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EDITORIAL

Forest adaptation and restoration under global change

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Forests and forest landscapes, characterised by dominant forest areas with other embedded land uses, fulfil multiple essential ecosystem services (ES). These include *(i) provisioning services* such as the provision of food, raw materials, freshwater and medicinal resources; *(ii) regulating services* such as carbon sequestration and storage for climate protection, regulation of the landscape water cycling and climate, moderation of extreme events and natural hazards; *(iii) cultural services for recreation*, mental and physical health, tourism, and aesthetic, cultural and spiritual experiences, as well as *(iv) supporting services* for preserving biodiversity (Hassan et al. 2005). For rural populations, forests are often the basis for their social identity, livelihoods, and the local economy. Forest landscapes are social-ecological systems shaped by multiple influences and they play an outstanding role, contributing to all 17 Sustainable Development Goals (SDG) (Mansourian 2018, Fig. 1).

However, forest landscapes are under pressure with the loss of forest areas by conversion to other land uses and degradation of existing forests, and reduced biodiversity. An estimated 10 million hectares of forest area have been lost between 2015 and 2020 (FAO and UNEP 2020) and an even larger amount is estimated to be degraded. Environmental and climate changes are rapidly altering the growth, survival, and regeneration conditions for forest ecosystems with direct and dramatic impacts on 3.2 billion people, in particular the most vulnerable (IPBES Land degradation assessment collaboration 2018). Tropical forests, for example, are home to over two-thirds of the Earth's terrestrial biodiversity and they are facing significant threats from human activities as well as climate change (Gardner et al. 2009). With this, forests and forest landscapes may lose their characteristic structural and ecological features, and societies worldwide face diminishing levels of ecosystem services provided by forest landscapes. Thus, along with the preservation of intact forest landscapes, forest adaptation and restoration are needed to prevent the continued global loss of ecosystem services and biodiversity, so that forest landscapes can meet the ecological, economic, and societal challenges due to global change.

In this topical collection *Forest Adaptation and Restoration under Global Change*, we present nine papers covering a wide spectrum of topics, with three articles illustrating the scope, contexts, concepts, and challenges of forest adaptation and restoration in general, on a transcontinental or global scale (Spathelf et al. 2018, Stanturf et al. 2019, Jandl et al. 2019). Another six papers discuss aspects of adaptation and restoration in different regions of the world (Europe: Chakraborty et al. 2019, Paul et al. 2019, Jandl et al. 2018; Asia: Hai et al. 2020, and Australia: Harper et al. 2019). Most of these papers result from collaborations in the global networks on *Forest adaptation and restoration under global change*, and

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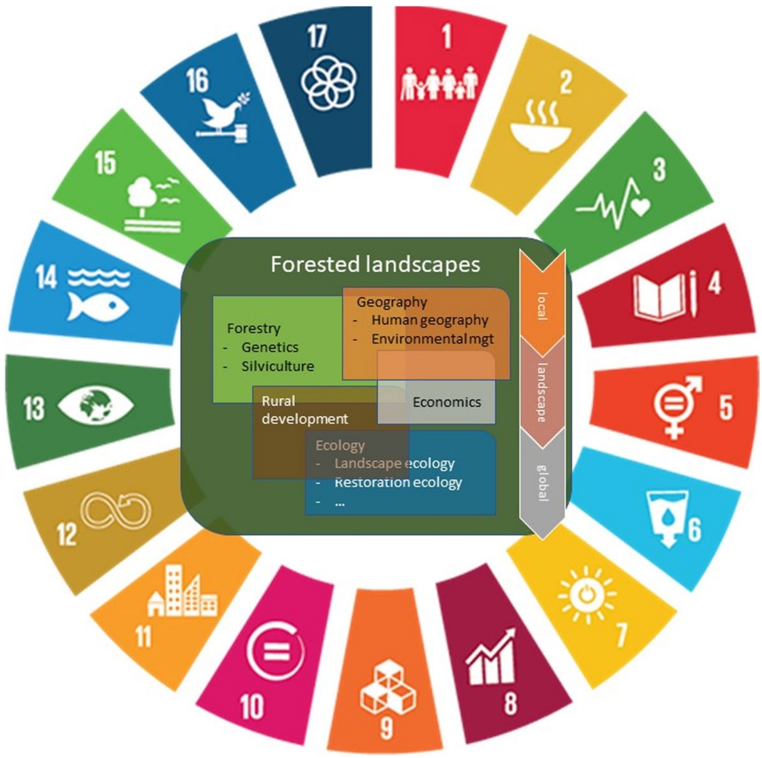

Fig. 1 Forested landscapes as multidisciplinary spaces contributing to all 17 Sustainable Development Goals (modified from Mansourian 2018)

the following one on *Transforming forest landscapes for future climate and human well-being.* Both networks were constituted as a Task Force (TF) within the International Union of Forest Research Organizations (IUFRO), an entity formed by 15,000 scientists of 650 participating organisations in 120 countries worldwide (IUFRO 2022).

1 Forest adaptation and restoration—concepts, challenges, and solutions

Spathelf et al. (2018) demonstrate that the conceptual merging of Forest Landscape Restoration (FLR) at the landscape scale with Adaptive Forest Management (AFM) on the stand scale provide an integrative approach for conserving, adapting, and restoring forest ecosystems. The separation of forest adaptation from the approaches of (functional) forest restoration in parts of temperate and boreal Europe and North America (cf. Höhl et al. 2020) is mainly based on cultural and educational barriers rather than on biophysical variation. The integrative Adaptive Measure (AM) approach presented in Spathelf et al. (2018) can overcome these barriers and help to streamline and focus existing concepts of forest adaptation and restoration. The approach also makes more use of the ability of ecosystems in the future to self-organize and adapt to changing environmental conditions instead of attempting to restore to a previous historical state.

The paper of Jandl et al. (2019) considers the strategy of non-management and of the reliance solely on natural forest dynamics as an optimal approach for adapting forests to climate change. Based on a thorough consideration of evidence from different forest types in the temperate zone of central Europe and northern America, the authors illustrate the limitations of non-management for most of the forest types considered. These limitations stem from long-term historic practices and management of forests with low intrinsic short-term adaptive capacities. They conclude that relying solely on natural mechanisms and continuation of traditional management are risky, and they recommend Adaptive Forest Management (AFM).

Stanturf et al. (2019) discuss implementation pathways of Forest Landscape Restoration (FLR) according to the ambitious global FLR goals of the Bonn Challenge Initiative and the New York Declaration on Forests. Based on 17 case studies from Asia, Africa, and Latin America, they demonstrate the overwhelming importance of building the capacity of local practitioners and stakeholders. Forest landscapes and their local populations are complex socio-ecological systems that require context-specific, not one-size-fits-all solutions. Stanturf et al. (2017, 2019) offer project cycle management as an effective, adaptive, and iterative framework for planning, implementing, and monitoring forest landscape restoration.

2 Forest adaptation and management solutions for Central Europe

The options and limitations of species and provenance introductions for forest adaptation in Austria is shown by Chakraborty et al. (2019) using the North American Douglas fir (*Pseudotsuga menziesii*) as an example. They analysed 19 provenance trials across Austria and modelled the effect of early and late frost on the survival rates of seedlings that depended on site conditions and provenance origin. No frost limitation was found for Douglas fir provenances from the transition zone from Pacific to continental climates in north-western North America; thus, provenance selection for forest adaptation may follow productivity, but early and late frost limitations for Douglas fir in general should be considered according to local site conditions.

Jandl et al. (2018) present results of a modelling study focussed on standing timber volume and carbon stock dynamics of protected high elevation cembrian pine (*Pinus cembra*) forests at the timber line in Austria. They studied possible profitable timber production in the face of climate warming and increasing productivity. According to different climate and management scenarios as well as government subsidy effects, the optimal solution was to leave the cembrian pine forests unmanaged.

In a combined empirical and modelling study Paul et al. (2019) look at the economic effect of altered survival probabilities in group-mixed and block-wise pure Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) stands in Germany. They found that optimal tree species mixes under simulated climate change effects could buffer but not completely mitigate undesirable economic consequences. The higher survival rates and economic overperformance of mixed stands, however, support existing subsidy schemes and concepts in Germany for forest transformation from pure to mixed stands with Norway spruce and European beech.

3 Reappraising forest management and mangrove restoration in Asia and Australia

The review paper of Harper et al. (2019) highlights the interaction of (restored) forest cover and water supply in the Perth region (western Australia) under ongoing climate change. Effects of deforestation and forest restoration on water quantity and quality, in particular salinity, are presented and discussed. Effects of growing population and decreasing precipitation in the region urge an integrative forest and water management approach to protect the ecological integrity and biodiversity of the forests in the region and to meet the growing water supply demand of the population in the Perth region. As a solution, the authors suggest considering water as a forest product and providing funds for forest management in the watersheds.

Hai et al. provide an overview of the recent mangrove restoration activities in Vietnam of more than 200,000 ha. Though impressive in area, the authors identify several project failures due to poor site and species selection and lack of incentives to engage local residents in the long-term management of the restored areas. By focussing on mangroves' functioning and adopting monitoring and reporting procedures that include local stakeholders, a more robust approach for future mangrove restoration is achievable.

4 Lessons to learn for future work on forest adaptation and restoration

Forest restoration and related forest adaptation are key contributions to mitigating climate change and helping ecosystems and societies to adapt to future conditions. Thus, the United Nations (UN) have declared this decade 2021–2030 as the UN Decade on Ecosystem Restoration (United Nation [UN] 2020). Tremendous efforts have been made worldwide to restore ecosystems, including forest landscapes in particular driven and supported by the Bonn Challenge and the New York Declaration on Forests with pledges to date totalling 210 Mio. ha for restoration (https://www.bonnchallenge.org/progress), and even greater efforts beyond these initiatives (Stanturf and Mansourian 2020).

However, there are still many challenges to be considered and questions to be answered in order to implement forest adaptation and restoration as well as to sustain the processes. The following aspects are relevant:

(1) Collaboration among researchers, decision makers, and practitioners
(2) Capacity building in regions and localities to be restored
(3) Integration of all relevant ecosystem services, and the demands of local populations
(4) Fair participation with and within (local) stakeholder groups
(5) Targeted communication to raise awareness
(6) Long-term financing of restoration and following management
(7) Governance that ensures fair, equitable, and representative decision-making processes
(8) Long-term monitoring and reporting of restoration processes and subsequent adaptive management

Forest restoration and adaptation are long-term activities, requiring decades or even centuries. Today's authorities and people fostering restoration activities will be replaced by those coming from the next generations. Therefore, restoration as a social rather than a strictly technical challenge must include long-term education programs and socio-cultural shifts over several generations.

The editors and authors hope that the audience of Annals of Forest Science will appreciate the content of this topical collection.

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Declarations

Ethics approval and consent to participate
The authors declare that they follow the rules of good scientific practice.

Consent for publication
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The authors declare that they have no competing interests.

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