Muys and Messier *Annals of Forest Science* (2023) 80:43
https://doi.org/10.1186/s13595-023-01208-5

INRAE

Annals of Forest Science

OPINION PAPER

Open Access

Climate-smart forest management caught between a rock and a hard place

Bart Muys[1*] and Christian Messier[2]

Abstract

Key message The UNFCCC COP 27 in Sharm El-Sheikh confirmed that climate policies too heavily rely on climate mitigation by forests rather than on de-fossilizing the energy system, to keep global warming within the safe 1.5 °C. Reliable mitigation by forests would imply healthy productive forests well adapted to climate change, and this is no longer the case. The current trend in loss of forest vitality shows that the adaptation of forests is urgently needed, but measures are being insufficiently adopted by foresters on the ground. In this letter, we wonder about the reasons for this inaction paralyzing climate-smart forestry and propose a way forward using a diversity-based no-regret approach in line with available knowledge.

Keywords Climate change, Disturbance, Mitigation, Adaptation, Conservation, Assisted migration, Tree diversity, Invasiveness, Exotic

1 Main text

Climate-smart forest management has been proposed as a nature-based solution integrating climate mitigation goals with adaption measures to enhance the resilience of forest resources (Verkerk et al. 2020). Weatherall et al. (2022) defined it as "sustainable adaptive forest management and governance to protect and enhance the potential of forests to adapt to and mitigate climate change." But with widespread loss in vitality of many world forests related to drought, beetle attacks, and other disturbances (Patacca et al. 2023), it is proposed that foresters' attention needs a further shift from climate change mitigation to adaptation (Messier et al. 2019; Jandl et al. 2019). A large majority of European and North American forest managers acknowledge human-caused climate change and its negative effects on forest vitality and productivity, but only a small minority have adopted adaptation measures so far due to a lack of clear guidance on implementation (Morris et al. 2016; Sousa-Silva et al. 2018). Even though a range of adaptation options has been proposed (Spathelf et al. 2018; Messier et al. 2019; Bauhus et al. 2021), uncertainties, trade-offs, and context dependence seem to paralyze decision-making (Hessburg et al. 2021).

Climate change adaptation in forests is a complex exercise of building social-ecological resilience (Nikinmaa et al. 2020), which requires balancing a multitude of trade-offs between objectives and scales of operation (Nikinmaa et al. 2023). Climate change adaptation also involves monitoring, experimentation, and learning while resolving a range of possible lock-ins, either technological, socio-economic, cultural, or institutional, which may hamper its implementation (Groen et al. 2023).

Land managers and policy makers implementing climate-smart forest management seem to feel they are caught between a rock and a hard place. We illustrate this by focusing on the two basic structural characteristics of the forest that adaptive management is targeting: forest composition and stand structure.

Handling editor: Erwin Dreyer

*Correspondence:
Bart Muys
bart.muys@kuleuven.be
[1] Department of Earth & Environmental Sciences, KU Leuven, Celestijnenlaan 200E Box 2411, Leuven 3001, Belgium
[2] Department of Biol. Sciences, UQAM, Montréal, Canada

Regarding forest composition, the science is advancing steadily (e.g., Benomar et al. 2022). On the one hand, there is increasing evidence of climate change-induced stress and tree mortality in forest ecosystems (Forzieri et al. 2021), with little possibility of natural tree species migration due to slow dispersal and strong landscape fragmentation (Collingham and Huntley 2000). On the other hand, assisted migration could bring clear benefits in terms of adaptiveness and tree productivity (Benito-Garzón and Fernández-Manjarrés 2015), but also holds potential risks, mainly related to biological conservation issues like invasiveness (Camenen et al. 2016) and lack of associated biodiversity, and to genetic conservation issues like outbreeding depression, possibly resulting in, e.g., unadapted day-length or frost sensitivity. Science-based decision support tools are being developed to maximize benefits and minimize risks of assisted migration (e.g., Bindewald et al. 2021; Fremout et al. 2021). There are cautious options like capitalizing on the genetic variation in local populations, complemented by slow introgression of more thermophile and drought-resistant provenances (Fady et al. 2016). Despite these opportunities, it remains a decision fraught with questions of ethical or political nature: whether to prioritize conservation of autochthonous material or promote novel species better adapted to providing ecosystem services under climate change. And even where managers see a clear course of action, execution may be hampered by national or regional regulations that, depending on the zoning (Natura 2000 area, for example), dissuade or sometimes prohibit assisted migration of non-native tree species or non-autochthonous provenances. In this context, Aubin et al. (2011) have offered a useful framework for national and local decision-makers to determine for what species and where and when assisted migration might be a desirable option.

Regarding forest structure, the optimal stand density one should strive for under climate change scenarios is still heavily debated in the forest management community. The focus of the discussion is whether to thin forests more intensively in order to allow precipitation to be distributed over fewer trees, as evidenced by, e.g., del Campo et al. (2022), or to thin less intensively to maintain a humid understory microclimate, as brought forward by Zellweger et al. (2020). At first, this appears to be a mere trade-off between management objectives (tree growth versus forest microclimate-dependent biodiversity), but there might be more to it. Although the available (meta-) studies about thinning effects on tree growth under drought stress (Sohn et al. 2016; Navarro-Cerrillo et al. 2019) are consistent in finding better vitality and growth in thinned stands, it is unclear if results would be conclusive for the full range of conditions, considering that few thinning experiments on moist microclimate-requiring late-successional species are available.

The mentioned adaptation strategies related to forest composition and stand structure illustrate that there are definitely management options to meet the challenges, but clearly, climate-smart forestry is currently caught between a rock and a hard place. In the case of species selection, the choice is between keeping less-adapted native tree species or promoting presumably better-adapted, more southernly growing tree species and provenances. In the case of regulating stand structure, the choice is between maintaining the forest microclimate in closed stands or increasing thinning intensity. These dilemmas have deterred many forest managers and decision-makers from moving ahead with adapting our forest to the uncertainties of climate change and other disturbances. The time has come for hard decisions to be made.

While some decisions await more scientific evidence, promoting diversity in both forest composition and stand structure is one of the clear, no-regret options available that could and should be immediately implemented. Boosting the establishment (and maintenance through stand tending) of functionally diverse tree species mixtures (Messier et al. 2019, 2021; Feng et al. 2022) does increase the overall resilience (Jactel et al. 2017), multifunctionality (Van der Plas et al. 2016), and productivity (Feng et al. 2022) of managed forests over a wide range of contexts. It has almost unanimous support from the scientific community and therefore could be readily implemented (Messier et al. 2021). Boosting stand structural diversity also seems a no-regret option but has not yet been largely studied. Apart from variation in diameter and age class distribution, spatial mosaics of dense and open canopies further accentuate variation in the abiotic conditions of landforms, slope, and aspect, creating varied microclimatic conditions and a broad range of habitats to accommodate a large set of species.

In the context of the heated debate on the European Nature Restoration Law, the here proposed no-regret adaptive management interventions might be interpreted as having a productivist view on forests, but this would be a serious misunderstanding. Also, for forests in conservation areas or targeting non-provisioning ecosystem services and conservation of forest-related biodiversity, the continuity of a vital tree cover is becoming paramount. The time has come to make hard decisions to help adapt our forests, whatever their societal function, to the many threats and uncertainties of the future.

Code availability

Not applicable.

Authors' contributions
BM and CM conceived the paper idea. BM drafted the manuscript. Both BM and CM commented and approved the final manuscript.

Funding
Christian Messier (C. M.) was awarded an International Collen-Francqui Chair from the Francqui Foundation, Belgium.

Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 14 December 2022 Accepted: 9 October 2023
Published online: 07 November 2023

References

Aubin I, Garbe CM, Colombo S, Dreve CR, McKenney DW, Messier C, Pedlar J, Saner MA, Venier L, Wellstead AM, Winder R (2011) Why we disagree about assisted migration: ethical implications of a key debate regarding the future of Canada's forests. For Chron 87:755–765

Bauhus J, Seeling U, Dieter M, Farwig N, Hafner A, Kätzel R, Kleinschmit B, Lang F, Lindner M, Möhring B, Müller J (2021) Die Anpassung von Wäldern und Waldwirtschaft an den Klimawandel. Berichte über Landwirtschaft-Zeitschrift für Agrarpolitik und Landwirtschaft

Benito-Garzón M, Fernández-Manjarrés JF (2015) Testing scenarios for assisted migration of forest trees in Europe. New For 46:979–994

Benomar L, Elferjani R, Hamilton J, O'Neill GA, Echchakoui S, Bergeron Y, Lamara M (2022) Bibliometric analysis of the structure and evolution of research on assisted migration. Curr For Rep 8:199–213

Bindewald A, Brundu G, Schueler S, Starfinger U, Bauhus J, Lapin K (2021) Site-specific risk assessment enables trade-off analysis of non-native tree species in European forests. Ecol Evol 11:18089–18110

Camenen E, Porté AJ, Benito GM (2016) American trees shift their niches when invading Western Europe: evaluating invasion risks in a changing climate. Ecol Evol 6:7263–7275

Collingham YC, Huntley B (2000) Impacts of habitat fragmentation and patch size upon migration rates. Ecol Appl 10:131–144

del Campo AD, Otsuki K, Serengil Y, Blanco JA, Yousefpour R, Wei X (2022) A global synthesis on the effects of thinning on hydrological processes: implications for forest management. For Ecol Manage 519:120324

Fady B, Cottrell J, Ackzell L, Alía R, Muys B, Prada A, González-Martínez SC (2016) Forests and global change: what can genetics contribute to the major forest management and policy challenges of the twenty-first century? Reg Environ Change 16:927–939

Feng Y, Schmid B, Loreau M, Forrester DI, Fei S, Tang Z, Zhu J, Hong P, Ji C, Shi Y, Su H, Xiong X, Xiao J, Wang S, Fang J et al (2022) Multispecies forest plantations outyield monocultures across a broad range of conditions. Science 376:6595

Forzieri G, Girardello M, Ceccherini G, Spinoni J, Feyen L, Hartmann H, Beck PS, Camps-Valls G, Chirici G, Mauri A, Cescatti A (2021) Emergent vulnerability to climate-driven disturbances in European forests. Nat Commun 12:1–12

Fremout T, Thomas E, Taedoumg H, Briers S, Gutiérrez-Miranda CE, Alcázar-Caicedo C, Lindau A, Mounmemi KH, Vinceti B, Kettle C, Ekué M, Atkinson R, Jalonen R, Gaisberger H, Elliott S, Brechbühler E, Ceccarelli V, Krishnan S, Vacik H, Wiederkehr-Guerra G, Salgado-Negret B, González MA, Ramírez W, Moscoso-Higuita LG, Vásquez A, Cerrón J, Maycock C, Muys B (2021) Diversity for Restoration (D4R): guiding the selection of tree species and seed sources for climate-resilient restoration of tropical forest landscapes. J Appl Ecol 59(3):664–679

Groen L, Alexander M, King JP, Jager NW, Huitema D (2023) Re-examining policy stability in climate adaptation through a lock-in perspective. J Eur Publ Policy 30:488–512

Hessburg PF, Prichard SJ, Hagmann RK, Povak NA, Lake FK (2021) Wildfire and climate change adaptation of western North American forests: a case for intentional management. Ecol Appl 31(8):e02432

Jactel H, Bauhus J, Boberg J, Bonal D, Castagneyrol B, Gardiner B, Gonzalez-Olabarria JR, Koricheva J, Meurisse N, Brockerhoff EG (2017) Tree diversity drives forest stand resistance to natural disturbances. Curr For Rep 3:223–243

Jandl R, Spathelf P, Bolte A, Prescott CE (2019) Forest adaptation to climate change—is non-management an option? Ann For Sci 76:1–13

Messier C, Bauhus J, Doyon F, Maure F, Sousa-Silva R, Nolet P, Mina M, Aquilué N, Puettmann K (2019) The functional complex network approach to foster forest resilience to global changes. For Ecosyst 6(1):1–16

Messier C, Bauhus J, Sousa-Silva R, Auge H, Baeten L, Barsoum N, Bruelheide H, Caldwell B, Cavender-Bares J, Dhiedt E, Eisenhauer N et al (2021) For the sake of resilience and multifunctionality, let's diversify planted forests! Conserv Lett 15(1):e12829

Morris HL, Megalos MA, Hubbard WG, Boby LA (2016) Climate change attitudes of southern forestry professionals: outreach implications. J Forest 114(5):532–540

Navarro-Cerrillo RM, Sánchez-Salguero R, Rodriguez C, Lazo JD, Moreno-Rojas JM, Palacios-Rodriguez G, Camarero JJ (2019) Is thinning an alternative when trees could die in response to drought? The case of planted Pinus nigra and P. sylvestris stands in southern Spain. For Ecol Manage 433:313–324

Nikinmaa L, Lindner M, Cantarello E, Gardiner B, Bredahl Jacobsen J, Jump AS, Parra C, Plieninger T, Schuck A, Seidl R, Timberlake T, Waring K, Winkel G, Muys B (2023) A balancing act: Principles criteria and indicator framework to operationalize social-ecological resilience of forests. J Environ Manage. 331117039. https://doi.org/10.1016/j.jenvman.2022.117039

Nikinmaa L, Lindner M, Cantarello E, Jump AS, Seidl R, Winkel G, Muys B (2020) Reviewing the Use of Resilience Concepts in Forest Sciences Current Forestry Reports 6(2):61–80. https://doi.org/10.1007/s40725-020-00110-x

Patacca M, Lindner L, Lucas-Borja ME, Cordonnier T, Fidej G, Gardiner B, Hauf Y, Jasinevičius G, Labonne S, Linkevičius E, Mahnken M, Milanovic S, Nabuurs G-J, Nagel TA, Nikinmaa L, Panyatov M, Bercak RR, Seidl R, Sever MZO, Socha J, Thom D, Vuletic D, Zudin S, Schelhaas M-J (2023) Significant increase in natural disturbance impacts on European forests since 1950. Global Change Biol 29:1359–1376

Sohn JA, Saha S, Bauhus J (2016) Potential of forest thinning to mitigate drought stress: a meta-analysis. For Ecol Manage 380:261–273

Sousa-Silva R, Verbist B, Lombab Â, Valent P, Suškevičs M, Picard O, Hoogstra-Klein MA, Cosofret V-C, Bouriaud L, Ponette Q, Verheyen K, Muys B (2018) Adapting forest management to climate change in Europe: linking perceptions to adaptive responses. Forest Policy Econ 90:22–30

Spathelf P, Stanturf J, Kleine M, Jandl R, Chiatante D, Bolte A (2018) Adaptive measures: integrating adaptive forest management and forest landscape restoration. Ann For Sci 75:1–6

Van der Plas F, Manning P, Allan E, Scherer-Lorenzen M, Verheyen K, Wirth C, Zavala MA, Hector A, Ampoorter E, Baeten L, Barbaro L et al (2016) Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. Nat Commun 7:1–11

Verkerk PJ, Costanza R, Hetemäki L, Kubiszewski I, Leskinen P, Nabuurs GJ, Potočnik J, Palahí M (2020) Climate-smart forestry: the missing link. Forest Policy Econ 115:102164

Weatherall A, Nabuurs GJ, Velikova V, Santopuoli G, Neroj B, Bowditch E, Temperli C, Binder F, Ditmarová LU, Jamnická G, Lesinski J, La Porta N, Pach M, Panzacchi P, Sarginci M, Serengil Y, Tognetti R (2022) Defining climate-smart forestry. In: Tognetti R, Smith M, Panzacchi P (eds) Climate-smart forestry in mountain regions. Springer International Publishing, pp 35–58

Zellweger F, De Frenne P, Lenoir J, Vangansbeke P, Verheyen K, Bernhardt-Römermann M, Baeten L, Hédl R, Berki I, Brunet J, Van Calster H (2020) Forest microclimate dynamics drive plant responses to warming. Science 368:772–775

Publisher's Note