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Review article

Condition, Tendency, and Dynamic Interactions in a Resilience Context of a Social-Ecological System

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Abstract

In this paper we will analyze the dynamics of a social-ecological system (SES), which requires an integrated understanding of both the interrelatedness of biophysical and socioeconomic components and the adaptive capacity of these system's components to external drivers. Social-ecological resilience, the adaptive cycle metaphor and livelihood development are presented as the guiding conceptual framework to analyze local strategies, aiming towards the sustainable use of natural resources and to encourage the participation of the community in the management of ecosystem services, thereby improving human well-being. Furthermore, in the light of recurring unpredictable changes, adaptive capacity building and a high responsiveness to these changes may serve as fundamental assets to increase both ecological resilience, including the protection of biodiversity, and social resilience, including social and human capital and institutional capacity. An integrated analysis of SESs considers i) the interplay of internal and external factors and their role in SES dynamics, ii) potential thresholds whose crossing may shift the system into an undesirable state, and iii) cross-scale spatial and temporal interactions. Ultimately, an SES approach favors ecosystem stewardship in that it enhances the sustainable use of natural resources and ecosystem services, and simultaneously resilient livelihood development.

1. Introduction

Over the past six decades, the effects of global environmental change (climate change, land use change, loss of biodiversity, invasion of exotic species) and social change (urbanization, migration, globalization) have had a drastic impact on the distribution, availability and condition of natural resources and ecosystem goods and services **[1]**, **[2]**. In particular, human appropriation of land and continuous land use change are currently the leading global change drivers due to pressing needs to support more than seven billion people with food, fiber, forage, water, and shelter. Without changes in land use policies, deforestation, land conversion, intensification of agriculture, exploitative water use, and air pollution may continue and likely negatively influence ecosystem functioning and will in the long-term jeopardize the provision of ecosystem goods and services **[3]** with direct impacts on human wellbeing **[4]**.

These complex conditions emerge from continuous interrelations and feedback among the socio-economic and biophysical components of these land use systems and thus require a conceptual framework that fully integrates both human and ecological dimensions. The concept of a complex social-ecological system (SES) was first introduced by Berkes and Folkert in 1998 to address human's dependency on ecosystem goods and services and the reciprocal influence of ecosystem dynamics on human decision-making, including terrestrial and aquatic systems. A SES consists of the subsystems of nature and humans, with all their biophysical and social-cultural-political-economic characteristics, respectively. Each subsystem has its own inherent elements, structures, functions and interconnections, which are changing over time. The subsystems are coupled, in that they are interrelated and interacting, while the nature, dynamics, and strength of interaction(s) may change over time in a non-linear fashion **[5]**, **[6]**. These ecological and human subsystems are also self-organizing and highly adaptive in response to internal or external biophysical and socioeconomic drivers of change **[5]**.

Hence, when considering production systems as SES, natural resource management requires not only fundamental understanding of the context in which the ecosystem functions but also its link to the cultural, political, social, economic, and technological aspects of system dynamics, as well as their feedbacks and impacts on human well-being **[6]**. Non-linear changes, unpredictable events, cross-scale interactions, and approaching thresholds of key variables are some of the underlying sources of system dynamics and inherent features of SES. For this reason, the management of an SES needs to consider multiple sources of dynamics and potential disturbances. It should also take into account a system's capacity to absorb the effects of a disturbance event without losing its structure and function, i.e. its resilience. Since SES are constantly changing at different rates and scales, management decisions need to be flexible and adaptive and not necessarily maximize production but rather enhance a system's capacity to maintain itself **[6]**. To reach this goal, the whole SES must be analyzed and fully understood, especially key interactions and relationships among social and environmental factors, including social vulnerability to unpredictable change. Novel sustainable management of SES needs to include the maintenance of resilience of favorable system states; this integrative approach has been termed ecosystem stewardship **[7]**, an inclusive framework addressing the capacity of the system to cope with and adapt to change and simultaneously consider options for innovation and renewal **[8]**.

This review identifies, characterizes and links the fundamental concepts that need to be considered, monitored and evaluated to understand the condition, tendency, and interaction dynamics of SES. In the following sections, we will explain the characteristics of an SES system and present the necessary conceptual and operational framework to analyze and manage these systems. We will highlight the importance of ecosystem services, livelihood development, adaptive capacity, capacity building and how they are necessarily linked.

2. Characteristics of the social - ecological system

The dynamics in an SES originate from two major sources **[9]**. On the one hand both the biophysical and socioeconomic subsystems consist of a series of slow and fast variables and processes **[10]**. The difference between the two resides in the rate of change: the dynamics of fast variables are detectable on a monthly to yearly basis, while those of slow variables act at a decadal to century scale. Each SES is in a sense idiosyncratic in that it has its own set of key slow variables that are responsible for system change. Examples of slow biophysical variables are perennial vegetation cover, plant species composition, soil organic matter content, and soil depth, while fast biophysical variables are annual precipitation, soil water content, inorganic nitrogen concentration in soil, or primary production. In the socioeconomic dimension, examples of slow variables are quality education, social networks, local environmental knowledge, while examples of fast socioeconomic variables are annual income, subsidy programs, commodity prices or annual crop yield **[11]**. It is important to identify the key slow variables that directly control the dynamics of SES and thereby, in turn, influence the rate of change of many fast variables **[6]** Conventional natural resource management focuses on the dynamics of fast variables, such as forage, crop or livestock production, as they are typically of primary interest. However, by managing fast variables, the slow variables of a system are also affected directly or indirectly **[12]**. The second source of system dynamics is the exogenous drivers that do not form part of the SES of interest, though they exert change on the dynamics of the system **[9]**. Examples of exogenous biophysical and socioeconomic drivers are climate change, invasion of exotic species, globalization, and change in legislation or policies. They may be stable for long periods of time.

It is important to distinguish between variable types and understand system dynamics and stability. Within a stable state of a system, one or more controlling variables of that system state may be changing beyond a certain range; here the system is said to be nearing or crossing a threshold of a certain system state and may enter an alternative state. An alternative state of an SES may be equally stable with different elements but similar functions and structure as the previous stage, but an alternative state of an SES may also be less favorable to a land user or other interest groups **[13]**. An SES can adopt several different states within what is termed a certain regime [14]; this depends on the biophysical and socio-economic buffer of a system [15]. Buffers may decline, e.g. through the loss of genetic or species diversity or the loss of human capital. In this case a certain SES has lost the response and/or adaptive capacity to external drivers, and a drastic change in one or several key slow variables may push the whole system across a "critical threshold" into a new regime [16]-[18]. This transition of the system is called "regime shift" [19], [20]. A regime shift causes dramatic functional and structural changes in the system, such as the shift from clear to turbid water in a lake or the conversion of a natural grassland into shrubland [19].

3. Resilience

A key characteristic of an SES in relation to its sustainability is the "resilience" [21] of a system [22], [12]. Resilience refers to the magnitude of change or disturbance a system can absorb without losing its structure, function and feedback processes; for instance, without losing the potential to providing ecosystem goods and services for the well-being of humans [23] including the livelihoods of smallholders.

When addressing the resilience concept in relation to SES it is necessary to always specify 1) what type of resilience one is referring to, e.g. ecological, social or social-ecological resilience; and 2) in what potential context of change. In other words, it is necessary to explicitly define "resilience of what and to what" in the light of potential changes, considering temporal, spatial and/or organizational scales [21]. When addressing the resilience of a system, it is necessary to focus on slow variables. It is also important to consider that the resilience of a certain state of SES may be desirable or undesirable (for instance, once a regime shift has occurred) for humans, depending on the social-ecological context.

In an SES, social and ecological resilience must be considered simultaneously because of the strong interconnectedness among subsystems. Social groups such as smallholders or communities directly depend on natural resources for their livelihoods. However, resilient ecosystems do not guarantee resilient societies and vice versa. Social resilience including the adaptation of individuals or social groups to environmental, socio-political, and/or socio-economic changes is crucial for the maintenance of rural livelihoods [24]. Resilience of livelihoods implies a high degree of adaptability in organization, management and iterative learning [22]. Livelihoods remain resilient to disturbances as long as key aspects including food security, reliable income, employment, and health are secured without affecting the reproduction and well-being of people.

4. Social-ecological system dynamics and the adaptive cycle metaphor

The notion of a system being adaptive was originally coined to recognize the highly unpredictable nature of ecological systems [25]. Its application has been extended and applied when considering the management of complex systems such as SES [6]. Complex systems are self-organizing, change non-linearly, have emerging properties and are unpredictable [16]. Hence, the breakdown of a system after a severe or extreme disturbance event may generate new possibilities for continuous development [26] in that the system recovers and self-organizes by passing through a series of adaptive (renewal) cycles [27]. Holling's (1986) adaptive cycle consists of four phases: exploitation phase (r phase), conservation phase (K phase), collapse/release phase (omega; Ω – phase, corresponding to the end) and reorganization phase (alpha; α - phase, corresponding to the beginning) [16] (**Figure 1**).

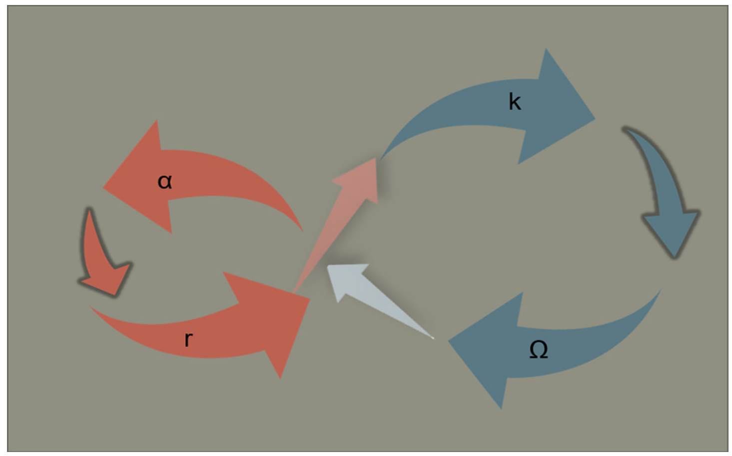

Figure 1: The adaptive cycle modified after (Holling, 1986): The figure shows the four phases of the adaptive cycle: exploitation phase (r phase), conservation phase (K phase), collapse/release phase (omega; Ω – phase, corresponding to the end) and reorganization phase (alfa; α - phase, corresponding to the beginning).

After a disturbance event a system can recover its previous state or adopt a new state depending on its accumulated resources [13]. Usually system recovery follows phase changes in the order of r, K, α and Ω. During the exploitation phase (r), the system grows (people, animals, and plant species) given a relatively high availability of resources and new opportunities. In this phase, system elements are weakly connected and/or regulated. When reaching the conservation phase (K), energy becomes increasingly conserved and material accumulates following certain rules. Targeting stabilization and efficiency of the system comes at the cost of losing system flexibility and resilience. However, by removing redundancies and maximizing outcome the system becomes increasingly vulnerable to unpredictable destabilizing extreme events, which may cause the system to collapse (Ω phase). This phase releases all resources and energies that were previously rigidly locked in the system and transitions to the phase of reorganization (α phase), with undefined open results. This means the system reorganizes to the previous state or develops to an alternative (new) state [14].

Adaptive management provides a framework that recognizes and considers the changing phases of a system [28]. Huber-Sannwald *et* *al.* **[15]** mention that short-sighted management practices often interfere with the adaptive cycle in a way that disregards system dynamics. Moreover, recognizing that the transition from the K to Ω phase is inevitable opens opportunities to guide the system into renewal at an early K stage to avoid the collapse of a highly rigid system. The renewal of a system can also offer opportunities for alternative, new management strategies **[29]**. Systems considering adaptive management as a strategy require systematic monitoring of key (slow and fast) variables and iterative evaluation of the impacts of disturbance and management on these variables and system performance. That way it is possible to understand feedback responses and potentially to adjust to new emerging social-ecological conditions and also to continuously inform policy development for the system **[30]**.

5. Ecosystem services link nature with human-wellbeing

Ecosystem services (ES) refer to the diversity of structures, functions and processes associated with natural ecosystems and the benefits they deliver to society **[31]**, **[3]**. According to the Millennium Ecosystem Assessment[1], ES are classified into four categories: provisioning, regulating, supporting and cultural **[3]**. While there exists a large number of studies on the role of land use in ecosystem services, researchers rarely consider all four categories of ES. Raudsepp-Hearne *et al.* **[32]** proposed the concept of ecosystem service bundles, i.e. a set of positively correlated ES, as the adequate approach to identify, analyze and manage ecosystem services in a spatially explicit context with clear trade-offs and synergies among the ecosystem services. However, planners and decision-makers are frequently unaware of the existence of the costs and benefits associated with integrated ES management **[33]**. Direct ES are those benefits derived from an ecosystem that are directly used by an economic agent (e.g. consumptive uses like harvesting goods) and non-consumptive uses (e.g. enjoyment of scenic beauty). In this case, the services are physically present. In contrast, indirect ES are those benefits derived from an ecosystem that are indirectly used by an economic agent and are not physically present where used (e.g. an agent at some distance from an ecosystem may derive benefits from drinking water that has been purified as it passed through the ecosystem) **[3]**, **[34]**.

The benefits of the ES that humans select or invest in are directly related to their activities and the purpose of the land use. Thus, consideration of an ampler use of ES could potentially result in a greater portfolio of benefits. People may increase the benefits of provisioning ES by investment into infrastructure, fertilizer use, irrigation, labor, or time. Moreover, the transformation from offered ES (i.e. the totality of ecosystem contributions that may provide benefits to humans today and/or in the future) into utilized ES requires deliberate and conscious actions and decision-making **[3]**, **[35]**. Von Haaren *et al.* **[36]** suggest that by adopting an integrated approach to ES, full understanding of the potential of this transformation may ensure that management of ES also includes unused services (i.e. offered but not used services). As landscape planning also influences the delivery of ES and thus human well-being, adequate knowledge of the full spectrum of ES by decision-makers is needed as well as policies that guarantee the sustainable use of ES. According to Mascarenhas *et al.* **[37]**, many decision-makers in landscape management know about the ES concept and its importance in spatial planning; however, this knowledge is frequently ignored in decision-making processes **[38]**, **[33]**. DeGroot *et al.* **[39]** stress the importance of incorporating ES in natural resource management and/or conservation planning. However, there remain doubts as to the usefulness of the concept of ES in the management of a region, for example because of a lack of knowledge about the ES and awareness of the opportunities and constraints of the concept of ES **[33]**, **[40]**.

The ES concept can be used as an economic test in debates between politicians and executives in decision-making processes **[33]**, **[40]**. On the other hand, the use of the concept of ES with an economic label (payments of ES) may be counterproductive in political decision-making, as a single-sided focus of ES on the economy will likely simplify the complexity of ecosystems **[41]**. This could mean that the ES concept does not take into account the complexity of an ecosystem, and this simplification may lead to the loss of the functioning of ecosystems, which may harbor additional significant biological and/or cultural wealth **[42]**, **[43]**. Undoubtedly, incorporation of the ES concept in decision-making processes may appear complex, particularly when actors are not fully familiar with this integrative approach. This calls for novel partnerships among the scientific community, land users and policy makers. For instance, in agricultural areas, apart from achieving high crop yields, integrated ES-focused management can also reduce pest infestation and effectively control soil erosion **[33]**.The importance of social participation and legitimacy in decision-making processes has to be further discussed **[40]**, as participation in decision-making processes is crucial to obtaining positive political outputs **[44]** and in this case improving the conservation of ES **[45]**. Finally, the concept of ES could simply be seen as a great opportunity to communicate complex issues related to nature and human well-being to a broad group of stakeholders in political, social, economic and environmental realms **[41], [40]**.

6. Rural livelihood development

According to Chambers and Conway **[46]**, people's livelihood refers to their means of living, food, income and assets and also includes knowledge about the natural resources that support their well-being and the strategies they adopt in response to changes in internal or external influences. A variety of determinants of a certain livelihood exist, such as birth place, gender, economy, society, and environment, and it is further influenced by education or migration of the people. A livelihood is considered sustainable as long as it can cope with and recover from shocks and maintain or enhance itself now and in the future, while not negatively affecting the natural resources a as their life-support system **[46]**.

1 The Millennium Ecosystem Assessment (MA) was called for by the United Nations Secretary-General Kofi Annan in 2000. Initiated in 2001, the objective of the MA was to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being. [3]

The sustainable livelihood framework (SLF) identifies five assets or building blocks of livelihood: the social, the human, the natural, the financial and the physical capitals **[47]**. These five assets are in direct interaction with political institutions or processes influencing the livelihood strategy people adopt. They also influence livelihood outcomes, such as income, food security and the use of natural resources **[48]**. The use of the SLF as an analysis tool permits the understanding of the connection between social elements (cultural, political, and economic) and biophysical factors in a particular livelihood. It conceptualizes the local system by considering how the macro level (i.e. societal or governance system) influences the micro level (e.g. individual users, consumers, production systems, etc.). During the analysis of the interaction between the social and the ecological subsystems, the SLF helps demonstrate how the ecological subsystem (natural capital) relates to the social subsystem by considering the human, social, economic and physical/infrastructure capital. Using this framework can provide information for policy makers and extension workers on how to improve the livelihood of communities. It is recommendable to apply, when studying marginal groups or groups that depend on natural resources and are exposed to environmental changes with little capacity to mitigate their negative effects **[49]**. This is especially important for smallholders, as they depend mostly on their own farm and on the inherent productivity of the soil **[50]**, **[51]**. This makes smallholders highly vulnerable to climate change, neoliberal policies or land tenure reforms **[52]**, **[53]**, **[15]**. Diversifying livelihood and integrating different agricultural processes (e.g. livestock and different crops) may increase the adaptability and support the reduction of the vulnerability of smallholders to external perturbations like global environmental changes or to responses to global market fluctuations **[54]**, **[53]**.

7. Land-use change and livelihoods

Land use implies a human dimension or purpose for which the land is used **[55]**. Changes in land cover (biophysical attributes of the earth's surface) and land use (human purpose or intent applied to these attributes) are among the most important influences of human use of land **[6]**. Land-use change includes the conversion of natural ecosystems to croplands, pastures, plantations, and/or urban areas. It implies human appropriation of natural resources and ecosystem goods and services, such as food, fiber, shelter, and freshwater **[4]**.

All land use affects regional climates, because the vegetation (land cover) influences processes such as net radiation, the division of energy into sensible and latent heat, the partitioning of precipitation into soil water, evapotranspiration, runoff **[56]**, **[57]**, emissions of greenhouse gases, surface roughness, and the production of aerosols **[57]**. Land-use change influences the carbon cycle and thus potentially affects regional and global climates **[58]**. Land use and land-use change are tightly linked to local livelihood development; however, depending on the land management type, land-use change may have negative impacts on the long-term provision of ecosystem services, biodiversity conservation and thus human well-being **[59]**.

Rural livelihoods of poorer people with limited access to land may more frequently change land use in response to fluctuations in commodity prices than that of wealthier people. Alternatively, poorer people may have to shift from agricultural activities to non-agricultural wage-labor activities to meet their daily living, and sometimes migration becomes inevitable **[60]**, **[15]**, **[61]**. In case of diversification of an agriculture based livelihood, land-use change may still occur by increasing crop diversity **[62]**, **[63]**. Diversification is a strategy to increase the capacity of coping with and adapting to disturbances and/or to changing economy **[64]**.

Land-use change and livelihoods depend on each other **[65]**, **[61]**, **[66]**. They are influenced by external and/or internal socioeconomic or political drivers. Human activities influence land-use functions **[4]** in order to maintain or further develop livelihoods **[66]**, which makes land use an important factor in local, regional or global changes in biophysical and social structures.

8. Building adaptive capacity

Capacity building is the development of the abilities of people, institutions, and systems to deal with changes or unforeseen challenges **[67]**. It can help communities to better cope with changes or disturbances associated with global environmental change and to improve ecological or social resilience, for example after a pest outbreak or economic crisis, respectively **[68]**. In a community, an improved capacity in the decision-making of individuals can increase consciousness and alertness to change. A community with a diversity of accumulated individual skills increases the ability to adapt effectively to changes **[69]**, hence the system becomes more socially resilient **[70]**. Adaptive capacity is the capacity of human actors to respond to or induce change within a certain state of SES. E.g. in social systems, adaptive capacity may be expressed in networks that create flexibility in problem solving, but also by aiming to obtain equilibrium in power distribution among interest groups **[17]** and it requires continuous interest and willingness to learn **[26]**.

In an SES, the understanding of ecosystem processes and social memory are tightly linked **[71]**, considering past experiences, and present and future practices to respond to environmental, political, economic or social changes **[72]**. Capacity building in adaptive capacity is therefore fundamental in complex SES, where unpredictability and high uncertainty govern system dynamics. Hence, adaptive capacity refers to the ability of the community or institutions to respond flexibly to uncertain situations and to manage them in an adaptive way without jeopardizing the resilience of the system **[6].**

The ability of a farming community to target its resilience improves by continuously interacting and exchanging with all key stakeholders and within and among social networks. This ability should be separated into adaptation and learning, recognizing however that a complex system is self-organizing. The self-organizing nature of a system buffers potential impacts from other systems and "does not need to be continually invested in, subsidized, or replenished from outside to persist" (Ostrom, 1999; Carpenter *et al.*, 2001; Holling, 2001; cited by Lebel *et. al.* **[8]**).

Capacity building in adaptive capacity strengthens different stakeholders and allows collective access and use of knowledge to achieve a communal desired result **[73]**.

Environmental education is targeted towards achieving sustainability and solving related problems; it also plays an important role in capacity building and the reduction of vulnerability to environmental stress **[74]**. Environmental education in complex SES in particular may increase ecological or social resilience **[63]**. People with a higher level of education are usually less vulnerable to potentially unstable or fluctuating economic activities like farming **[75]**, **[76]**. People with a better education recover faster and handle the immediate as well as mid- and long-term impacts of a severe disturbance event (e.g. a natural disaster) better than those with less education **[77]**.

The interest of an individual to change and adapt to a new situation may include his or her ability to intervene in the labor market (age and education, among others), social network strategies to approach environmental consciousness, resource use and the use of technology **[78]**. Singh **[79]** argues that environmental education improves skills in decision-making processes, and makes a person take more responsibility for the environment. Change in an individual's attitude can support the resolution of environmental problems, which can be used as a tool for increasing environmental consciousness **[80]** and to broaden the perception of problems. Opinions, visions, and participatory actions of a community may greatly improve the decision-making process **[81]**, since one of the key strengths of environmental education is participation **[82]**. The Sustainable Development Goals (SDG) of the United Nations Agenda 21, in particular SDG 17, highlight the importance of partnerships and alliances in development negotiations **[83]**.

Capacity building plays an important role in obtaining a resilient SES. In the process of improving the management of resources and maintaining human well-being, local communities as well as institutions should be included in the decision-making processes. In particular, the adaptive capacity to respond in a resilient way to uncertainties and external perturbations should be priority in a sustainable development context. This includes the understanding of social-ecological functions but also the self-organizing principles of complex systems **[84]**.

9. Adaptive co-management

Adaptive capacity is a component of resilience that reflects the learning aspect of system behavior in response to disturbances **[16]**. This gives the system the possibility of managing perturbations without any significant loss in important functions like primary productivity, hydrological cycles, social or economic assets. The loss of resilience, and therefore of adaptive capacity, means the loss of opportunities for a system during the period of reorganization **[85]**. Adaptive management considers monitoring and accumulating knowledge and constantly adjusting the activities of human beings in response to changes or uncertainties in an SES. Adaptive management allows managers to learn from management results **[6]**. When resource management seeks social-ecological sustainability through cross-scale, multi-stakeholder involvement and intentional learning from experience and practice, this translates into adaptive co-management as collective action based on exchange of experience and consensus **[86]**, **[87]**. Active adaptive co-management is a useful approach for resilience-building in SES. It supports learning and the increase of adaptive capacity in system management. It requires and facilitates a social context in the system with flexible open institutions and multi-level governance systems **[88]**.

Building adaptive capacity as an immediate and/or long-term response to system change is fundamental in SES management; it is the basis for handling change as an inherent property of an SES at all levels from smallholder/producer to policy maker. It requires iterative learning and a continuous re-evaluation of policy actions based on mutual learning and knowledge sharing. Improving the adaptive capacity of management rises the adaptability to changes and maintains the provisioning of ecosystem services and thus human well-being.

10. Local strategies for sustainable management

Sustainable land management implies maintaining concomitantly the well-being of people and the conservation of natural resources. Hence, a social-ecological systems approach is fundamental and requires full understanding and consideration of the above discussed concepts: complex system dynamics, resilience, ecosystem services, land use change and livelihood development, building adaptive capacity, and adaptive co-management. As SESs are complex systems, it is fundamental to acknowledge the cyclic nature of system collapse and renewal and thus learn how to deal with and manage system change caused by external and/or internal drivers, as they may provoke shifts in system states or regimes. When managing for higher resilience, SES may be less vulnerable to changes, and the livelihoods and environmental resources may be maintained. Human activity and decisions can strongly impact adaptability to changes and hence the resilience of the system. That means that we have to include the people in local strategies.

To achieve sustainable landscape management based on ecosystem services and sustainable livelihoods, it is necessary to analyze all SES components, factors, and processes and identify participative strategies so communities will adapt to changes. A main interest should be how capacity development can work as an instrument to improve the resilience of a community in an SES through the inclusion and improvement of the available ecological services, land use and adaptive processes when facing system changes.

Folke *et al.* **[88]** suggest that policies should i) strengthen the perception that humanity and nature are interdependent and interacting and stimulate development that enhances the resilience of SES, recognizing the existence of thresholds, uncertainty, and surprise; and ii) create areas for flexible collaboration and management of SES, with open institutions that allow for learning and building adaptive capacity.

Resilience-based ecosystem stewardship recognizes managers as an integral component of the system with the goal of sustaining the supply of ecosystem goods and services in the light of continuous change. Resilience-based stewardship aims at sustaining SES considering all their socio-economic and biophysical variables and their interconnections **[85]**. The changes in one domain may influence another, for example debt levels in the economic domain may cause overexploitation of natural resources **[12]**. Access to natural resources, diversity in varieties and types of crops, education and skill development, and social networks can strengthen groups like smallholder famers when having to cope with conditions of stress and change **[89]**, **[53]**, **[90]**. Diversifying income does not only have direct positive feedback on diverse aspects of livelihood development but makes individual livelihoods more adaptable to market changes, and less vulnerable to inter-annual variability in precipitation and crop yield **[90]**.

According to Cowling *et al.* **[91]** there is importance in awareness raising, knowledge sharing, organizational and institutional capacity for integrating ecosystem structure and function in planning processes. Still the integration of the ES concept in policies and planning is poorly developed. The knowledge of practitioners and decision-makers should be included in the spatial planning of multifunctional landscapes as well as in assessment of the provisioning of ES and how they link to human wellbeing at the local, regional and global scale **[37]**, **[3]**. The conversion of traditional cultural landscapes to intensified agricultural landscapes or land abandonment may imply the loss or degradation of many valuable cultural and/or ecological elements, including ES **[92]**. Rural communities in cultural landscape rate several ES types as fundamental for their daily lives. In these areas, traditional land-use practices maintain ecologically valuable landscapes and give citizens the opportunity to earn their living. When the aspiration of the inhabitants is shifted toward other strategies there is the risk that socio-economic interest may impair the provisioning of important ES **[93]**.

11. Conclusions

Sustainable landscape management must include resilience thinking in decision-making processes. Resilience-based ecosystem stewardship is able to sustain the benefits for society, which are directly and indirectly related to the provision of ecosystem services. The maintenance of the well-being and the livelihood of the people as well as the resources and the ecosystem services of the ecosystem depend on the resilience of the system, which can be enhanced with a stewardship approach.

Land use and livelihood depend on each other and/or together transform ecosystems and the multi-functionality of landscapes, which feed back into the climate and the provision of natural resources and ecosystem services. The drivers responsible for changing land use or livelihoods may indirectly influence the resilience of an SES. Building the adaptive capacity of the community and adopting an adaptive co-management approach may greatly increase the ecological and social resilience of the system and thereby strongly contribute to the wellbeing of people.

Hence, aiming towards the sustainable management of a social-ecological system in a rural context requires an integrated cross-disciplinary, cross-sectorial approach that considers not only key variables or assets but rather emerging system properties such as resilience, cyclical transitions of system phases, interlinked ecosystem services bundles and continuous iterative learning and knowledge sharing. Only then is it possible to fully understand, manage and regulate the condition, tendency, and dynamic interactions of a social-ecological system in the light of sustainable development.

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