The paradigm of human-environment systems

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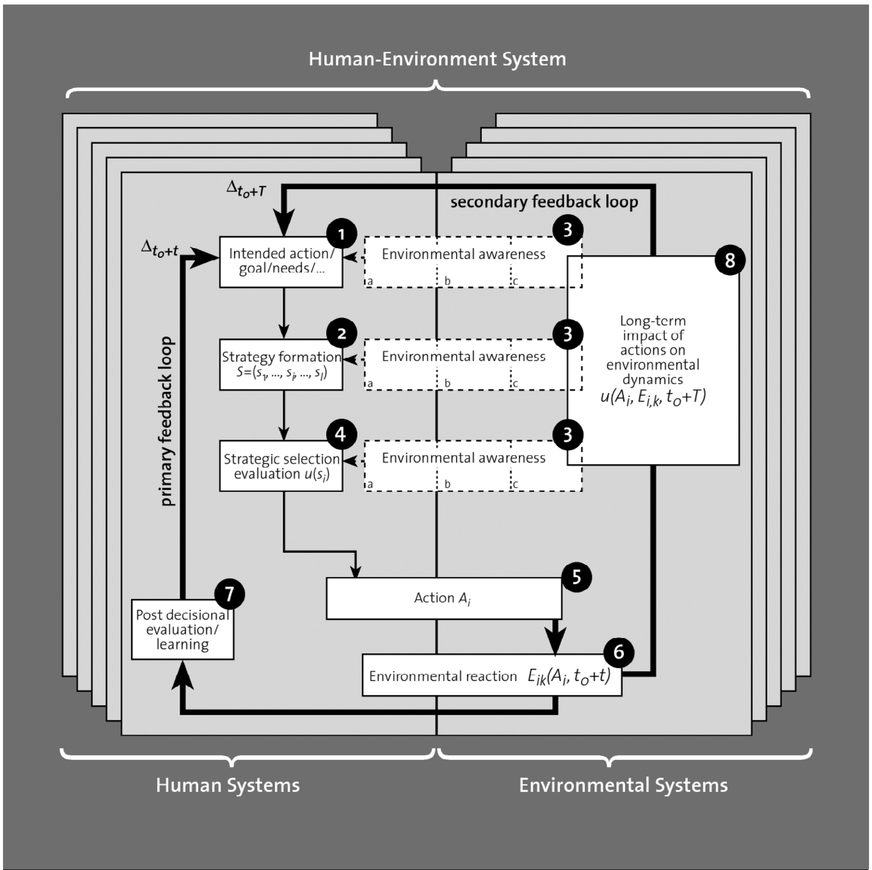

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The Paradigm of Human-Environment Systems

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Contents

Abstract

Human-environment systems (HES) are all environmental and technological systems that are relevant for or affected by humans. This paper presents a process structure model (PSM) to investigate regulatory, feedback, and control mechanisms (RFC-mechanisms) in HES. The model separates human and environmental systems. The interaction between both systems is given by the environmental awareness of humans and the short- and long-term environmental impacts and feedback loops of human action. Human decision-making is considered a key factor in this model, as humans can regulate and control the type of interaction within HES. The model distinguishes between goal formation, strategy building, strategy evaluation, action, and evaluation/learning. The environmental system reacts and gives feedback to human action, allowing for humans to learn and adapt their behavior. Evaluation/learning is based on the feedbacks of the environmental system to human action. We distinguish various types of environmental awareness and learning, which differ with respect to time and spatial ranges (primary and secondary feedback loops). Human systems are conceptualized on a multi-level hierarchy including cell, organ, individual, group, organization, and society a systems. Each level differs in its regulatory and control options regarding HES, as well as in the perceived environmental feedback. We illustrate the model with an example from environmental hygiene.

Key words: Human-environment systems, regulatory mechanisms, control mechanisms, feedback mechanisms, interfering regulatory mechanisms, cholera, the Black Death

The Rationale of the Human-Environment Systems Paradigm

Human-Environment Systems (HES) are conceptualized as a mutualism between two different systems that exist in essential dependencies and reciprocal endorsement. The HES-relationship is not symmetric, yet the mutuality is considered beneficial or necessary for existence for at least one of the two subunits of this system. Examples for mutualisms in different disciplines are: the predator-prey relationship in biology (Volterra, 1931), the mother-child connection in developmental psychology (Bowlby, 1951, 1982), or the doctor-patient relationship in medical sciences (Silverman, 1998).

The term human systems has been used since the time of the ancient Greeks with respect to the meaning of social systems, ranging from society to individuals (Apostle, 1952). These systems are supposed to have a memory, language, foresight, consciousness etc. In contrast to the concept of human or social systems, the term environmental systems is not older than 200 years. The definition of environment as the "conditions under which any person or thing lives or is developed; the sum-total of influences which modify and determine the development of life or character" (Simpson & Weiner, 1989 p. 315) arose in the 19th century, when environmental impacts of the industrial age could already be readily observed. Our notion of systems refers to J.F. Miller, who defines systems as "a set of related definitions, assumptions, and propositions that deal with " cut-outs of" reality as an integrated hierarchy of organizations of matter, energy", and/or organisms (Miller 1978, p. 9).

Because of the novelty of the term environmental system, research under the name environment is relatively new. Table 1 differentiates between one sided and mutual impact chains and between different viewpoints that dominate research on the human environment relationship. The $E \rightarrow H$ *impact chain* has predominantly been studied from the human perspective. Indeed, Hippocrates had already dealt with environmental impacts on human health in early medicine in 420 BC. Environmental psychology, for example, primarily focuses on "the influence of physical and social features on large-scale, everyday environments of human behavior and well-being" (Stokols, 2000, p. 220; see also Stokols & Altmann, 1987; Bronfenbrenner, 1979).

The $H \rightarrow E$ *impact chain* was also initially examined from the human perspective. In the early 18th century, forest engineers investigated how legal or economic restrictions affect the texture of forests (von Carlowitz, 1732). Agricultural, forest, and resource economics have evolved from these beginnings such that modern analyses focus on the question of how agricultural and forest yields can be most efficiently obtained (Goodwin, 1977; Drummond and Goodwin, 2001) From the environmental research perspective, the $H \rightarrow E$ impact chain has quite a different focus, namely how human activities affect the environment or environmental equilibrium and how these impacts can be mitigated (Wood, 1995, Freedmann, 1995).

The reciprocity between human and environment systems, or the $H \leftrightarrow E$ *impact chains*, can be approached from the environmental as well as from the human perspective. The former looks at optimizing environmental quality by integrating human models into ecosystem analysis (Naveh & Lieberman, 1994). The latter investigates the impact of regulatory mechanisms on the state of the environment, taking an anthropogenic perspective (Hammond, et al., 1995). For example, "human ecologists study the influence that our surroundings exert on the physical and social growth of humans from conceptus to death" (retrieved from the net, 13.02.03, Clarke, 2003; Tengström, 1985).

A special focus is given to *H∩E* within the $H \leftrightarrow E$ relationship. The GAIA approach (Lovelock, 1979) "views the earth as a single organism, in which the individual elements coexist in a symbiotic relationship. Internal homeostatic control mechanisms, involving positive and negative feedbacks, maintain an appropriate level of stability." (Kemp, 1998, p.160) GAIA is an example of an integrative, qualitative approach for studying HES. Integrative modeling starts from coupled systems and provides a quantitative analysis (Bossel, 1998; Carpenter et al., 1999; Walker et al., 2002). Many of these modeling approaches are shaped by general system theory.

Table 1: *Examples for research fields on HES according to the focused impact chain(s).*

	Primary object of research	
Impact chain	**Environment system**	**Human system**
$E \rightarrow H$	—	Toxicology, public health, environmental psychology, human geography, etc.
$H \rightarrow E$	Environmental natural sciences (e.g., environmental chemistry); conservation biology, soil protection, Environmental Impact Assessment	Agriculture, forest, food, and resource economics or management
$E \leftrightarrow H$	Integrative Ecosystems, Landscape ecology, Biocybernetics, etc.	Human ecology, Pressure state models, etc.
	H∩E	
	GAIA, General system theory, Integrative modeling, HES	

Most of the proponents of the various aforementioned integrative approaches (H∩E) operate either at a specific scale, (e.g., Carpenter et al., 2002, performed integrated modeling at a regional scale) or utilize one concept as the basis for their investigations and then integrate across scales, (e.g., general system theory, Miller, 1978). However, to our knowledge no systematic link of these two approaches, in particular, general system theory and integrative modeling, has been carried out. That is, the approaches either remain at one scale-level and investigate certain feedback loops or they identify different levels in a system hierarchy but neglect either the interaction among these levels or the feedback loops between the human and environmental system.

In this paper, a first step is made towards overcoming this gap. With the HES paradigm we present a process structure model (PSM), which is derived from integrative modeling, system theory, basic cybernetic feedback loop modeling, cognitive sciences, and decision research (Ashby, 1957; Simon, 1957; Scholz, 1987). The PSM allows for investigating regulatory, feedback, and control mechanisms (RFC-mechanisms) in HES. We focus on understanding the mechanisms rather than on describing and defining units of operation. The HES paradigm includes three main characteristics:

Higher ordered feedback loops: Game theory (Harsanyi, 1967), clinical psychology (Laing, 1967), cognitive sciences (Freeman, 2000) and other branches consider higher ordered feedback loops as a means to model stable systems. Multiple feedback loops are considered to function as a balancing strategy in coupled systems because of the interaction between positive and negative loops. HES research investigates higher ordered feedback loops within and between the human and environment systems.

Interfering regulatory mechanisms: The understanding of interfering regulatory mechanisms has become one of the scientific challenges of HES-research. For ecological systems, this has already been acknowledged by Hartvigsen, Kinzig, & Peterson (1998) who stated that: "Understanding how change on one level of biological organization will alter emergent patterns or mechanisms at another level of biological organization is one of the most pressing problems in ecology." (p. 429)

Relating and integrating disciplinary knowledge: The PSM model and the hierarchy concept proposed in the HES paradigm overcome the disciplinary structure of research but allows for utilizing the potential of disciplinary knowledge. The multi level hierarchy of human systems makes the relationship to disciplinary knowledge explicit as disciplinary views from microbiology, environmental psychology, business sciences, earth sciences etc. can be allocated to a specific hierarchy level. Within each level, insights from sub-disciplines can be integrated into the PSM. This is particular of interest, if sustainable action is the object of research: "One way to generate more robust foundations for sustainable decision making is to search for integrative theories that combine disciplinary strengths while filling disciplinary gaps." (Gunderson, Holling, & Ludwig, 2002, p. 8).

Structure of the paper

We *first* present a *blueprint of the processes-structure model* of HES. This model comprises the basic units and the central processes of the HES relations that can be applied to the different levels of human systems. *Second*, we introduce a *multi-level hierarchy of regulatory systems*, i.e. cell, organ, individual, group, organization, society and supra-national. For these levels we provide a definition of core concepts and introduce processes and mechanisms that are offered as examples to understand the dynamics. *Third,* we illustrate with an example from epidemiology how the HES paradigm and the hierarchy levels can be used as tools for understanding the complex phenomena of HES.

Theoretical foundations

A blueprint of a HES-research framework

Figure 1 presents a structure-process model for investigating HES. It is based on game and decision theory and includes principles from cybernetics and allows for understanding the structure of the relationship between the human and the environmental system. Thus, regulatory mechanisms, feedback loops and potential control mechanisms (RFC mechanisms) can be represented.

The model is divided into human systems (left) and environmental systems (right). The plural is used here to indicate that different systems (e.g., differing in subject matter or physical scale) can be considered on both sides (as indicated by the different layers in Figure 1). For example, in the human systems different hierarchy levels are identified (see below, e.g. Figure 2). The interface between both systems is given by the environmental awareness of humans (3) and the environmental impacts (short (6) and long-term (8) reaction) of human action (5).

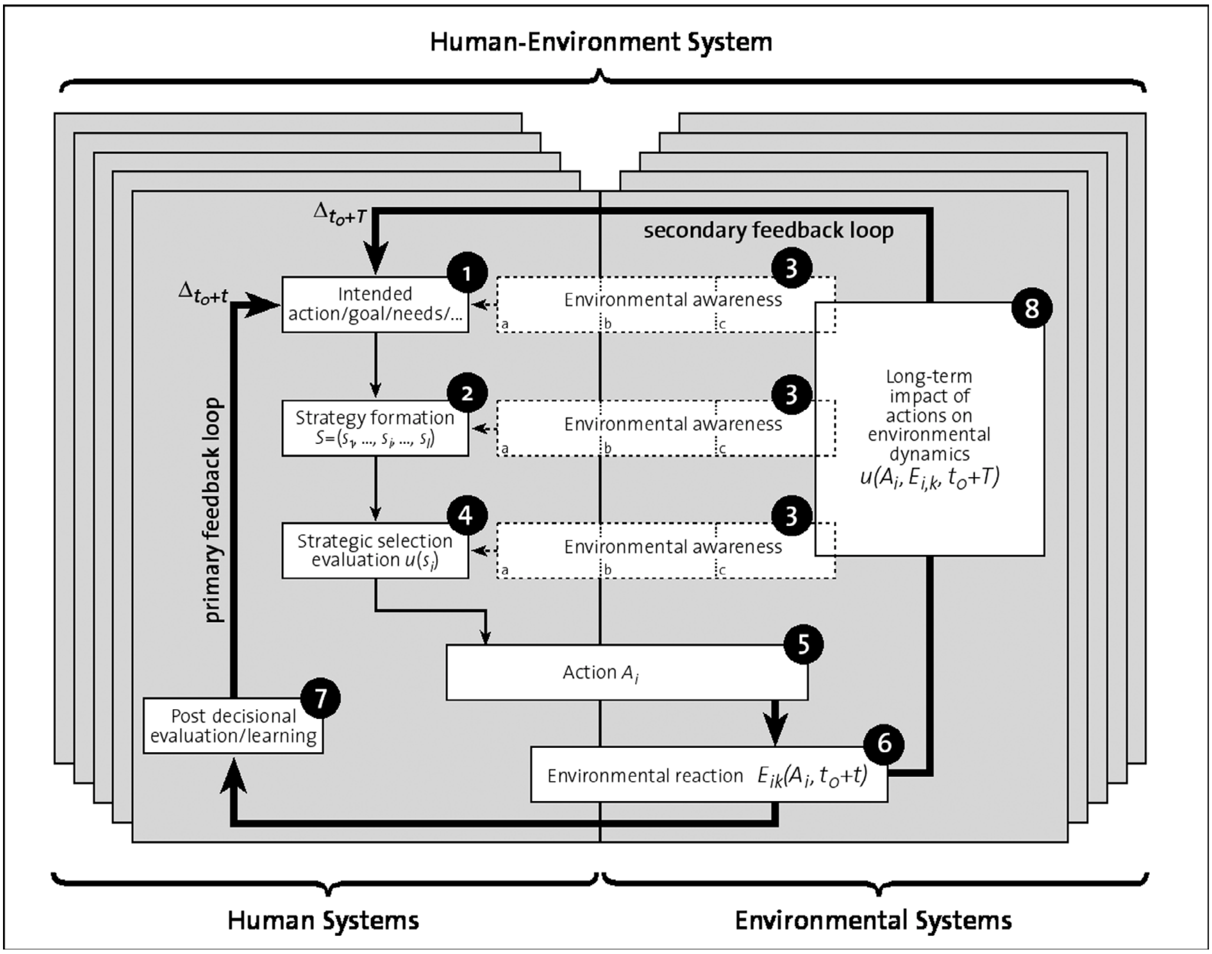

Figure 1: *A structure - process model of HES. The numbers 1-8, correspond to structures or processes explained in the text. The notion of the letters a, b, and c in the environmental awareness boxes are explained in the text.*

We start with intentions or goals (1), as we consider human behavior to be goal directed and purposeful (Brunswik, 1952, Scholz & Tietje, 2002,). In order to conceptualize mutualism in HES, we introduce the environmental awareness box (3) in the model. The degree of environmental awareness in the human system determines the extent to which environmental concerns are included in goal formation. We, thus, distinguish between (a) self-centered, environmentally ignorant goals, (b) environmentally sensitive, aware, or conscious goals, and (c) environmentally directed goals. In self-centered goal formation, the environment is completely ignored or treated as a constant, unlimited, static resource pool. When defining environmentally sensitive goals, the human system shows environmental awareness or environmental consciousness, which consists of a heightened perception, cognition, and appreciation of both the options and the consequences of potential action on the environment. For environmentally directed goals (c), such as environmental protection or deep ecology (Drengson, 1995), the environment can become the main or exclusive subject of goal formation.

Strategy formation (2) follows goal formation. In this context we refer to a game theoretic conception of a strategy in extensive games (Osborne & Rubinstein, p. 92). We define a strategy, $s_i \in S$, as a complete plan that provides a behavioral directive for each situation in the course of goal attainment and postulate that human systems build a set of strategies $S := (s_1,...,s_i,..s_I)$. Strategy formation in human systems can show the same differentiation with respect to environmental awareness as in goal formation (see Figure 1). For the sake of simplicity and without loss of generality, we only consider a countable set of action alternatives.

Strategy selection is tied to evaluation (4) and precedes action. We assume that the human system can subjectively evaluate the supposed expected utility or gain of a strategy, denoted $u(s_i)$. This stage is called foresight or anticipation. We speak of environmental awareness at level c) at this stage if the consequences, i.e., the environmental changes caused by an action, are completely included in the evaluation.

A_i is the action resulting from a strategy s_i, under given environmental circumstances and constraints[1]. The human and the environmental systems physically alter after a human action. Many actions resemble decision making under uncertainty, as the human system does not know, which impact (here environmental reaction (6)) $E_{i,k} \in E(A_i) := (E_{i,1},...,E_{i,k},...,E_{i,K})$ will result if an action A_i is carried out.

[1] In the ideal, deterministic case A_i is completely determined by s_i. However, in the probabilistic real life situation, strategies have to be designed when the concrete situation is not yet completely known or fixed. Thus, it is not foreseeable which action A_i will be elicited from s_i because of uncertainty either in the environment or probabilistic choice mechanisms in the human system.

Within the human system a post-decisional evaluation (7) takes place in close temporal relation to the environmental reaction and can be conceived of as learning. The human system is supposed to learn based on the planned behavior (i.e. goal formation, strategy evaluation), the shown behavior (i.e. action) and the reaction from the environment (i.e., reaction). This is done by a triple difference assessment $\Delta_{t_0+t} := \Delta_{t_o+t}(u(s_i), u(A_i), u(E_{i,k}))$ of the "expected" utility of a planned strategy $u(s_i)$, the utility of an action, $u(A_i)$, and the utility of a return from the environment by an event, $u(E_{i,k})$. We consider the effect of post-decisional evaluation on goal formation to be the primary feedback loop.

The post decisional evaluation is considered to take place in close temporal relation to the environmental reaction. This is indicated by the time variables $t_0 + t$. The small t indicates a (small) time range that is considered to be temporally proximate to the action. However, human action can result in side effects, i.e. unintended dynamics, which alter the environmental system in a favorable or unfavorable manner. Side effects are often delayed or dislocated, as, from the human system perspective, they are not directly related to the perceived environmental reaction. These temporal (or spatial) delays (dislocations) in the environmental system are considered to be second order feedback to the human system (indicated by the variables $t_0 + T$), as the individual will notice the effects later (or at other places). A critical question is whether, in which way (i.e. by which "algorithms"), and when a delayed or dislocated impact is evaluated.

As indicated by the term $\Delta_{t_0+T} := \Delta_{t_o+T}(u(s_i(t_0)), u(A_i), u(E_{i,k}(t+t_0)), u(E_{i,k}(t_0+T)))$, human systems also learn by comparing the intended outcome of a selected strategy and the utility resulting from an event that was caused by an action at time t_0 (if the expected utility of a planned strategy $u(s_i)$ and action, $u(A_i)$ are still accessible by the human system's memory), with the evaluation of the side effects at time $t_0 + T$.

Of particular interest is the fact that human action at one level of the human systems, may lead to environmental impacts, which in turn provide feedback to the human systems at a level different to the one of action. That is, feedback loops do not necessarily occur within one scale or level of the human system, but across levels. In addition, the human systems might differ in their goals, and strategies, generating interfering actions and environmental feedbacks. For example, fast financial success in a market can trigger slow, but deep changes in structures on another level. "Thus modern economists are frustrated in their attempts to understand the interactions between fast- and slow moving variables that create emergent dynamics." (Gunderson et al. 2002, p. 8)

A multi-level hierarchy: Conceptualizing human systems

Human systems can be conceptualized by using the hierarchy principle dating from time of Aristotle (Apostle, 1952; Patee, 1974; Simon, 1974; Silverstein, 2000): "… control or regulation mechanisms that produce stability are usually interpreted in terms of hierarchy, …" (Forman, 1995, p. 505) A hierarchy of human systems can differ in range, degrees of differentiation and perspectives. For HES analysis we depart from Miller's (1978) seven hierarchical levels. At each hierarchy level specific human – environmental relationships and regulatory mechanisms are encountered. Figure 2 presents a hierarchy ranging from the cell level through the organ, individual, group, organization, and society levels with the final level being that of supranational or global systems. According to the hierarchy principle, each higher level includes the lower ones. In this paper we do not deal with the supranational level.

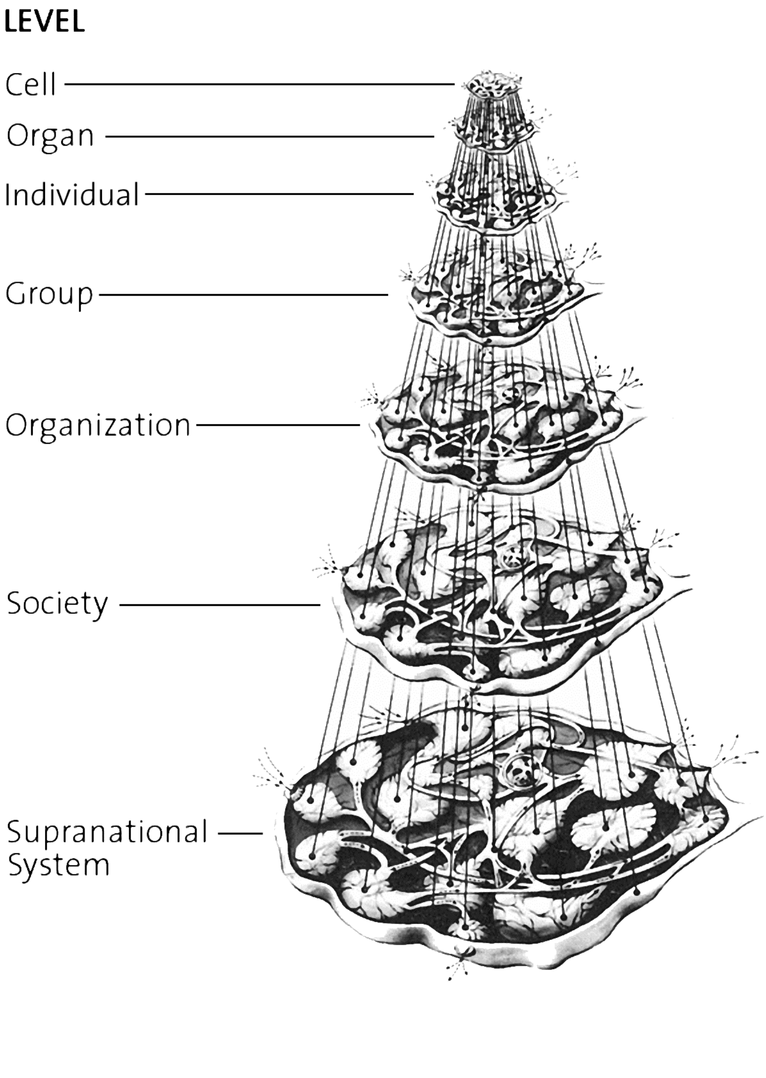

***Figure 2:** Levels of hierarchy modified according to Miller (1978).*

Table 2 provides a brief definition, examples, and some regulatory mechanisms that are essential in shaping the human-environment interaction for each hierarchical level. At each hierarchical level, the regulatory mechanisms refer to the elements and relations presented in Figure 1. Conceptualizing the regulatory mechanisms is considered the most important part of HES research. In this paper we only deal with two issues, which might be uncommon to the environmental scientist: (i) The role of concepts as a crucial unit in regulation from the individual level to the societal level; and (ii) the role of institutions and institutionalization.

Concepts are the building blocks of cognition and an efficient means of reducing complexity. Concepts such as "miasma", "resilient", "no risk", "safe", or "sustainable" produce categorizations and may function as attractors in goal formation and strategy selection. For example, risk can be seen as a specific evaluative function in strategy selection[2] at all hierarchical levels (at least) starting at the individual. Risk combines the evaluation of the probability and the outcomes of uncertain events, which are linked to action alternatives, A_i. In answering the question which risks are acceptable, western society has implicitly agreed to accept the new environmental or technological risks to which people are exposed, if the mortality rate is less than 1/100,000 (Wilde, 1994). However, both society and individuals differ largely. Fischhoff et al. (1979) have shown that risks from voluntary activities tend to be judged lower and are thus more likely to be accepted. Thus the mortality rate of car accidents is about 10/100,000 and of smoking 300/100,000 (CDC, 1999). These mortality rates and the question which risk is acceptable are matters of dispute and measures both on and between many levels of human systems. For example, an individual has to tradeoff the benefits and the potential harms of smoking. However, the fact that he/she smokes also has an impact on the levels of his/her peer group, health insurance, and society.

Society per se has larger time scales than lower hierarchical levels, e.g. organizations, or individuals. Society has the specific task of managing environmental dynamics and establishing secondary feedback loops (monitoring systems) to secure its own future (i.e., quantity and quality of resources). Institutions provide a structure by which society can fulfill these goals. They give the boundary conditions for strategy selection at all hierarchical levels. Institutionalization itself takes place in a secondary feedback loop.

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[2] Note that the risk concept and risk management can be traced back 5.000 years to the Mesopotamians (Oppenheim, 1977). According to Slovic, Fischhoff, and Lichtenstein (2000), risk has a kind of personality. Obviously, decision makers are not only taking the statistical data into account, but are rather strongly influenced by their own interpretation of the situation characteristics. For instance, air travel is judged more risky than travel by car though it is much safer on a per mile basis. This clearly is due to the uncontrollability of air travel by passengers and the cognitive salience of spectacular accidents (see Nisbett & Ross, 1980).

Table 2: *Brief definition, examples, and some regulatory mechanisms that are essential in shaping the human-environment interaction.*

Hierarchy level	Definition	Example	Regulatory Mechanism (examples only)
Cell	Smallest self-functioning unit composed of: (a) a boundary (b) a reproduction unit, (c) a power plant, (d) a production unit, and (d) a clean up mechanism to adapt to the environment (Miller, 1978)	Eukaryontic Prokaryontic cells	• Change of proportion of volume and number of cell nuclei to cell organelles (primary feedback loop) • Mutation (secondary feedback loop) • Classical conditioning (learning, Brembs. et al., 2002)
Organ	Part of the body with special functions, which depends on other parts of the body for functioning. The functions all covered by each cell are divided into different organs Riede et al. 1989)	Heart, lung, liver, kidney	• Regeneration by building new tissue (self regulation) • Adaptation by changing the number of cells depending on stress (primary feedback loop) • Loss of function when over demanded (primary or secondary feedback loop; secondary in case of chronic demands)
Individual	A single person with a specific life history, stage of development and experiences. The individual is governed by driving forces such as (i) drives (Freud, 1920; Lorenz 1963) (ii) needs (Maslow, 1954; Douglas et al. 1998) (iii) emotions (Izard, 1977; Keltner & Ekmann, 2000) (iv) motivations (Weiner, 1990; 2000) (v) attitudes (Fishbein & Ajzen, 1975) (vi) values (Rockeach, 1973; Schwartz 1992) (vii) cognitions (Neisser, 1976)	Pupil, adult	• Consistency, equity, and balance as ubiquitous principles (in strategy selection and post decisional evaluation, Festinger 1957)) • Positive attractors (imitation, learning through models, Bandura, 1971; e.g. in goal formation and strategy selection)
Group	Defined amount of people, who interact and form a unity in a defined period of time for a defined task and in a certain place. There is no formal requirement to enter a group. Open, closed, psychological, sociological and other groups can be differentiated	Play group Skaters, environmentalists	• Group norms (Ash, 1956); Conformity (Sherif, 1935; goal formation and strategy selection) • Dominant person/authority pressure (Milgram, 1974; strategy selection, primary feedback loop) • Decision schemes (e.g., absolute or relative majority, Davis, 1973, strategy selection)
Organization	Social systems or economic subunits, which produce goods or motivate and coordinate people to certain actions. Membership is necessary.	Firms, World Wildlife Fund	

(will be continued on next page)

Table 2 *(continued)*

Hierarchy level	Definition	Example	Regulatory Mechanism (examples only)
Society	A historically established association containing interrelated, interdependent parts, which are social structures or subsystems (see (i) to (iv) and institutions (Parsons, et al., 1951).	Western, eastern society	
	(i) Economic subsystem: Facilities, measures and transactions that relate to the production, trade and consumption of goods	Market economy Centrally planned economy Barter economy	Regulatory mechanisms related to market economies: • Emission charges (Hanley et al., 1997), Subsidies, market permits (Crocker, 1996; Dales, 1968), etc. (primary feedback loop)
	(ii) Legal system: Normative rules and societal conventions required for keeping upright a society. It includes laws, conventions and practices within a society	Roman law Anglo-Saxon law	Constitution, laws, norms, and decrees (e.g., environmental regulation and decrees; goal formation, strategy selection, secondary feedback loop)
	(iii) Political system: Characterizes the regime and the authoritative structure of a society	Democracy Dictatorship Oligarchy	• Regulation occurs through the release of laws or implementation of market mechanisms
	(iv) Cultural system: Reflects preferences and values of a society in language, science and art. The bases are the moral, ethical and religious standards of a society.	Swiss French American	• Guided variation: learning and rational calculation in response to environmental changes (information as driving factor), strategy selection, primary feedback loop • Biased transmission: selection of information and strategies based on specific preferences (e.g., satisfaction) • Natural selection: dying of culture because they selected the wrong strategy (secondary feedback loop)
	Institutions: Persistent practices, relationships and organizations in the life of society that center on fundamental needs, activities, values of cardinal position for maintaining society. Manifested by social regulatory agencies (Websters, 1993). We differentiate legal, economic , political and cultural institutions	Marriage, EPA, court, banks, government, language,	Institutionalization: process of establishing an organizations and functions that strengthen and maintain societal structures

Adaptation of explanatory models and environmental dynamics in urban sanitation

We illustrate the PSM and the multi-hierarchy dynamics of the HES by an example from environmental hygiene, i.e. cholera management. This is considered to be an appropriate example of the linkage of different feedbacks between system levels and time horizons. It shows the necessity of relating different disciplinary methodologies for understanding sustainable development.

A radical change in the 10^5 year history of human occurred about 5000 B.C., when Mesopotamians started living in cities (Benevolo, 1957). At that time the world population was approximately 20 million. With an increasing growth rate, the world population reached 320 million by AD 1000. This growth can be considered as an outcome of goal, strategy formation and action on the individual level (e.g., reproduction strategies, innovation, and efficacy and efficiency in work division) that was manifested on and supported by the societal level. The support function is related to the building of institutions, which allowed for the labor diversification and division (Boserup, 1981). The new arrangements of the human species, i.e., living in cities, caused major changes in water and nutrition supply as well as in waste and sewage disposal as secondary feedbacks. This fundamental change in the setting of living caused benefits but also catastrophes originating from unknown dynamics in the environment.

The increasing and up to then unknown crowding in urban systems was accompanied by epidemics such as the Black Death epidemic, cholera and typhoid fever. As can be seen from Figure 1, some of these epidemics almost decimated the population. For example, in Europe, in each of the two pest epidemics (AD 542 and AD 1351) more than 25% of the population died (Figure 3).

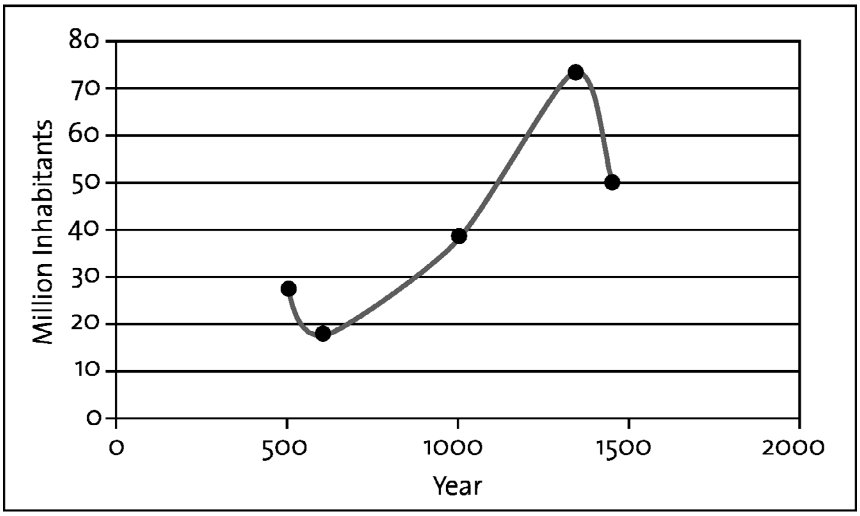

Figure 3: *The impact of pest epidemic on population in Europe (Source: adapted from Bolognese-Leuchtenmüller, 1997)*

To understand societal learning, the historical development of explanatory cause and effect models is most intriguing and insightful and can be used to document the learning that occurs at different hierarchy levels of the human system. The ancient scientists had to answer the question of whether or not the Black Death was caused by the devil, witches, fungi or small animals. Viruses and bacteria were not accessible with their instruments. The Black Death was associated with the devil and priests and medical doctors were not obliged to support sick people. The scientific explanation resulted in the “Miasma theory” (Zweifel, 1989) where the belief was that bad odors transmitted the disease. These odors originated both from fecal matter and rottenness and could also contaminate soils. Therefore, avoiding bad odors was seen as the solution for eliminating the epidemic. In the terminology of the PSM we speak of goal formation of societal agents. In the course of experiencing the Black Death, society developed strategies such as road and harbor blockades, quarantines and disinfections using lime, bases and sulfur (Brockhaus, 1865). The assumption was that these measures helped to suppress the pandemic character of pest. Today it is known that the Black Death is caused by a bacterium Yersinia Pestis (detected by the French physician Yersin in 1894) and flourishes in humid environments when temperatures are between 20 and 24 degrees Celsius. These are the optimal conditions of reproduction of rat fleas (Xenopsylla cheopes), which are the transmitter of the disease. In addition, the population dynamic cycle of rats, as part of the environmental dynamics, seems to be relevant[3]. Floe bits transmit the bubonic plague, the milder form of the Black Death. If not treated it might develop into “lung pest”, which is an airborne infection.

With respect to the framework provided in Figure 1, three lessons can be learned:

Human species, as an agent, altered not only the human system, but also affected the environmental system, represented by the growth of the rat and flea populations. The outbreak of the Black Death is, thus, considered a secondary long-term feedback loop of human action.

The human learning related to the understanding of environmental feedback loops shifted from "mystic and pre-logical" (e.g., Black Death is caused by witches, see also primitive man's collective representations, Levy Bruhl, 1932) to complementary logical, cause-impact schemes (e.g., miasma theory). The latter referred to various potential, but invalid assumptions and conclusions about the genesis of the disease.

As we know from propositional logic, truth (right action) may result from false assumptions[4]. In this case various means of disinfections and hygiene reduced the spread of the Black Death by a providing less attractive environment for rats.

[3] Within the time of reproduction, the living conditions or rats are crowded, forcing them to search for food outside their normal environment. They intrude the human settlements and the fleas can more readily transmit the Black Death.

[4] This aspect refers to the principle of probabilistic stabilization in Brunswik’s theory of probabilistic functionalism (Brunswik, 1952), as wrong behavior can be occasionally rewarded.

Until World War II infectious diseases were the primary cause of death in Europe. Cholera, which was prevalent in the mid-19th century, was considered to be the follow up disease of the Black Death. Cholera is an acute intestinal infection caused by the bacterium Vibrio Cholerea. It has a short incubation period, from less than one day to five days, and produces an enterotoxin, that causes a watery diarrhea that can quickly lead to severe dehydration and death if not treated promptly. It is transmitted by contaminated water and food. Large outbreaks are usually caused by a contaminated water supply (WHO, 2003).

It is believed that the first outbreaks of cholera can be traced back to Ancient Greece (460 to 377 BC), as Hippocrates described a similar disease in his writings (Cook, 1996, p. 19). The first pandemic outbreak originated in 1817 in Calcutta, India, and spread to China, Russia (1830), Poland, Germany, etc. In 1832 it also reached the US (Brockhaus, 1865, p. 455). It was recognized that cholera spread mostly along traffic routes, in particular rivers. The 7th pandemic originated in 1961 in Indonesia and, through sailors, entered to South America for the first time in 1991 in Peru (Islam, Drasar, & Sack, 1996). Cholera can, thus, be seen to be a result of another advancement, the globalization of material and human fluxes. It is estimated that 2.5 million people died of cholera in 1997 (Weiss, in press).

We reconstruct the regulatory mechanisms related to cholera epidemic along the proposed process structure model (Figure 1). We are particularly interested in the progress of understanding the genesis of cholera and the strategies formed relating to the evolving environmental awareness of physicians and society.

Goal formation. Three goals can be identified: (i) avoiding infection, (ii) preventing the spread of the disease, and (iii) curing sick people. In principle, goals (i) and (iii) apply to all levels in the human system, whereas goal (ii) is relevant only to the societal and group level. Obviously curing itself occurs at the cell and organ level as known from immunology.

Strategy formation. In 19th century Europe, scientists and decision makers had already learned from the Black Death epidemic. They had also developed a structured, hypothesis based research pattern, which they applied to the new situation (Goltz, 1998, p. 213). We focus on the first two goals and omit the discussion of the medical treatment. Strategy formation was based on the miasma theory (Zweifel, 1989). This theory dominated strategy formation, even though at that time Snow, in 1849, had already shown that cholera infection was related to the consumption of contaminated drinking water (Leary, 1998, p. 129). That is, at this stage, water was not included in the environmental awareness as a transmission media for pathogens as the focus was on soil and air. If water appeared to be clean and clear, tasted well, and was without adverse smell, then it was considered safe.

Despite the fact that the medical doctors knew that cholera was an epidemic; their theories did not properly explain the mechanisms related to cholera prevention, cholera treatment and cholera dissemination. This is reflected in the large amount of strategies emerging and being tested at that time (Goltz, 1998)[5]..

At the societal level the following options were available (see Shakespeare, 1890, pp. 819): (i) block off (isolating) the city, (ii) designing disinfections programs for houses, (iii) placing city districts under quarantine, (iv) placing infected individuals under quarantine, (v) cleaning the "Ehgräben"[6], and (vi) developing a sewage system. The individual had the following options: (i) leaving the city, (ii) participating in a group to keep the neighborhood clean, or (iii) refraining from leaving the house. Not considered in the strategy formation was for example boiling of water.

Strategy selection and action. Some of strategies were not chosen either because of ignorance or because of trade offs with other issues. For example closing roads and cities had presumably stopped the spread of the disease, however, the dependence on foreign regions for supplies did force authorities to keep the city open to traffic (Brockhaus, 1865, Shakespeare, 1890, p.820)[7]. This required compromises at a societal level. In Berlin, for example, 60 districts were defined each with a public health officer with executive police rights, an occurrence, which can be regarded as institutionalization (Deutsches Hygiene Museum, 1995). In addition, rooms and apartments were placed under quarantine.

In Zürich, after the epidemic of 1854, the technology for cleaning the "Ehgräben" was imported from New York. The cleaning of the "Ehgräben" was performed only early in the morning or at night so that the odor could not "contaminate" other people. The gases coming out of the Ehgräben were burned, or neutralized according to the knowledge of modern urban hygiene (Gesundheitsamt, p.9; Illi, 1987, p.77).

Environmental reaction. The strategies chosen were obviously not sufficient. In Berlin, 1,462 people died, among them Georg Friedrich Hegel in 1831. Between 1831 and 1933 the epidemic returned 13 times (Deutsches Hygiene Museum, 1995). In Zürich, the epidemic came back in 1865/66.

Post-decisional evaluation/learning Exemplifying a post decisional learning process, the Miasma theory was not revisited in Zürich, but rather the strategies and actions were adapted. A sewage system was built, which collected the fecal matter from all households, transporting it to the river down stream from the city. From that point onwards, cholera was eradicated.

5 For example, still in 1879, the prevalence of carbon dioxide was considered successful for preventing the genesis of cholera (Kronser, 1879; Leary, 1998).

6 Ehgräben were open canals at the border of the streets, where people dumped their excreta into, waiting for the rain to clean them away (Illi, 1987).

7 This is a typical cost-benefit trade off as modeled in decision theory.

Looking back, the strategy selection leading to the building of sewage canals in the length of 88 km in just five years (i.e., 1868 until 1873, Condreau, 1995, p.14) in Zürich was also motivated by the general crisis of the public health system. The environmental action of building the sewage canals was demanded by the public as a tribute to overcome the overall social crisis (Condreau, 1995, p.12). Thus to fully understand societal action related to improving environmental condition, it is necessary to consider boundary conditions promoting or inhibiting action.

When Koch discovered the bacterium Vibrio Cholerea in 1883 in India (Leary, 1998), the right measures could be taken, such as disinfecting drinking water. It is said, that the smell of chlorine lay over the large European cities (Deutsches Hygiene Museum, 1995). Today, in western societies and parts of the developing world, cleaning of drinking water and canalization and sewage systems, collecting liquid wastes (fecal matter and urine) are all well-established technical systems.

Conclusions and Outlook

The HES paradigm is a typical approach for dealing with the complexity of human environment dynamics. This section first summarizes the accomplishments of the HES paradigm and then discusses its properties and implications as they relate to the theory of science.

Within the HES paradigm we presented a process-structure model for investigating RFC-mechanisms in Human-Environment Systems. It provides

Structure for HES research: The human and the social system are considered semiautonomous, interlinked systems. They are interlinked through different types of environmental awareness and different types of feedback loops. Feedback results on different time scales.

Multi-level hierarchy of the human system: The framework includes a hierarchical view of the human system. Within each hierarchy level, different regulatory mechanisms with respect to the environmental system can be encountered and have to be defined. The understanding of these mechanisms allows for the identification of interfering regulatory mechanisms.

A game and decision theoretic framework: This framework allows for conceptualizing human behavior through goal and strategy formation, strategy selection, action and learning with respect to the immediate and delayed feedbacks of the environmental system.

From a theory of science perspective, the HES paradigm has significant properties and implications.

Integrating quantitative and qualitative data and knowledge (Tietje & Scholz, 2002): The HES paradigm requires a qualitative, conceptual definition of the core units and their relationship at the levels under consideration, such as the driving forces in goal formation and the principles of strategy selection and learning. When using the approach and techniques of conceptual game theory or system theory/cybernetics quantitative analysis becomes possible[8].

Representing equilibration, adaptation, and assimilation dynamics: With the HES paradigm learning mechanisms and principles of behavioral change can be specified. Thus system properties such as vulnerability, stability, or resilience can be made explicit.

a) Mastering complexity in system modeling: The HES Paradigm allows for defining a manageable set of semiautonomous units. Therefore, the whole system becomes stepwise approachable by considering only the most essential interactions. This facilitates simplicity in modeling, in particular of the decision-making process within the human systems. In this context, approaches such as bounded rationality (Simon, 1957; Gigerenzer & Selten, 2001) provide a good example.

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[8] Though the historical example of the Black Death did not extensively utilize quantitative data, population statistics would be possible, based on the conceptual model presented. Another approach, which provides spatially explicit data, has been suggested by Collins (1996).

b) Integrating different hierarchy levels and time dimensions: The multi-layered PSM and the human systems of the HES paradigm permits for integrating different hierarchy levels and time dimensions. This is in line with the panarchic modeling suggested by Holling (2001, p.192, see above), which gives access to the study of how changes on one level of a system will alter emergent patterns at another level.
c) Interdisciplinarity: The HES paradigm requires one to deal with the natural and social science interface when considering the different levels of human systems, the dynamics of human and environmental systems, and the interaction between these systems. Within HES research, interdisciplinary and transdisciplinary[9] research are not conceived of as contradictions, but as complementary activities to high quality disciplinary research. Both, specialists for integrative modeling and specialists in disciplinary subject matter should cooperate for developing specific HES models.
d) Generality and specifity: In principle, the HES paradigm is general in the sense that the structural relationships have the potential to be applicable for many issues. However, in any application, the modeling must acknowledge the specifity of the situation and the problem to be dealt with.

We are aware, that environmental science requires and has already entered the stage of integrative theory building and modeling. With the HES paradigm we want to contribute to this most challenging process.

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[9] HES research becomes transdisciplinary if knowledge and values of case agents or members of the non-scientific community are integrated in the modeling process (Scholz, 2000).

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