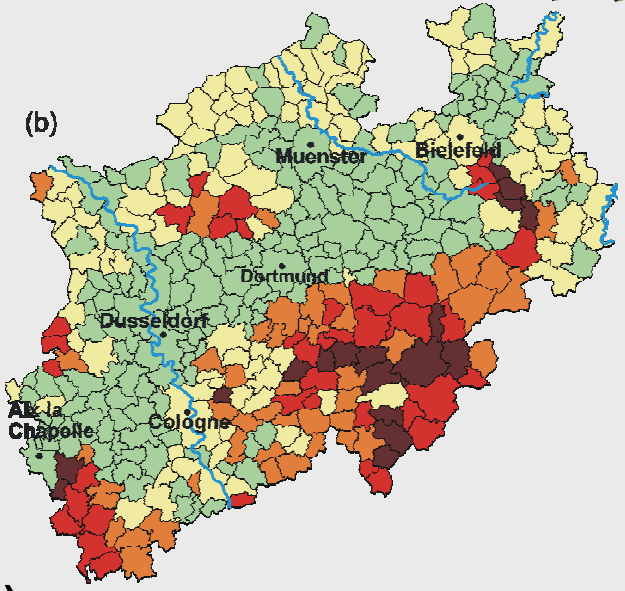
a) Heatwaves (population density, elderly people)

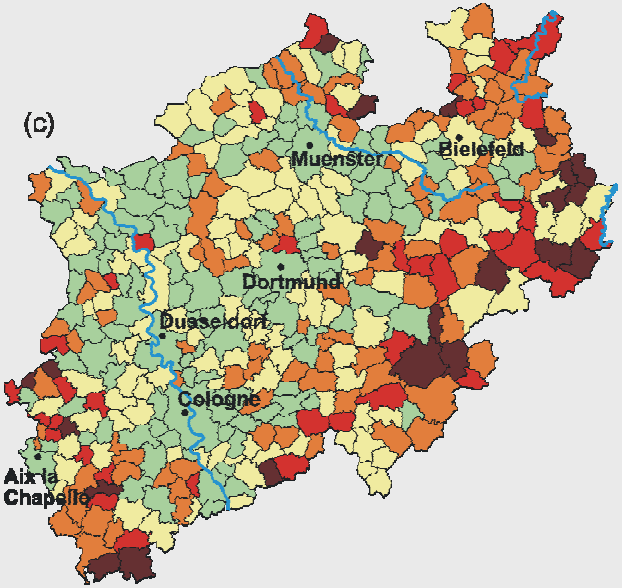
b) Forest sector (tree type composition)

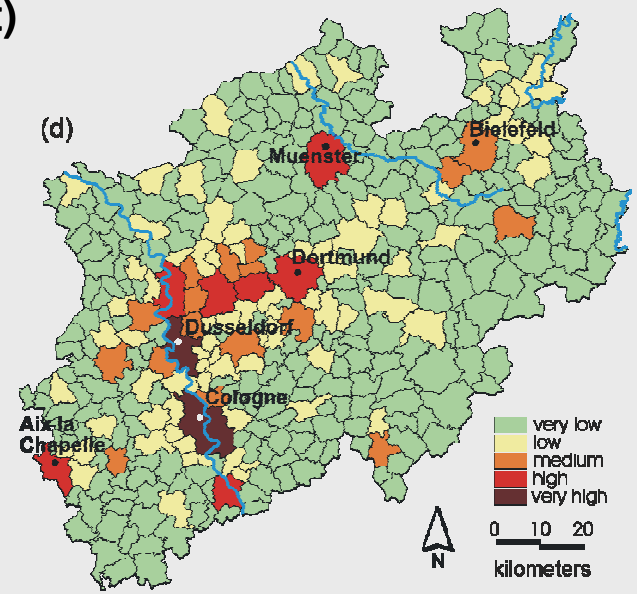
c) Local labour market (seasonal unemployment)

d) Production loss by traffic collapse through extreme events (commuting employees)







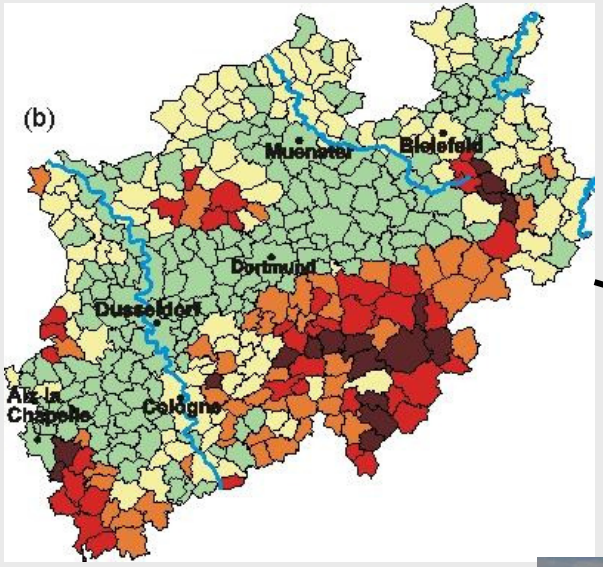


Source: Kropp et al. 2005, Climatic Change, forthcoming

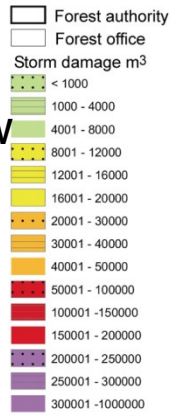
Sectoral Vulnerability North-Rhine Westphalia/Germany (1999)

Source: Kropp et al. 2006, Climatic Change

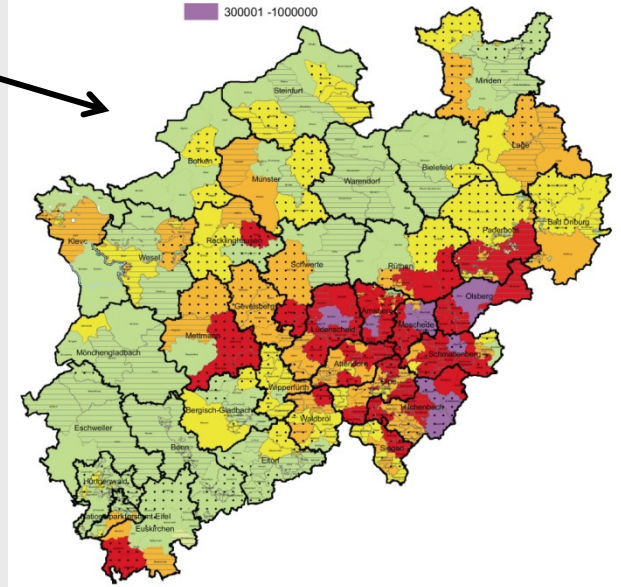
Stimulus: Storm
Exposed unit:
Forest sectors
Indicators:
Tree types, slope, rel. storm intensity/frequency

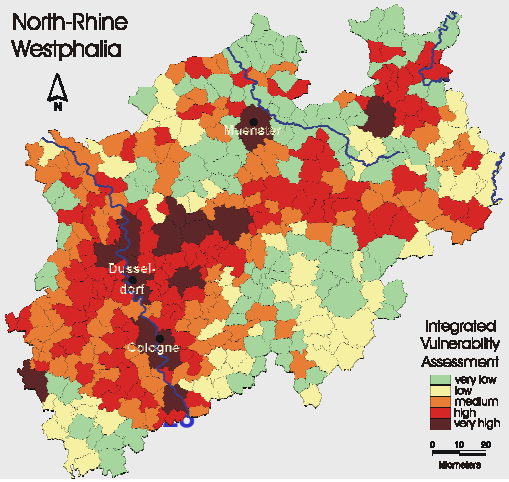


Vulnerability Assessments allow to identify risk prone areas in a comparative way!



Actual Damage 2007 after Cyclone Kyrill





Qualitative Differential Equations

Motivations

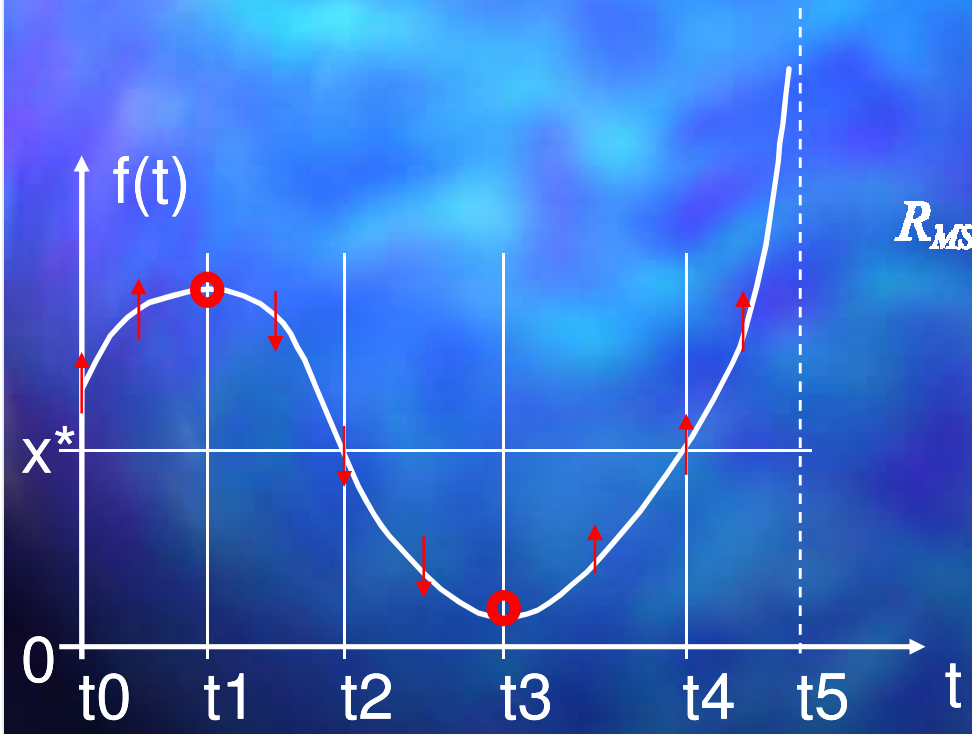
- Uncertainty
- Generalizing from particular cases
- Translating knowledge from different disciplines to a common language

Premises

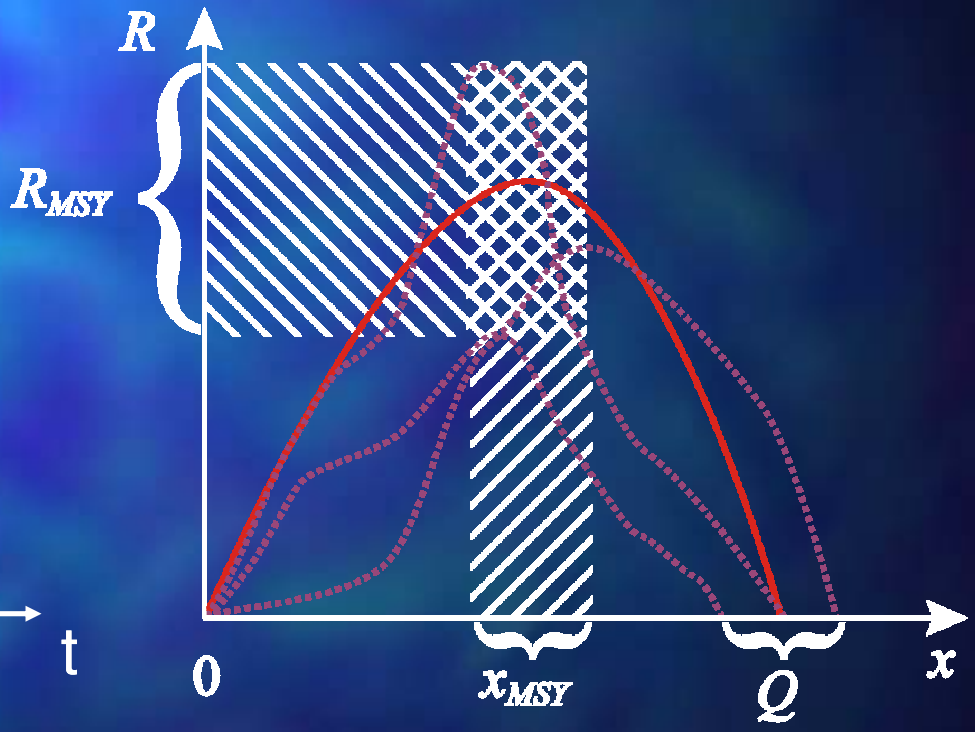
- The object under investigation can be structured by variables.
- Variables have ordinal scale and change continuously (they can be characterised by their direction of change).
- Some rules about the inter-relationship of the directions of change can be posed.

after Kuipers 1994

Example for abstraction of functions

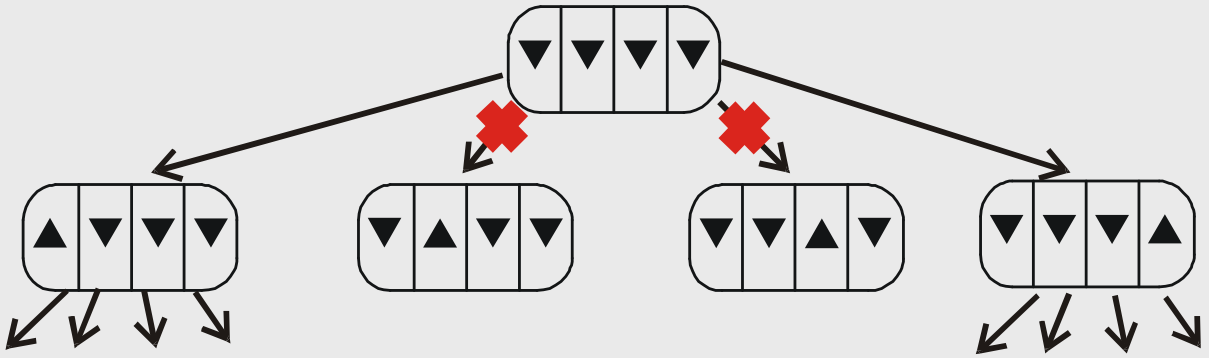


The standard recruitment case: Schaefer type



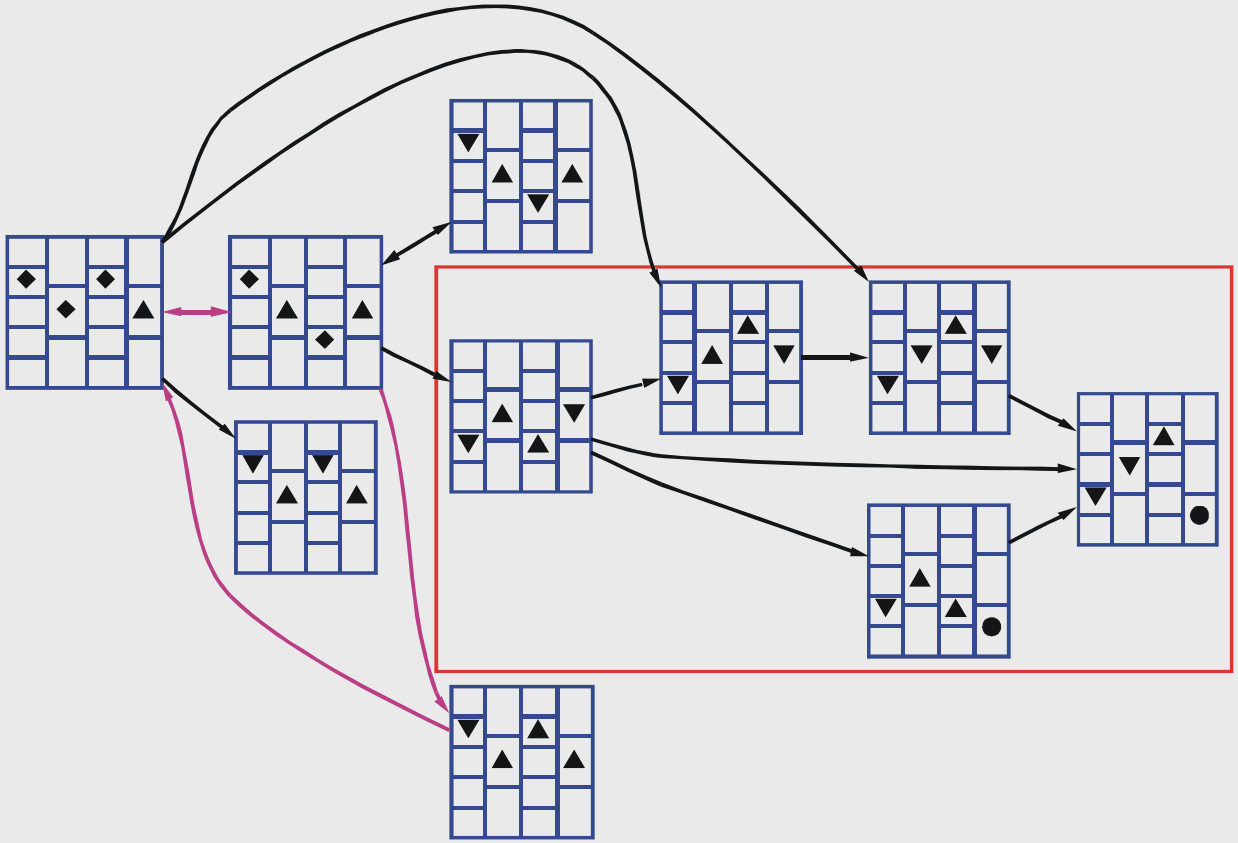
The Concept of Qualitative Differential Equations (QDEs)

- By the help of QDE you can indentify branchings in future developments: there is no single future. According to our restricted knowledge about the mechanisms multiple futures are possible.
- Like in intuitive scenario building we identify what is impossible or at least very improbable instead of trying to identify an unambiguous future development.



cf. e.g. Eisenack/scheffran/Kropp (2006)
J. Econ Dyn. Control

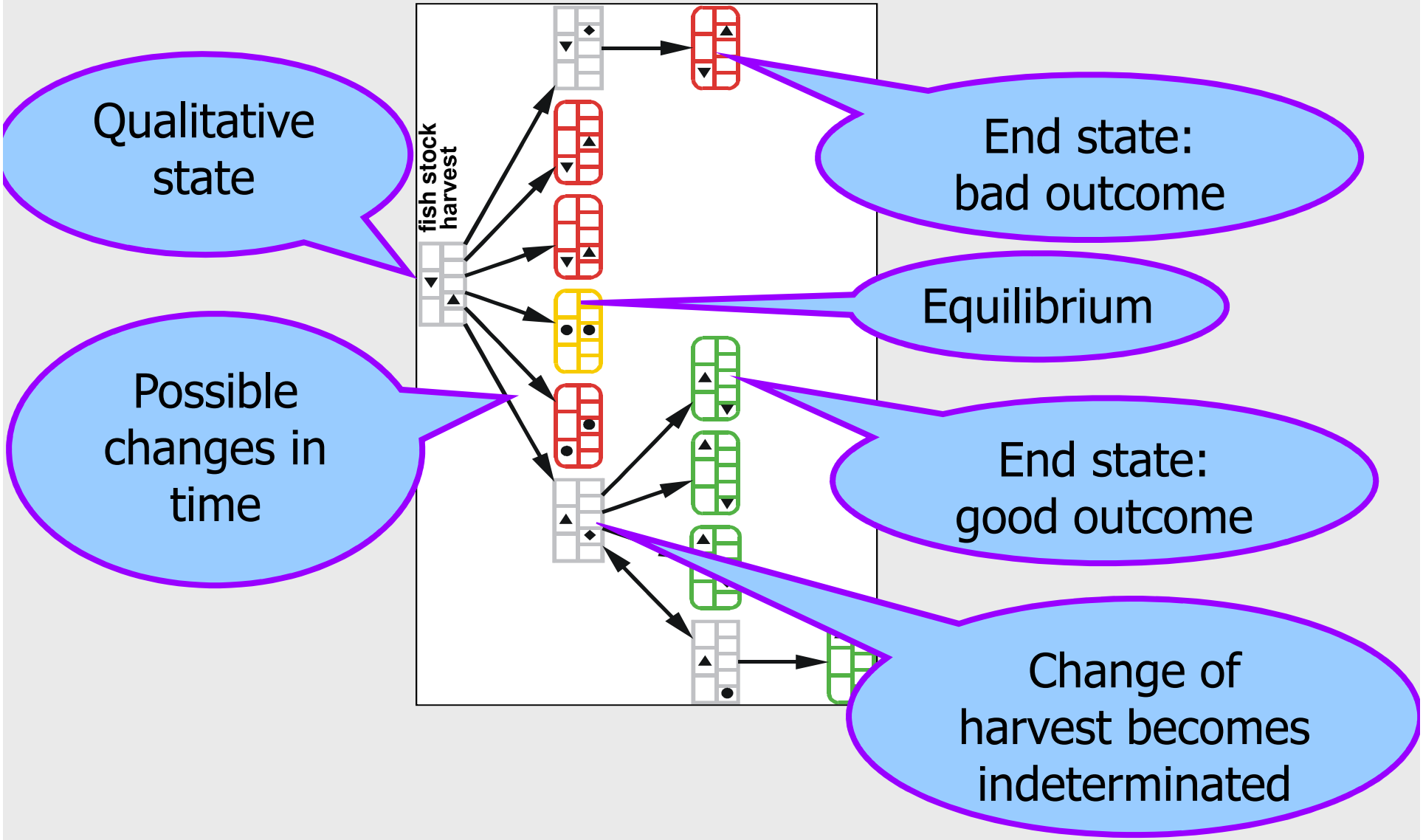
The State Transition Graph of a Qualitative Model



- Vertices: possible states of the system
- Arrows: possible transitions
- Structure: cycles and Lockings (= “dead end” or “vicious cycle”)

K. Eisenack and G. Petschel-Held (2002):
Graph Theoretical Analysis of Qualitative Models in Sustainability Science

Qualitative Differential Equations: Output of qualitative models



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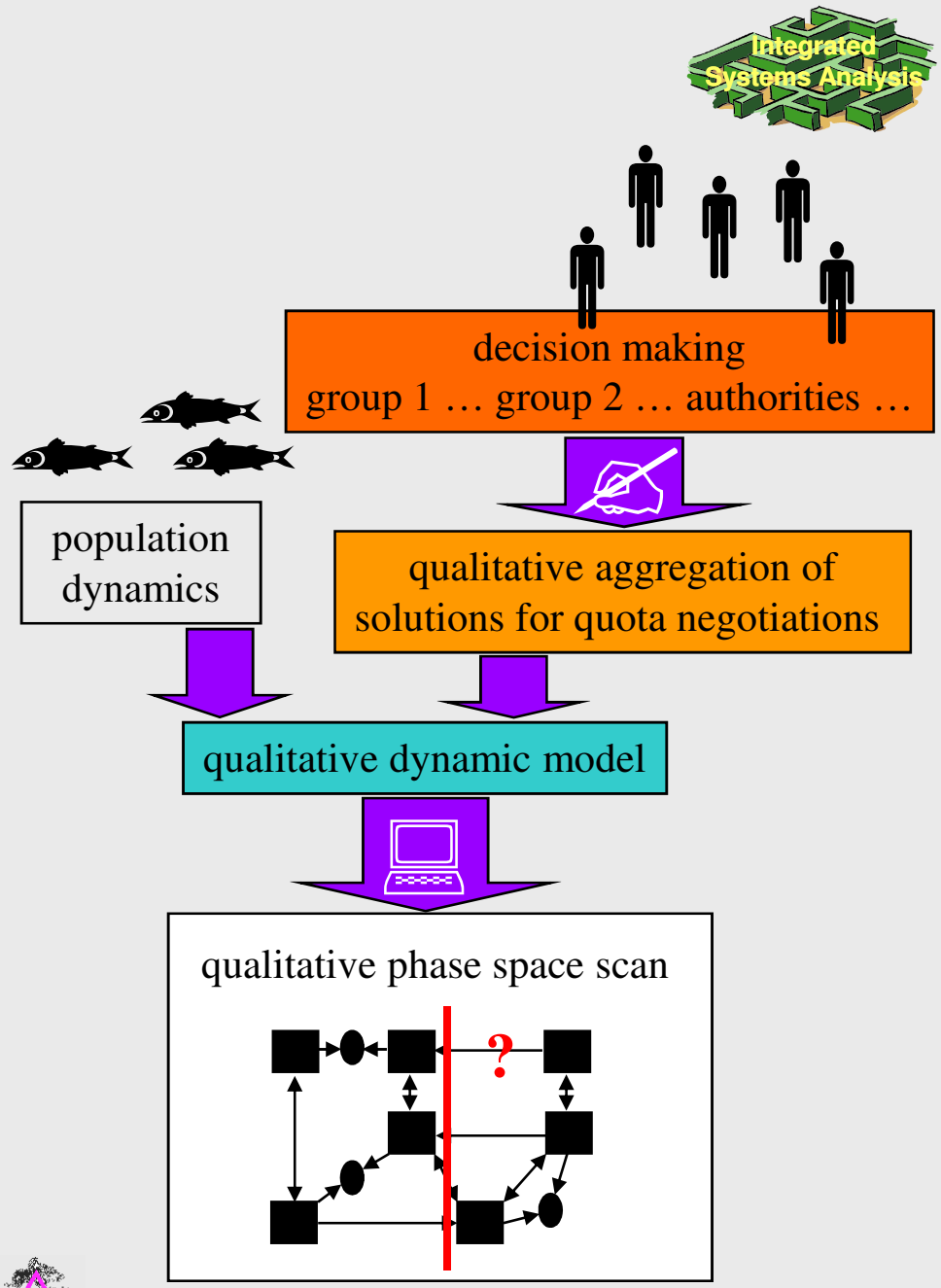
Modelling Strategy

- **Analytical model of population dynamics**
- **Analytical game theoretic model of decision making with heterogeneous agents**
- **Qualitative abstraction**
- **Simulation by Qualitative Differential Equations (QDEs)**
- **Identification of viable pathways**
- **Characterisation of pre-conditions for sustainable management**
- **Suggestions for effective managements**



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„Integrated“ Dynamic Fisheries Model

- Stock dynamics, and recruitment relation *R(x)*

$$\dot{x} = R(x) - Nh$$

- Aggregated harvest rate *h* which is an outcome of negotiation process

$$\dot{C} = I - \delta C$$

- Capital relation *C*, depending on investments and depreciation rate δ

$$\dot{I} = \frac{1}{C_{II}(I)}\left((\eta + \delta)c_I(I) + v_C\right)$$

- Investment function *I*

- Equality between marginal costs and marginal revenue

$$v_h = \left(1 - \frac{\varepsilon}{N}\right)p(Nh)$$

$$h = TAC(x, q_0, q_1, q_2, ...)$$

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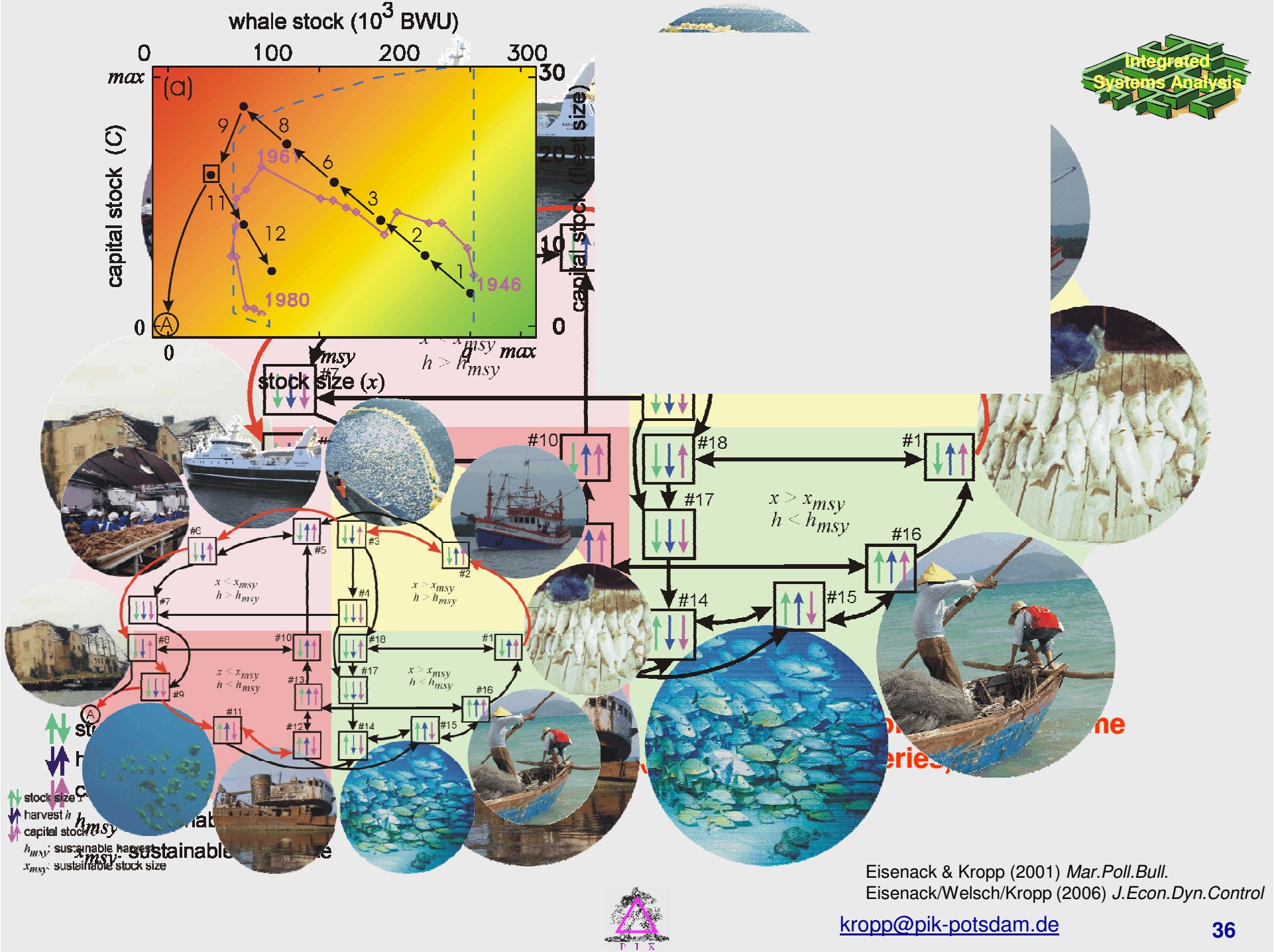

Eisenack & Kropp (2001) *Mar.Poll.Bull.*
Eisenack/Welsch/Kropp (2006) *J.Econ.Dyn.Control*

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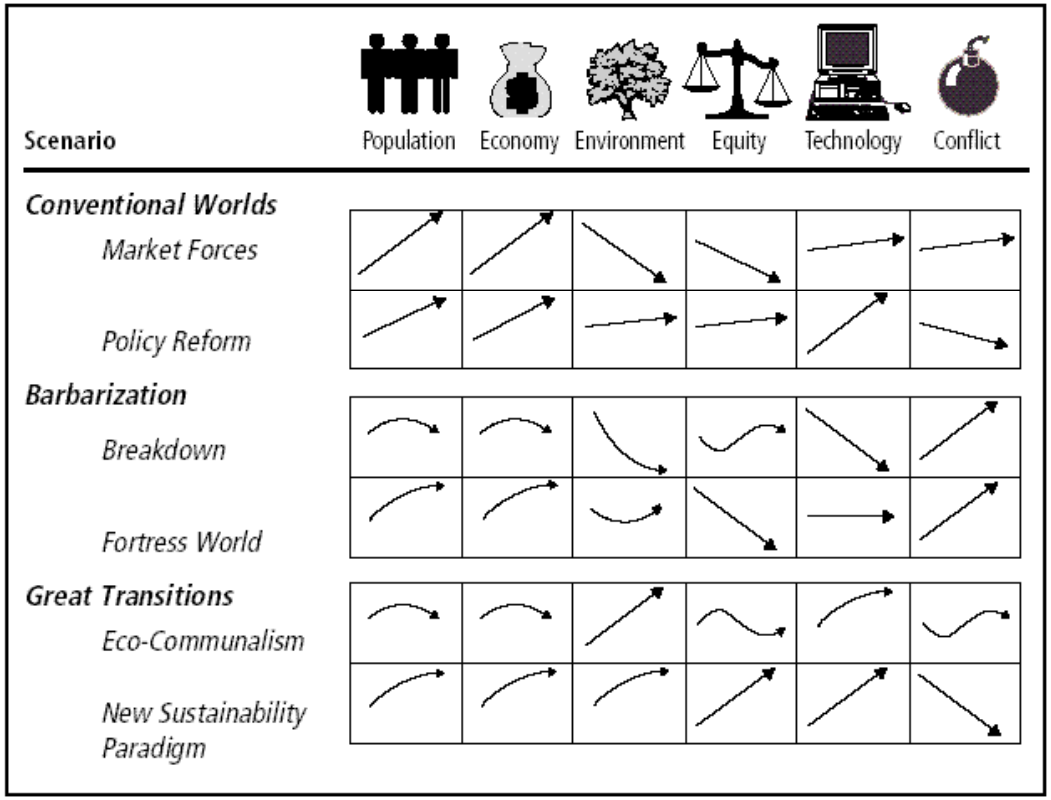
Scenarios: Narratives and Numbers

From. „Great Transition“, Raskin et al. 2002, Global Scenario Group, SEI



Source: Gallopín et al. (1997)

- **several** possible futures
- characterized by **trend-combinations**
- of generalized variables
- and changes of trend-combinations

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Fortress World: **A Narrative**

By 2002, the market euphoria of the last decade of the twentieth-century seems like a naïve and giddy dream. A global economic recession chastens the irrational exuberance of dot-com investors, and the 9/11 terrorist attack awakens a sleepwalking global elite

deteriorate. Multiple stresses—pollution, climate change, ecosystem degradation—interact and amplify the crisis. Disputes over scarce water resources feed conflict in regions with shared river basins. Environmental degradation, food insecurity and emergent diseases foster a vast health crisis.

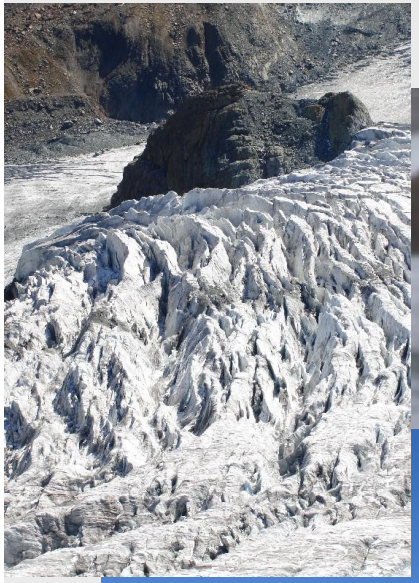
institutional frameworks. The affluent live in protected enclaves in rich nations and in strongholds in poor nations—bubbles of privilege amidst oceans of misery. In the police state outside the fortress, the majority is mired in poverty and denied basic freedoms.

- triggering single events
- mechanisms, to make the scenario plausible
- descriptions

Integrated Systems Analysis

Fragen, Kommentare, Diskussionsbeiträge.....

Impressions from Great Theodul Glacier – Matterhorn/Monte Rosa area, Swiss Alps; Sept., 2006; 3,200 – 4,300 m asl.



Thank you for your attention! Action is needed more than ever....

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