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Center for Development Research
University of Bonn

Working Paper 133

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Approaches to managing disturbance and change:
Resilience, vulnerability and adaptability

ISSN 1864-6638 Bonn, June 2014

Cover Photo: Farmers in the West African Sudan Savannah take advantage of the conjunction of favorable seasonal rainfall, space availability and limited manpower to cultivate micro plots. These 'small' investments spread risk, generate non-accounted benefits and prevent food insecurity directly.

(Photo: D. Callo-Concha, Dassari, Benin, August 2012)

ZEF Working Paper Series, ISSN 1864-6638
Department of Political and Cultural Change
Center for Development Research, University of Bonn
Editors: Joachim von Braun, Manfred Denich, Solvay Gerke and Anna-Katharina Hornidge

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Acknowledgements

My thanks to Frank Ewert for having introduced me to the topic, and to the Crop Science Research Group of the University of Bonn for hosting me along my first steps.

Also to Julia Kloos for reading and commenting on the manuscript and adding the vision of the 'risk community'; to Manfred Denich and Franz Gatzweiler for their helpful observations and suggestions to ease the coherence and readability of the paper; to Margaret Jend for her committed proofreading; and to Christoph Brummel for the thorough formatting.

This work was conducted within the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) umbrella, financed by the German Federal Ministry of Research and Education.

Table of Contents

List of Tables

List of Figures

List of Boxes

List of Abbreviations

A-LUS	Agricultural Land-Use Systems
IFAD	International Fund for Agriculture
IPCC	Intergovernmental Panel on Climate Change
PRA	Participatory Rural Appraisal
SES	Social-Ecological Systems
UNEP	United Nations Environment Programme
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use
WCED	World Commission on Environment and Development

Box 1: Farming systems in the Austrian Alps

Traditional farming in the Nature Park Sölktäler in the Austrian Alps is highly labor demanding. Current societal changes that encourage out-migration and adverse policy settings devised by the common agricultural policy of the European Union make it hard for alpine farming to remain economically viable.

Milestad and Hadatsch (2003) carried out an empirical study to evaluate how the perspectives offered by organic agriculture fit with the current agricultural policy aiming at means to improve the social-ecological resilience of local farms.

The authors established the SES as the framework of analysis. They devised a concentric multi-layered scheme with the farm as the core, and the numerous influencing factors related to economic, political, institutional and natural aspects hierarchized by geographic and political scales. The family farm through a range of on-farm and off-farm activities generates income and relates to local and regional institutions and settings like farmers' associations, markets, small industries or the Nature Park Sölktäler itself and its administration, where farmers relate their social and economic networks, and learn about possibilities to maintain and improve their living conditions. The external circle refers to high-level factors, such as European and national policies, large industries and markets, infrastructure, and the wider ecological background on which farmers have little or no influence but rather depend strongly on it. It is therefore the main source of vulnerability to their economic and social subsistence.

3. Approaches to managing disturbance and change

In this section, the most frequently cited concepts and approaches for studying system disturbance and change are reviewed, lessons for their application extracted and examples visited. Although the review of concepts is general, the examples mostly refer to Agricultural Land-Use Systems (A-LUS).

3.1 Resilience

In the 1970s, the ecologist C.S. Holling was the first to use the term resilience to refer to how "*multiple stability domains (…) relate with ecological processes, random events (…) and heterogeneity of temporal and spatial scales"*. Holling observed that during the occurrence of an event, various stable states tend to appear successively, which grants stability to the whole system. These phenomena follow non-linear responses and are therefore unpredictable (Holling 1973: 17 in Folke 2006: 254).

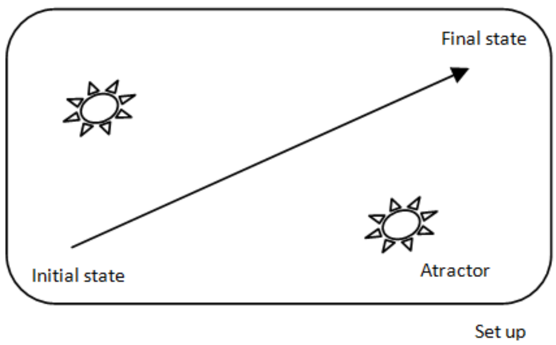
This insight led to a revolutionary focus for the study of ecological systems, which until then had favoured the idea of a unique equilibrium point and pre-determined stability boundaries. Hence, ecological resilience was defined as a quality that "(…) *determines the persistence of relationships within a system and (…) a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist*" (Holling 1973: 17).

These qualities were later recognized in non-ecological systems and applied throughout. In anthropology, Vayda and Macay (1975) questioned the equilibrium-based concept of culture and suggested instead the idea of behavioural resilience, Common and Perrings (1992) applied resilience principles for the study of ecological economics, and Zimmerer (1994) utilized resilience as a guiding premise for the study of human geography. Furthermore, 'social resilience' was coined to refer to the ability of human groups and communities to withstand external shocks, stresses and disturbances resulting from social, political, economic and environmental upheavals (Adger 2000, Anderies et al. 2004).

Carpenter et al. (2001) underlined the dual condition of resilience by proposing the term 'social-ecological resilience', later defined as the "(...) *capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks"* (Walker et al. 2004).

Thus, the term resilience referred first to ecological systems, then to social and later to socio-ecological systems, and provided a new foundation for the study of the human component in interaction with its surroundings and the generation of alternative situations of stability.

Figure 1: Components of resilience: trajectory (initial to final stage), attractors and setting



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Initially, resilience clearly invoked two components: 1) the amount of disruption that a system is able to absorb and remain able to reorganize itself, and 2) the capability of the system to continue performing the roles assigned to it (Carpenter et al. 2001). Accordingly, Folke (2006: 254) defined resilience as the "*(…) amount of disturbance a system can take before its controls shift to another set of variables and relationships that dominate another stability region*".

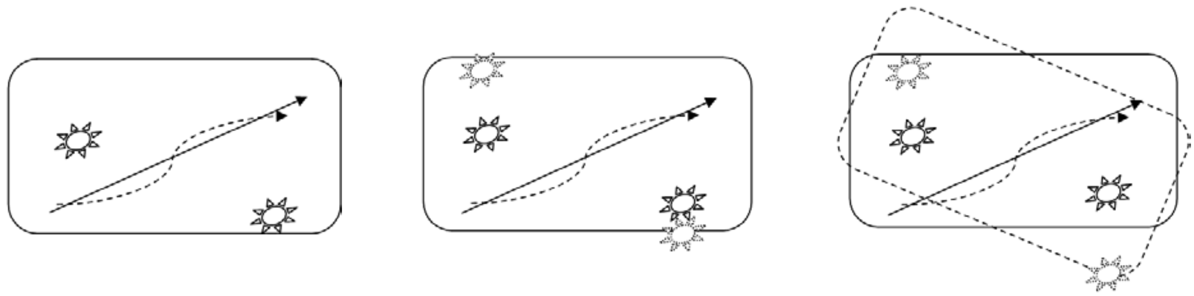
Ultimately, the notion of threshold (see section 4.2) began to play a key role in the resilience concept. Since transition occurs among stable stages, management may refer to the administration of thresholds. For that reason resilience was re-defined as the "(…) a*bility of system to absorb shocks, to avoid crossing a threshold into an alternate and possible irreversibly new state, and to regenerate after disturbance"* (Resilience Alliance 2007: 1).

Gallopín (2006) portrayed resilience as a trajectory from an initial to a final state determined by a succession of situations occurring in response to the influence of an attractor or a series of them in certain conditions (Figure 1).

Keeping this in mind, the resilience of a system increases in complexity in proportion to which its components vary. Hence, resilience could increase in complexity according to the cumulative changes in the trajectory (decisions, behaviours, changes, etc.), attractors (influencing factors) and settings (economic, ecological, institutional contexts, etc.). They are labelled correspondingly as engineering, ecological and landscape resilience (Figure 2a, b and c).

Figure 2: Cumulative change in the components of resilience interplay

a) Engineering resilience	b) Ecological resilience	c) Landscape resilience
Dotted line traces changes in trajectory in response to influence of attractors	Added to engineering resilience including changes in the attractors themselves	Cumulative includes changes in trajectory, attractors and setting



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These are heuristic models aiming to dissect the resilience components for better depiction, but in reality changes are not always causal. Multi-stable stages differ depending on the scale at which the system operates, i.e., increases on one side might signify decreases on another (Walker et al. 2004). Thus, engineering resilience is restricted to the analysis of linear and non-linear systems during short periods of time, implying the proportional increase of outputs as a function of inputs (Holling 1996). With the inclusion of more components, these relational progressions no longer exist, thus leaving room for process-dependent and feedback-dominated behaviour, which is characteristic of complex systems (see section 5) (Holland 1995, Levin 1999) where the scope of change is much wider, and trajectories are impossible to predict (O'Neill 1999).

Based on those ideas, Folke et al. (2003) pointed out that resilience in complex systems should focus most on the systems' capability to adapt and shape themselves according to eventual disturbances. This assertion qualitatively changes the epistemology of resilience: The seminal idea that focused on the capacity to absorb shocks and recover functions shifted to stress on the capacity for renewal and reorganization then (see Box 2)

Attributing this 'evolving' quality to resilience would entail the possibility to recombine processes that reshape the features and trajectories of the system (Smith and Wandel 2006). This could also open up opportunities for innovation and development (Gunderson and Holling 2002, Walker et al.

2002, Berkes et al. 2003) that, properly managed, could lead to sustainable measures and eventually sustainable management (Walker and Meyers 2004, Adger et al. 2005).

Finally, it is worth noticing that resilience does not refer always to a 'positive' situation in the sense that it tends to remain in a desirable setting. A system might also be 'negatively' resilient when it tends to stay in a non-desirable momentum and has difficulties in changing to more desirable stages (Scheffer et al. 2001, Gunderson and Holling 2002, Walker et al. 2004).

Box 2: Resilience in Polynesian farming systems

A good example of resilient SES is given by the Samoan farmers in the Polynesian archipelago. Exposed to a high incidence of climatic upheavals, e.g., more than 40 cyclonic storms since 1831 (about one every five years!), these human groups have developed a large number of social and ecological practices to increase their resilience and guarantee their survival. Colding et al. (2003) identified as the most relevant farming practices the high crop diversity, intensive and extensive use of polycultures, and agroforestry with the overall objective to spread the risk of loss, assure food security and generate other by-products and services. Nonetheless, the sine qua non condition to implement these measures happened to be an inherent characteristic of the studied populations: the capability for reorganization and restructuring of habitual processes after the occurrence of the disturbance.

3.2 Vulnerability

The definition of vulnerability depends strongly on the context in which it is applied (Gallopín 2006). In the context of natural hazards, e.g., floods or droughts, vulnerability relies mainly on exposure, susceptibility and coping capacity as indicators of how prone to threats a population is. In development issues, e.g., food or health security, vulnerability is a backbone premise with respect to a condition that has to be prevented. Furthermore, in relation to the effects of global (mostly environmental) changes, like global warming, vulnerability is a platform that comprises the multiple effects (predictable and unpredictable) that these changes can lead to (Liu et al. 2008).

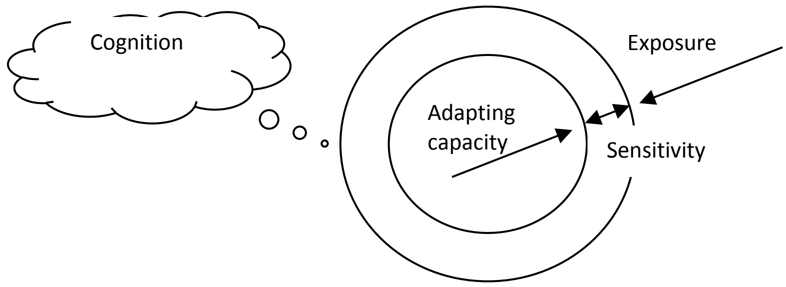
Conceiving vulnerability as the susceptibility to change of a system exposed to certain disturbances implies the assumption that a system is vulnerable to an explicit event or factor that accentuates such a condition but not to other(s) (Turner et al. 2003, Adger 2005). This linear understanding of vulnerability where scientific discovery is directly implemented in policy making can trigger reactive measures that may be reductionist and/or counterproductive (Vogel et al. 2007). In the same direction, van der Leeuw (2001) states that "(…) *if resilience refers to the system's capacity to recover from changes, vulnerability refers to the capacity to preserve it".* Although this points to a crucial dichotomy in the understanding of disturbance and change, its application should be questioned. Methodologically, vulnerability tends to be about sources of susceptibility in the system, while resilience is not so much about the source of resilience but more about the identification of thresholds of change. Finally, not only resilience and vulnerability but also several other factors determine the performance of a system (Gallopín 2006).

Hence, the current conceptualization of vulnerability is defined by *"(…)diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes*" (IPCC 2012: 32), where the behavior of individuals and societies are the major determinants (Berkes et al. 2003, Adger et al. 2005) (see Box 3).

To be operative, this broad definition needs to include, besides the potential impact on the system, the system's ability to cope with these impacts and the extent to which such coping ability may be constrained by environmental and societal conditions (Tyler et al. 2007). Hence, other concepts help to better express what vulnerability factors embrace, i.e., exposure, sensitivity, adaptive capacity and cognition. Exposure refers to the degree, duration and extent to which a system is in contact with a disturbing factor (Adger 2006, Kasperson et al. 2005), and therefore depends mainly on how the system interacts with the external disturbance. Sensitivity refers to the degree to which a system is affected or can absorb impacts without suffering long-term harm (Adger 2006), and relies mostly on the internal and intrinsic qualities of the system to react to the stimuli. Adaptive capacity (capacity to adapt, capacity of response or coping capacity) refers to the ability to cope with the constraints that a system faces and to surmount them and reach new stability stages (Brooks et al. 2005). Finally, cognition refers to the human capability to administrate (receive, perceive, exchange, evaluate, update, etc.) information and implement it through a decision-making process (Acosta-Michlik and Espaldon 2008).

Exposure is considered an *external* factor of the system, while adaptive capacity (feedback by a manager's cognition) is seen as an *internal* factor, and sensitivity, is the result of the interaction of both (Rounsevell et al. 2006, Gallopín2006) (Figure 3).

Figure 3: Ontology of the components of vulnerability



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The term 'inter-vulnerability' refers to the human behavior that supports the reception, exchange and evaluation of risks and subsequent identification, and weighs alternatives to improve the individual's profile and its performance (Acosta-Michlik and Rounsevell 2005).

Box 3: Local strategies to reduce climate change vulnerability of small farmers in northern Ghana

Conceiving vulnerability as a 'double structure' phenomenon, where the first structure relates to the exposure of the subjects to the stressor, determined by the intrinsic or contextual characteristics of the subject to be affected by a disturbing factor, and the second structure that refers to capabilities of the subject to cope with the stressor disturbing influences. Kanchebe (2010) studied the vulnerability of small farmers in northern Ghana to climate change.

He identified as the main sources of vulnerability as being rainfall variability, poor soil fertility, and the existing socioeconomic conditions and cultural practices, such as large number of dependents and resource-demanding customary rites. On the other hand, he identified as strategies to reduce vulnerability: a) diversification of economic livelihood activities, from subsistence farming to other activities like food processing, migration and trade; b) soil conservation and management of degraded lands, including traditional forms of manuring; and c) cropping system adaptation, including multiple farms and drought resistant varieties.

However, key to implementing these successfully are kinship and networking, either horizontally between households/compounds and with the community, and vertically from generation to generation.

In the disaster reduction community, adaptation often appeals to other concepts, such as hazard as a situation that poses a threat to life, health, property, and risk and refers to the probability of the system being affected. Here, there is a shift to utilize approaches that investigate risks resulting from multiple hazards that a system is exposed to and how they interact (Kappes et al. 2012).

Finally, it has to be said that vulnerability does not always connote a negative situation; it is possible that subsequent changes in a system can lead to beneficial transformations (Gallopín 2003).

3.3 Adaptation and adaptibility

As in the case resilience and vulnerability, adaptation has received numerous definitions resulting in a wide application. In biology, adaptation refers to genetic and behavioural characteristics that enable organisms and systems to cope with environmental changes in order to survive and reproduce (Futuyama 1997). In social sciences, adaptation was re-addressed to analyse capabilities of individuals, groups and institutions to adjust in response to changing situations in the environment, or to changes of other elements in demography, economics or organization (Denevan 1983).

In the latter context where adaptation developed further, Pielke (1998) defined adaptation as the behavioural adjustments of individuals, groups and institutions to reduce society's vulnerability. Butzer (1980) and O'Brien and Holland (1992) emphasized the 'cultural repertoire' as a core adaptation factor, since it sustains the accumulation of knowledge of societal groups of how to cope with changes.

Hence, Smit and Wandel (2006: 282) proposed a consolidated definition of adaptation, which "(…) *refers to a process, action or outcome in a system in order to better cope with, manage, or adjust to some changing condition, hazard, risk or opportunity*".

The notion of adaptive capacity (also called capacity of response or coping capacity) refers to the ability to become adapted to an environment subject to contingencies, and therefore exists prior to the occurrence of the disturbance (Brooks et al. 2005). Thus, adaptive capacity opens up a wide gamut of possibilities to enforce responses and strengthen stability, e.g., diminishing the exposure, adjusting the sensitivity, etc.

Adaptive capacity achieved wide attention in the context of climate change as the "*adjustment in natural or human systems to actual or expected climate stimuli and their effects*" IPCC (2001). But a more general definition was given by the Resilience Alliance (2007) that defines it simply as the capability of humans to influence and manage resilience in SES.

It is recognized that elements and processes that represent adaptive capacity are not punctual but are rather broad categories (Smit and Wandel 2006). That is how adaptive management has emerged, i.e., as a response to on-the-ground difficulties to operationalize adaptation, for example to identify the political and organizational decisions determinant for the implementation of management practices (Gunderson 2003).

Widening the scope of action of adaptation towards SES implies that analyses will include multiple domains of stability and overlapping processes, from testing a single hypothesis towards sorting multiple hypotheses, each with particular management peculiarities. The proposed terms for this are adaptive ecosystem management and adaptive governance when institutional policymaking is included (Folke 2006).

However, adaptability based on a system's ability to change when changes occur (Andresen and Gronau 2005) implies the occurrence of modifications in the system along a timeline or, in other words, lists the successive adaptive changes of interaction between the system and its environment.

Box 4: Adaptive capacities of Minnesotan farmers and Tanzanian agro-pastoralists

The dissimilar settings of the following two examples show the divergences in the adaptation strategies and the procedures applied for their evaluation of adaptation in farming systems.

A. The adaptation of Minnesotan farmers to natural disasters was evaluated by Blann et al. (2003), who identified the management principles and practices that facilitate the renewal of organizations and the specific elements that trigger local responses to natural catastrophes. Methodologically, farmers were asked about their response during periods of natural crises. Their responses fitted in the adaptive cycle (see section 4.1), a heuristic model that portrays the succession of destruction and recovery. They observed that the farmers' management practices were addressed by overall principles such as 'putting the brakes on release' and 'conserve memory and opportunity for renewal'. Thus they constantly generated new practices to substitute the traditional ones once these were no longer working, and these were conceived and implemented at multiple scales.

B. Combining semi-structured, in-depth interviews, Participatory Rural Appraisal (PRA), and secondary information Tengö and Hammer (2003) evaluated the adaptive capacity of northern Tanzanian agro-pastoralists.

The authors a) described the case-study area with some historical background; b) outlined the agro-ecological setting, farming systems and land-use change drivers; c) identified the local customary farming practices (e.g., water management); d) analysed the roles of institutions (e.g., water access regulation); and e) identified the adaptive practices for resources management, e.g., turns, technology, etc.

3.4 Joining resilience vulnerability and adaptability

As seems evident when going through the concepts discussed above, a constant overlapping can be perceived. The review of field studies supports this idea. In the field, these concepts can be applied interchangeably (Janssens and Ostrom 2006, Callo-Concha and Ewert 2014). Therefore, their joint usage has been repeatedly suggested (Vogel 2006, Vogel et al. 2007).

The precursory idea of van der Leeuw (2001) that states that if resilience refers to the capacity of the system to recover from changes, vulnerability indicates the capacity to preserve the structure of the system. Although not entirely accurate, because of the participation of determinant factors not necessarily related to either resilience or to vulnerability (Gallopín 2006), it contributes to build a heuristic model based on the continuous interaction of these two elements.

The dichotomy resilience/vulnerability would be complemented by a third component: the concomitant adaptations occurring as responses to disturbances. This understanding, rather than increasing confusion, could be clarifying. However, this requires turning this ambiguity into conceptual integrity. To do so should not discriminate among semiotics, semantics and even methodologies; rather it should emphasize operationalization criteria, and thus focus on problem solving (Callo-Concha and Ewert 2014).

4. Operationalization tools

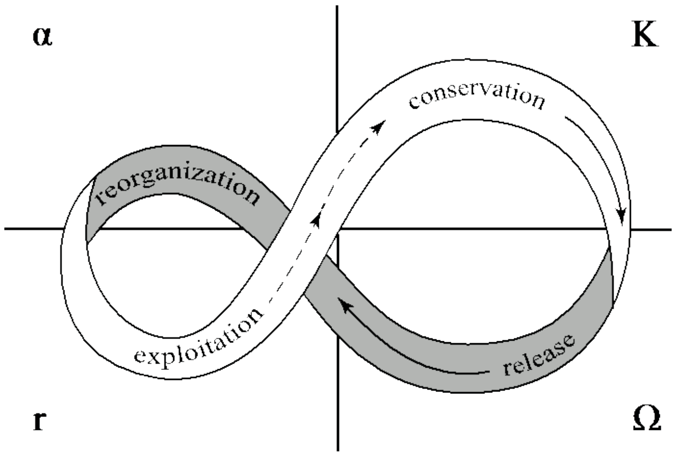
In this section, methodological tools used to operationalize the above-described concepts/approaches are described; neither judgments of value nor critics accompany their characterization. The intention is rather to highlight their foci and potential application.

4.1 The adaptive cycle

The adaptive cycle, adaptive renewal cycle or adaptive capacity cycle was developed by Gunderson and Holling (2002). Inspired by ecosystem dynamics, it is a heuristic model that schematically represents the evolution of the dynamics of complex systems across time due to changing circumstances.

In the adapted cycle, the natural evolution of a system follows four alternating phases: 1) ‘r’ exponential change (exploitation); 2) ‘K’ growing stasis (conservation); 3) ‘Ω’ readjustment and collapse (release); and 4) ‘α‘ reorganization and renewal. The first two phases are grouped together as the *frontloop* and focus on the system’s organization and growth, e.g., production patterns, growing yields, resource conservation, etc. Phases 3 and 4 are collectively named *backloop* and correspond to situations like the vegetation recovery after a storm or population growth following a famine (Figure 4) (Gunderson and Holling 2002, Berkes et al. 2003).

Figure 4: The adaptive cycle



Source: Gunderson and Holling 2002, adapted

The adaptive cycle aims at providing a scheme to understand a system and eventually address it, e.g., a fast frontloop (transition from ‘r’ to ‘K’) would imply the need to pay attention to the variables that could provoke change or exert stronger control on the resources stock in order to maintain the system’s resilience. On the other hand, a fast backloop (transition from ‘Ω’ to ‘α‘) implies that the events in the system shifted to a stable setting, similar or completely different to the previous one, and indicates the susceptibility of a system to losses in a particular domain and determine a set of conservation measures (Walker et al. 2002).

The shift from the frontloop to the backloop (transition from ‘α‘ to ‘r’) is intermediated by a ‘collapse’. This may be triggered by creeping or sudden changes, where the system re-configures itself in a ‘new’ stable state, which might be similar to the precedent ‘r’ state, e.g., the regeneration of a primary forest after a fire. Or it might be a different one, e.g., breaking a democratic system via a *coup d’état* and the installation of a dictatorship (Anderies et al. 2006). (See Box 5).

Each phase of the adapted cycle has characteristics that can serve to portray the systems capabilities to adapt, i.e., a) *potential* to generate intended products, b) *connectedness* among components, and c) *resilience*, which is the capacity to recover and find a new stable setting (Tab 1).

Tab 1: Assessment of the phases of the adaptive cycle related to the adaptability profile of a system

	Potential (capacity)	Connectedness	Resilience
α : reorganization	High	Low	High
K : conservation	High	High	High
r : exploitation	Low	Low	High
Ω : release	Low	High	Low

Source: Holling et al. 2002

The combination of these phases determines the behaviour of the SES along the adaptive cycle. Among these, two 'pathological states' that could lead to instability have been identified: poverty trap and rigidity trap. The poverty trap can occur when all three properties (potential, connectedness and resilience) have low values: The system's stocks are depleted, inter-linkage is weak and the system is unable to recover, e.g., in the case of intensive mining or fishing. The rigidity trap may occur in systems that, despite being resilient and rich, are highly connected but rigid and inflexible, e.g., highly bureaucratic institutions with little room for innovation (Gunderson and Holling 2002).

Box 5: Slash-and-burn agriculture: Dayaks from Borneo and indigenous Amazon farmers.

Slash-and-burn agriculture plays a significant role in production and natural resources management in tropical lands. Land preparation prior to cultivation is done by slashing and burning the fallow vegetation. The subsequent continued cultivation of the field for a determinate period of time (two to three seasons) is followed by a period of recovery (twice to three times the cultivation phase). Properly managed, it contributes to the accumulation of biomass and nutrients for the subsequent cropping period, suppression of weeds, pumping nutrients from deep soil layers upwards, control of soil erosion, and maintenance of agrobiodiversity.

The indigenous Dayak have lived in the Kalimantan Borneo forests for about 35000 years with livelihoods based on hunting, forest gathering, fishing and agriculture. As active practitioners of slash-and-burn agriculture, the Dayak combine traditional beliefs, e.g., in the selection of swidden areas, with day-by-day needs, e.g., incorporation of rice cultivation as the most important staple food. Alcorn et al. (2003) applied the adaptive cycle to explain the intermingled cultivation of rice within the successive slash-and-burn agriculture phases: a) slash and burn (th day-by-day needs, e.g., incorporation of rice cultivation as the most important staple fo regeneration (r = exponential change), and d) secondary forest climax (K = growing stasis).

4.2 Thresholds

Attached to the adapted cycle is the concept of threshold, which occurs when the degree of the disturbance overcomes a certain degree of stability of the system. In the framework of the adaptive cycle, it refers to the point when the trajectory of a system switches from one to another of the four phases, i.e., exploitation to conservation, conservation to release, release to reorganization, and reorganization to exploitation (Gallopín 2006).

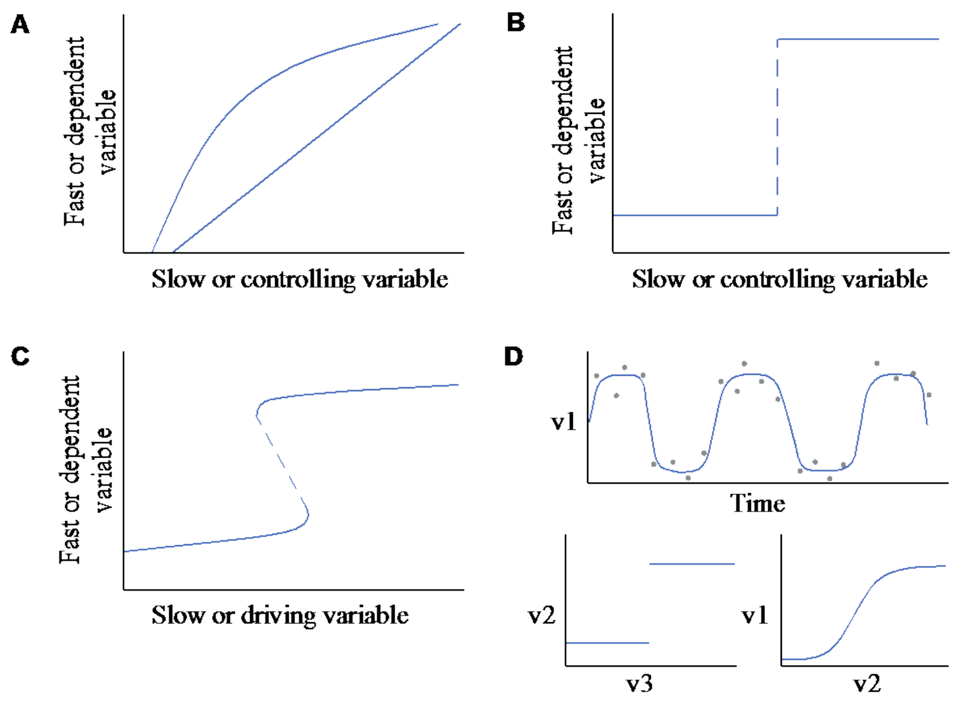
The reasons why and when a system transits from one phase to another are extremely variable. The transition frequently occurs when the preceding phase is no longer stable; the persistence of a system depends on its ability to change to a more stable phase. Sometimes the change is imposed by the need of one/some of the components to enforce their own permanence. In addition, transiting a threshold can provoke changes in other, apparently non-related, components (cascade effect).

However, it is important to recognize that transiting a threshold is a two-sided phenomenon: switching from an old stable phase to a new one will surely lead to changes in the characteristics of the system. Therefore, the understanding of the mechanisms that trigger their occurrence, i.e., dynamics, reversibility, frequency and scale, are important to derive opportunities for policy making. In certain way, adaptive management is a direct consequence of the decisions facing thresholds (Walker and Meyers 2004). (See Box 6)

Based on these characteristics, a threshold typology was proposed by Walker and Meyers (2004):

- Continuous transition, smooth and reversible, e.g., seasonal consumption of a resource and its natural recovery as in sustainable fishing or grazing.
- Sudden transition with no influence of alternate attractors, e.g., increase in value of a commodity on the stock market, the change is given and other elements have no alternative but to adjust.
- Sudden transition with participation of alternate attractors, e.g., revolution, social-political turmoil, and reshaping of society.
- Combinations of the above three transition types: v1 cyclical production, e.g., slash-and-burn (see Box 5); v2 sudden market price variation, e.g., food price spikes after market imperfections; v3 progressive growth and stabilization, e.g., greenhouse gases emissions and stabilization (Figure 5).

Figure 5: Main thresholds types



Source: Walker and Meyers 2004, adapted

Box 6: Thresholds in Australian agricultural systems

Allison and Hobbs (2004) applied the adaptive cycle model to interpret the history of the agricultural sector in western Australia. During a period of approximately 100 years, two successive cycles were identified (see section 4.1).

The first cycle started with the growing global demand for wheat and wool, which happened to be the main regional products (1889-1929; 'r' exploitation and 'K' conservation), followed by the economic depression and subsequent Second World War (1939-1945; 'Ω' release), and ending with the subsequent recovery by the injection of scientific and technological innovations (1945-1949; 'α' reorganization).

The second cycle started with the post-war boom fuelled by the expansion of the agricultural horizon and the intensive use of agrochemicals, water and machinery (1949-1969; 'r' exploitation and 'K' conservation), continued with a decade of decline as the consequence of the increase in oil prices, introduction of market regulations, and land degradation (1969-1979; 'Ω' release), and was terminated by a phase of environmental awareness (1980-1990; 'α' reorganization).

In both cases, external forces, i.e., world war and sprint of oil prices, imposed thresholds hard to cope with and finally triggered the change, forcing farmers to adapt. Furthermore, political leaders managed to 'catch up' with the structural changes in accordance with contemporary social, political and environmental priorities, e.g., by introducing and promoting environmental protection through setting up habitat conservation zones (1980-1990), and later by reforming state administration to encourage environmentally friendly natural resource management (1990-2000).

4.3 Transformability and panarchy

Walker et al. (2004) developed the concept of transformation (together with latitude, resistance and precariousness) to label the specific momentum when, through its adaptive behaviour, a system reconfigures itself to fit into new conditions. They formally coined transformability as the "(…) *capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable*" (Walker et al. 2004).

Good examples of transformation are changes in land use, e.g., conversion of forests into agricultural fields to take advantage of commercial opportunities, or agricultural lands into graze lands because of exhaustion of soil fertility. In both cases, the aim is to keep the system somehow productive, although the conditions and purpose of the systems could have changed greatly.

The tension between maintaining the system's status (resilience) and opening up to upcoming changes (transformation) creates chances to include and/or to promote features considered desirable, e.g., via governance (Anderies et al. 2006). In general, transformation creates the idea of active change, where the conditions for a new stability are shaped by the system's operators (Löf 2011) with the intention to reduce the system's vulnerability by changing it from an undesirable state to a desirable one.

Panarchy refers to the replication of the adaptive cycle in several nested (cross-scale) levels to address various phenomena occurring successively (Gunderson and Holling 2002). These changes from one adaptive cycle to another might mean strengthening or weakening the adaptive capacity, but can also result in a complete re-shaping of the system's profile and dynamics (Berkes et al. 2003).

Holling et al. (2002) suggested that panarchy can not only portray the transition of one system from one homeostatic stage to another but can also represent changes across different spatial and temporal levels, e.g., the re-growth of a forest after a fire. It operates differently in different species and communities by subsequent competition and dominance processes, leading to a species re-arrangement growth and stability momenta, and horizontal and vertical spatial distribution.

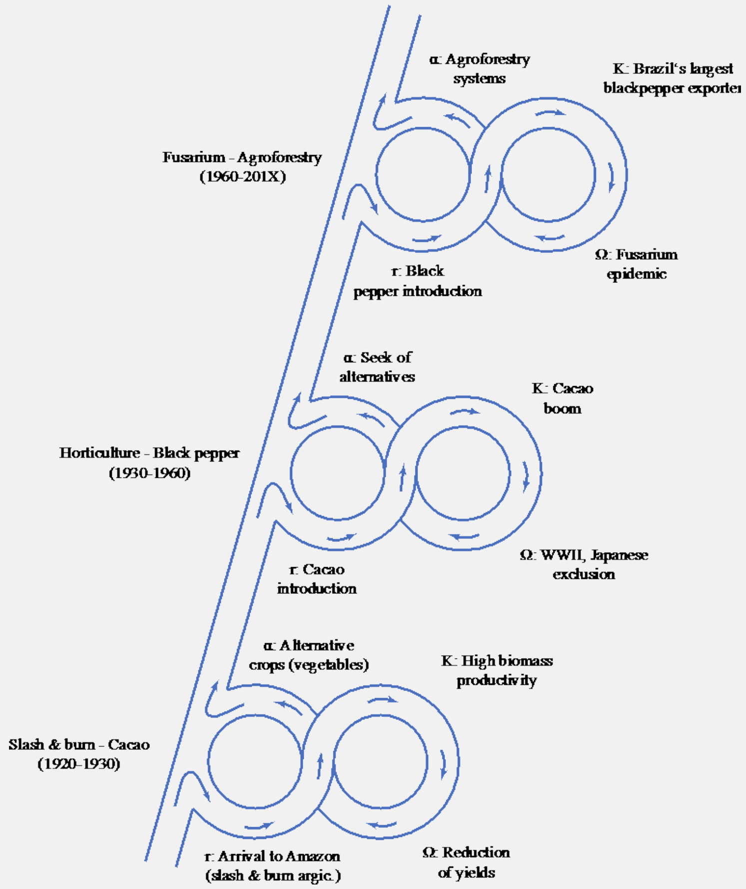
By interaction, these changes may affect other sub- and supra-systems and extrapolate their effects at various spatial and temporal levels. However, these changes will be discontinuous and multimodal, and therefore unpredictable.

Anderies et al. (2006) used 'collapse and reorganization' to refer to the transition from the reorganization (α) to exploitation (r) phase. This notion fits well with the idea of transformation, i.e., conversion of a system into another one with completely different settings but anyhow stable, but also with the transition from one adaptive cycle to another, i.e., panarchy.

However, it must be said that the adaptive cycle and panarchy are heuristic models sustained on the observance of behavioural repetitions of socio-ecological systems. Therefore, the assertions made about them are empirical and qualitative. Thus, their application should be made ad-hoc, and care taken with their extrapolation.

Box 7: Panarchy of the Tomê-Açú agroforestry model

The Tomê-Açú community was founded in 1929 as part of the Brazilian-Japanese immigration program to colonize the Amazon region. In the beginning, the Japanese settlers concentrated on the removal of forests to establish cacao (*Theobroma cacao L.*), which eventually failed due to their lack of technical knowledge. This forced them to replicate native peoples' farming methods. Later, they focused on the cultivation of rice, corn, beans, manioc, and vegetables, initially for self-consumption and later for selling regionally, which became an important source of income (Anderson 1990, Smith et al. 1995).



In the late 1930's, black pepper (*Piper nigrum L.*) was introduced and soon became the most widespread crop in the region Tomê-Açú and the country's main export. In 1957, an epidemic of the fungal disease *Fusarium solani* badly affected the pepper fields, compelling the farmers to develop alternative production systems. They diversified them mainly by including perennial (woody) cash crops (Smith et al. 1995). Since then, the Tomê-Açú nikkei inhabitants have developed a large variety of agroforestry systems, which proved to be biophysical and economically viable in time. The success of this model relies on not only on the high agroecological efficiency of the system, but also on a strong community organization and technical support for production, post-production and commercialization (Jordan 1987).

The panarchy model is applied to the evolution of Tomê-Açú land-use systems, identifying its three main moments: cacao plantation (1920-1930), black pepper introduction (1930-1960) and Tomê-Açú agroforestry model (1960-today) (Callo-Concha 2009).

4.4 Adaptive management

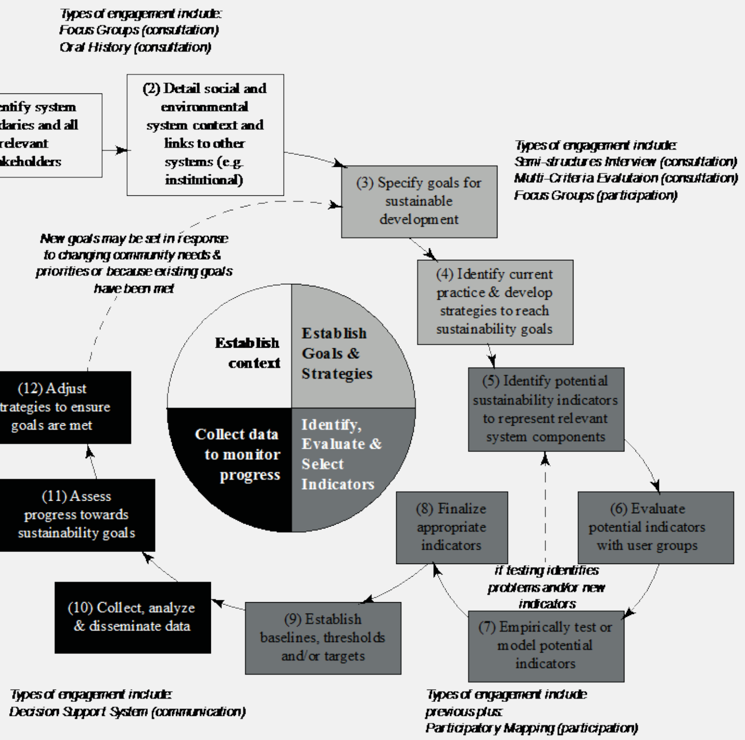
Adaptive management refers to the operationalization of the concepts described above with a specific objective. It relies on iteration as a key element since it assumes that decisions to be taken in future will base on knowledge gained until then. So, when facing a specific problem and identified measures to be taken, adaptive management proposes the implementation of policy, monitoring of the results, and finally reviewing accuracy to refine further decisions (Stringer et al. 2006).

In order to gain legitimacy and accuracy, adaptive management has to rely on multi-stakeholder participation, which implies the need to build capabilities in institutions and organizations in charge of the adaptive management at various levels (Olsson et al. 2004, Folke 2006).

Streamlining goals and objectives at all levels could create an adaptive governance scheme, probably the highest operational instance of these disturbance and change approaches. But to reach this stage, all precedent stages should be fulfilled, i.e., clear portrayal of the SES in question (components, trajectory, attractors, boundaries, etc.), depiction of the SES adaptive cycle phases, identification of thresholds, identification of alternatives to increase adaptability (based on the diminishment of vulnerabilities and augmentation of resilience), and only then, construction or strengthening of institutions, organizations and networks capable of supporting adaptive management/governance (see Box 8).

Box 8: Participative adaptive management of rangelands in Botswana and vulnerability in southern Africa

An example of the implementation of adaptive management on the ground can be found in pastoralist communities in the rangelands of Botswana. Through several participatory techniques, stakeholders were asked about their understanding and management preferences for sustainable use of rangelands. The procedure considered four main steps: 1) Establishment of the socio-ecological context, 2) definition of the aimed goals and the means the community has to achieve them, 3) identification, evaluation and selection of indicators to observe the evolution of goals, and 4) analysis and dissemination of decisions, and readjustment of mechanisms to ensure achievement of goals (Stringer et al. 2006).



5. Premises of implementation

A paradigm offers an agreed way to think about something and at the same time to establish a ground to elicit related ideas. Kuhn (1996) listed the roles that paradigms perform in science by determining what to observe, what questions to formulate, how to structure these questions, and how to interpret the results (Kuhn 1996). Although changes in scientific paradigms are not uncommon, changes in procedures and tools tend to be slower (Giampiertro 2004). This provokes a 'time in between', where an amount of information is generated based on premises no longer considered valid or at least not hegemonic.

The concepts presented in this paper confirm this. Although progressively in use, they are not always acknowledged and therefore implemented. The main reason seems to be the tendency to simplify a complex reality through the implementation of well-understood methods that, though useful, tend to be reductionist. One good example is mathematical optimization, e.g., maximum sustainable yield, which is good in capturing causal responses but incapable of handling large sets of factors and their interaction (Walker et al. 2002). Another is the control theory, which assumes a hierarchical and unidirectional flow of information and decision making, but does not prevent each level in having a different stability momentum, thus making a top-down harmonization futile (Gunderson 2003).

The acknowledgement of complexity as an inherent quality of any system and the consequent shift from atomistic to systemic approaches, the wide involvement of stakeholders (participation) favoring bottom-up insights, and the prioritization of research to obtain useful outputs (functionality) are exposed and argued as necessary paradigms for the implementation of approaches of disturbance and change.

5.1 Complexity, systems, and complex adaptive systems

Complexity relies on the assertion that by reducing the analysis from the whole to its parts, the understanding of the whole is reduced (Schein 1980). Hence, it becomes worthwhile to identify a set of components large enough to disclose their interplay to make sense of a phenomenon.

In reality, most social and natural phenomena do not occur in isolation, rather they are subject to constant disturbances, showing non-deterministic and therefore unpredictable behaviour (Holland 1995, Levin 1999, O'Neil 1999).

While seeking an operational approach, the above notion of complexity has been coupled with the concept of system. A system is roughly defined as a set of interacting or interdependent components forming an integrated whole. The systems theory presents the idea that a great number of phenomena can be handled as systems, since there are 'isomorphic principles' widely applicable independent of the area of specialization (Bertalanffy 1950).

A systemic view relies on the identification of the components, context, connectedness and feedback loops among components and with other (supra- and sub-) systems via cross-boundary inflows and outflows (Hart 1985, Giampietro 2003).

These basic principles have generated several approaches, analytical frameworks and even fields of knowledge, e.g., organizational theory, systems dynamics, systems of systems, ecological thinking, ecosystem approach, systems thinking, etc. These are widely applied in disciplines such as biology, ecology, social sciences, computer science, etc., and more recently on the interface of these.

As systems present complexity as one, if not the most important, of its features, and as systemic insights appear to be the adequate approach for handling complexity, the term *complex systems* to address these situations emerged (Folke 2006, Vogel et al. 2007). A complex system refers to a system composed of numerous components with numerous types of relationships, and exhibiting as a whole different/more properties than the ones that each component shows individually.

The study of complex systems has to focus not on goals but on processes, and the extent of these processes might last long enough to impede their proof. In consequence, the assessment and management of complex systems have to consider the ability to cope with, adapt to, and shape the system's behaviour without losing options for future adaptability. This is known as *complex adaptive system* (Folke et al. 2003). A logistical consequence is the adoption of SES as a unit of analysis, widely used in the resilience, vulnerability and adaptability scientific communities (Berkes and Folke 1998, Adger 2006).

5.2 Participation

Local expertise offers robust factual information on reality, facilitating the necessary level of understanding of social and institutional structures for stakeholders to disclose and address the complexity of SES, i.e., to embrace resilience and support adaptation (Walker et al. 2002, Marquardt 2008). Furthermore, capturing positions from neglected stakeholders allows first, to prevent disturbances, and second, once the disturbance has occurred, to find the way to new stability stages.

Among others, participation minimizes the bias resulting from disciplinary insights and central planning, strengthens the factual base and legitimacy of inputs and outputs, fosters social learning concerning adapting capacities of populations, and in an advanced phase operationalizes pro-democratic normatives (Stringer et al. 2006).

Enforcing participation requires not only changing the perspectives by swapping roles between the ones at the top and the others at the bottom, but also by involving stakeholders across the whole range of the decision-making chain and including the intermediate stakeholders whose goal is key to bridging and operationalizing collaboration (Folke et al. 2005).

Vogel et al. (2007) cite as key factors to promote successful participatory processes to a) implement flexible mechanisms to facilitate feedback and social learning, b) determine a manageable scale at which to operate, c) define an institutional framework of feasible political and environmental management, and d) promote multi-stakeholder involvement.

5.3 Functionality

In practice, complexity is indistinguishable to the observer, who cannot identify either components or relationships at first sight. Rather (s)he sees a 'whole' that generates some output(s) and performs certain function(s), and eventually requests some inputs.

This indistinguishability is prone to give place to perplexity, and this severely limits the capacities to understand and react conveniently. As stated by Zadeh (1973: 28) "(…) *as the complexity of a system increases, our ability to make precise and yet significant statements about its behaviour diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics*".

Alternatively, Funtowicz and Ravetz (2008) reflect on paradigm shifts that science should experience, and coined the idea of *post-normal science* that questions the orthodoxy of current science practice, which is limited to the description, characterization and interpretation of specific phenomena. They argue that this exercise is futile, and that we should on the contrary re-orient our analysis towards pragmatic situations where the function(s), i.e., expected role(s) from the analysed systems, is prioritized and eventually anticipated. This makes room for the determination of useful policy decisions (Funtowicz and Ravetz 2008).

Generically, functionality relies on the principle that the sustainable performance of a system can be reached only through the enhancement and intensification of involved processes and the simultaneous generation of useful outcomes to satisfy not only the ecological but also the socio-economic demands of stakeholders (Callo-Concha 2009).

6. Conclusions

In four sections, this working paper summarizes, dissects and explains, via ad-hoc examples, the dominant concepts/approaches that deal with changes in human-dominated systems.

The first section introduced the premise of ‘disturbance and change’ instead of ‘stability’ to understand and operationalize sustainability, and underlined the importance of an integrative unit of analysis: the SES. The second section revised the most important approaches to deal with disturbance and change in SES, i.e., resilience, vulnerability and adaptability; their semantics, logics, and criteria of application were detailed and explained. The third section reviewed some of the most frequently used methodological tools developed and adapted for the implementation of the approaches described above, i.e., the adaptive cycle, thresholds, panarchy, transformability, and adaptive management. Finally, the fourth section briefly discussed the principles on which the implementation of the previously described approaches should rely, i.e., complexity and systems thinking, functionality and participation.

I hope that this paper achieves its main goal to shed some light on this exciting domain ‘manage disturbance and change to operationalize sustainability’, for two main reasons: its inherent suitability to handle a large number of real-life situations, and its growing importance in the interface academia and decision making. This growing importance although extensively discussed is, however, rarely implemented.

Therefore, the pending task for all of us remains: to convert this powerful set of concepts and approaches into operational gears of management and change.

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Zentrum für Entwicklungsforschung
Center for Development Research
University of Bonn

Working Paper Series

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Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Straße 3
D – 53113 Bonn
Germany

Phone: +49-228-73-1861
Fax: +49-228-73-1869
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