



HAL
open science

Adaptive measures: integrating adaptive forest management and forest landscape restoration

Peter Spathelf, John Stanturf, Michael Kleine, Robert Jandl, Donato Chiatante, Andreas Bolte

► **To cite this version:**

Peter Spathelf, John Stanturf, Michael Kleine, Robert Jandl, Donato Chiatante, et al.. Adaptive measures: integrating adaptive forest management and forest landscape restoration. *Annals of Forest Science*, 2018, 75 (2), pp.55. <10.1007/s13595-018-0736-4>. <hal-02128084>

HAL Id: hal-02128084

<https://hal.science/hal-02128084v1>

Submitted on 13 May 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



Adaptive measures: integrating adaptive forest management and forest landscape restoration

Peter Spathelf¹ · John Stanturf² · Michael Kleine³ · Robert Jandl⁴ · Donato Chiatante⁵ · Andreas Bolte⁶

Received: 22 March 2018 / Accepted: 13 April 2018 / Published online: 7 May 2018
© INRA and Springer-Verlag France SAS, part of Springer Nature 2018

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.

Handling Editor: Erwin Dreyer

Key message 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. The Adaptive Measures concept can be helpful in streamlining and focusing existing concepts on forest adaptation and restoration as well as 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-analogue ecosystems to potentially provide the 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.

✉ Peter Spathelf
Peter.Spathelf@hnee.de

¹ Eberswalde University for Sustainable Development, Alfred-Moeller-Straße 1, 16225 Eberswalde, Germany

² IUFRO Research Group 1.06.00 ‘Restoration of Degraded Sites’, Forest Management Planning and Wood Processing Technologies, Estonian University of Life Sciences, Tartu, Estonia

³ IUFRO, Marxergasse 2, 1030 Vienna, Austria

⁴ Institut für Bodenforschung, Universität für Bodenkultur (BOKU), Peter-Jordan-Straße 82, 1190 Vienna, Austria

⁵ Dipar. di Biologia, Sezione di Botanica Generale e Centro di Studio del CNR per la Biologia Cellulare e Molecolare delle Piante, Univ. degli Studi di Milano, Via Celoria 26, I-20133 Milan, Italy

⁶ IUFRO Task Force Forest Adaptation and Restoration under Global Change, Thünen Institute for Forest Ecosystems, Alfred-Moeller-Straße 1, 16225 Eberswalde, Germany

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).

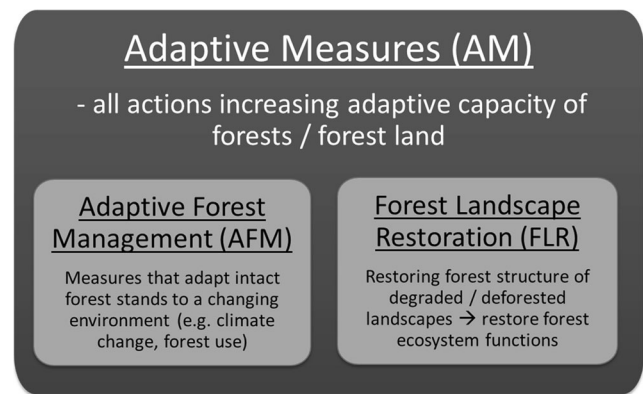


Fig. 1 Integrative adaptive measures (AM) concept combining adaptive forest management (AFM) and forest landscape restoration (FLR)

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 aspects 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; Jørgiste 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 agedness 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 ecosystem 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.

Acknowledgements The article is an activity within the work of the IUFRO Task Force 31 “Forest Adaptation and Restoration under Global Change.” We acknowledge the support of John Parrotta, IUFRO Vice-President and head of TFs, and the fruitful discussion within the TF 31 group.

Compliance with ethical standards

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

References

Aitken SN, Bemmels JB (2016) Time to get moving: assisted gene flow of forest trees. *Evol Appl* 9(1):271–290

- Aitken SN, Whitlock MC (2013) Assisted gene flow to facilitate local adaptation to climate change. *Annu Rev Ecol Evol Syst* 44:367–388
- Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, Kitzberger T, Rigling A, Breshears DD, Hogg E (2010) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecol Manag* 259:660–684
- Allen CR, Fontaine JJ, Pope KL, Garmestani AS (2011) Adaptive management for a turbulent future. *J Environ Manag* 92:1339–1345
- Bauhus J, Puettmann K, Messier C (2009) Silviculture for old-growth attributes. *For Ecol Manag* 258:525–537
- Black KG, Farrell EP (2006) Carbon sequestration and Irish forest ecosystems. In: Black KG, Farrell EP (eds) Carbon sequestration and Irish forest ecosystems. COFORD, Dublin, p 76
- Bolte A, Ammer C, Löf M, Madsen P, Nabuurs G-J, Schall P, Spathelf P, Rock J (2009) Adaptive forest management in central Europe: climate change impacts, strategies and integrative concept. *Scand J For Res* 24:473–482
- Bolte A, Madsen P, Derkyi MAA, Stanturf JA (2017) Forest adaptation and restoration under global change—concept and status of an IUFRO Task Force. *Flora Mediterranea* 27:6
- Brang P, Spathelf P, Larsen JB, Bauhus J, Bončina A, Chauvin C, Drössler L, Garcia-Güemes C, Heiri C, Kerr G, Lexer MJ, Mason B, Mohren F, Mühlethaler U, Nocentini S, Svoboda M (2014) Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. *Forestry* 87:492–503
- Brauning A, Bolte A, Nabais C, Rossi S, Sass-Klaassen U (2017) Editorial: studying tree response to extreme events. *Front Plant Sci* 8:506. <https://doi.org/10.3389/fpls.2017.00506>
- Buckingham, K. 2016. Beyond trees: restoration lessons from China's Loess Plateau. In China's new sources of economic growth: reform, resources and climate change, Volume 1, edited by Ligang Song, Ross Garnaut, Cai Fang & Lauren Johnston, ANU Press, The Australian National University, Canberra, Australia. 379–396
- Casteller, A. Häfelfinger, T., Donoso, E.C., Podvin, K., Kulakowski, D., Bebi, P. 2017. Assessing the interaction between mountain forests and natural hazards at Nevados de Chillán, Chile, and its implications for Ecosystem-based Disaster Risk Reduction. *Nat Hazards Earth Syst Sci* (in press)
- Côté SD, Rooney TP, Tremblay J-P, Dussault C, Waller DM (2004) Ecological impacts of deer overabundance. *Annu Rev Ecol Evol Syst* 35:113–147
- Davis MA, Chew MK, Hobbs RJ, Lugo AE, Ewel JJ, Vermeij GJ, Brown JH, Rosenzweig ML, Gardener MR, Carroll SP (2011) Don't judge species on their origins. *Nature* 474:153–154
- Digiovannozzo P, Ficetola GF, Bottoni L, Padoa-Schioppa E (2011) Scenarios to reduce forest fragmentation and improve landscape multifunctionality: a study from northern Italy. *Carpathian J Earth Environ Sci* 6:23–34
- Drever CR, Peterson G, Messier C, Bergeron Y, Flannigan M (2006) Can forest management based on natural disturbance maintain ecological resilience? *Can J For Res* 36:2285–2299
- Dumroese RK, Williams MI, Stanturf JA, St Clair JB (2015) Considerations for restoring temperate forests of tomorrow: forest restoration, assisted migration, and bioengineering. *New For* 46: 947–964
- Emborg J, Walker G, Daniels S (2012) Forest landscape restoration decision-making and conflict management: applying discourse-based approaches. In: Stanturf J, Lamb D, Madsen P (eds) Forest landscape restoration. Springer, Dordrecht, pp 131–153
- Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK (2005) Global consequences of land use. *Science* 309:570–574
- GPFLR – The Global Partnership on Forest Landscape restoration 2018. <http://www.forestlandscape restoration.org/> (07/03/2018)
- Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration. *Trends Ecol Evol* 24(11):599–605
- Hobbs RJ, Hallett LM, Ehrlich PR, Mooney HA (2011) Intervention ecology: applying ecological science in the twenty-first century. *Bioscience* 61:442–450
- Holmes, T.P., McNulty, S., Vose, J.M., Prestemon, J.P., Harbin, L. 2014. A conceptual framework for adaptive forest management under climate change. In: Vose, J.M., Klepzig, K.D. (eds.). Climate change adaptation and mitigation management options. A guide for natural resource managers in southern forest ecosystems CRC Press - Taylor and Francis. 45–60
- Hulvey, K.B., Standish, R.J., Hallett, L.M., Starzomski, B.M., Murphy, S.D., Nelson, C.R., Gardener, M.R., Kennedy, P.L., Seastedt, T.R., Suding, K.N. 2013. Incorporating novel ecosystems into management frameworks. In: Hobbs, R.J., Higgs, E.S., Hall, C.M. (Eds.), Novel ecosystems: intervening in the new ecological world order. John Wiley and Sons. 157–171
- IUFRO 2016. Helping forest and people adapt to changing times and climes. IUFRO Spotlight #43. Online under [https://www.iufro.org/publications/iufro-spotlights/article/2016/12/19/iufro-spotlight-43-helping-forests-and-people-adapt-to-changing-times-and-climes/\(07/10/2017\)](https://www.iufro.org/publications/iufro-spotlights/article/2016/12/19/iufro-spotlight-43-helping-forests-and-people-adapt-to-changing-times-and-climes/(07/10/2017))
- Jacobs DF, Oliet JA, Aronson J, Bolte A, Bullock JM, Donoso PJ, Landhäuser SM, Madsen P, Peng S, Rey-Benayas JM, Weber JC (2015) Restoring forests: what constitutes success in the twenty-first century? *New For* 46:601–614
- Jögiste, K., Korjus, H., Stanturf, J.A., Frelich, L.E., Baders, E., Donis, J., Jansons, A., Kangur, A., Köster, K., Laarmann, D. 2017. Hemiboreal forest: natural disturbances and the importance of ecosystem legacies to management. *Ecosphere* 8
- Johnstone JF, Allen CD, Franklin JF, Frelich LE, Harvey BJ, Higuera PE, Mack MC, Meentemeyer RK, Metz MR, Perry GL (2016) Changing disturbance regimes, ecological memory, and forest resilience. *Front Ecol Environ* 14:369–378
- Joyce LA, Briske DD, Brown JR, Polley HW, McCarl BA, Bailey DW (2013) Climate change and North American rangelands: assessment of mitigation and adaptation strategies. *Rangel Ecol Manag* 66:512–528
- Kätzel, R. 2009. Möglichkeiten und Grenzen der Anpassung an Klimaextreme. Eine Betrachtung der baumartenspezifischen Risiken aus Sicht der Ökophysiologie. In LFE (Ed.): Wald im Klimawandel – Risiken und Anpassungsstrategien. Eberswalder Forstliche Schriftenreihe Band 42. 22–34
- Keenan RJ (2015) Climate change impacts and adaptation in forest management: a review. *Ann For Sci* 72:145–167
- Kolström M, Lindner M, Vilén T, Maroschek M, Seidl R, Lexer MJ, Nethere S, Kremer A, Delzon S, Barbat A, Marchetti M, Corona P (2011) Reviewing the science and implementation of climate change adaptation measures in European forestry. *Forests* 2:961–982
- Lambin EF, Meyfroidt P (2011) Global land use change, economic globalization, and the looming land scarcity. *Proc Natl Acad Sci* 108: 3465–3472
- Maginnis S, Jackson W (2007) What is FLR and how does it differ from current approaches? In: Rietbergen-McCracken J, Maginnis S, Sarre A (eds) The forest landscape restoration handbook. Earthscan, UK
- Mansourian S, Stanturf JA, Derkyi MAA, Engel VL (2017) Forest Landscape Restoration: increasing the positive impact of forest restoration or simply the area under tree cover? *Restor Ecol* 25:178–183
- Mason WL, Bathgate PS (2012) Silvicultural strategies for adapting planted forests to climate change: from theory to practice. *J For Sci* 58(6):265–277
- McArthur RH, Wilson EO (2001) The theory of island biogeography. Princeton University Press, New Jersey, p 224
- Navarro, L. and Pereira, H.M. 2015. Rewilding abandoned landscapes in Europe. In: H. M. Pereira, L. M. Navarro (eds.): Rewilding European landscapes. 3–23

- O'Hara KL, Ramage BS (2013) Silviculture in an uncertain world: utilizing multi-aged management systems to integrate disturbance. *Forestry* 86:401–410
- Park A, Puettmann K, Wilson E, Messier C, Kames S, Dhar A (2014) Can boreal and temperate forest management be adapted to the uncertainties of 21st century climate change? *Crit Rev Plant Sci* 33(4): 251–285
- Perring MP, Standish RJ, Hobbs RJ (2013) Incorporating novelty and novel ecosystems into restoration planning and practice in the 21st century. *Ecol Process* 2:1–8
- Pretzsch H, Block J, Dieler J, Dong P, Kohnle U, Nagel J, Spellmann H, Zingg A (2010) Comparison between the productivity of pure and mixed stands of Norway spruce and European beech along an ecological gradient. *Ann For Sci* 67:712–723
- Pretzsch H, Schütze G, Uhl E (2013) Resistance of European tree species to drought stress in mixed versus pure forests: evidence of stress release by inter-specific facilitation. *Plant Biol* 15:483–495
- Putz FE, Redford KH (2010) The importance of defining 'forest': tropical forest degradation, deforestation, long-term phase shifts, and further transitions. *Biotropica* 42:10–20
- Radeloff VC, Williams JW, Bateman BL, Burke KD, Carter SK, Childress ES, Cromwell KJ, Gratton C, Hasley AO, Kraemer BM (2015) The rise of novelty in ecosystems. *Ecol Appl* 25:2051–2068
- Redpath SM, Young J, Evely A, Adams WM, Sutherland WJ, Whitehouse A, Amar A, Lambert RA, Linnell JDC, Watt A, Gutiérrez RJ (2013) Understanding and managing conservation conflicts. *Trends Ecol Evol* 28:100–109
- Rooney, T.P. Buttenschön, R., Madsen, P., Olsen, C.R., Royo, A.R., Stout, S.L. 2015. Integrating ungulate herbivory into forest landscape restoration. In: *Restoration of boreal and temperate forests*, Second Edition. CRC Press. 69–84
- Sabogal, C., Besacier, C., McGuire, D. 2015. Forest and landscape restoration: concepts, approaches and challenges for implementation. *Unasylva* 245, Vol 66. 3–10
- Scherer-Lorenzen M (2011) Bedeutung der Biodiversität im Wald. Drei Jahrzehnte Naturnaher Waldbau in Baden-Württemberg. *AFZ-DerWald* 65:28–29
- Seidl R, Rammer W, Spies TA (2014) Disturbance legacies increase the resilience of forest ecosystem structure, composition, and functioning. *Ecol Appl* 24:2063–2077
- Sohn J, Gebhardt T, Ammer C (2013) Mitigation of drought by thinning. Short-term and long-term effects on growth and physiological performance of Norway spruce (*Picea abies*). *For Ecol Manag* 308: 188–197
- Spathelf P, van der Maaten E, van der Maaten-Theunissen M, Campioli M, Dobrowolska D (2014) Climate change impacts in European forests: the expert-views of local observers. *Ann For Sci* 71(2): 131–137
- Spathelf P, Bolte A, van der Maaten E (2015) Is Close-to-Nature Silviculture (CNS) an adequate concept to adapt forests to climate change? *Landbauforschung* 65(3/4):161–170
- Spiecker H, Hansen J, Klimo E, Skovsgaard JP, Sterba H, von Teuffel K (2004) Norway spruce conversion—options and consequences. In: *European Forest Institute Research Report*, vol 18. Brill, Leiden, p 269
- Spittlehouse DL, Stewart RB (2004) Adaptation to climate change in forest management. *BC J Ecosyst Manag* 4:1–11
- Stanturf JA (2015) Future landscapes: opportunities and challenges. *New For* 46:615–644
- Stanturf J, Palik B, Dumroese RK (2014a) Contemporary forest restoration: a review emphasizing function. *For Ecol Manag* 331:292–323
- Stanturf JA, Palik BJ, Williams MI, Dumroese RK, Madsen P (2014b) Forest restoration paradigms. *J Sustain For* 33:161–194
- Stanturf JA, Kant P, Lillesø J-PB, Mansourian S, Kleine M, Graudal L, Madsen P (2015) Forest landscape restoration as a key component of climate change mitigation and adaptation. International Union of Forest Research Organizations, Vienna
- Stanturf J, Mansourian S, Kleine M (eds) (2017) Implementing forest landscape restoration. A practitioner's guide. IUFRO-SPDC, Austria, p 128
- Stanturf J, Madsen P, Sagheb-Talebi K, Hansen O (2018) Transformational restoration: novel ecosystems in Denmark. *Plant Biosystems* 152:536–546. <https://doi.org/10.1080/11263504.2018.1435586>
- Stojnic S, Suchocka M, Benito-Garzon M, Torres-Ruiz JM, Cochard H, Bolte A, Coccozza C, Cvjetkovic B, De Luis M, Martinez-Vilalta J, Raebild A, Tognetti R, Delzon S (2017) Variation in xylem vulnerability to embolism in European beech from geographically marginal populations. *Tree Physiol* 38(2):173–185
- Taeger S, Sparks TH, Menzel A (2015) Effects of temperature and drought manipulations on seedlings of Scots pine provenances. *Plant Biol* 17(2):361–372
- Thorsen, B.J., Mavsar, R., Tyrvalnen, L., Prokofieva, I., Stenger, A. 2014. The provision of forest ecosystem services. Volume 1: quantifying and valuing non-marketed ecosystem services. *EFI – What Science Can Tell Us* 5. p. 76
- Trumbore S, Brando P, Hartmann H (2015) Forest health and global change. *Science* 349:814–818
- Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. *PNAS* 100(14):8074–8079
- Wagner S, Nocentini S, Huth F, Hoogstra-Klein M (2014) Forest management approaches for coping with the uncertainty of climate change: trade-offs in service provisioning and adaptability. *Ecol Soc* 19(1):32
- Williams MI, Dumroese RK (2013) Preparing for climate change: forestry and assisted migration. *J For* 114:287–297
- Williams JW, Jackson ST (2007) Novel climates, no-analog communities, and ecological surprises. *Front Ecol Environ* 5:475–482
- Wingfield MJ, Brockerhoff EG, Wingfield BD, Slippers B (2015) Planted forest health: the need for a global strategy. *Science* 349:832–836
- Xi W, Wang F, Shi P, Dai E, Anoruo A, Bi H, Rahmlow A, He B, Li W (2014) Challenges to sustainable development in China: a review of six large-scale forest restoration and land conservation programs. *J Sustain For* 33:435–453
- Yousefpoor R, Temperli C, Jacobsen JB, Thorsen BJ, Meilby H, Lexer MJ, Lindner M, Bugmann H, Borges JG, Palma JHN, Ray D, Zimmermann NE, Delzon S, Kremer A, Kramer K, Reyer CPO, Lasch-Born P, Garcia-Gonzalo J, Hanewinkel M (2017) A framework for modeling adaptive forest management and decision making under climate change. *Ecol Soc* 22(4):40
- Zalasiewicz J, Williams M, Steffen W, Crutzen P (2010) The new world of the Anthropocene. *Environ Sci Technol* 44:2228–2231