Enhancing resilience to address challenges in forest management

B 9

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We present different definitions of forest resilience and discuss how this concept can be used to guide forest management under a changing climate. Forest resilience can be seen as an overarching concept of nested hierarchies, with engineering resilience being nested inside ecological resilience, which in turn is nested inside social-ecological resilience. Active land use and targeted pro-active management to increase forest resilience are crucial strategies to address increased disturbance risks. Indicator-based resilience assessments offer great potential in monitoring of forest vulnerability and steering forward-looking risk management strategies towards enhanced forest resilience. More experience needs to be gathered to identify good practice examples and recommend suitable metrics to operationally adopt the forest resilience concept for safeguarding future forest ecosystem services, including the conservation of biodiversity in a changing climate.

In the nineteenth and twentieth centuries, European forestry has put much effort into overcoming former large-scale deforestation and widespread forest degradation. The context has changed in recent decades, and halting biodiversity loss and responding to and mitigating climate change are the two largest current challenges to which European forests can contribute. Our current toolbox of management strategies seems no longer sufficient to cope with unprecedented extreme climatic events and disturbances affecting forest ecosystem service provisioning, and alternative concepts are being explored. One of these concepts is 'forest resilience'. As biodiversity (the main focus of most chapters in this book) is a crucial component of forest resilience, it is pertinent to ask in this chapter if the resilience concept can help forest management practices better cope with these major challenges. Resilience has received increasing attention in recent years, and is applied in many different contexts, particularly when it comes to dealing with uncertainty. A search for the term 'resilience' in Google Scholar yields more than 2.6 million results (search done in June 2020). Unfortunately, despite its increasingly widespread use, there is considerable confusion about the meaning of the concept of resilience. Furthermore, an operational definition remains lacking, which contributes to the rarity of the cases in which the concept has been applied to guide decision making in forestry.

< Fig. B 9.1. The Bavarian National Park was strongly affected by storm and large-scale bark beetle outbreaks and serves as one of the rare examples where the effects of large-scale disturbances on forest dynamics and the resilience of subsequently developing forests and the entire landscape can be studied (Photo: Ulrich Wasem).

The situation is remarkably similar to the ambiguity that exists for other popular concepts such as 'sustainability', which developed from a narrowly defined origin – sustainable timber yield as framed in the early eighteenth century (Carlowitz 1713) – to many different contexts, especially since the early 1990s, including the very broad application in the context of the sustainable development goals (United Nations 2015). Developing an operational implementation of such ambiguous concepts takes time and effort (Linser *et al.* 2018; Päivinen *et al.* 2012). After 25 years of work on criteria and indicators for sustainable forest management, their role in monitoring, assessing, and reporting on forest conditions and trends is no longer questioned (Linser *et al.* 2018). Learning from this experience, it may not take quite as long to adopt the resilience concept into practice with transparent definitions and operational methods, but this will take considerable effort and close collaboration by scientists and practitioners.

Overview of selected interpretations of resilience

In forest science, three main resilience concepts have been used:

(i) Engineering resilience defined as "The time that it takes for variables to return towards their equilibrium following a disturbance" (Pimm 1984);

(ii) Ecological resilience refers to "The system's capacity to absorb disturbance without changing as well as the ability to self-organize and build adaptive capacity" (Holling 1973); and

(iii) Social-ecological resilience which is understood as "The capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning, and adaptation" (Resilience Alliance 2020).

In this chapter, we provide examples of how these alternative concepts have been applied in the forest science literature.

Engineering resilience: Engineering resilience starts from the assumption that an ecosystem will recover to its pre-disturbance state. If this is not the case, the concept cannot be used. A rather widespread application of engineering resilience is in the analysis of tree responses to drought by measuring pre-drought growth rates, growth during drought, and post-drought growth (Lloret *et al.*

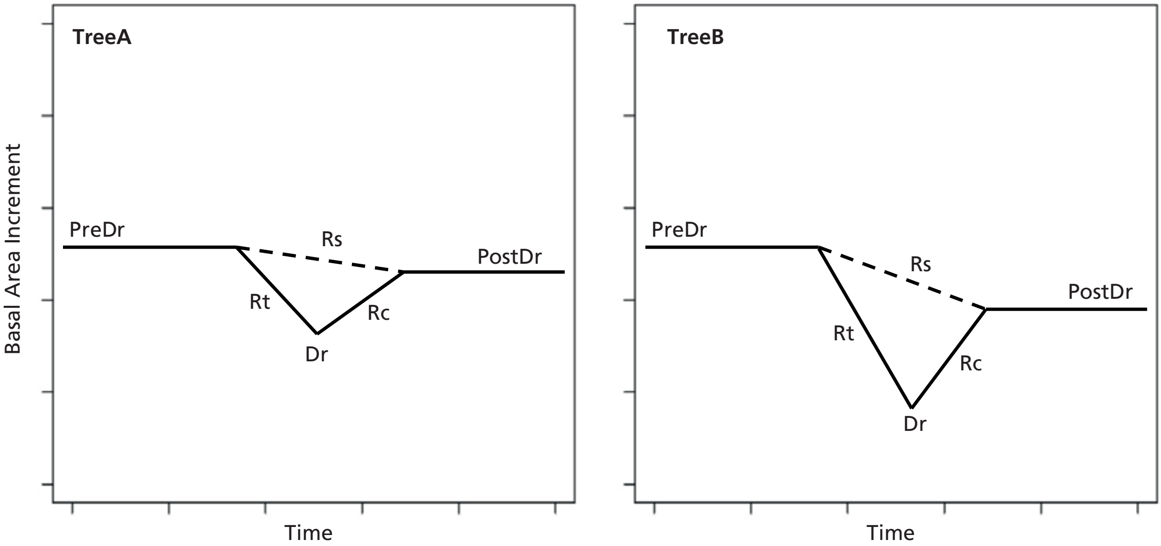

Fig. B 9.2. Analysis of tree growth responses during and following a period of drought as proposed by Lloret *et al.* 2011 (here adopted from Pretzsch *et al.* 2013; modified). Resilience (Rs) describes post-drought growth (PostDr) relative to pre-drought growth (PreDr); Resistance (Rt) measures how much the growth is depressed during the drought (Dr) relative to PreDr; Recovery (Rc) measures PostDr relative to Dr. Two different growth responses are shown: tree A is more resilient to drought than tree B, measured by comparing basal area increment of the trees.

2011, cf. fig. B 9.2). An example of this type of resilience assessment is the study on the resistance of the growth of European tree species to drought stress in mixed versus pure forests (Pretzsch *et al.* 2013). Drought resistance in pure stands increased from Norway spruce (*Picea abies*; lowest), to beech (*Fagus sylvatica*; intermediate), to sessile oak (*Quercus petraea*; highest). Interestingly, although 'drought resilience' and the 'speed of recovery following drought' were found to be species specific, they did not follow the same patterns as 'drought resistance': while oak and beech recovered only slowly from drought, spruce showed a faster recovery. The drought resilience of beech was significantly higher in mixed stands, particularly where the species occurred in mixtures with oak (Pretzsch *et al.* 2013).

Ecological resilience: Climate change may alter the disturbance regimes to an extent that recovery to a previous state may not be realistic or even desirable (Seidl *et al.* 2016). Studies of ecological resilience explore the ability of ecosystems to return to past ecosystem properties. Figure B 9.3 illustrates the 'past basin of attraction', which represents past states of the system (including its variability) and can be quantified by the historical range of variability of the system (Keane *et al.* 2009). Disturbances commonly push systems towards the edge of their basin of attraction (e.g. old-growth conditions for forests developing naturally), as they lead to the loss of live biomass. Following the disturbance, the forest develops again towards the basin of attraction (i.e. mature forest, including old-growth characteristics if the system is left to develop naturally, or the desired conditions by humans in managed forests). In case of an event of unprecedented disturbance severity, such as exceptionally intense wildfires exacerbated by climate change, the ecosystem may be pushed outside of its historical range of variability. From this state, the ecosystem may either return to the past basin of attraction (i.e. recover to a state that is similar to the one before the disturbance), but under certain conditions the system may also develop towards an alternative basin of attraction (e.g. to a forest composed of different tree species or even a steppe ecosystem).

Social-ecological resilience: The application of the social-ecological resilience concept can be exemplified with a study on community resilience and land degradation in forests and shrubland socio-ecological systems in Italy (Kelly *et al.* 2015). In the study region, forest productivity decline was driven by historic forest mismanagement and overgrazing as well as extreme climatic events, which led to land degradation that negatively affected the community. Stakeholder interviews revealed that community resilience was significantly affected by the lack of economic development (affected by poor road and communication infrastructures, rural depopulation, and land abandonment). However, the role of land abandonment in community resilience had mixed effects, as it may result in reduced soil erosion because of slope stabilisation following vegetation re-growth. On the other hand, it also increases wildfire risk with subsequent increased soil erosion risk. Declining local environmental knowledge and skills were pointed out as another critical threat to community resilience. This case study demonstrated the complex interplay between economic, institutional, social, cultural, and natural

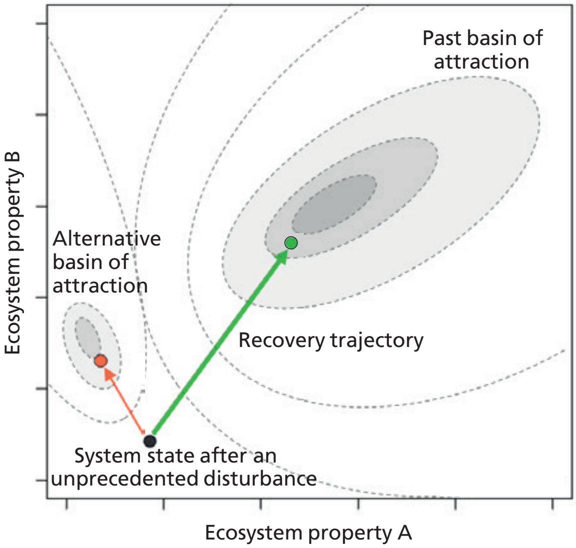

Fig. B 9.3. Schematic visualisation of the constituents characterising an ecosystem's resilience to novel disturbance regimes (from Seidl *et al.* 2016). Changes in the disturbance regime can push the forest system (black dot) outside of its past basin of attraction (indicated by the grey ovals). The resilience to such a change describes whether (ecological resilience) and how fast (engineering resilience) the system returns to the past basin of attraction (e.g. a closed forest; green trajectory), or whether the system shifts instead to a state within an alternative basin of attraction, such as a shrubland (red trajectory).

domains in determining the resilience of socio-ecological systems at multiple scales (Kelly *et al.* 2015).

The above examples illustrate that the alternative resilience concepts have similarities, for example in the disturbances studied. However, they also document different perspectives: whereas engineering and ecological resilience focus on the capacity of a system to resist change and recover from disturbance, social-ecological resilience often stresses transformation and evolution of the system as a crucial part of resilient systems (Nikinmaa *et al.* 2020). The definitions of the three concepts further illustrate differences in complexity: engineering resilience focuses mainly on recovery of the system; ecological resilience includes aspects of both resistance and recovery of the system and acknowledges the possibility of multiple stable states; and social-ecological resilience includes resistance, recovery, adaptive capacity, and the ability to transform to new system states (Folke *et al.* 2010). Rather than stressing the differences between alternative resilience concepts, resilience can thus be understood as an overarching concept of nested hierarchies, with engineering resilience being nested inside ecological resilience, which in turn is nested inside social-ecological resilience. Moving from one concept to another either adds or removes dimensions from the system under study as the system boundaries change (Nikinmaa *et al.* 2020; cf. fig. B 9.4).

Resilience science is currently shifting from understanding resilience to active resilience building, with a growing emphasis on measuring and evaluating resilience (Moser *et al.* 2019). Researchers have identified many indicators for quantifying resilience in each of the resilience concepts described

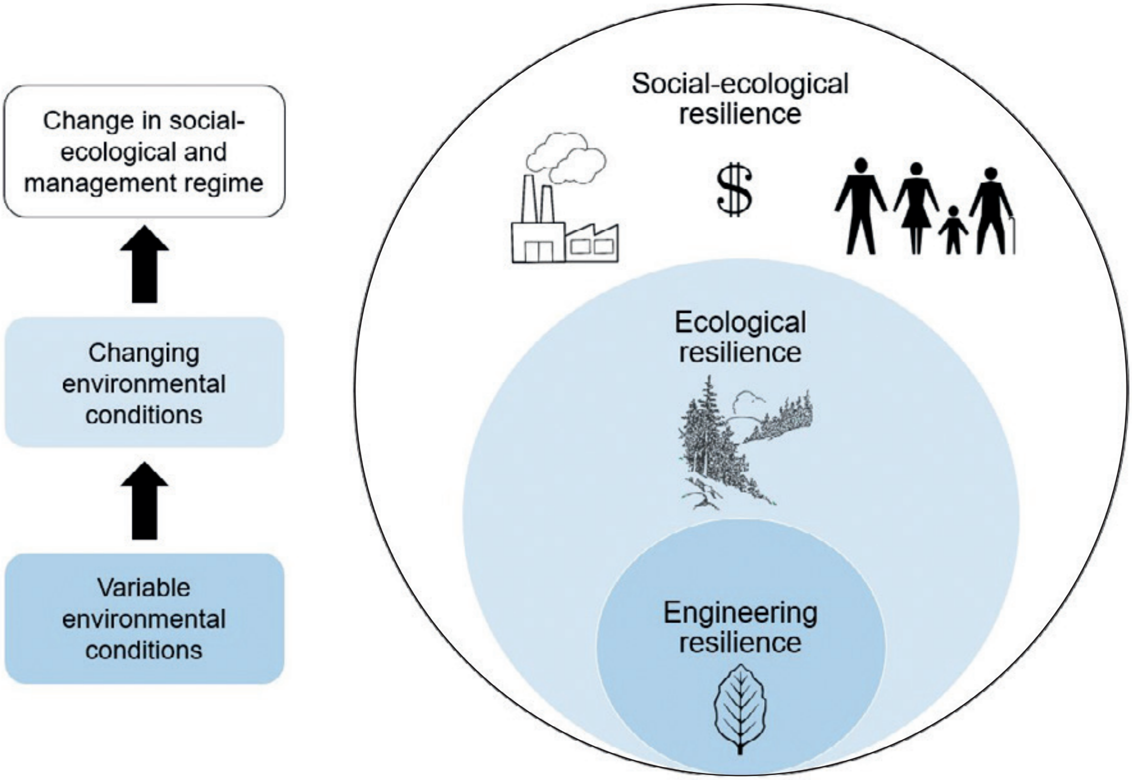

Fig. B 9.4. The hierarchy of resilience concepts and assumptions behind each concept (modified from Nikinmaa *et al.* 2020). The circles on the right show how the three main resilience concepts are related to one another. The boxes on the left indicate increasing complexity in the systems that are studied by the respective resilience concepts. Variable environmental conditions imply that conditions vary but remain in the historical range of variability, whereas under changing environmental conditions they leave the range of historical variability.

above (Nikinmaa *et al.* 2020). Engineering and ecological resilience share many of the same indicators. Typically, these indicators describe the state of the forest community or population. For example, vegetation cover and basal area increment are frequently used in studies assessing forest resilience to drought or fires. In contrast, studies applying the social-ecological resilience concept use a distinctively different set of indicators. These indicators describe the state and function of the social part of the social-ecological forest system in detail, while the state of the ecosystem is usually described in broader terms, for example by the level of biodiversity. Therefore, when choosing indicators to quantify resilience, the complexity of the system analysed, and the chosen resilience concept need to be taken into account. Furthermore, the selection of indicators should be carefully considered, as it has considerable influence on the degree to which a forest is resilient or not (Müller *et al.* 2016). Consequently, a comprehensive set of indicators should be used (ideally authorised through a consultation process with relevant stakeholders) to avoid a narrow perspective on resilience.

So how can we measure and evaluate resilience in practice to enhance forest ecosystem services delivery? The first step is to identify the system of interest (and its boundaries), and to assess whether it is likely to change in the future (Grimm and Wissel 1997; Nikinmaa *et al.* 2020). Is the main interest to assess the resilience of one important tree species, the ecosystem services provided by a forest landscape, or a regional supply chain of a wood products manufacturer? Are the social and environmental conditions changing and to what extent? The second step is to identify the perturbations

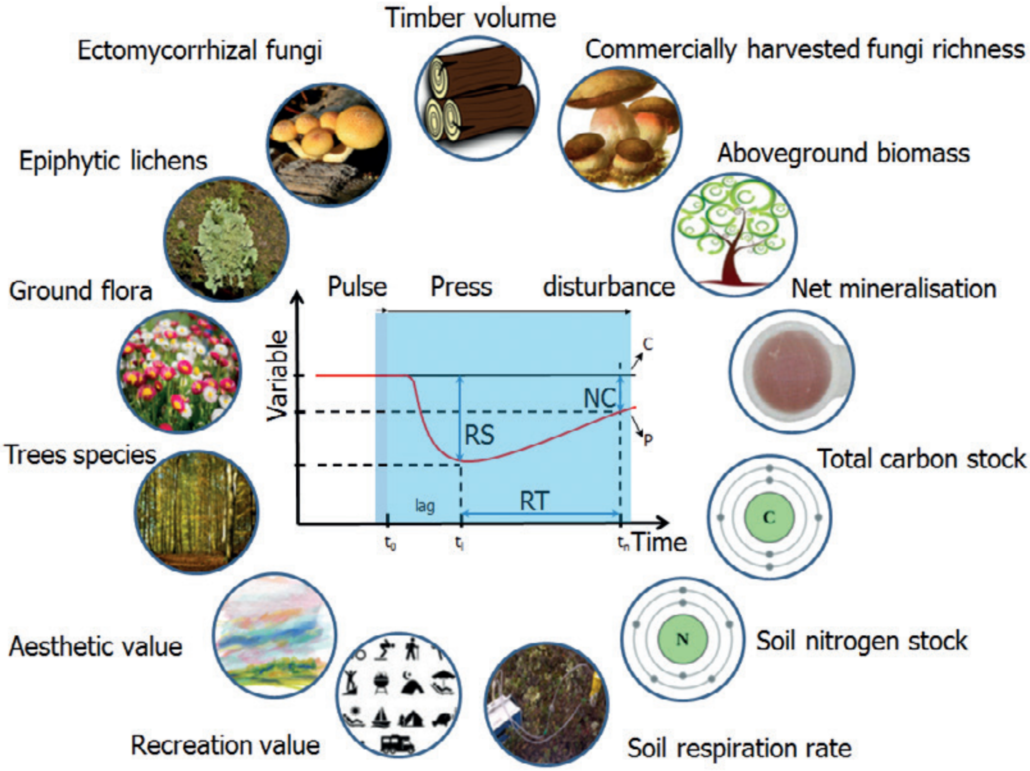

Fig. B 9.5. Selection of 13 indicators chosen to measure and quantify resilience of ecosystem services in a temperate forest landscape (Cantarello *et al.* 2017). The inside graph exemplifies the resistance (RS), recovery time (RT), and net change (NC) of a response variable (i.e. indicator) to a pulse and press disturbance. The black upper line represents the control variable (C) and the red line the perturbed variable (P).

that could potentially affect the system of interest. Is the disturbance of concern a single event (e.g. a storm; pulse disturbance), a continuous stressor (e.g. ungulate browsing; press disturbance), or a combination of both (e.g. climate change, with both a continuous increase in stress and more pronounced extreme events)? How are perturbations interacting (amplifying or dampening)? Engineering resilience can be used in situations where it is possible to go back to the pre-disturbance state, while ecological resilience is a powerful concept when several interacting disturbance types and the complex responses of ecosystems are in focus. Social-ecological resilience should be used if the system of interest also includes the social dimension, such as management responses, a whole forest wood chain, or changing societal demands for forest ecosystem services. The third step is to identify relevant time scales. Engineering resilience is a powerful concept best applied on a short timescale (a few years). For longer timescales, either ecological or social-ecological resilience are better suited, as focusing on short-term recovery might lead to the overlooking of important factors determining the long-term resilience of a system (e.g. to which state is the system recovering).

Recently, forest resilience has been investigated in several regional case studies as a basis for guiding management decision making. For example, the resilience of multiple ecosystem services including habitat services (biodiversity) was investigated using 13 indicators in a temperate forest landscape in the New Forest, a National Park in southern England made up of ancient broadleaved woodlands, lowland heathland, valley mire communities, and acid grassland (Cantarello *et al.* 2017). Three components of resilience, namely resistance, recovery, and net change of response variables were measured to explore the impacts and spatiotemporal patterns of different disturbance intensities on ecosystem service provisioning (fig. B 9.5). Key conclusions included that managers should adopt specific management actions to support each of the three components of resilience separately, as these may respond differently to disturbance. In addition, the consideration of both pulse and press disturbances was important in the selection of management interventions to prevent threshold responses to disturbances.

Risk management and resilience

The concept of resilience is particularly relevant in the context of risk management (e.g. Angeler *et al.* 2018). Disturbance risk management was dominated in the past by command-and-control type efforts to anticipate and contain disturbance impacts (Seidl 2014). Risk management has favoured suppression (e.g. removing wildfire from the landscape) and combating disturbance spread (e.g. by sending airplanes to fight fires across Europe, or by containing bark beetle outbreaks). In contrast, enhancing the ability of forests to recover from disturbances and forming more resilient forests with lower disturbance susceptibility has received considerably less attention, with the exception of forests protecting against gravitational hazards such as rockfall or snow avalanches (Brang 2001; Wohlgemuth *et al.* 2017). Climate change has already contributed to increased forest disturbance in Europe, and projections indicate further increases in the frequency and severity of disturbances (Seidl *et al.* 2017). Temperature extremes have substantially increased since 1950, and even more so than what was projected by climate models (Lorenz *et al.* 2019). Extended drought periods, heat waves, and other extremes are creating novel situations, as witnessed for example in the drought-induced mortality affecting beech and silver fir *(Abies alba)* in central Europe in 2018–2019 (c.f. Schuldt *et al.* 2020). In the case of extreme and/or novel disturbance, conventional disturbance management may fail to contain risks (e.g. Dobor *et al.* 2020). Extreme wildfires and recent large-scale bark beetle outbreaks underline that command-and-control approaches may become insufficient to deal with magnified disturbances under climate change (Castellnou *et al.* 2019; Hlásny *et al.* 2019).

Enhancing resilience as a guiding concept in forest management

Active land use and targeted pro-active management to enhance forest resilience are promising tools to address increased disturbance risks. For example, in the New Forest study in southern England, Cantarello *et al.* (2017) recommended protecting tree regeneration from herbivores and limiting the current practice of heathland burning as management options to enhance forest resilience. In Mediterranean ecosystems, encouraging livestock grazing and promoting agroforestry are recognised as useful tools to mitigate wildfire risk (Damianidis *et al.* 2020). Furthermore, modifying landscape configuration and species composition via forest planning at scales larger than the stand level holds potential to increase forest resilience (Honkaniemi *et al.* 2020). However, it is important to note that disturbances are natural components of ecosystem dynamics; their role in ecosystems needs to be understood well in all efforts to enhance forest resilience (Hlásny *et al.* 2019). Therefore, while management cannot entirely prevent disturbances from happening, it can contribute to reduce the probability and severity of disturbances, foster the ability of forest ecosystems to recover quickly, and to continue to deliver ecosystem services.

One example of how resilience can be integrated in forest management is given by so-called protection forests on steep slopes (see Antkowiak *et al.,* chapter B 6 in this book). The management of these forests in Switzerland tries to balance the need for both permanent forest cover and high ecological resilience (Brang 2001), or even social-ecological resilience since criteria like feasibility and economic proportionality are also applied. Biological requirements include permanent cover, maximum gap size, and minimum basal area (Brang *et al.* 2006), all assuring delivery of the relevant ecosystem service, i.e. prevention or slowdown of mass movements. While very dense stands have the highest preventive effect, they are more prone to disturbance (in particular from wind and snowload) than more open stands, and do not allow for continuous patchy renewal of the overstorey, which is required for a long-term continuous protective effect (Schönenberger and Brang 2004). Moreover, vertically and horizontally structured stands with small openings allow for the establishment of regeneration in their understorey, which confers a stand with higher resilience in the case of disturbance, since it speeds up post-disturbance recovery (Brang 2001). All these requirements are formalised in the Swiss guidelines for protection forests which ensure managers follow a structured decision-making process by assessing a suite of indicators (Brang *et al.* 2006). These indicators and the associated target values are site- and hazard-specific and partly relate to the ecosystem service (e.g. protection against snow avalanches), and partly to resilience (i.e. by a visual assessment of the density, size, and composition of the regeneration, or of the proportion of microsites suitable for future seedling establishment). The decision-making process requires projection of stand development over 10 and 50 years for each indicator and thus allows early detection of unwanted developments. Currently, the guidelines are adapted by integrating tree species suitable for future climates, and by integrating altered disturbance regimes in the projections.

Similar approaches of practical guidance on enhancing forest resilience are needed for other forests to make resilience more than a buzzword for scientists. Recent advances in resilience science underline the large potential for the approach to address the pressing challenges in forest management under climate change. As European forest ecosystems are widely altered owing to changes in climate and societal demands, forest management guidance needs to consider adaptation to these changes both in the natural and the human system components, and therefore the wider social-ecological resilience concept should generally be adopted. An indicator-based resilience assessment will allow targets for critical indicators to be set and may also be used for monitoring of forest vulnerability and resilience. However, quantifying resilience in the field remains a challenging task. More experience needs to be gathered to identify good practice examples and recommend suitable metrics that cover the multiple dimensions involved, spanning both ecological and social-economic components of forest social-ecological systems, as well as short-term and long-term resilience dynamics. Nevertheless, there is reason to believe that forward-looking risk management strategies focusing on enhancing forest resilience offer an important contribution to safeguarding future forest ecosystem services, including the conservation of biodiversity in a changing climate.

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