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OPINION PAPER

Adaptive measures: integrating adaptive forest management and forest landscape restoration

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1 Introduction

Adaptive forest management (AFM) and forest landscape restoration (FLR) are two major concepts for forest (landscape) adaptation enhancing the functionality of both forests and forest landscapes under multiple pressures of global change (Mansourian et al., 2017; Trumbore et al., 2015). Global change includes the alteration of growing conditions for forests due to climate change impacts, in particular due to extreme weather events (Allen et al., 2010; Bräuning et al., 2017) and accompanying pathogen pressures (Bolte et al., 2009). However, also, the requirements for ecosystem services by an expanding world population and shifting social demands for food, bioenergy, and water supply are rapidly increasing (Thorsen et al., 2014). To meet these geographically variable social requirements in the face of the effects of climate change on local growing conditions is one of the major challenges in the twenty-first century for the management of forests and forest landscapes.

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Key message Adaptive Forest Management and Forest Landscape Restoration do not contradict – ecosystemintegrityand health are benefits and central goals in both concepts, and thus can beintegrated. The Adaptive Measures concept can be helpful in streamlining and focusing existingconcepts on forest adaptation and restoration as well as to help forest restoration to focusmore on the ability of ecosystems to self-organize in the future and to adapt to changingenvironmental conditions instead of attempting to restore to a previous historical state.There is an urgent need to consider novel or no-analogue ecosystems to potentially providethe best mix of ecosystem services in the future under uncertainty.

This paper is part of the topical collection on *Forest Adaptation and Restoration under Global Change*

Contribution of the co-authors Peter Spathelf developed the structure and wrote the manuscript. John Stanturf contributed with major revisions and further valuable thoughts/ideas to the manuscript. Michael Kleine, Robert Jandl, Donato Chiatante, and Andreas Bolte contributed significantly to the manuscript.

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In this paper, we analyze and discuss the two concepts of AFM and FLR in order to assess the options and constraints to integrate both concepts into a common approach for restoring and managing forest landscapes to be adaptive in the face of global drivers of changing conditions, values, and expectations. To this end, we introduce the concept of adaptive measures (AM) as an overarching approach to forest conservation in the Anthropocene (Zalasiewicz et al., 2010). This integrative approach forms the concept for the work of the Task Force on Forest Adaptation and Restoration under Global Change within the global network of the International Union of Forest Research Organizations (Bolte et al., 2017, IUFRO, http://www.iufro.org/science/task-forces/forest-adaptation-restoration/).

2 Adaptive forest management—the local concept

AFM is forward-looking and aims to preserve and develop the functionality of specific forests as a prerequisite for fulfilling the future need for forest ecosystem services (Holmes et al., 2014; Bolte et al., 2009). This is dedicated to all measures that adapt intact forests to changing growth and management conditions due to environmental setting, but also, e.g., due to diverse economic perspectives (Fig. 1). Yousefpour et al. (2017) introduced three pillars of AFM: (1) *knowledge* of both environmental settings including uncertainties, but also of perception changes among decision-makers; (2) *options* to identify forest adaptive capacity, to protect forest performance and to apply AFM strategies; and (3) *decisions* to repeatedly optimize AFM according to significant evaluation outcomes. Thus, the AFM concept produces feedback loops of silvicultural interventions and management aims against the background of changing environments and varying owners' perspectives (Wagner et al., 2014). With this, AFM represents a flexible forest management concept, but with distinct local reference considering small-scale variations of climate and site conditions.

To be clear, AFM is not the same as adaptive management although AFM may be usefully applied within an adaptive management framework. Contrarily, adaptive management may not be useful in guiding adaptation under rapidly changing climatic conditions as it relies on information gained from management experiments under current conditions to guide future actions that may be conducted under quite different conditions of novel climate (Williams and Jackson, 2007; Allen et al., 2011). Several strategies for adaptation under global change have been described in relation to tolerance of ecological novelty, or how different the future ecosystem is relative to the historic past (Joyce et al., 2013; Perring et al., 2013; Radeloff et al., 2015; Stanturf et al., 2015).

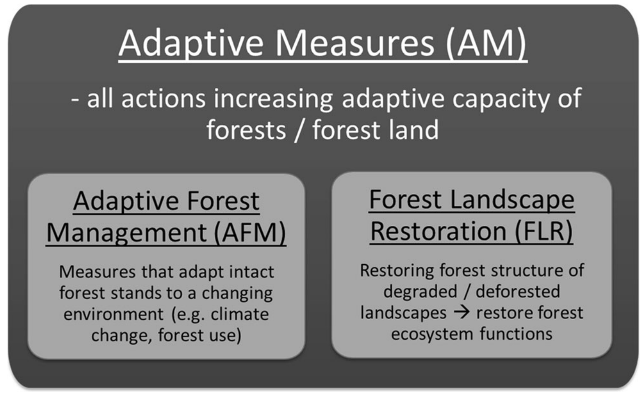

Fig. 1 Integrative adaptive measures (AM) concept combining adaptive forest management (AFM) and forest landscape restoration (FLR)

3 Forest landscape restoration—the regional concept

FLR, in contrast, is the process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes (Fig. 1; GPFLR, 2018). The FLR approach seeks to balance different values/functions at the landscape scale such as water regulation, wildlife habitat, and biodiversity or carbon storage (Stanturf et al., 2015; Sabogal et al., 2015; Jacobs et al., 2015). Most of the many relevant restoration techniques for FLR are not new (Stanturf et al., 2014a), but the new is that FLR requires the involvement of a wide range of stakeholders and competences to fulfill the landscape approach in populated regions. Nevertheless, a central element in restoration management is the use of ecological key concepts such as succession, disturbance, functional characteristics of species, or safe sites.

The contexts of FLR projects vary according to biome, landscape history, and social factors such as governance, tenure, and technical capacity (Mansourian et al., 2017; Stanturf et al., 2017). FLR projects are highly heterogeneous also because they begin with different initial objectives such as offering employment in economically constrained areas, reduction of soil erosion in agricultural land (China) (Buckingham, 2016; Xi et al., 2014), landscape rehabilitation in abandoned farmland (Eastern Europe) (Navarro and Pereira, 2015), reduction of natural hazards (human-populated mountain areas) (Casteller et al., 2017), carbon sequestration (Ireland) (Black and Farrell, 2006), or reconstruction of fragmented habitats in degraded landscape (Italy) (Digiovinazzo et al., 2011). Too often, FLR is backward-looking and aims to return to historical conditions of species composition, stand structure, or both (Stanturf et al., 2014b) but this is not inherent in the FLR approach (Hobbs et al., 2011; Hulvey et al., 2013; Stanturf et al., 2015).

Nevertheless, the FLR concept is still being refined to accommodate new perspectives, such as technical problems (lack of large-scale experience), goal conflicts between the various stakeholders involved (Emborg et al., 2012; Redpath et al., 2013), the inclusion of non-forest land use within the landscape including agroforestry measures, or even the appropriate measure of success (Maginnis and Jackson, 2007; Stanturf, 2015; Mansourian et al., 2017).

4 Integrative adaptive measures concept—helpful for adaptation and restoration success?

AM comprises all actions that increase adaptive capacity of forests and forest landscapes to changing environmental conditions (IUFRO, 2016). Examples hereby are compiled in Kolström et al. (2011) or Brang et al. (2014) and either consist of stand measures (such as regeneration, tending, or thinning) or extend to the landscape scale (e.g. disturbance management) (Spittlehouse and Stewart, 2004; Keenan, 2015).

In the following, we discuss how the AM concept could serve as the link between FLR and AFM. In addition, two essential ambits of stand and landscape-related concepts of AM and their contribution to maintain or restore forest functionality are looked at in more detail.

5 AM interaction with biodiversity issues

There is strong evidence that tree species richness and high genetic diversity positively affect the adaptive capacity of forests against climate change (Spathelf et al., 2015; Brang et al., 2014; Spathelf et al., 2014). But can species-rich and genetically diverse forests better restore basic functions in forest landscapes? One of the emerging research questions is how biodiversity affects the functionality of a forest ecosystem (functional biodiversity research; Scherer-Lorenzen, 2011). Forests rich in woody species often contain plants with different "strategies" concerning establishment and competitiveness (plant functional types, according to McArthur and Wilson, 2001). Therefore, resources such as light, water, and nutrients can be spatially and temporally used by different species, which in some cases lead to a superior productivity of diverse compared to mono-specific forests (e.g., Pretzsch et al. 2010). Moreover, does tree species diversity positively affect resistance/resilience of forests to disturbances or stresses (Pretzsch et al., 2013)? That is, could pre-disturbance functionality be better restored in a diverse stand, because tree species with different response patterns to these stresses can compensate for losses of more vulnerable species (Drever et al., 2006)? In this respect, there is increasing agreement on the role of non-native species in the provision of important ecosystem services such as desired products or habitat for other species in the future (Davis et al., 2011; Hulvey et al., 2013; Radeloff et al., 2015). The difficulty of removing all non-native species from ecosystems contradicts the still dominant goal to push ecosystems back to historical composition and function (Hobbs et al., 2009).

Another important measure to enhance the restoration capacity of a forest after disturbance is to retain a significant amount of ecosystem legacies (e.g., seed trees, deadwood, stand remnants), thus increasing the structural diversity of stands (Seidl et al., 2014; Johnstone et al., 2016; Jõgiste et al., 2017). Legacies provide seed dispersal, nutrient translocation, water storage, and the maintenance of genetic information in the recovery phase of an ecosystem after disturbance (Bauhus et al., 2009; Drever et al., 2006). Moreover, stand-level legacies contribute as important habitat to faunal species richness, e.g., as antagonist species which can curb biotic disturbances. Therefore, legacies increase the number of potential pathways for ecosystem restoration after disturbance. This fits well with the general goal to manage forests for resilience.

Advantageous hereby are multi-aged stands with structural diversity—they have the potential to increase the resistance and resilience of both stands and forests. There are several ways and approaches to achieve this. In central Europe, even-aged mono-specific forests are currently being converted into uneven-aged mixed forests for multiple purposes (Spiecker et al., 2004). Moreover, the integration of disturbance into forest management can be a means to achieve this goal. Here, O'Hara and Ramage (2013) give an overview of concrete measures to promote uneven ageness and structural diversity: emulation of disturbances and carefully designed salvage operations, emphasizing the important role of retained elements of the stand and variable treatment intervals or intensities. Most of these measures are more feasible at the landscape scale because uneven-aged stands with high structural diversity gradually lose their stand compartment structure. With the integration of stand and landscape perspectives in the AM concept, adaptive features like tree species richness, structural diversity, and enhanced gene flow can be managed more effectively both at the stand and landscape levels.

6 AM contribution to reduce vulnerability and increase resistance and/or resilience

Vulnerability can be described as the probability with which an environmental system can be damaged through changes in the environment, society, or both after taking into account reduction of its adaptive capacity (Turner et al., 2003). A variety of measures that reduce vulnerability in a forest stand or landscape play a positive role in restoring the resilience potential of a forest ecosystem after disturbance.

Site preparation can be a central measure to enhance the regenerative capacity of an ecosystem by removing inhibiting factors for seedling's growth or by increasing the variability of site conditions. Furthermore, the use of stress-tolerant plant material (improved seedlings) or stress-tolerant provenances is essential to overcome the vulnerable juvenile growth phase of trees or to reclaim a disturbed or degraded ecosystem (Jacobs et al., 2015).

Another important tool to reduce vulnerability of forest ecosystems is assisted migration of more adapted or adaptive species (Williams and Dumroese, 2013; Park et al., 2014; Dumroese et al., 2015) whereby species (often non-natives) are intentionally transferred to regions outside of their natural range that are characterized by a matching climate which represents the artificial extension of the range distribution of a more resilient species. Many forest conversion activities in Europe in the past decades have already applied this approach to replace endangered species (Mason and Bathgate 2012; Spiecker et al., 2004). Moreover, in regions where past land use led to significant degradation (e.g., Denmark), the transfer of suitable mostly non-native species proved to be successful in establishing ecosystems with a high degree of novelty (transformational restoration; Stanturf et al., 2018). Assisted migration also encompasses the choice of appropriate stress-tolerant provenances, e.g., towards extreme weather events like heat and drought (Bräuning et al., 2017). This goes along with the assisted gene flow concept to translocate pre-adapted individuals to facilitate adaptation of planted forests to climate change (Aitken and Whitlock 2013; Aitken and Bemmels, 2016). In particular, marginal provenances originating near the drought-induced range limits can provide tree species ecotypes more tolerant to drought (Stojnic et al., 2017; Taeger et al., 2015). Yet, there is evidence that these ecotypes often maintain their stress tolerance at the expense of growth ("growth or defence?"; Kätzel, 2009).

Restoring forest landscapes can be accompanied by systematically combining plant (tree) species with specific adaptive traits that make the ecosystem more resilient against climate change (Park et al., 2014; Hobbs et al., 2009). During the course of stand management, the reduction of stand density most likely increases the individual stability and stress resistance of the remaining trees in the stand, especially if management is concentrated on previously selected superior future crop trees (e.g., Sohn et al. 2013). At the same time, in specific cases, the increase of stand density with different tree species could be beneficial in terms of resilience potential and provision of ecosystem services. The application of silvicultural systems, maintaining—on a long term—low or moderate stocking levels or smaller target diameters, does not contribute that much to increase the forest's resilience but certainly decreases the risk for disturbances, such as storm and fire (Brang et al., 2014).

A comprehensive vulnerability reduction needs to account for biotic stress. Climate change modifies the population dynamics of pests and pathogens and needs to be considered by AFM as well as FLR (Wingfield et al., 2015). Moreover, more advanced forest adaptation and restoration measures need to acknowledge the overarching challenges that reduce their effectiveness such as loss or degradation of forest land (Foley et al., 2005; Putz and Redford, 2010; Lambin and Meyfroidt, 2011) or damage by ungulates (Côté et al., 2004; Rooney et al., 2015).

7 Conclusions

Adaptive forest management and forest landscape restoration do not contradict—ecosystem integrity and health are benefits and central goals in both concepts and thus can be integrated within the multi-scale adaptive measures concept. AFM measures can be embedded in FLR strategies providing local elements of landscape-oriented restoration approaches. Over the long term, a lack of adequate AM frequently leads to forest or landscape degradation and to a loss of ecosystem and landscape functionality. The AM concept can be helpful in streamlining and focusing existing concepts on (1) forest adaptation and restoration as well as (2) to help forest restoration to focus more on the ability of ecosystems to self-organize in the future and to adapt to changing environmental conditions instead of attempting to restore to a previous historical state. There is an urgent need to consider novel or no-analog ecosystems to potentially provide the best mix of ecosytem services in the future under uncertainty. In particular, the link to the large-scale concept of assisted migration and assisted gene flow is important to integrate forest adaptation strategies from the local to the international scale (Bolte et al., 2009).

Research gaps and obstacles to transferring information are still impediments to applying both concepts and necessitate establishing clear goals, including local participation, and carefully analyzing the local context and the difficulty of upscaling research to operational level, and last but not least securing inclusion of impact monitoring of the measures taken as a precondition for adaptive measures.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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