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Assessing the resilient provision of ecosystem services by social-ecological systems: introduction and theory

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ABSTRACT: The concepts of resilience and ecosystem services broaden the opportunities for assessing sustainability of social-ecological systems (SESs). The lack of operational frameworks for assessing the resilient provision of ecosystem services by SESs impedes greater integration of resilience thinking in natural resource governance. The greatest challenge so far has been to understand the capacity of the SES to (re)organize itself and sustain the flow of benefits from nature to people under various global and local pressures and trade-offs between ecosystem services users. To assess the resilience of an SES within a single framework, we propose a new approach which is a combination of: (1) the Driver-Pressure-State-Impact-Response (DPSIR) framework; (2) social-ecological indicators; and (3) scenario building. Practical application of the approach is demonstrated with the example of European polar and altitudinal treeline areas. The DPSIR framework analyzes causal relationships between the components of the SES. Social-ecological indicators quantify processes in the SES and estimate trends in the DPSIR factors. Combined top-down and bottom-up scenarios envision plausible development paths of the SES in the future based on expected global environmental and social changes which create context specific dynamics between DPSIR factors at specific localities. The proposed approach represents the analytical framework of the European Cooperation in Science and Technology (COST) action SENSFOR (Enhancing the resilience capacity of SENSitive mountain FORest ecosystems under environmental change) and can be applied to promote systemic resilience thinking in any SES.

KEY WORDS: Human–environment interaction · Ecosystem services · DPSIR framework · Resilience · Social-ecological indicators · Scenarios

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1. INTRODUCTION

Achieving a sustainable and balanced human–environment relationship is an important societal challenge. Two concepts, in particular, seem promising for assessing the sustainability of coupled social–ecological systems (SESs): ecosystem services (ESs) and resilience. ESs encompass the benefits of nature to people, and emphasize that ecosystem structures and processes provide a range of services which underpin human well-being (MA 2005, Honey-Roses & Pendelton 2013). Several classifications of ESs have been developed such as those in the Millennium Ecosystem Assessment (MA 2005) or the Economics of Ecosystem and Biodiversity (www.teebweb.org). In order to ease navigation between different classifications, a Common International Classification of Ecosystem Services (CICES 2013) has been developed, which identifies 3 classes of ES: (1) provisioning ESs (products obtained from ecosystems, e.g. food, wood, water); (2) regulation and maintenance ESs (moderation or control of environmental conditions, e.g. flood control, water purification by aquifers, carbon sequestration by forests); and (3) cultural ESs (non-material benefits obtained from ecosystems, e.g. recreation, education, aesthetics). Many of these classifications consider ESs as unidirectional flows between the supply/demand and producer/user systems, neglecting the fact that the provisioning of many ESs may be strongly dependent on and regulated by social systems, which are governed by various policies and instruments (Heikkinen et al. 2012). For example, many cultural ESs have been co-produced by social and ecological systems and evolved through centuries of human–environment interactions.

Sustainable provision of ESs in coupled SESs requires more than just sustainable natural resource management (Xu et al. 2015), but resilience thinking that goes beyond the resilience of the ecosystem. The concept of resilience was first introduced by Holling (1973) as persistence (elasticity) in natural ecosystems and as the ability of an ecosystem to recover from disturbances. In its broader social-ecological meaning, resilience can be defined as the amount of change a system can undergo and still retain the same controls on its function and structure, and the degree to which the system is capable of self-organization, and it is enhanced by the ability of a system to increase its capacity for learning and adaptation (Resilience Alliance 2015). Sustainable provision of ESs thus requires maintaining the functionality of the SES when it is perturbed (i.e. enhancing resilience) or fostering its transformation to an alternative state when the system is in an undesirable state (i.e. eroding resilience) (Walker et al. 2002, Angeler & Allen 2016).

Resilience literature often analyzes general principles that enhance resilience (Folke et al. 2010, Nykvist & von Heland 2014). A simultaneous consideration of the central and specified questions of resilience, the 'resilience of what to what' (Carpenter et al. 2001), 'resilience for whom' (Lebel et al. 2006), and who should contribute to building resilient SESs and how (Kofinas et al. 2013), would help natural resource managers, nature conservationists and policy makers to better understand how social and governance contexts enhance or erode the resilience of SESs. In order to be able to make such an assessment, we need a conceptually and operationally functional framework, which carefully integrates all the factors that determine the dynamics of the SES.

Numerous combinations of the concepts of resilience and ESs have been proposed by, among others, Robards et al. (2011), Biggs et al. (2012), and Ruhl & Chapin (2014). Robards et al. (2011) argue that resilient flow of ESs is inhibited by asymmetries, complex power dynamics, and political struggles between groups of people. They identified rigidity/poverty traps, power asymmetries and scientization of policy/politicization of science as main obstacles for human ability to assess the sustainable flows of ESs. Biggs et al. (2012) identified 3 principles upon which the resilience of SESs to deliver ESs depends, and 4 principles addressing resilience of governance systems for sustainable management of ESs. These principles are worth operationalizing further. Ruhl & Chapin (2014) used ecological systems thinking while exploring the connection between ESs and resilience from 2 perspectives: how ecological resilience can be enhanced by using the ES concept, and how the ES concept can support resilience of governance systems. However, in analyzing resilience of SESs, it seems inadequate to focus only on ecosystems as the entities for ES provision. The social part of the SES should also be included (see also Biggs et al. 2012). Moreover, Ruhl & Chapin (2014) identified an enhanced knowledge base as a key factor enhancing resilience of governance systems. However, social relationships and interactions between governance and stakeholders, and the scope and quality of stakeholder participation within governance instruments are also key factors explaining the resilience of governance systems.

The Research Program on Water, Land and Ecosystems (CGIAR) has recently developed a framework to assess resilience of ESs in agricultural landscapes (CGIAR 2014). They used a categorization of SESs that corresponds well with the Driver-Pressure-State-Impact-Response (DPSIR) dimensions. However, the CGIAR approach does not include scenarios in assessing the resilience of SESs in delivering ESs.

A further combination of the concepts of resilience and ES has been provided by the OpenNESS EU project (Operationalization of Natural Capital and Ecosystem Services: From Concepts to Real-World Applications), in which critical issues that should be solved in marrying the ES and resilience concepts have been identified. For example, it has been asked at what point along the ES cascade (see Potschin & Haines-Young 2015) resilience should be addressed (Kretsch & Stange 2015). Another relevant question with regard to ES and resilience is how different viewpoints of both concepts dynamically interrelate within the DPSIR framework and along the ES cascade (Müller & Burkhard 2012).

Despite all these efforts to combine ESs with the concept of resilience, it remains challenging to understand their compatibility within a single analytical framework. The major challenge so far has been to understand the capacity of a SES to (re)organize itself and sustain the flow of benefits from nature to people under various global and local pressures and trade-offs between ES users. A look into possible and plausible futures of SESs through scenario analysis could complement the resilience analysis and prevent it from becoming a buzzword without operational implications. An enhanced understanding of the combination of ESs and resilience would help policy makers, land managers, and other stakeholders, including the scientific community, develop strategies for maintaining sustainable human–environment relationships.

The objective of this paper is to present an approach for assessing resilience of SESs to sustain ESs under various global and local pressures and trade-offs between ES users. The proposed approach is based on innovative integration of 3 key frameworks which environmental science has long used to monitor the state of, and changes in, the environment: (1) the DPSIR framework; (2) social-ecological indicators; and (3) scenario building (cf. Rounsevell et al. 2010). The DPSIR framework links the components of SESs, and explains causal relationships between the differing types of components (Rounsevell et al. 2010, Sparks et al. 2011). Indicators identify relevant trends and provide operational measures essential for monitoring the resilient provision of ecosystem services (Mace & Baillie 2007, Layke et al. 2012). Scenarios explore the plausible dynamics and various complex linkages between the components of SESs in the future (Kok et al. 2011).

2. ANALYTICAL FRAMEWORK

2.1. The DPSIR framework

The DPSIR framework is a well-established tool amongst environmental scientists, policy-makers and public agencies (e.g. EEA 2001) for explaining the interactions between society and the environment. However, there are variable interpretations and applications of this framework, making it essential to clarify its meaning in the context of ES and resilience of SESs (Rounsevell et al. 2010, Biggs et al. 2012). The DPSIR framework starts from consideration of 'driving forces' (including political, economic, ecological, demographic, and social) which cause direct 'pressures' on the SES (e.g. climate change and land-use change). In turn, these pressures affect the 'state' of the SES (e.g. areas and stakeholders linked to tree-line ecosystems) and their ability to deliver a range of ESs. 'Impacts' are the subsequent changes in ES delivery from the SES (e.g. changes in benefits stakeholders gain from treeline areas). Furthermore, changes in SESs and their ability to sustain the provision of services for people create the need to develop societal 'responses' to mitigate pressures (e.g. governance measures targeting treeline areas) (cf. Rounsevell et al. 2010, Sparks et al. 2011).

2.2. Social-ecological indicators

Indicators have been often constructed to reflect different DPSIR dimensions (Mace & Baillie 2007), and widely used in environmental assessments (e.g. Sparks et al. 2011). Social-ecological indicators can be characterized as policy-relevant when they identify missing information on the sustainable use of ESs, communicate trends in ESs, and support resource management in line with relevant public policies (Layke et al. 2012, Müller & Burkhard 2012). Individual indicators may not be as relevant for policy making as composite indicators presented explicitly in the DPSIR framework (Mace & Baillie 2007). Composite indicators with explicit links to driving forces, pressures, state, impacts, and responses can develop a coherent story about social or environmental change and resilience better than isolated indicators (Sparks et al. 2011, Layke et al. 2012, Reyers et al. 2013, Dwiartama & Rosin 2014).

2.3. Scenarios

Whereas most indicators are quantitative, scenario and visioning exercises can combine quantitative and qualitative approaches. They often operate at the boundary between social and natural science, and they link science to policy (see MA 2005). Scenarios are one way to envision possible environmental futures. They can be used to guide and help policy makers, scientists, market actors, and other stakeholders in coping with uncertainties (Raskin et al. 2002, Kok et al. 2007).

3. THE APPROACH

An application of the combined DPSIR-Indicator-Scenario approach is described using the example of treeline areas. Treeline areas can be considered as flagship SESs for monitoring the delivery of ES under changing climate and land-use regimes (Holtmeier 2009). The areas at and near the treeline ecotone together with treeline-related administrative areas and associated landscapes and ecosystems (Sarkki et al. 2016b) are multi-functional and provide a range of ESs to potentially conflicting stakeholders. This makes treeline areas an interesting and complex object for multi-disciplinary research (Sarkki et al. 2016a). This paper outlines only a general view on the links between the concepts of ESs and resilience (Table 1); detailed analyses with case study applications are available in Kyriazopoulos et al. (2014), Kyriazopoulos et al. (2017, this Special), S. Sarkki et al. (2017, this Special).

3.1. Drivers, Pressures, State, Impacts, and Responses

The understanding of causal relationships between the DPSIR factors presented here shows a slight divergence from the common understanding of the DPSIR framework (Rounsevell et al. 2010, Sparks et al. 2011, Fig. 1) which can be summarized in 4 points.

Firstly, focusing on ESs and the DPSIR framework elements, Sparks et al. (2011) have proposed that impacts could instead be understood as benefits to better comply with the ES dialectics which define ESs as benefits of nature to people. However, we consider that impacts may not necessarily be just benefits, since the impacts of pressures can have positive or negative consequences for people. This bipolar interpretation of impacts is similar to the bipolar understanding of ESs as services and disservices. More importantly, the social dimension of an impact has not been fully accounted for in current approaches to resilience assessment. The utilization of ESs by one

Table 1. Definitions of dimensions of the DPSIR framework and their linkages to the concepts of resilience and ecosystem services (ESs) (developed from Carpenter et al. 2001, Lebel et al. 2006, Robards et al. 2011, Biggs et al. 2012, Kofinas et al. 2013, Díaz et al. 2015). SES: social-ecological system

DPSIR dimension	Relationship to the ES concept	Relationship to the resilience concept	New definition with respect to resilient provision of ESs by SESs
Driving forces	Direct natural and anthropogenic drivers at multiple spatial scales	Indirect causes of disturbances	Ecological, technological, economic, demographic, and social large-scale developments and processes that cause direct pressure on the SES
Pressures	Direct natural and anthropogenic drivers at multiple spatial scales	Resilience to what	Pressures and disturbances that threaten the ability of a SES to provide ES or affect sustainability of ES provision
State	State of ecological system being the base for ESs	Resilience of what	Capacity of social and ecological components of SESs to sustain the provision of ESs
Impacts	Changes in benefits and values for people (i.e. changes in the delivery of ESs)	Resilience for whom	The extent to which the capability of a SES to provide ES is changed, and the impacts of change on benefits for various stakeholders and the extent of trade-offs between them
Responses	Policy, governance, and other indirect drivers	Resilience by whom and how	Capability of governance arrangements and stakeholders to maintain or increase their capacity to mitigate pressures and take adaptation measures to sustain their benefits from ESs

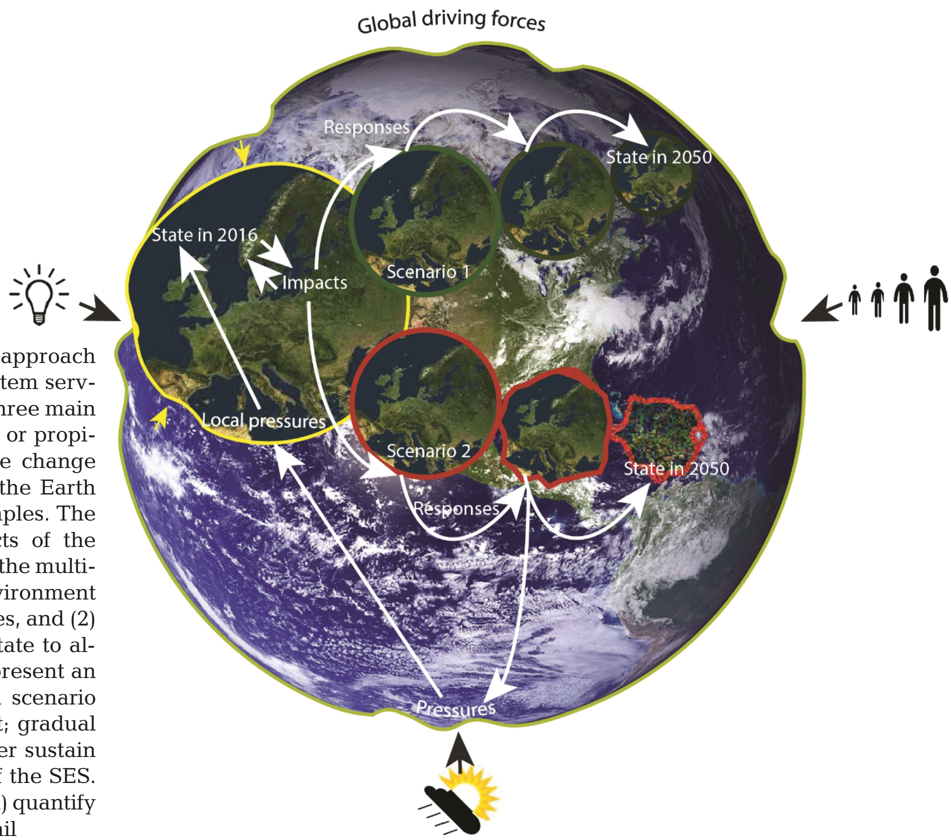

Fig. 1. Combined DPSIR-Indicator-Scenarios approach for assessing the resilient provision of ecosystem services by social-ecological systems (SES). The three main global driving forces being either pernicious or propitious (i.e. human population growth, climate change and innovations) cause direct pressures on the Earth and its subsystems (e.g. Europe), seen as dimples. The yellow arrows stress the sub-global impacts of the global driving forces. The white arrows show the multilevel interactions between society and the environment with respect to (1) impacts caused by pressures, and (2) responses, i.e. the movement from current state to alternative futures. The set of green circles represent an archetype of the favorable Great Transition scenario and red circles illustrate its greatest contrast; gradual collapse of the SES and its inability to further sustain ESs by 2050, seen as increased pixellation of the SES. Linked social-ecological indicators (not shown) quantify all the DPSIR dimensions into the detail

group may function under a resilient governance system, but may have negative impacts on other stakeholders (Sarkki & Karjalainen 2015). We argue that the systems analysis view that the DPSIR framework is based on should be extended with the social network view, which interprets actions and reactions of the elements constituting the SES as a function of their embeddedness in the system.

Secondly, responses do not only mitigate negative impacts of pressures, but also aim to restore the preferable state of an SES or foster habituation to changes (Fig. 2). A desirable state of an SES may not necessarily be its last state which deteriorated due to the negative impacts of pressures, but any alternative state that the SES can take to sustain ESs. Examples include protected areas newly established in the treeline areas as a response to mitigate negative impacts of land-use pressures. Possible responses to insect outbreaks and forest fires include restoration forest management to maintain existing forest stand structures and landscape features which are not necessarily optimal in terms of ES provision. An example of a common adaptive response in treeline areas is the use of artificial snow in downhill skiing resorts to further secure benefits threatened by climate change. Snow-making has usually been considered negative with regard to environmental impacts. However, it may also be seen as an opportunistic response of current institutional arrangements and policy makers, as it can diversify tourism products and services and thus enhance the resilience of tourism-dependent

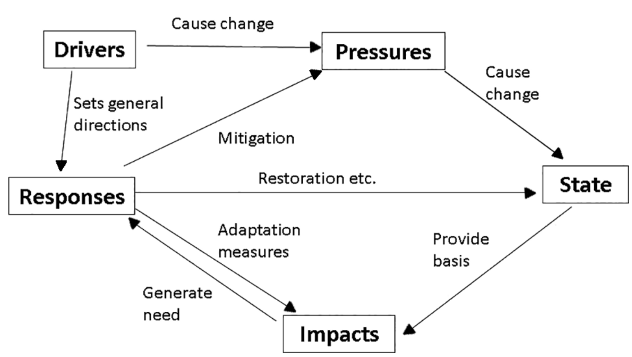

Fig. 2. Application of the DPSIR framework (developed from Rounsevell et al. 2010, Sparks et al. 2011). In standard DPSIR applications drivers cause pressures, pressures cause changes in state that lead to impacts in ES delivery. Responses are performed to cope with changes and to mitigate pressures. In this figure it is considered that responses can also aim to restore a state or adapt to impacts. Finally the global drivers enable certain kinds of responses while undermining others (e.g. climate change may take policy attention away from other environmental problems)

mountain communities. Thus, the resilience of the SES to deliver ESs can be enhanced not only by mitigating pressures, but also by active restoration of the state of the SES that is temporarily regarded as optimal.

Thirdly, in ES assessment frameworks, policy drivers are often referred to as indirect drivers which frequently affect ecosystems by controlling human use of nature (Díaz et al. 2015). We argue that these indirect policy and governance drivers should rather be considered as responses. There are 2 reasons for this: (1) If policies are considered as drivers, this would mean that we acknowledge them as a strong unreachable and untouchable factor that predestines the SES dynamics; and (2) any policy is inherently dependent on the dynamics of (interconnected) SESs, and always a response to some socially (un)desired process in the environment or society. Using ES language, we refer to large-scale economic, technological, social, ecological, and demographic issues as driving forces that cause direct pressures on SESs. Some ES frameworks (e.g. Díaz et al. 2015) do not make a difference between Driving forces and direct pressures, but refer to both as direct natural and anthropogenic drivers. Also acknowledging driving forces makes it possible to connect local pressures on SESs to large-scale developments and processes, which is especially important for the scenario exercises.

Finally, the DPSIR framework clearly implies that responses are always able to mitigate pressures and support adaptations. However, non-compliance of land users and other stakeholders towards existing policies and governance decisions, and potentially different worldviews and conceptualizations of natural resource management, complicate the picture (Ficko & Boncina 2015). Therefore, this uncertainty between the changes of governance and actual changes in stakeholder behavior is also critical to scenarios, as it complicates simplistic causal assumptions between changes in governance and human behavior.

3.2. Indicators

SENSFOR indicator work is ongoing, especially in terms of linked composite indicators. In analyzing the resilience of treeline SESs, 7 social and 9 ecological indicators have been proposed (Broll et al. 2016). We considered composite and common ecological indicators useful for Responses. Ecological indicators relating to food and timber production cover key provisioning services of the treeline areas. Finally, a link to direct pressures on treeline ecosystems is made via the indicator describing disturbance factors (e.g. forest fires, insect and fungi attacks, wind-throw).

Social indicators emphasize the link between ESs and resilience. For instance, not only do governance indicators (e.g. grants available as incentives and subsidies; the level of participatory land-use planning; public/private land ownership; existence of conflicts) link to responses; they also enable the assessment, or even quantification, of the capacity of the SES to enhance the delivery of ESs (Biggs et al. 2012). Social indicators complement ecological indicators of the state of the SES by taking into account age and population structure of people living in the treeline areas and their linkages to nature (e.g. via culturally important livelihoods). Furthermore, the capacity of social actors to self-organize, manage contradictions, and adapt to the changes is covered by an indicator relating to self-determination.

The example DPSIR indicators in Table 2 help

Table 2. Examples of composite social-ecological indicators under a DPSIR framework (see Broll et al. 2016, Kyriazopoulos et al. 2017, this Special)

Driving forces	Pressures	State	Impacts	Responses
CO_2 emissions (amount of greenhouse gasses in atmosphere)	Local climate changes (precipitation and temperature)	Changes in snow cover and in preconditions for winter tourism (snow cover studies)	Shortening season for ski resorts (annual incomes and employment rates)	Use of artificial snow to restore state; Diversification of tourism products to adapt to impacts
Urbanization	Land abandonment (number of local residents / pastoralists, extent of areas under use)	Encroachment of treeline areas, nitrification due to overload of number of livestock units (LSU); Change in cultural landscape; Change in age and population structure	Decreasing proportion of pastures; Level of income from pastoralism; Ageing of pastoralists; Loss of local environmental knowledge	The agri-environmental schemes, e.g. management of low-intensity pasture systems, min-max LSU load control, *Rumex alpinus* control in nitrate-rich environments; Programs targeting young pastoralists

Table 3. Overview of 4 exploratory scenarios on climate change and land-use intensities in European treeline areas. ES: ecosystem services

Scenario	Climate change intensity	Land-use intensity
Global markets	Most intense climate change due to global markets without mitigation measures	Lowest land-use due to moving production from rural areas to cheaper locations and lack of subsidies for food production
Self-sufficient economies	High climate change due to lack of mitigation measures, but global markets decline	Most intensive land-use due to need for European and national self-sufficiency in food and energy production: food and energy production is heavily subsidized
Balanced use of ES	Low climate change due to proactive orientation of policy to environmental problems	High intensity of land-use promoted by policy goals on sustainable and balanced use of treeline areas as multi-functional landscapes
Tyranny of climate governance	Lowest climate change due to global top-down technocratic climate change mitigation policies	Low intensity in land-use due to decline of global markets for goods and services, and lack of environmental protection policies except for climate change

underline some important points. While identification of ES indicators for all the provisioning, cultural, and regulating ESs is important (e.g. Kandziora et al. 2013), the indicators proposed in Table 2 are linked to specific stakeholders. Therefore, they transparently show the dynamics of benefits and challenges for certain stakeholders. This helps to manage the inherent political nature of ES indicator selection, since indicators are always reductions of real-life complexity and stress certain perspectives and challenges while ignoring others. Another benefit of DPSIR indicators sensitive to local stakeholders is that they can tell a coherent story linked to the dynamics between driving forces, their local social-ecological impacts on certain stakeholders, and particular measures to cope with change.

Often ES indicators informed by the DPSIR framework (Müller & Burkhard 2012, Kandziora et al. 2013) concentrate mainly on state and impact indicators — that is, to measures of ecological integrity and ESs — while the indicators proposed here (Table 2) in addition cover more explicitly driving forces, pressures, and responses (e.g. Rounsevell et al. 2010). Considering the dynamics between responses and other DPSIR dimensions can help one avoid viewing the ES as an automated flow of services from nature to people (see Norgaard 2010). Therefore, indicators should take into account active measures made by specific stakeholders to actively manage and manipulate benefits from the environment. The skiing resort example revealed that the locally available responses cannot actually meet the pressures through mitigation, and therefore they focus on restoring a preferable state and adapting to change (Table 2).

Finally, viewing landscape as social-ecological and cultural instead of ecological has implications on how relationships between people on the one side and nature and ESs on the other, are understood. Culture cannot be considered simply as a benefit of nature. Instead a cultural landscape produces ESs for various stakeholders, and maintains or even produces a certain kind of ecological state (Heikkinen et al. 2012). The ESs from cultural landscapes not only relate to ecological factors, but also to cultural factors (e.g. using grazing animals as tourist attractions; enabling certified local products). Our framing can also capture local knowledge of the environment as part of the state of treeline SESs, and loss of such knowledge due to, for example, land abandonment can be considered as a disservice.

3.3. Scenarios

Scenarios are understood as well-informed narrative storylines on how the SES may work in the future. Scenarios can be either exploratory or normative (e.g. van Notten et al. 2003, Kok et al. 2007, 2011). We suggest the use of combined top-down and bottom-up exploratory scenarios. In top-down exploratory scenarios, the 3 global change scenario classes (Conventional Worlds, Barbarization and Great Transitions) (Raskin et al. 2002) and 4 European scenarios (Markets First, Security First, Policy First, Sustainability First) (Kok et al. 2011) were adapted to treeline areas to explore the possible dynamics of change in European treeline areas. The global and European large-scale scenarios were adjusted to reflect different degrees of land-use change and climate change as key pressures on European treeline areas, their impacts on treeline SESs, and potential governance responses (Table 3). By relating the scenarios to the DPSIR framework, we improved the coherence between the local and global drivers. Downscaling of global drivers to trends in direct pressures on treeline SESs is the key link between global narratives and specific impacts on treeline areas. An important link to the DPSIR framework is provided by constructing the pragmatic decision space around the scenario trajectories in which policy decisions on responses are most likely to happen (Sarkki et al. 2016b).

The normative proposals to enhance the resilience of treeline SESs to sustain the delivery of ESs for various stakeholders have been developed by analyzing good environmental management in 11 case studies of European treeline areas. Special emphasis was put on analyzing and clustering key proposals through which environmental sustainability and equity of governance of treeline areas can be improved in the future (Sarkki et al. 2017).

4. CONCLUSION

Our approach to resilience analysis is applicable to the understandings of past and future dynamics of ESs in SESs under the impacts of pressures that arise with global change at the sub-national level. We consider resilience as an unquantifiable latent property of the SES, the level of which can only be indicated by the amount of ESs. By using the DPSIR-Indicator-Scenario approach, we encourage researchers to treat the resilient delivery of ESs as a systems property of the SES that is either increased or eroded depending on the trade-offs between ES users and the pragmatism of science and policy in choosing the responses. The capacity of the SES to (re)organize itself and sustain the flow of ESs under various global and local pressures and trade-offs between ES users is primarily dependent on governance and policy, which tends to focus on global change issues. The domination by either ecological or social notions of resilience in resilience science leads to a preoccupation with defining the single best resilience management scheme instead of taking care of functional links between the drivers, pressures, state, impacts, and responses. An integrated assessment of ES delivery by SES requires inputs from natural and social sciences to enable the consideration of all the factors that shape the future of the environment.

The experiences collected in the SENSFOR project stress that scientists with a holistic understanding of both ecological and social components of the SESs are needed to integrate the separate disciplinary sciences such as ecology, environmental psychology, and anthropology for an improved assessment of resilience. Combining various quantitative and qualitative methods in one analytical framework can facilitate the participation of many experts, who could feed their expertise into different parts of the resilience assessment.

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