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Social-Ecological Analysis of Climate Induced Changes in Biodiversity – Outline of a Research Concept

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Abstract: The interactions of changes in climate and biodiversity with societal actions, structures and processes are a priority topic within the international scientific debate – and thus, a relevant subject matter for BiK^F's work. This paper outlines a concept for transdisciplinary research within BiK^F. It focuses on the analysis of social-ecological systems supporting society with biodiversity driven ecosystem services. Such research is considering different issues: defining sustainable societal adaptations to climate induced biodiversity changes; permitting adequate understanding of the social-ecological reproduction of ecosystem functions, including their conservation and restoration; analysing the societal values and socio-economic utilisation of ecosystem services. Gaining knowledge in these areas provides an improved basis for decision-making in biodiversity and resource management.

1 Introduction

The issue of "Biodiversity" has altered its fringe existence within the debate about Global Change. In a sequence of international conferences and reports the issue caused public attention[1] and indicated that the decline of biodiversity is now recognized as one of the major global challenges for human societies, comparable to that of climate change. The situation is aggravating because changes of biodiversity and climate change proceed not independently of each other but are mutual linked. Therefore, in the discourse on Global Change the interactions between climate and biodiversity play an increasing role. But a lack of shared concepts is an obstacle for a consistent interlinkage of knowledge about climate change with knowledge originating from biodiversity research (Gasch 2002).

Meanwhile it is also a common place in the international debate that climate and biodiversity are affected by human activities and that both affect human welfare and the functioning of societies. But the scientific knowledge about the affecting interactions and systemic risks is still unsatisfactory. Gradually, a comprehensive new research agenda becomes apparent for reliable knowledge about the interactions between climate, biosphere and human society. By and by the dependence of global and local changes of climate and biodiversity on human actions and decisions on the one hand and the impacts of these changes on human societies on the other get part of the new research agenda.

Climate change as well as biodiversity are central themes in international programmes and research networks like the *World Climate Research Programme* (WCRP), the *International Geosphere-Biosphere Programme* (IGBP), or the international network for biodiversity research DIVERSITAS. Each of them is seeking in their own way to include the impacts of human action in their respective conceptual models. These programmes are seen as parts of Global Change Research and they also organise a global division of labor within the international science community, resulting in a decomposition of the new research

[1] The USA National Forum on BioDiversity, held in 1986, placed the term *biodiversity* in the public debate and put it on the scientific agenda. Discussions around the Millennium Ecosystem Assessment (MEA 2005), the UN Summit on the Millennium Development Goals (MDG 2010), the 10[th] Conference of Parties (COP 2010) in Nagoya (Japan) are milestones of the political debate about the decline of biodiversity and the erosion of ecosystem services.

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agenda by focussing on global problems in different research fields and impact lines. This decomposition favours unilateral causal relationships and aggravates the analysis of mutual impacts and feedbacks.

Beside strong obstacles arising from the lack of shared concepts and languages, geoscience-oriented *climate research* attempts to include both the biosphere and the anthroposphere in their earth system models (Pielke et al. 2003; Reid et al. 2010). The impacts of biosphere (B) and anthroposphere (A) on the climate (C) is a central research question in climate research. In a symbolic notion: $\Delta B \rightarrow \Delta C$; $\Delta A \rightarrow \Delta C$. Here Δ denotes changes of A, B or C. *Climate Impact Research* has its focus on the effects of climate change on human societies and on the biosphere: $\Delta C \rightarrow \Delta A$; $\Delta C \rightarrow \Delta B$. In both research fields the integration of the different subcomponents on the conceptual and the modelling level is crucial for understanding the functioning of the Earth System. The conceptualisation of human impacts in geo-biological earth system models is a key question on a conceptual level. The CLIMBER-2 model[2] is an illustrative example (see fig. 1). Human impacts are represented by the emissions of greenhouse gases and aerosols, the impacts on the global carbon circle and the change of terrestrial vegetation by land use.

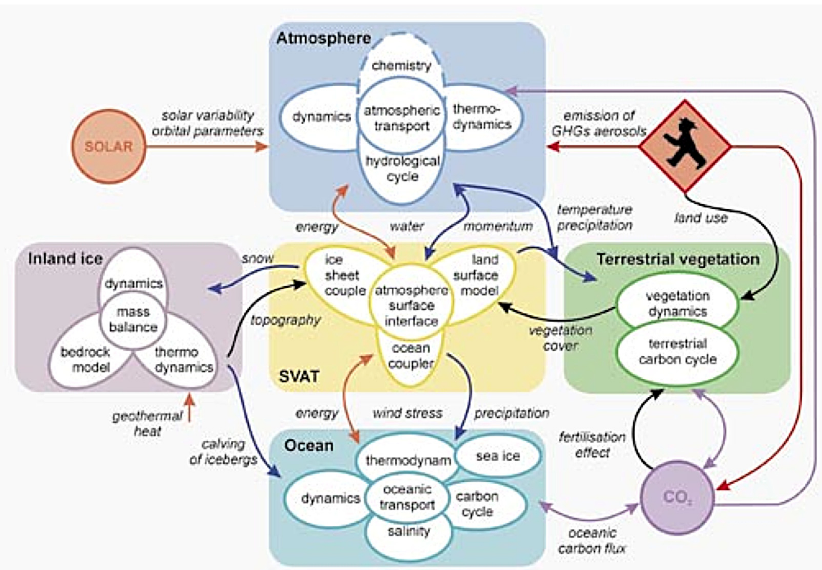

Fig. 1: CLIMBER-2-model. Source: Pielke et al. (2003: 12).

The interactions of global environmental change with societal actions, structures and processes are in the centre of different international research programmes and networks. The *International Human Dimensions Programme on Global Environmental Change* (IHDP), a programme dominated by human geography and economics, studies in numerous projects the human and societal aspects of the phenomenon of global change. IHDP aims to frame, develop and integrate social science research on global change, and promote the application of its key findings in politics and economy. It strives to develop research approaches that put societies at the centre of the debate, looking at current global environmental problems as social and societal challenges[3].

The UNESCO programme *Man and the Biosphere* (MAB), founded in 1970, has a regional orientation and explores the linkages between humankind and the biosphere, whereby the "biosphere is understood to comprise all the realms of the Earth, home to living organisms – i.e. the atmosphere, hydrosphere and pedosphere." In practical terms, the implementation of the concept of UNESCO Biosphere Reserves is now the main activity. "Such reserves are sections of representative landscapes in which all components of sustainable development – ecological, economic and socio-cultural – are monitored, researched and lived." (UNESCO 2010)

A strong orientation on cultural landscapes and the complex interactions between society and nature is a dominant attribute of the international network *LTSER – "Long-Term Socio-economic and Ecosystem Research"*. The building of research platforms for selected regions and cultural areas is the main goal. On these platforms regional research institutions and projects are linked to adjusted networks (Ohl et al. 2010).

2 The CLIMBER (CLIMate and BiosphERe) models are a family of earth-system models of intermediate complexity (EMICs) developed at PIK (Montoya et al. 2005).

3 IHDP research is conducted by its ten projects. Its six core projects, focus on how humans affect and are affected by climate change, with specific topics including human security, urbanization, industrial transformation and environmental governance as they relate to global change. Two of its six core projects are also core projects of the International Geosphere-Biosphere Programme (IGBP) and focus specifically on coupled human-environment systems such as land use, and coastal zones. It also has four joint projects on the Earth's carbon cycle, water systems, human health and food systems with the other three global change research programmes (ESSP).

2 The general Research Agenda of BiK^F

The LOEWE Biodiversity and Climate Research Centre (BiK^F) does at its core not define itself as part of global change research. A regionalised organism-oriented climate impact research is on top of its agenda. The focus of research is the impact of natural and anthropogenic climate change on biodiversity: ($\Delta C \rightarrow \Delta B$). *Biodiversity* is understood as the diversity of life in space and time on the levels of genes, species and ecosystems. On these levels, diversity indicates the ability of the biosphere and the embedded forms of life for adaption and evolution. Therefore, programmes with a regional orientation like MAB, DIVERSITAS, IHDP or LTSER could be a source of conceptual inspirations.

In BiK^F the term ($\Delta C \rightarrow \Delta B$): *"climate impacts on biodiversity"* denotes the impact of climate change on the diversity of genes, species and ecosystems[4]. Effects in the opposite direction ($\Delta C \leftarrow \Delta B$): "impacts of biodiversity changes on climate change" shall also be subject of research: climate affects biodiversity and is affected by it. But the term *biodiversity* can have many interpretations with different perspectives. It offers a new and value-laden idea for conservation and an issue-driven research perspective for scientists (Faith 2007).

Within BiK^F the research area F plays a special role. On the one hand the aim is *transfer of knowledge* from the biological and geological based research to the social sciences and to discourses and decision processes in politics, economy and society. For this a conceptual model was developed by ISOE and applied in several projects (Jahn 2008; Jahn et al. 2010). But what kind of knowledge is transferred from natural to social science? What is the conceptual framing and theoretical context? What are the cognitive conditions for reception of natural-science knowledge in a social-science context? These are still open questions. On the other hand the aim of area F is an original social-ecological analysis of climate-induced changes in biodiversity and basic research on social-ecological systems. For this aim a research concept is also indispensable.

In a social-ecological analysis the effects of ΔC and ΔB on human societies move into the centre of attention[5]: Research questions are: "What are the impacts of climate-induced biodiversity changes on societal action and decision-making? What are the impacts of societal action and decision-making on biodiversity and climate?" These questions constitute a challenging research agenda. On a general level, the overall research question refers to dynamic interactions and relations among natural, social and economic processes at different temporal, spatial and social scales. Human action and geo-biological processes are closely intertwined, and natural and anthropogenic causes of the dynamic changes of biodiversity interfere. They constitute the genuine subject of a social-ecological analysis. But in many cases, processes within ecosystems take place at temporal, spatial and organisational scales different from those in which institutional processes, social practices as well as the generation and distribution of knowledge take effect. Social-ecological research therefore is confronted with a complicated *problem of scale*: How is it possible to define common scales for ecological and social processes?

In many cases climate-induced biodiversity changes breed *social-ecological problems*, with the latter not being assignable to one or the other of two exclusive categories, 'nature' or 'society'. This is a basic assumption of the social-ecological perspective. In contrast to biodiversity changes in the geological past the recent changes are not only a result of a biogeochemical dynamics, but also of human actions and decisions. These actions and decisions are influenced by social, cultural, political and economic settings, and in turn biodiversity changes influence these settings. In this sense, biodiversity changes indicate transformations of societal relations to nature, that is, the relational network formed by individuals, societies and nature in interaction (Becker et al. 2006; Becker et al., forthcoming). Societal relations to nature are historically and culturally specific *patterns and practices* by means of which societies attempt to materially regulate, and culturally symbolise, their various relationships to nature. They emerge out of interferences of a nexus of causal effects ("Wirkungsgefüge") within a field of symbolic meaning ("Deutungszusammenhang"). Therefore, they always exist as intertwined physical and symbolic forms.

Both the epistemological and ethical dimensions of the transformation of societal relations to nature are characterised by uncertainties, ignorance and contested knowledge, while the political decision-making process at the same time faces high expectations in terms of the results expected. In light of uncertainties, scientific knowledge and scientific practices of analysis become contested objects in the course of various societal negotiation processes, with the latter including conflicts over the validity of different interpretations of a specific problem such as, for example, conflicts

[4] The term *climate change* refers to the state of the atmosphere and the underlying land (lithosphere and pedosphere) or water (hydrosphere) in a long time scale. Climate change is an attribute of the whole geosphere. Average values of temperature, humidity and atmospheric pressure, wind regime and water temperature indicate the climate.

[5] More precisely spoken, it is the impact chain ($\Delta C \rightarrow \Delta B \rightarrow \Delta A$).

between nature protection and resource utilisation (Jahn 2008). Therefore, the concept of biodiversity is highly context-dependent and has been both a political and scientific concept (Jentsch et al. 2003: 122). Research located in this 'hybrid field', i.e. at the intersections of nature and society must therefore not only deal with geo-biological and socio-economic cause-effect relationships, but also with cultural contexts of interpretation. This requires developing integrated theoretical concepts and methods, moving beyond the simple addition of existing concepts from natural and social science. However, the entire complex network of relations between climate-induced changes of biodiversity and society is difficult to deal with, both in theoretical and empirical research. From a theoretical point of view, two multidimensional complexes, *climate* and *biodiversity*, are related on various space and time scales with societal processes and structures. For a deeper understanding of these complex relationships integrative concepts are necessary. The concept of social-ecological systems (SES) seems promising, since it seeks to couple ecological systems and social systems and to offer an integrated perspective. From an empirical point of view, the complex network of relations has to be reduced to significant causal relations, whereas the significance depends on values and decisions, often articulated by stakeholders with conflicting interests. Therefore, a well-defined area must be determined, in which social-ecological problems conglomerate and on which research should be focused. As will be argued in this paper, the concept of supply systems based upon natural resources offers great potential for such a research focus in BiK^{F}.

3 Social-ecological systems

There is no doubt that human activity is a major force in the global changes shaping ecosystem dynamics from the level of biotic interaction in local biotopes to biogeochemical and water cycles on the global level of the earth system. On the other hand, human societies and globally interconnected economies increasingly depend on ecosystems services and the maintenance of the latter's functions. Within the last few decades, this commonsensical observation has given rise to numerous studies and reports in global change research, earth system analysis and sustainability science. There is not much dispute among scholars in these research areas that global climatic change, the depletion of ecosystems and over-exploitation of natural resources, as well as economic, political and cultural globalisation yield to new social inequalities and polarisations. They require novel ways of analysing the interactions among nature and society, and new forms of societal dealing with these interactions (Vitousek et al. 1997; Kates et al. 2001; Schellnhuber et al. 2004; MEA 2005; Norberg/Cumming 2008). Given the manifold interdependencies between natural and social processes at different temporal and spatial scales, it is argued that the practice of science appropriate to sustainable development research should be primarily systemic, and social-ecological systems should be considered as the basic units for sustainability research (Gallopín et al. 2001). Thus, sustainability research increasingly addresses the 'complexity' of the dynamic interactions between nature and society, recognising that "understanding the individual components of nature-society systems provides insufficient understanding about the behavior of the systems themselves" (Clark/Dickson 2003: 8059).

In the course of the development of this research field, studies have shifted from focusing either on ecological systems or on social systems toward more comprehensive conceptualisations and models dedicated to the analysis of coupled 'human-environment systems' (e.g. Turner et al. 2003); 'socio-ecological systems' (e.g. Gallopín et al. 2001) or 'social-ecological systems' (Berkes/Folke 1998; Gunderson/Holling 2002; Folke 2006; Liehr et al. 2006; Becker, forthcoming). Movements towards systemic approaches can be observed in multi-, inter- and transdisciplinary oriented research fields such as Human Ecology and Industrial Ecology (Sieferle 1997; Allenby 1999) and Social Ecology (Fischer-Kowalski 2004; Becker/Jahn 2006). Quite heterogeneous discourses have been developed in these overlapping fields, with each having specific cognitive and social orders, and, as a result, with each working with different system concepts and theoretical terms of references.

Meanwhile, there is a widely shared view that the processes under study are so tightly entangled that it does not make sense to analyse the social and physical incidents in the conventional manner as being independent form each other. Particularly for meso-scale studies it seems adequate to select a hybrid research object, which can be conceived as a complex dynamic system from a social-ecological point of view (cf. Hummel 2008).

3.1 Human-Nature Interactions Conceptualised as Systems

Human-nature interactions are the common point of reference in systemic sustainability science; however, this common reference point has not yet been embedded in a comprehensive theoretical framework. According to the standard definition, a system is "a set of objects together with relationships between the objects and between their attributes" (Hall/Fagan 1956: 18). Formally, systems are defined in terms of sets of related elements viewed as mathematical objects and classes of abstraction. In research-oriented definitions of the notion 'system,' these set-theoretical entities are re-interpreted empirically via the replacement of 'element' by 'thing', 'object', 'component' etc.; and 'relationship' is redescribed as 'coupling', 'interaction', 'connection', 'linkage' etc. (Liehr et al. 2006: 268; Becker/Breckling 2011). Systems theory distinguishes between different system types, such as functional systems, structural systems and hierarchical systems with different attributes (closed, open, static, dynamic, simple, complex etc.). Thus, the answer to the question, what are the specific attributes of a system, depends in the end on the system definition selected; and, as system-theoretical debates illustrate, there are different possibilities here.

As yet, there is no homogeneous, consistent and uniform concept of social-ecological systems (SES). In a fairly broad definition, SES can be regarded as "any system including ecological (or biophysical) and human components, ranging in scale from the household to the planet" (Gallopín et al. 2001).

But this definition does not reflect the general assumptions about an adequate use of the term *system*, especially the necessity of spatial or functional boundaries is missing. Glaser et al. (forthcoming) define SES more concretely: "A social-ecological system consists of a bio-geo-physical unit and its associated social actors and institutions. Social-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context" (Glaser et al., forthcoming).

In these definitions, SES appear to be something existing in the real world of concrete spatial-temporal phenomena, and it remains open whether or not the term 'complex adaptive system' is used as a formalised analytic concept or merely as a heuristic metaphor. In contrast to a widespread ontological position, which regards SES as given objects in the 'real world', we may follow the 'model-based constructivist' approach suggested by Becker/Breckling (2011). From this perspective SES represent models of knowledge about real-world phenomena. One has to distinguish between concrete things and processes (phenomenological level) and an 'ideal world' of abstract objects (model level). In this sense, systems are "abstract objects in an ideal world" (ibid.) – e.g., graphic models; verbal, metaphorical or conceptual descriptions; mathematical equations; etc. Between systems as abstract objects and real-world phenomena there exists a model relation. Thus, SES always represent abstractions – models – of real world contexts, processes and structures. As such, they represent an analytical category that permits the formalised description and modelling of societal relations to nature. Hence, according to this view, it is just the difference between model and reality that constitutes the starting point for construction and reflection of systems as models (see also Liehr et al. 2006).

Modelling human-nature interactions as done by SES, assumes that the sphere of the natural and that of the social are analytically distinguishable. This requires, first, separating and opposing both spheres, and then, reintegrating them within a comprehensive model. However, the discursive practices in which the 'social' and the 'natural' are distinguished are historically and culturally located and thus variable, with such discursive practices of distinction taking place within wider discourses and accompanied by different images of nature. At the same time, such differentiations are associated with norms, valuations and hierarchies. Thus, the distinction between nature and society results from a process of societal self-distinction. Therefore, nature is only conceivable within the horizon of society, *nature* is a societal category (Becker/Jahn 2006: 164ff.; cf. Knorr-Cetina 2002; Rheinberger 2006).

3.2 Characteristics of Social-Ecological Systems

A complex system approach would seem to be an adequate instrument for analysing interactions and cross-scale linkages, and to be capable of linking different types of knowledge in integrative analyses in support of a social-ecological analysis of climate induced biodiversity.

In the SES literature, the following attributes are emphasized for complex systems (Glaser 2006; Liehr et al. 2006; Folke 2006): First, they are characterised by a *multiplicity of legitimate perspectives*. They can be described differently, because they depend on the observer's position. For example, the solution of a conflict over common property cannot be reached without considering the perspectives and interests of different stakeholders, with none being the true or correct perspective. Furthermore, they are characterised by a *multiplicity of scales*, i.e. they are hierarchic in the sense that each element of the system is a subsystem of a smaller-order system, and the system itself can be a subsystem of a larger order supra-system. There is strong coupling between the different scales, and systems at different scale levels exhibit different kinds of interactions and different characteristic rates of change. Complex systems also display *non-linearity*, i.e. the relations between their elements are non-linear, resulting in the magnitude of the effects not being proportional to the magnitude of the causes and issuing a large repertoire of behaviour. Non-linear dynamics generates path dependency, e.g. future developments are influenced, enabled and constrained by structures that have grown out of particular historical developments. Another attribute of complex systems is *emergence,* i.e. the properties of the parts can only be understood within the context of the larger whole and the whole cannot be entirely analysed in terms of its parts. Complex systems are able to shape novel structures, patterns and characteristics due to the dynamic co-action of their elements. These emergent phenomena can only be deduced from the knowledge of the elements' attributes and their interactions, but they can only be described at an aggregated level, which goes beyond the system's components. True novelty can emerge from the interactions between the elements of the system. This is connected to *self-organisation*: Interacting components co-operate to produce large-scale coordinated structures and behaviour. Processes of self-organisation generate spontaneous evolution of the system, without external influences and due only to the internal meshwork of relations. Complex systems, furthermore, feature *adaptivity* in their ability to develop new structures in response to new basic conditions[6]. Finally, they are marked by *uncertainty.* Non-linear systems are highly dependent on their boundaries and initial conditions. This means that minimal differences in the initial conditions or small perturbations can rapidly result in huge changes in future system states. As a result of their incorporating non-linear processes and self-organisation, the predictability of future developments of complex systems is low and there is a high incidence of surprise, which renders such systems less controllable.

Given these attributes, it is a strong but also innovative commitment to conceptualise social-ecological systems as complex systems. SES represents non-decomposable systems because they emerge from the dynamic interplay between social and ecological components. This complexity leads to ambiguous social goals, as different societal actors – ranging from international organisations, global enterprises to national politicians, labor unions down to individual consumers and household members – each with their own perspective, problem perception and interests – pursue their different goals. Social, economic, technical and natural dynamics are regarded as part of one unique integrated system, and any delineation between social and natural systems would be artificial and arbitrary (Berkes/Folke 2002). Hence, the social dimension is seen as an integral and inseparable, co-evolving part of the social-ecological system. Accordingly, SES theory aims "to understand the source and the role of change in systems, particularly the kinds of changes that are transforming, in systems that are adaptive. Economic, ecological and social changes occurring at different speeds and spatial scales are the target of the analysis of adaptive change" (Holling et al. 2002: 5).

Taken for granted, that the general attributes of complex systems hold also for social-ecological systems, then the question arises, whether or not the general subject of biodiversity research displays also attributes of complex systems. In this case, climatic changes influence processes of evolution, adaption and genetic expression on different levels of complex and hierarchical biological systems. In other words, biodiversity would be a feature of these systems. Therefore, the knowledge produced by geo-biological research in BiK[F] has to be reformulated as knowledge on complex biological systems.

4 The Resilience Approach

One influential approach on SES is represented by the Anglo-American and Swedish scholarly network radiating from the Resilience Alliance: Stockholm Environment Institute (SEI), the Beijer International Institute of Ecological Economics, and the Stockholm Resilience Centre (cf. Janssen et al. 2006). According to this view, ecosystems' responses to societal resource utilisation and the reciprocal response of people to changes in ecosystems constitute coupled dynamic systems, which display adaptive behaviour. In addition it has been argued that in order to manage ecosystems sustainably one has to understand the combined functioning of the social-ecological system as a whole (Folke 2006; Folke et al. 2005, Folke et al. 2003).

This SES approach focuses primarily on the use and management of meso-hemerob ecosystems, and seeks to analyse system dynamics, which produce 'desirable system states'. It describes the properties of an ecosystem (coastal zone, forest, landscape…), which enable it to adapt to processes of change. Fig. 2 is an example of a visual representation of a social-ecological system, as developed by Berkes/Folke (2002). It emphasizes the central role of knowledge, understanding and social learning. The components of the nested hierarchical structure of ecological and social-institutional systems are connected through ecological knowledge and understanding, which then constitutes management strategies.

[6] Referring to complexity theory (Holland, Gell-Mann and others at Santa Fé Institute) Norberg & Cumming (2008: 2) describe SES as complex adaptive systems (CAS), emphasizing in addition to complex-only systems "the capacity of the system to change in response to prevailing … conditions by means of self-organization, learning, and reasoning".

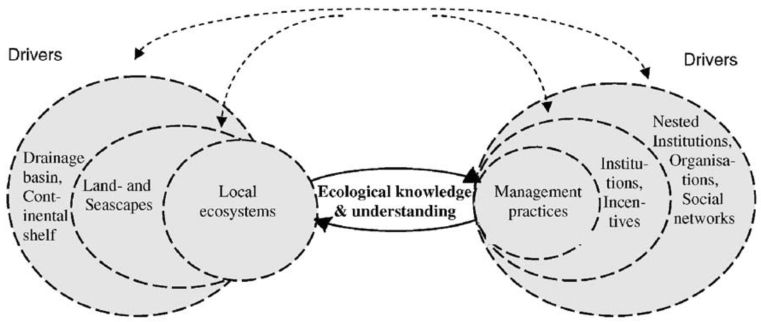

Fig. 2: The 'Resilience approach' of social-ecological systems. Source: Folke 2006: 261.

Resilience

Ecosystems exhibit the property of *resilience*. Resilience can be described as (1) the amount of disturbance a system can absorb while still remaining within the same state or domain of attraction; (2) the degree to which the system is capable of self-organisation and (3) the degree to which the system can build and increase its capacity for learning and adaptation (Carpenter et al. 2001; Norberg/Cumming 2008)[7]. As an analytical concept, resilience is a measure of the elasticity and buffer capacity of a system in the face of internal or external perturbations. In an SES context, resilience is usually defined as "the capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" (Folke 2006: 259). From a normative point of view, the resilience of social-ecological systems resides in self-reinforcing mechanisms that inhibit shifts into system configurations that are undesirable (Folke et al. 1998; Gunderson/Holling 2002; Berkes et al. 2003).

Recent notions of resilience emphasize the interplay of disturbance and reorganisation within the system dynamics. In this sense, the resilience perspective also has normative implications: change is regarded as something which always happens and which must be 'handled'. Given the complexity of SES this implies the necessity of enabling ranges of fluctuation which are wide enough to have a dampening effect on processes of change and narrow enough to sustain structures and functions which are desired instead of seeking optimal system states[8].

The resilience concept has been used by various scientific disciplines as an approach to analysing ecological, social as well as social-ecological systems, and represents, alternatively, a descriptive concept, a normative concept, or a hybrid concept in which normative and descriptive parts are intermingled (Brand/Jax 2007). While earlier concepts of resilience focused on ecological or ecosystem resilience, i.e. on the robustness of ecological systems to withstand shocks while maintaining their function, more recent interpretations emphasize, in addition to the interplay of perturbations and reorganisation within a system, the aspects of transformability, learning and innovation, i.e. social-ecological resilience (Folke 2006). Interpretations of social-ecological resilience thus combine natural and social dimensions, with the focus on nested cycles of adaptive change in SES in which persistence and novelty are intertwined.

The specific properties of SES such as non-linearity, uncertainty and low predictability have led to an emphasis on *adaptivity* as a necessary system characteristic (Norberg/Cumming 2008: 2f.), and on resilience management as an inter- and transdisciplinary approach (c.f. Glaser 2006: 131). As Folke (2006) illustrates, resilience is not only about being resistant to, or robust in the face of disturbance, but also about the opportunity that disturbance offers to recombined, evolved structures and processes, and about the possibility of a renewal of the system and the emergence of new trajectories. "In this sense, resilience provides adaptive capacity ... that allow for continuous development, like a dynamic adaptive interplay between sustaining and developing with change. Too much of either will ultimately lead to collapse. It does not imply that resilience is always a good thing. It may prove very difficult to transform a resilient system from the current state into a more desirable one" (Folke 2006: 259).

In brief, social-ecological resilience has three features: 1) the extent of change the system can undergo and still retain the same control over function and structure[9]; 2) the degree to which the system is capable

[7] As Norberg & Cumming (2008: 3) stress, resilience primarily serves as a concept "that is intended to guide thought rather than a scientific hypothesis that should be tested with quantitative data. This distinction does not mean that *aspects* of resilience cannot be measured".

[8] Resilience is a good example of a concept transfer in which, for example, biological concepts are imported into social scientific or interdisciplinary domains. It originated in biological ecology and is there usually defined as the capacity of ecosystems to tolerate disturbance without collapsing into a qualitatively different state (Holling 1973).

[9] As Abel et al. (2006: 17) point out, there are also SES which are not changing, but "undergo a crisis and reorganize whithout regime change or transformation".

of self-organisation (Abel et al. 2006); 3) the ability to build and increase the capacity of a social ecological system for learning and adaptation (cf. www.resalliance.org).[10]

As becomes apparent, resilience is closely related to other topics such as 'vulnerability', 'adaptivity', and 'transformability', but sometimes the relation between the different terms is confusing, since there is already a considerable variety of definitions, interpretations and reformulations of each of these concepts due to their various disciplinary and intellectual traditions, as well as to their fields of application (Adger 2006; Folke 2006; Gallopín 2006; Smit/Wandel 2006).

Vulnerability is usually portrayed as the susceptibility of a system to be harmed by environmental change and is conceptualised in terms of components that include exposure and sensitivity to perturbations or external stresses, as well as the capacity to adapt (Adger 2006: 270). However, vulnerability must not necessarily be a negative attribute. There are cases where change leads to beneficial transformations and 'windows of opportunity' for improvement (Gallopín et al. 2001: 295).

Adaptivity (or 'adaptability' and 'adaptive capacity', which are usually treated as synonyms) refers to the ability of a system to evolve in order to accommodate changes and to expand its range of variability. In this sense, adaptations represent ways of reducing vulnerability: "Adaptations are manifestations of adaptive capacity. Adaptations, or changes in the system to better deal with problematic exposures and sensitivities, reflect adaptive capacity" (Smit/Wandel 2006: 287).

The term 'adaptability' originally stems from biology, where 'adaptiveness' means the ability of a biological entity, such as a cell, organism, species or population, to live and to reproduce within a specific environment. With respect to the human context, and the context of the human dimensions of global change and climate change in particular, adaptation is usually defined as a process, action or outcome in a system (e.g. household, community, sector, region or country) leading to better cope with, managing or adjusting to changing conditions, stress, hazard, risks etc. It can also mean adjustments in individual groups and institutional behavior in order to reduce vulnerability (ibid. 282).

It is important to note that adaptability as a response of social-ecological systems to perturbations can be reactive, anticipatory or proactive, and includes various forms such as technical, financial, institutional or informational processes (ibid. 288). In the context of the resilience framework, adaptability refers in particular to the capacity of actors to influence resilience. A characteristic feature of complex adaptive systems is self-organisation without intent; and although the dynamics of SES are dominated by individual human actors who do exhibit intent, the system as a whole does not. Assuming that human actions dominate in SES, adaptability of the system might be regarded as being mainly a function of social components, and the actions of individuals and groups influencing resilience, intentionally or unintentionally (Walker et al. 2004).

Adaptivity or adaptive capacity is always context-specific, varying from country to country, among social groups and individuals, and within time and space. Furthermore, it varies within each specific social-ecological structures, as well as physical conditions. In other words, the determinants of adaptability exist and act differently in different contexts.

There is a good deal of debate concerning adaptivity with respect to the degree and depth of change or transformation, as well as regarding the issue whether adaptation to change remains within the existing system structures or leads to radical structural changes that give rise to the emergence of a completely new system. In this context, Kasperson et al. (2005) propose to distinguish between 'adjustments' and 'adaptations'. In their view, adjustments are system responses to disturbances or stress that do not fundamentally alter the system itself, and they are usually, but not necessarily, short-lived and involve relatively minor system modifications. Adaptations are system responses to perturbations that sufficiently alter the system itself, sometimes shifting it to a new state (Gallopín et al. 2001: 300). In contrast, other authors (Walker et al. 2004; Gunderson et al. 2006; Olsson et al. 2006) suggest using the term *transformability* in order to distinguish between system modifications and transformations. According to this view, adaptability refers to the dynamics of a particular system with respect to sustaining a specific system state, whereas transformability refers to the capacity of creating a fundamentally new system when ecological, economic, social and political conditions make the existing system untenable. By introducing new components and ways of governing SES, a novel system configuration emerges.

[10] Quite similar to the Resilience approach discussed above, Elinor Ostrom (2007) proposes a nested framework for analyzing interactions and outcomes of SES.

5 Social-Ecological Systems as Supply Systems

For a better understanding of the social-ecological dimensions of resource use, biodiversity dynamics and management, the perspective of supply systems, developed at the Institute for social-ecological research (ISOE) offers great potential for the biodiversity research of BiK[F].

Supply systems developed by societies provide goods and services such as food, water, or energy; they are based on ecosystems and their geophysical environments and they impact biodiversity, for example, via land-use or water-extraction. Supply systems are regulated by *societies*, and at the same time they depend on natural conditions and are affected by their viability. They cover material-energetic dimensions (e.g., climate, soil conditions, biological diversity or technical artefacts such as wells or bridges), and cultural-symbolic aspects of life (e.g. gender and social structures, needs, values, attitudes, cognitive orders). Given these attributes, supply systems can be conceptualised as SES (Lux et al. 2006; Hummel et al. 2008; Hummel, forthcoming): they are characterised by a coupling of natural and social elements, which together, in their interactions and corresponding sets of problems, engender specific societal relations with nature.

Comparing the concept of a supply system with the Stockholm model of SES similarities and differences are evident. In a supply system resources and the users are central and they are linked by resource flows and societal decisions and actions[11]. If we adopt the formal structure of the Stockholm model and use it in a first step as a heuristic model[12] for a graphical representation of supply systems we get the following figure (fig. 3).

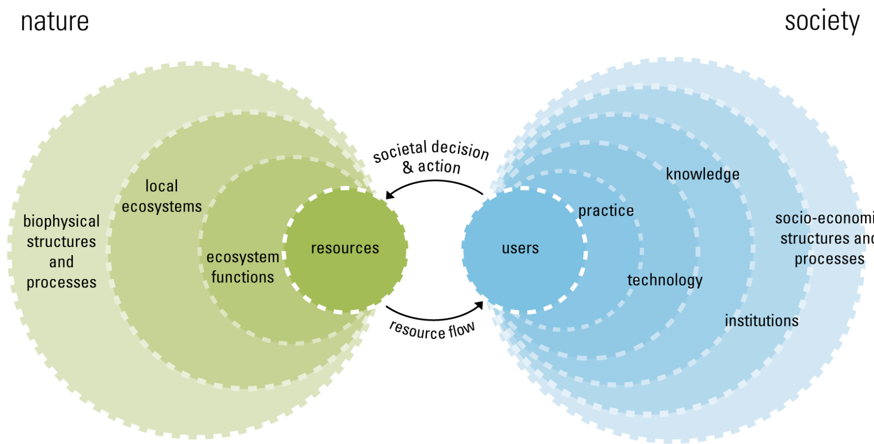

Fig. 3: Heuristic model of SES (own illustration).

The decomposition of both the biophysical and the socio-economic structures and processes into tiers is different from those in the Stockholm model of SES. Natural resources and their users are major components in the process of resource utilisation for particular societal purposes. *Resources* comprise the material-energetic, organic and spatial structures within an ecological and biophysical complex that are validated as relevant and useable for supply systems such as food, water, or energy. Renewable and non-renewable resources as well as further ecosystem services, such as climate regulations or sinks for pollutants and waste etc., are considered resources[13]. Regulation of access to resources determines the level of provisioning and the degree of provisioning security. By means of resource utilisation, supply systems are coupling ecosystems such as rivers, forests or coastal zones with social systems, i.e. societal actions and decision-making.

A key feature of this heuristic model is that *users* are understood to be an integral part of supply systems. 'User' refers to actors and actor constellations, and includes both providers and receivers of supply system services, i.e. producers and consumers, and it can be distinguished in terms of the direct and indirect, as well as quantitative and qualitative, use of resources. Each group of users must be analysed for a specific regional supply system. For instance, water

[11] This is similar to the multitier framework for analyzing social-ecological systems developed by Ostrom (2007), where also resources and users are the central parts of the system. In any attempt to compare different models or frameworks the respective aim should be accounted for: They are always models ore frameworks for a certain aim.

[12] We differentiate between heuristic models and analytical models. A heuristic model serves as a basis for a description and structuring of a problem situation, while an analytical model is used for the concrete development of research questions and the definition of variables and correlations in the transdisciplinary research process.

[13] In a common understanding, ecosystem services (ESS) are defined as the benefits people obtain from ecosystems. These include provisioning services such as food and water, regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth (Daily 2000; MEA 2005; cf. Costanza et al. 1997). In the context of this paper, ESS is used as an interdisciplinary term – open for both, natural and social sciences. For approaching ESS as integrative concept and possibilities for application cf. Loft/Lux 2010a, Loft/Lux 2010b.

supply systems' user groups usually encompass various items such as individuals, households, public water utilities, industry, and agriculture. Within food supply systems, individuals and households, as well as the groups of people who produce and distribute foodstuffs (e.g. farmers, food industry and trade), represent societal user groups. Depending on specific supply systems, distinctions must be made between and within different user groups (individuals, households, urban or rural habitants, consumer sectors). These distinctions can also highlight competition among different user groups and among purposes of resource use (e.g. cultivating crops as aliment, as animal feed, or as bio-fuels), as well as conflicts between societal use of resources and preservation of ecosystem functions.

The process of resource utilisation, however, does not involve a direct relation between users and resources. Rather, their specific interactions are determined by contextual factors: practices, technology, knowledge, and institutions as symbolized in fig. 3. These contextual factors specify how resources are made available and allocated, and they determine the vulnerability, adaptivity, scope and options of provisioning. *Practices* represent routinised types of behavior, which encompass forms of bodily and mental activities, practical activities and their representations, as well as their interactions. The term includes both social, discursive practices, and material ones, all of which are carried out by various specifically situated societal actors. *Technology* comprises all material structures designed, built and controlled by humans for achieving specific purposes, including physical infrastructures, logistics and other technical elements used by producers or consumers of provided services. *Knowledge* comprises both scientific and expert knowledge, on the one hand, as well as everyday life knowledge, on the other. *Institutions* represent societally established rules of action, including both informal constraints and formal rules, with such rules of action being structured by, and themselves structure political, economic and social interactions, thus constituting a framework of action.

These contextual factors are related to one another in specific ways depending on each particular context. For example, land use is embedded in each specific institutional contexts (socio-cultural, economic, political), including practices such as gender-specific divisions of labour, knowledge about appropriate cultivars, availability and application of technical equipments, financial resources, legislation, subsidies, etc. Depending on the problem situation, the regional and cultural context, the kind and purpose of provisioning, the specific relevance and relation between the contextual factors practices, technology, knowledge, and institutions needs to be identified and related. Therefore, for transdisciplinary research projects, the heuristic model of SES must be transformed into an analytical model of supply systems conceptualised as SES. Moving from a heuristic to an analytical model allows the representation of the contextual factors and their relations in *one* system. They constitute the relevant dimensions that mediate the relation between resources and users. Supply systems conceptualised as SES in fig. 4 is a graphic representation of the described connections. This model consists of very few components and the premises can be easily translated into variables for empirical research.

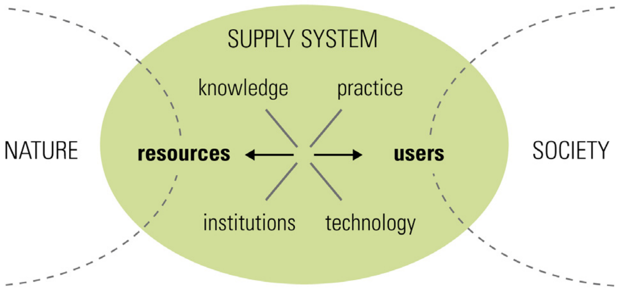

Fig. 4: Analytical model of supply systems as SES. Source: Hummel et al. (2008: 48).

The interior dynamic of supply systems gives rise to a specific configuration of the relation between users and resources. At the same time, the interior dynamic has feedback effects on societal relations to nature: the relations between society and nature transform as the relations between users and resources change. In sum, these interactions constitute social-ecological systems at different temporal, spatial and social scales.

6 Social-Ecological Supply Systems and Ecosystem Services in BiK^F-Research

The concept of supply systems permits to focus the analysis of the interactions of climate-induced changes of biodiversity and society in BiK^F on the issue of *provisioning* and it facilitates the analysis of societal utilisation of ecosystems and natural resources. By means of the analytical concept of supply systems, mesohemerob ecosystems can be conceptualised as social-ecological systems that provide societies with basic ecosystem services and which can be shaped and managed by societies. As fig. 5 illustrates, 'nature' comprises the overall biophysical structures and processes, while 'society' covers the socio-economic and cultural structures and processes. The intersection between the natural and the social system, i.e. the actual social-ecological system, comprises resources, on the one hand, and their utilisation, on the other. Thereby the resource potential results from ecosystem functions. From the natural side, ecosystem services provide society with natural goods, while from the societal side, the demands and valuation of different users impact the resource potential by means of resource management.

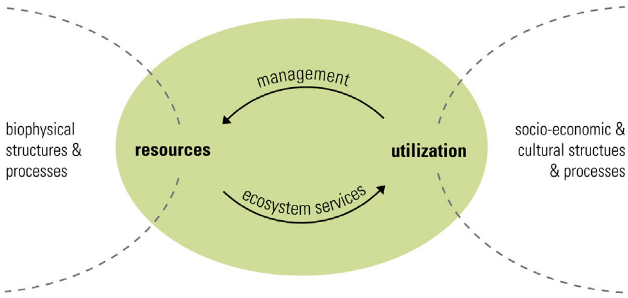

Fig. 5: Social-ecological supply systems in BiK[F] research (own illustration).

To give an example, forests can be conceptualised as social-ecological systems (see figure 6): Depending on their geographical location and biogeographical character, forests deliver a multitude of ecosystem services. Timber production is a provisioning ecosystem service as well as pulp production or the supply with game; these *provisioning services* are in the focus of forestry and estimated as main products of the forests. Many Central-European forests are "working forests" in that they are actively managed to yield timber and pulpwood. Furniture and cabinetmakers use oak, beech, and hickory. Oak is common for hardwood flooring, and is also used for wood veneer, trim, millwork, plywood, and pallets. Spruces are popular for construction lumber. Manufacturers convert a variety of softwood and hardwood species to pulp for making cardboard, office paper, tissue, and other paper products. Some provisioning services are prominent in forest management; others such as the "forstliche Nebenprodukte" (or "non-timber forest products") are very often regarded as negligible (cf. Bundschuh, Schramm 2009). Goal conflicts between game keeping resp. high game density for hunting on the one hand, and timber and pulpwood production on the other hand are increasingly investigated leading to management recommendations.

Trees absorb carbon dioxide during photosynthesis. Some of this carbon becomes stored or "sequestered" in branches, trunks, and roots; following the decay of leaves and other parts of trees, a small part of the sequestered carbon becomes even stored in soils. Carbon sequestration is an essential process for controlling the global climate. The benefits obtained from a forest ecosystem's control of natural processes such as climate, erosion ("avalanche forest") or water flows are regarded as essential. But forest landowners typically do not receive payments or compensation for providing these *regulating services*.

Cultural services are the nonmaterial benefits obtained from an ecosystem such as recreation, aesthetic enjoyment, and spiritual renewal. Central-European forests provide a setting for a range of outdoor recreation and touristic activities, such as wandering, mountain biking, and viewing wildlife. The forest's cultural ecosystem services play a key role for leisure, education and tourism and thus makes a significant contribution to regional economy.

From the natural side, forests comprise biophysical structures and processes, including ecosystem functions evaluated as provisioning, regulating, cultural and supporting ecosystem services. From the societal side, socio-economic and cultural structures and processes such as economic and demographic developments influence them. If the biophysical and the socio-economic and cultural processes are balanced, the ecosystem services are able to supply societies' needs in the long run. But it is also possible that the social-ecological system is no enduring supply system.

For instance the utilisation of the forest ecosystem's provisioning and cultural services by people (e.g. collecting mushrooms or berries, geo caching) may lead to a consolidation of the soil and a change in vegetation as well as a change in the soil filtering capacity. Especially intensive utilisations for recreation and leisure purposes may lead to a degradation of the forest and its ecosystem services.

Depending on the particular demands in each specific supply system, forests provide ecosystem services and resources such as timber, game, plants, berries, opportunities for recreation etc. Hence, different user groups must be distinguished such as walkers living near by the woodland or remote, hunters and gatherers collecting medical plants or fruits, but also actors such as timber industry and food trade (berries, mushrooms). Practices determining the provision of forest goods and services include gathering plants, mushrooms and herbage, lumbering, fattening of animals such as wild boars, roe deer etc. The forest goods can be used for subsistence, or for selling. For example, chanterelles are collected widely in the Baltic forests, providing some income for the residents, and are brought to market by food companies in Central European countries. Knowledge of the processes and dynamics of the forests comprises scientific knowledge, e.g., of forestry and agronomy, but also local and indigenous knowledge. Each provisioning activity is connected with specific technologies, such as clearance or young forest plantations. Different institutions determine the resource use of forest goods and services such as the designation of preserve areas, legal orders for hunting and lumbering etc. Regulations in the nature protection laws of some Central European countries try to limit an intensive extraction of mushrooms (leading also to a decline of future ecosystem services and its utilisation).

Up to now forest management is orientated towards main provisioning services and to the supporting services. Only certain aspects of the regulating services such as erosion control are in the focus of forest management. The utilisation of cultural services is very often regarded solely as a disturbance. The SES perspective allows a comprehensive understanding of the social utilisation of the forest.

Conceptualised as a supply system the SES approach allows to analyse also the addressed problems of the ecosystem services perspective: A forest can be considered as a bundle of different ecosystem services. But the dissimilarity of the services demands a variety of different, but coordinated measures for supporting the management of the ecosystem services.

Hitherto conventional forest management is widely neglecting the production of the different ecosystem services and the necessity of supporting its reproduction. The SES perspective of the forest ecosystem as a system supplying society with a bundle of different ecosystem services may lead to a better understanding of its management needs and an adaptative management of the ecosystem services.

If we conceptualise the forest as a supply system providing ecosystem services we gain a comprehensive understanding of these systems and a new perspective for their sustainable management. Therefore it will be necessary conducting case studies concerning the following research questions: Which ecosystem functions are threatened? What amount of the potential of specific ecosystem services might be used in a sustainable way? What regulations are needed to sustain the services? What management efforts are needed to support the reproduction of threatened ecosystem functions and of the supply system as a whole?

In sum, the concept of social-ecological supply systems helps to structure the problem-oriented analysis of coupled nature-society-systems and permits to formulate research questions concerning the shaping of the anthropogenic influence on ecosystems and their management.

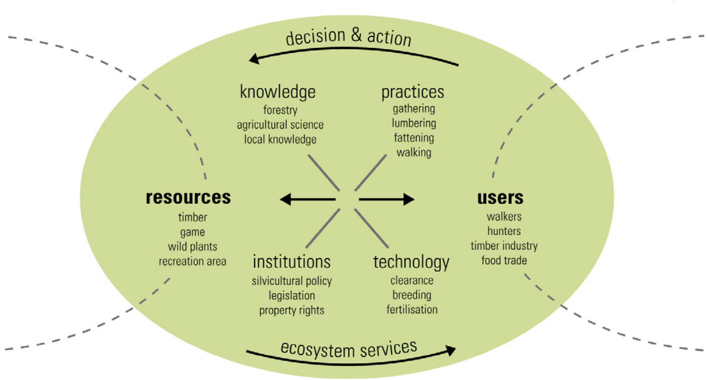

Fig. 6: Forest as social-ecological supply system (own illustration).

7 Perspectives

As it has been argued in this paper, the SES approach enables a systematic description and analysis of the interactions between ecosystems, biodiversity and societal utilisation of resources. It can further help to optimise foundations for decision making in the biodiversity and resource management. The concept of social-ecological systems can be used to structure the overall research question of PB F "What are the impacts of climate-induced changes in biodiversity on societal action and decision-making? What are the impacts of societal action and decision-making on biodiversity?" for future transdisciplinary research in BiK^F. The overall research question comprises the following key questions:

1. How can foundations for decision-support be deduced from research results of BiK^F with respect to the utilisation of ecosystems and their biodiversity for providing society with ecosystem services?
2. What are sustainable societal adaptations to climate-induced biodiversity changes and what are sustainable strategies for the protection and utilisation of ecosystem services?
3. What are the appropriate transfer methods and –instruments to assist and support societal actors in the implementation of measures of biodiversity conservation and climate protection by means of the research results of BiK^F?

By means of the SES concept the foundations for decision-making in biodiversity and resource management can be optimised, using the perspective of provisioning and supply systems as a conceptual roof. Adaptive management of SES/supply systems seeks to improve the resilience of ecosystems. Thereby, foundations for governance must be developed which enable the combination of institutional regulations, social practices, knowledge and technology in a manner that facilitates the adaptive management and which renders the human use of ecosystem services sustainable. What remains to be done in future research in PBF is to refer the natural scientific research results in BiK[F] to the identification of societal benefits and values of the resulting ecosystem services. Thereby, ESS can be conceptualised as part of social-ecological supply systems. With this perspective it can be analysed what is needed for the further development of regulation approaches (e.g., financing, governance, and management concepts) for the sustainable use of life-support systems and the preservation of biodiversity.

8 References

Abel, Nick/David H. M. Cumming/John M. Anderies (2006): Collapse and reorganization in social-ecological systems: questions, some ideas, and policy implications. Ecology and Society 11(1), 17

Adger, Neil W. (2000): Social and ecological resilience: are they related? Progress in Human Geography 24 (3), 347-364

Adger, Neil W. (2006): Vulnerability. Global Environmental Change 16, 268-281

Allenby, Braden R. (1999): Industrial Ecology. Policy Framework and Implementation. New Jersey: Simon & Schuster

Becker, Egon (forthcoming): Social-ecological Systems: A View from the Critical Theory of Societal Relations to Nature. In: Marion Glaser/Gesche Krause/Beate Ratter/Martin Welp (Eds.): Human/Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis. London: Routledge

Becker, Egon/Broder Breckling (2011): Border zone between ecology and systems theory. In: Astrid Schwarz/Kurt Jax (Eds.): Ecology Revisited: Reflecting on Concepts, Advancing Science. Den Haag: Elsevier

Becker, Egon/Thomas Jahn (Eds.) (2006): Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen. Frankfurt/New York: Campus

Becker, Egon/Diana Hummel/Thomas Jahn (forthcoming): Gesellschaftliche Naturverhältnisse als Rahmenkonzept. In: Matthias Groß (Ed.): Handbuch Umweltsoziologie. Wiesbaden: VS-Verlag

Becker, Egon/Thomas Jahn/Diana Hummel (2006): Gesellschaftliche Naturverhältnisse. In: Egon Becker/Thomas Jahn (Eds.): Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen. Frankfurt/New York: Campus, 174-197

Berkes, Fikret/Johan Colding/Carl Folke (2003): Navigating Social-Ecological Systems. Building Resilience for Complexity and Change. Cambridge: Cambridge University Press

Berkes, Fikret/Carl Folke (2002): Back to the future: Ecosystem dynamics and local knowledge. In: L.H. Gunderson/C.S. Holling (Eds.): Panarchy: Understanding Transformations in Human and Natural Systems. Washington, D.C.: Island Press, 121-146

Berkes, Fikret/Carl Folke (1998): Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge: Cambridge University Press (2nd Edition)

Brand, Fridolin/Kurt Jax (2007): Focusing the Meaning(s) of Resilience: Resilience as a Descriptive Concept and a Boundary Object. Ecology and Society 12 (1), 23. http://www.ecologyandsociety.org/vol12/iss1/art23

Bundschuh, Anne/Engelbert Schramm (2009): Soziale Funktionen und soziale Nutzung des Waldes. BiK[F] Knowledge Flow Paper, 4. Frankfurt am Main

Carpenter, Steve/Brian Walker/J. Marty Anderies/Nick Abel (2001): From Metaphor to Measurement: Resilience of What to What? Ecosystems 4 (8): 765–781

Clark, William C./Nancy M. Dickson (2003): Sustainability science: The emerging research program. Proceedings of the U.S. National Academy of Sciences 100 (14), 8059-8061

Costanza, Robert/Ralph D'Arge/Rudolph De Groot/Stephen Farber/Monica Grasso/Bruce Hannon/Karin Limburg/Shaheed Naeem/Trobert O'Neill/Jose Paruelo/Robert Raskin/Paul Sutton/Marjan van den Belt (1997): The Value of the World's Ecosystem Services and Natural Capital. In: Nature 387, 253-360

Daily, Gretchen C. (2000): Management objectives for the protection of ecosystem services. In: Environmental Science & Policy 3, 333-339

Faith, Daniel P. (2007): Biodiversity. In: Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/entries/biodiversity/

Fischer-Kowalski, Marina (2004): Gesellschaftliche Kolonisierung natürlicher Systeme. Arbeiten an einem Theorieversuch. In: Wolfgang Serbser (Ed.): Humanökologie. Ursprünge-Trends-Zukünfte. München: oekom, 308-325

Folke, Carl (2006): Resilience: The emergence of a perspective of social-ecological systems analyses. Global Environmental Change 16, 253-267

Folke, Carl/Thomas Hahn/Per Olsson/Jon Norberg (2005): Adaptive Governance of Social-Ecological Systems. Annual Review of Environment and Resources 30, 441-473

Folke, Carl/Johan Colding/Fikret Berkes (2003): Synthesis: building resilience and adaptive capacity in social-ecological systems. In: Fikret Berkes/Johan J. Colding/Carl Folke (Eds.): Navigating social-ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge, 352–387

Folke, Carl/Fikret Berkes/Johan Colding (1998): Ecological practices and social mechanisms for building resilience and sustainability. In: Fikret Berkes/ Carl Folke (Eds.): Linking Social and Ecological Systems. Cambridge: Cambridge University Press, 414-436

Gallopín, Gilberto (2006): Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change 16, 293-303

Gallopín, Gilberto/Silvio Funtowicz/Martin O'Connor/ Jerry Ravetz (2001): Science for the 21st century: from social contract to the scientific core. International Social Science Journal 168, 219-229

Gasch, John (2002): Natural Science, Social Sciences: Integration or Summation. In: Global Change Newsletter 49, 24-26

Glaser, Marion (2006): The Social Dimension in Ecosystem Management: Strengths and Weakness of Human-Nature Mind Maps. Human Ecology Review, 13 (2), 122-142

Glaser, Marion/Gesche Krause/Beate Ratter/Martin Welp (Eds.) (forthcoming): Human/Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis. London: Routledge

Gunderson, Lance H./Steve R. Carpenter/Carl Folke/ Per Olsson/Garry Peterson (2006): Water RATs (Resilience, Adaptability, and Transformability) in Lake and Wetland Social-Ecological Systems Ecology and Society 11 (1), 16. http://www.ecologyand society.org/vol11/iss1/art16/

Gunderson, Lance H./C. S. Holling (Eds.) (2002): Panarchy. Understanding Transformations in Human and Natural Systems. Washington D.C.: Island Press

Hall, Arthur D./Robert E. Fagan (1956): General Systems. I, 18-28. In: Walter Buckley (Ed.) (1968): Modern Systems Research for the Behavioral Scientist. Chicago: Aldine Publishing Company, 81-92

Holling, C. S. (1973): Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4, 2-23

Holling, C. S./L. H. Gunderson/D. H. Ludwig (2002): In quest of a theory of adaptive change. In: Gunderson, L.H. and C.S. Holling (Eds.): Panarchy: Understanding Transformations in Human and Natural Systems. Washington, D.C.: Island Press, 3-22

Hummel, Diana (forthcoming): Population dynamics and adaptive capacity of supply systems. In: Marion Glaser/Gesche Krause/Beate Ratter/Martin Welp (Eds.): Human/Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis. London: Routledge

Hummel, Diana (2008): Adaptive Capacity of Supply Systems. The nexus of population, nature and society in social-ecological system analysis. In: Diana Hummel: Die Versorgung der Bevölkerung. Studien zur Bevölkerungsdynamik und Transformation von Versorgungssystemen. Habilitationsschrift. Frankfurt am Main, 147-188

Hummel, Diana/Christine Hertler/Steffen Niemann/ Alexandra Lux/Cedric Janowicz (2008): The analytical framework. In: Diana Hummel (Ed.): Population Dynamics and Supply Systems. A Transdisciplinary Approach. Frankfurt/New York: Campus, 11-69

Jahn, Thomas (2008): Transdisziplinarität in der Forschungspraxis. In: Matthias Bergmann/Engelbert Schramm (Eds.): Transdisziplinäre Forschung. Integrative Forschungsprozesse verstehen und bewerten. Frankfurt am Main: Campus, 21-37. http:// www.isoe.de/english/ftp/Jahn_2008_Transdisciplinarity.pdf

Jahn, Thomas/Alexandra Lux/Anna Klipstein (2010): Vom Wissen zum Handeln. Grundlagen des Wissenstransfers. BiK[F] Knowledge Flow Paper, 8. Frankfurt am Main.

Jahn, Thomas/Peter Wehling (1998): Gesellschaftliche Naturverhältnisse: Konturen eines theoretischen Konzepts. In: Karl-Werner Brand (Ed.): Soziologie und Natur: Theoretische Perspektiven. Opladen: Leske + Budrich, 75-95

Janssen, Marco A./Michael L. Schoon/Weimao Ke/Katy Börner (2006): Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. Global Environmental Change 16, 240-252

Jentsch, Anke/Heidi Wittmer//Kurt Jax/Irene Ring/ Klaus Henle (2003): Biodiversity. Emerging Issues for Linking Natural an Social Sciences. GAIA 12 (2), 121-128

Kasperson, J.X./R.E. Kasperson/B.L. Turner II/A. Schiller/W.-H. Hsiel (2005): Vulnerability to global environmental change. In: J.X. Kasperson/R.E. Kasperson (Eds.): Social Contours of Risk, II. London: Earthscan, 245-285

Kates, Robert W./W.C. Clark/R. Corell/J.M. Hall/C.C. Jaeger/I. Lowe/J.J. McCarthy/J.H. Schellnhuber/B. Bolin/N.M. Dickson/S. Faucheux/G.C. Gallopín/A. Grübler/B. Huntley/B. Jäger/N.S. Jodha/R.E. Kasperson/A. Mabogunje/P. Maston/H. Mooney/B. Moore/T. O'Riordan/U. Svendin (2001): Sustainability Science. Science 292 (5517), 641-642

Knorr-Cetina (2002): Wissenskulturen. Ein Vergleich naturwissenschaftlicher Wissensformen. Frankfurt am Main: Suhrkamp

Liehr, Stefan/Egon Becker/Florian Keil (2006): Systemdynamiken. In: Egon Becker/Thomas Jahn (Eds.): Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen. Frankfurt/New York: Campus, 267-283

Loft, Lasse/Alexandra Lux (2010a): Ecosystem Services – Ökonomische Analyse ihres Verlusts, ihre Bewertung und Steuerung. BiK[F] Knowledge Flow Paper, 10. Frankfurt am Main

Loft, Lasse/Lux, Alexandra (2010b): Ecosystem Services – Eine Einführung. BiK[F] Knowledge Flow Paper, 6. Frankfurt am Main

Lux, Alexandra/Cedric Janowicz/Diana Hummel (2006): Versorgungssysteme. In: Becker, Egon/Thomas Jahn (Eds.): Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen. Frankfurt am Main: Campus, 423-433

MEA – Millennium Ecosystem Assessment (2005): Ecosystems and Human Well-Being. Synthesis. Washington, D.C.: Island Press

Montoya, M./A. Griesel/A. Levermann/J. Mignot/M. Hofmann/A. Ganopolski/S. Rahmstorf (2005): The earth system model of intermediate complexity CLIMBER-3α. In: Climate Dynamics 25 (2), 237-263

Nelson, Gerald C./Elena Bennett/Asmeret A. Berhe/Kennth Cassman/Ruth DeFries/Thomas Dietz/Achim Dobermann/Andrew Dobson/Anthony Janetos/Marc Levy/Diana Marco/Nebojsa Nakicenovic/Brian O'Neill/Richard Norgaard/Gerhard Petschel-Held/Dennis Ojima/Prabhu Pingali/Robert Watson/Monika Zurek (2006): Anthropogenic Drivers of Ecosystem Change: an Overview. Ecology and Society 11 (2), 29. http://www.ecologyandsociety.org/vol11/iss2/art29

Norberg, Jon/Graeme S. Cumming (Eds.) (2008): Complexity theory for a sustainable future. New York: Columbia University Press

Ohl, Cornelia/Karin Johst/Jürgen Meyerhoff/Martin Beckenkamp/Volker Grüsgen/Martin Drechsler (2010): Long-term socio-ecological research (LTSER) for biodiversity protection – A complex systems approach for the study of dynamic human–nature interactions. Ecological Complexity 7 (2), 170-178

Olsson, Per/Lance H. Gunderson/Steve R. Carpenter/Paul Ryan/Lous Lebel/Carl Folke/C.S. Holling (2006): Shooting the Rapids: Navigating Transitions to Adaptive Governance in Social-Ecological Systems. Ecology and Society 11 (1), 18. http://www.ecologyandsociety.org/vol11/iss1/art18

Ostrom, Elinor (2007): A diagnostic approach for going beyond panaceas. In: PNAS, 104 (39), 15181-15187

Pielke, R.A./H.J. Schellnhuber/D. Sahagian (2003): Non-linearities in the Earth System. In: Global Change NewsLetter 55, 11-15

Reid, W./D. Chen/L. Goldfarb/H. Hackmann/Y.T. Lee/K. Mokhele/E. Ostrom/K. Raivio/J. Rockström/H.J. Schellnhuber/A. Whyte (2010): Earth system science for global sustainability: Grand challenges. Science 330, 916-917

Rheinberger, Hans-Jörg (2006): Experimentalsysteme und epistemische Dinge. Frankfurt am Main: Suhrkamp

Schellnhuber, H.J./P.J. Crutzen/W.C. Clark/M. Claussen/H. Held (Eds.) (2004): Earth System Analysis for Sustainability. Boston: MIT Press

Sieferle, Rolf Peter (1997): Kulturelle Evolution des Gesellschaft-Natur-Verhältnisses. In: Marina Fischer-Kowalski et al. (Eds.): Gesellschaftlicher Stoffwechsel und Kolonisierung der Natur. Amsterdam: Overseas Publishers Association, 37-53

Smit, Barry/Johann Wandel (2006): Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282-292

Turner, B.L. II/Pamela A. Matson/James J. McCarthy/Robert W. Corell/Lindsey Christensen/Noelle Eckley/Grete K. Hovelsrud-Broda/Jeanne X. Kasperson/Roger E. Kasperson/Amy Luers/Maribeth L. Martello/Sven Mathiesen/Rosamond Naylor/Colin Polsky/Alexander Pulsipher/Andrew Schiller/Henrik Selin/Nicolas Tyler (2003): Illustrating the coupled human-environment system for vulnerability analysis: three case studies. Proceedings of the U.S. National Academy of Sciences 100 (14), 8080-8085

UNESCO (2010): Ecological Science for Sustainable Development: Man and the Biosphere Programme http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/man-and-biosphere-programme/

Vitousek, P.M./H.A. Mooney/J. Lubcheco/J.M. Melillo (1997): Human domination of earth's ecosystem. Science 277: 494-499

Walker, Brian/C.S. Holling/Stephen R. Carpenter/Ann Kinzig (2004): Resilience, Adaptability and Transformability in Social-Ecological Systems. Ecology and Society 9 (2), 5. http://www.ecologyandsociety.org/vol9/iss2/art5

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