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OPINION

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Diverse forests are cool: Promoting diverse forests to mitigate carbon emissions and climate change

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Abstract

Climate change is one of the most pressing threats to humanity, inducing a global increase in temperatures and more frequent extreme climatic events. Considering this, global reforestation initiatives are proposed to capture carbon and mitigate climate change. Global restoration and reforestation programs and their targets have inspired both unparalleled enthusiasm worldwide and intense scientific criticism and debate regarding their feasibility and implementation. We agree that global reforestation forecasting and efforts require a nuanced discussion and approach. In that vein, we would like to emphasize the potential of increasing existing forest diversity to enhance climate change mitigation by increasing aboveground and belowground carbon storage. Moreover, we argue that focusing on planting diverse forests in reforestation efforts can help to reduce climate change effects on ecosystems: first, by increasing resistance and resilience to extreme climatic events, and second, by buffering microclimatic conditions in natural and urban areas. Diversifying forests plantations and reforestation projects may not always be feasible and cannot solve the climate crisis by itself. However, we highlight that a focus on diverse forests could maximize the benefits of reforestation programs by promoting sustainable land management.

KEYWORDS
biodiversity-ecosystem functioning, carbon storage, climate mitigation, ecosystem services, microclimate buffering

1 | CLIMATE CHANGE AND NATURE-BASED MITIGATION

Climate change threatens humanity and other life on Earth.[1,2] The IPCC reports (2013, 2021) highlighted the crucial role of anthropogenic carbon dioxide (CO_2) emissions in climate change, estimating that CO_2 emissions contributed to about 0.75°C of the 1°C global warming over the last century.[1,2] In addition to global warming, climate change induces more frequent and intense extreme climatic events, such as heatwaves and droughts. Enhancing photosynthetic carbon capture by increasing tree cover and restoring degraded forests has been suggested as one of the most effective approaches to mitigate climate change.[3,4] The IPCC (2013) projected that 1 billion ha of forest would be needed to keep global warming increases below 1.5°C by 2050.[1] This estimate was downscaled by Bastin et al.,[3] who predicted that planting 0.9 billion ha could store 205 Gt of

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carbon while investigating available areas for reforestation worldwide. However, these numbers have been heavily criticized since their publication.[5,6] The main concern is that the study overestimated the carbon storage potential of forests, thus underestimating the land area needed to achieve current carbon storage goals. Therefore, one major source of debate is that a global reforestation initiative to store 205 Gt of carbon would compete with other land uses (e.g., cropland, urban areas).

2 | DIVERSIFYING FORESTS TO MITIGATE CARBON EMISSIONS

There is increasing evidence that tree diversity has a positive effect on multiple measures of ecosystem functioning in forests (i.e., multifunctionality).[7–9] Especially diverse forests were shown to increase aboveground[10,11] and belowground[12,13] carbon storage (Figure 1), for example, by increasing tree complementarity while reducing soil carbon loss by erosion.[7,10,14] For instance, in subtropical climates, species-rich forests of 20 tree species per ha store three times more carbon than monocultures.[13] We argue that diversifying existing forests and reforestation projects will increase and stabilize forest carbon storage, therefore reducing the land needed for global reforestation projects, and thus the competition for land between reforestation projects and other important land uses. However, even if these patterns seem to be consistent globally,[12] better global coverage of research across biomes is needed to predict the carbon storage potential of locally diversified forests. Promising initiatives in this context include the increasing availability of forest inventory data, for example,[15] the global network of tree diversity experiments (TreeDivNet[16]), and global restoration initiatives with a biodiversity focus (e.g., Restor: https://restor.eco/). Likewise, promoting species-rich plantations will enhance the carbon storage potential of managed forests in addition to reforestation projects. Transdisciplinary projects are needed to understand both biodiversity and production constraints and objectives.[8] Here, we suggest that biodiversity-ecosystem functioning (BEF) research should take a sharp turn toward transdisciplinary research to better meet the practical demands of land managers, practitioners, and restoration initiatives.[8] For instance, Mao et al.[17] proposed and applied a holistic modelling framework to link biodiversity conservation and socioeconomic goals in French mountain resort areas.

3 | DIVERSE FORESTS TO MITIGATE THE CONSEQUENCES OF CLIMATE CHANGE

Climate change is expected to increase the frequency and intensity of extreme climatic events as well as biological responses to those events, such as drought, fire, and insect outbreaks,[8,18] increasing tree mortality and reducing forest heath. Climate change could contribute to reduce forest cover in the tropics by more than 200 million ha by 2050.[3] Concurrently, tree diversity experiments have shown the high potential of diverse forests to buffer extreme climatic events (see Reference 19 for context-dependencies,[20]). For example, tree diversity mitigates drought effects on forest productivity[20] by increasing the asynchronous response of tree species to climatic variability,[21] thereby stabilizing ecosystem services.[8,9] Likewise,

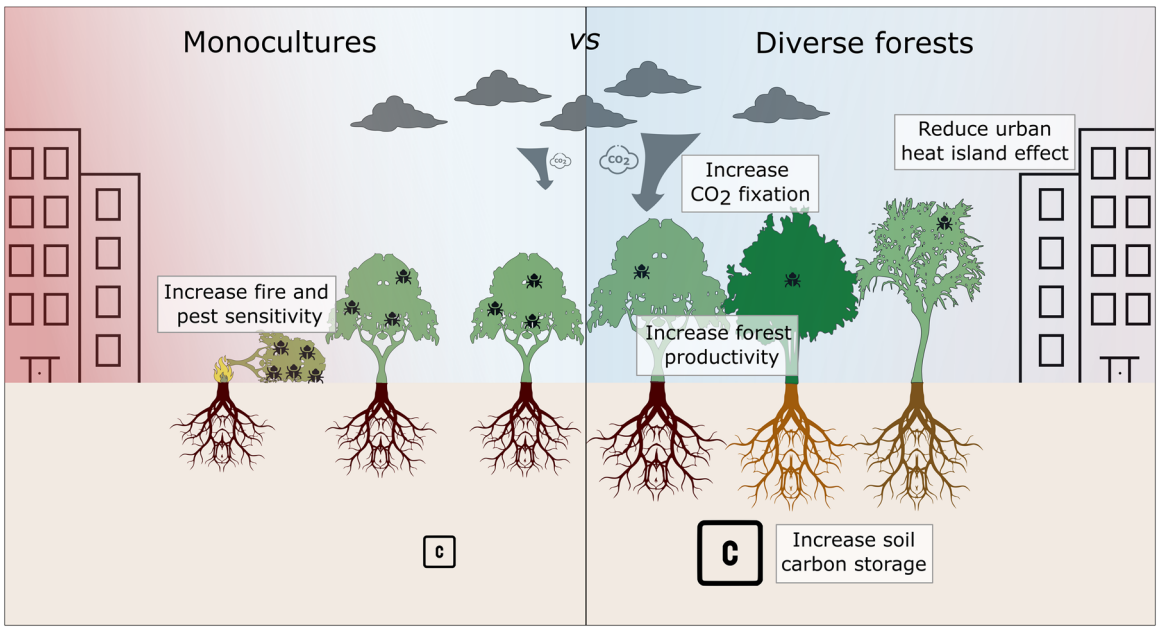

FIGURE 1 Conceptual figure of the effects of tree diversity on ecosystem properties related to climate change mitigation. Briefly, diverse forests have been shown to fix more atmospheric carbon, store more carbon above- and belowground, decrease the likelihood and severity of fires and pest outbreaks, and mitigate microclimatic conditions under climate change

increasing tree diversity stabilizes long-term carbon storage by reducing forests' susceptibility to fire and thus the net release of carbon dioxide.[8] Moreover, diverse forests are naturally resistant to extreme insect outbreaks and herbivory pressure by supporting multitrophic biodiversity.[7,22] Given the many advantages that diverse forests provide, promoting diverse forests in existing forests and in reforestation projects present multiple benefits to protect forests from climate change in a sustainable way (Figure 1).

4 | DIVERSE FORESTS TO INCREASE HUMAN WELL-BEING IN CITIES

In cities—where most humans live—temperature increase is amplified by sealed surfaces and a lack of vegetation (so-called urban heat island effect), intensifying summer heatwaves, and exacerbating intense climatic effects on human well-being.[2] Increasing urban tree cover and planting urban forests have been shown to reduce the urban heat island effect and to improve human well-being by shading surfaces.[9] Urban forests could account for up to 1% of the total global reforestation potential,[3] which is an efficient space to improve millions of lives. Simultaneously, tree diversity increases aboveground productivity in forests[10,11] and tree crown structural complementarity.[14] Therefore, we expect tree diversity to increase canopy buffering of macroclimatic fluctuations[23] and thus reduce the microclimatic temperature below the canopy under warm conditions.[24] Increasing tree diversity in and around the urban matrix has the potential to enhance forest cooling effects (Figure 1), but more experimental work is needed to explore this phenomenon and its magnitude. Here, we argue that public policy should take advantage of urban areas to plant diverse forests locally and contribute to climate change mitigation while increasing population well-being.

5 | OUTLOOK

We argue that diversifying existing forests and planting diverse forests through reforestation programs will promote forest carbon storage and can thus contribute to climate change mitigation. Moreover, increasing tree diversity will promote forest multifunctionality and protect forest functioning against climate change-induced threats (e.g., extreme climatic events, insect outbreaks). Finally, we suggest that tree diversity should be promoted in urban areas to locally buffer warming while improving human well-being. There is strong momentum for re-/afforestation initiatives like the *UN Decade on Ecosystem Restoration (2021-2030)*, the *Bonn Challenge*, and the *European Green Deal*, as well as sustainable management of forests (see UN Sustainable Development Goals: 6, 11, 13, 15). We acknowledge that reforestation is not possible everywhere and may also impose serious pitfalls, like the reduction of water availability or increase of social iniquity.[25] Therefore, to increase the likelihood of success of these initiatives, transdisciplinary approaches are needed to connect scientists, land managers, and politicians to address sustainable land use and climate change mitigation. Further research is essential to better assess how diverse forests will maximize reforestation potential to mitigate climate change. In particular, we need to determine the conditions under which diversifying forests is feasible[25] and which tree community will provide the greatest benefits, and the limits under which diverse forests can mitigate the effects of climate change and extreme climatic events.[19]

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ETHICS STATEMENT

The authors confirm that they have adhered to the ethical policies of the journal.

AUTHOR CONTRIBUTIONS

Conceptual framework: Rémy Beugnon, Emma Ladouceur, Marie Sünnemann, Simone Cesarz and Nico Eisenhauer. *Manuscript writing*: Rémy Beugnon. *Manuscript revisions*: Emma Ladouceur, Marie Sünnemann, Simone Cesarz and Nico Eisenhauer.

DATA AVAILABILITY STATEMENT

No data are involved in this study.

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