frontiers | Frontiers in Forests and Global Change

TYPE Opinion
PUBLISHED 22 January 2024
DOI 10.3389/ffgc.2024.1346966

Check for updates

OPEN ACCESS

EDITED BY
Jacqueline R. England,
Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

REVIEWED BY
Shawn M. McKenzie,
McMaster University, Canada

*CORRESPONDENCE
Arshad Ali
arshadforester@gmail.com;
arshadforester@hbu.edu.cn

RECEIVED 30 November 2023
ACCEPTED 10 January 2024
PUBLISHED 22 January 2024

CITATION
Ali A (2024) Global change solutions must embrace biodiverse multifunctional planted forests. *Front. For. Glob. Change* 7:1346966. doi: 10.3389/ffgc.2024.1346966

Global change solutions must embrace biodiverse multifunctional planted forests

Arshad Ali *

Forest Ecology Research Group, College of Life Sciences, Hebei University, Baoding, Hebei, China

KEYWORDS

biodiversity, ecosystem functioning, plantations, global change, forest management, silviculture, forest products

1 Forests and global change

Natural forests are important habitats for most of the terrestrial biodiversity (plants, animals, microbes, and others) and reservoirs of carbon sequestration that underpin human well-being through the provision of numerous ecosystem services (FAO and UNEP, 2020; Cabon et al., 2022; Malhi et al., 2022). Since 1990, a substantial amount of natural forest has been degraded and even cleared (at a decreasing rate of loss), whereas the area of planted forests has increased by 123 million hectares (FAO, 2020). Human activities and grazing animal disturbances have severely damaged the stability of global natural forest ecosystems (Seidl et al., 2017; Canelles et al., 2021; Lapola et al., 2023). However, pest and pathogen attacks can further decrease biodiversity and stand structural complexity, and alter demographic processes of already human-altered natural forests, thereby negatively impacting overall ecosystem multifunctionality under increasing impacts of global change (Seidl et al., 2017; Canelles et al., 2021). As such, the ability of human-altered natural forest ecosystems to mitigate global warming through carbon sequestration and to maintain a stable provision of many other ecosystem services is threatened by the rise in frequency and severity of wildfires, storms, heat events, floods and droughts (Corlett, 2016; Curtis et al., 2018; Bowd et al., 2019; Lapola et al., 2023). Thus, in response to these impacts, people are planting trees for several different socio-ecological reasons such as forest-based market demands, biodiversity conservation, increasing ecosystem services, improving environmental conditions, promoting socioeconomic conditions, conserving cultural and spiritual values, and legislative requirements (Malkamäki et al., 2018; Brancalion and Holl, 2020; Gómez-González et al., 2022; Bose et al., 2023). Yet, further diverse multidisciplinary insights and conversations are needed into how to scientifically design and implement socio-ecologically feasible, biologically diverse, multifunctional planted forest ecosystems to combat global change impacts. Here, the concept of "biologically diverse, multifunctional planted forest ecosystems" refers to mixed plantations with numerous tree, shrub and grass species as well as animals and microbes for the supply of numerous ecosystem services through multifunctionality, rather than being rigorously developed and managed for quick forest-based targeted products (Figure 1).

2 Challenges and solutions to commercial short-rotation tree planting

Replanting short-rotation (i.e., usually <20 years) trees is generally considered a potential strategy to improve the socioeconomic conditions of a region. However, such plantations usually encourage the establishment of resource-acquisitive, fast-growing commercial tree species through monoculture designs that quickly produce the targeted forest-based products to meet the global market demands (Paquette and Messier, 2010; Brancalion and Holl, 2020; Mcewan et al., 2020). While this strategy can reduce rotation lengths as compared to long-term tree species-diverse, multifunctional planted forests, the frequent replanting of commercial tree species, such as species from the genera *Pinus*, *Eucalyptus*, *Acacia*, *Populus*, and *Elaeis* (oil palm), can greatly limit the regeneration potential of natural forests (Brancalion and Holl, 2020; Mcewan et al., 2020; Bose et al., 2023). Consequently, less diversified multifunctional planted forests, such as monocultures, are often recognized to be less resilient to natural disturbances such as pest and pathogen attacks that may be further intensified by human disturbances and climate change including droughts and extreme temperatures (Paquette and Messier, 2010; Mcewan et al., 2020; Gómez-González et al., 2022).

In the future, there will likely be a higher demand for quick-growing forest-based products, but decisions on where to establish commercial short-rotation plantation systems should prioritize the ecological impacts on the land to be used (Brancalion and Holl, 2020; Mcewan et al., 2020; Bose et al., 2023). These plantations

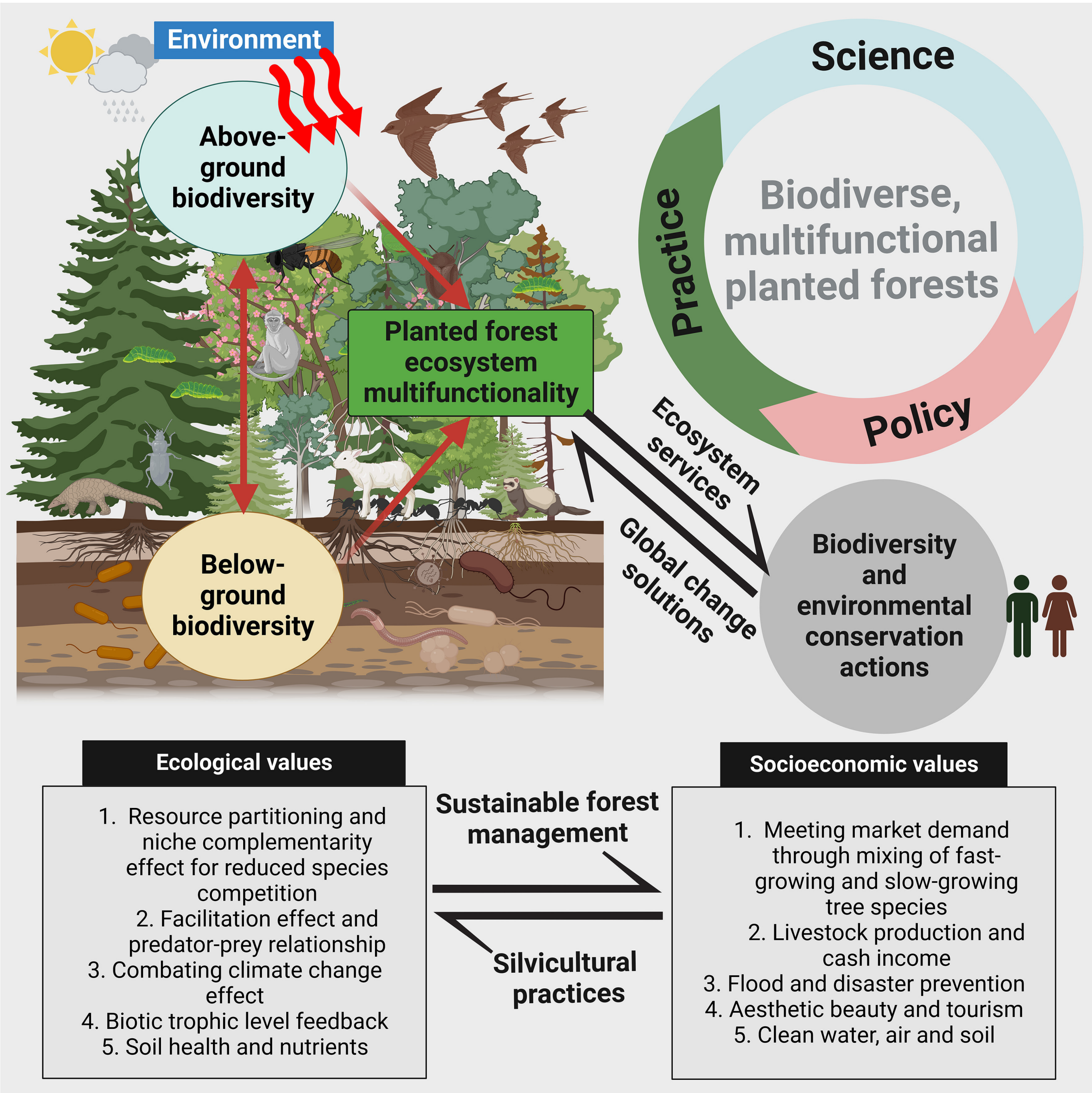

FIGURE 1
An ideal biologically diverse, multifunctional planted forest ecosystem as a substitute for restoring degraded natural forests and halting biodiversity loss while considering the quick market demands through the mixing of suitable fast- and slow-growing tree species. The concept of a biologically diverse, multifunctional planted forest ecosystem is framed by three key elements, i.e., Science, Policy, and Practice.

should be established in areas that are not highly sensitive to global change and should not disrupt natural forests, grasslands, and other ecosystems (Ferrier, 2020; Silveira et al., 2022). It is usually possible to integrate agricultural crops under well-designed agroforestry systems, but consideration must be given to the potential impact on food production and the environment if commercial agricultural lands are to be used (Paquette and Messier, 2010; Brown et al., 2018). However, using marginal or unused land for short-rotation plantations is a promising option, as it can provide wood products and food yields on poor soil quality which enhances short-term socioeconomic benefits to rural communities (Ranacher et al., 2021). In addition to focusing on forest-based products, commercial short-rotation plantations need to consider the extra socio-ecological benefits of planting trees, such as mitigating the effects of droughts, heat events, and floods, by introducing tree species that are suitable for specific sites based on their positive interactions with the environment (Paquette and Messier, 2010; Brancalion and Holl, 2020; Gómez-González et al., 2022). Unused urban areas near buildings, roads, and public parks can also be utilized to meet market demands, enhance the aesthetics of the surroundings, and reduce the impacts of global change by implementing feasible designs for planting urban trees that benefit both nature and people (Pataki et al., 2021).

3 Current insights into diverse multifunctional planted forests

The concept of "tree species diversified multifunctional planted forests" refers to mixed plantations with two or more tree species typically maintained for the supply of numerous ecosystem services through multifunctionality rather than being developed and managed for fast-grown, forest-based targeted products (Paquette and Messier, 2010; Brancalion and Holl, 2020; Messier et al., 2022). Under the concept of the niche complementarity effects, the promoting effects of tree species richness, having a variety of tree sizes (i.e., tree heights, diameters and/or crown dimensions), functional traits and evolutionary history, on ecosystem functions (e.g., aboveground biomass) have been widely recognized in both natural and diversified planted forests (Ruiz-Jaen and Potvin, 2011; Osuri et al., 2020; Yuan et al., 2020; Feng et al., 2022; Ali, 2023a). Such forests provide numerous ecosystem services that underpin human well-being and are more resilient to disturbances caused by pests, pathogens, drought and heat, due to their higher tree diversity (Seidl et al., 2017; Gómez-González et al., 2022; Messier et al., 2022). However, under the concept of mass ratio and selection effects, functionally dominant tree species (based on the community-weighted mean of specific trait values) and large trees (based on tree sizes) overrule the effects of tree diversity on ecosystem functions (Fotis et al., 2018; Ali, 2023a). Moreover, the niche complementarity and mass ratio effects are further complicated by the trade-offs and synergies between traits and ecosystem functions over short (i.e., grow fast and persist short) versus long (grow slow and persist long) time periods (Reich, 2014). However, this does not mean that functionally redundant trees should be solely planted for targeted forest-based products, because forest ecosystem functions are regulated by tree species coexistence mechanisms in interactions with climate and soil conditions (Hector et al., 2001; Duffy, 2009; Feng et al., 2022; Messier et al., 2022). In this scientific context, it can be predicted that diversified multifunctional planted forests having fast-growing resource-acquisitive trees may quickly meet the socio-economic and market demands for forest-based products whereas slow-growing resource-conservative trees may continue to improve the resistance of planted forests to global change drivers (Poorter et al., 2021; Feng et al., 2022; Ali, 2023b).

4 Moving toward biologically diverse, multifunctional planted forest ecosystems

Despite the strong scientific evidence and growing societal support for the multiple ecosystem services and reduced global change risks associated with diversified multifunctional planted forests (Paquette and Messier, 2010; Ruiz-Jaen and Potvin, 2011; Brancalion and Holl, 2020; Feng et al., 2022; Gómez-González et al., 2022; Messier et al., 2022; Ali, 2023b), a significant portion of global planted forests continue to be established and maintained as monocultural plantations (FAO, 2020). This situation shows a gap between forest science, policy and practice as most of the world's planted forests are not strictly designed, implemented and managed under scientific guidelines through best-practice silviculture, and feasible actions for biodiversity and environmental conservation (Mori et al., 2017; Brancalion and Holl, 2020; Achim et al., 2021; Ali, 2023b). Further, the general widespread understanding is that planting trees (either monocultural or mixed species) is not the simple solution to combating the impacts of global change drivers. Focusing (either short-term or long-term) solely on tree species cannot simply replace the ecosystem functions and services provided by natural undisturbed forests which are largely regulated by both above- and below-ground biodiversity (including plants, animals and microbes) as well as soil and climatic conditions (Figure 1; Gómez-González et al., 2022; Ali, 2023a). For example, recent studies have shown that forest ecosystem multifunctionality is largely regulated by both above- and below-ground biodiversity along environmental conditions (Lefcheck et al., 2015; Schuldt et al., 2018; Yuan et al., 2020). Yet, we still lack widespread research on how plant, animal and microbial biodiversity (i.e., trophic levels) jointly regulate forest ecosystem functions for the provision of multiple ecosystem services (Van Der Plas, 2019; Ali, 2023a). As such, proper silvicultural practices, and forest management policies and practices are largely lacking in implementing biologically diverse, multifunctional planted forest ecosystems (Mori et al., 2017; Achim et al., 2021; Ali, 2023b). Thus, it is very important to focus on the whole forest ecosystem when designing plantations, not just on planting trees, by managing stand structural complexity through best-practice silviculture and promoting ecological intensification through best-action biodiversity and environmental conservation (Paquette and Messier, 2010; Brancalion and Holl, 2020; Achim et al., 2021; Gómez-González et al., 2022; Messier et al., 2022). To this end, I put forward two important guidelines for successful biologically diverse, multifunctional planted forest ecosystems while considering short-term commercial plantations (Figure 1).

(1) To restore degraded natural forest ecosystems and combat the loss of biodiversity due to global change drivers, it is imperative that tree planting initiatives prioritize and incorporate biodiversity conservation. While planting trees is an initial step toward restoring degraded forest ecosystems, it is equally important to implement simultaneous conservation efforts that promote soil health through the preservation of animal and microbial biodiversity. By embracing biologically diverse, multifunctional planted forest initiatives, we can ensure long-term sustainable forest management through proper silvicultural practices that meet the needs of both present and future generations, while also serving as a replacement for already degraded natural forest ecosystems. Although the adoption of diverse multifunctional tree species is prevalent worldwide, the challenges surrounding the promotion and re-introduction of native animal and microbial biodiversity may require further policies and practices informed by scientific research. This can be achieved by looking to local undisturbed natural forests as a model for actively or passively restoring degraded forests, guided by the principles of the science of silviculture while considering the designs of biologically diverse, multifunctional planted forest ecosystems.

(2) To effectively meet the growing demands of the market and industry for forest-based products, commercial plantations must shift their focus toward incorporating multipurpose tree species, rather than solely relying on monocultural plantations. These planting initiatives must be carried out in commercial or otherwise marginal lands, rather than disrupting natural biodiversity hotspots. Additionally, it is important to recognize the significance of other open biomes, such as grasslands and agricultural crops. By doing so, we can mitigate the risks of global change divers such as pest and pathogen attacks, as well as minimize the impacts of droughts and heat events. This approach not only ensures the preservation of a high-quality environment but also safeguards the natural and biologically diverse, multifunctional planted forests in the surrounding areas. However, further advanced research and practical strategies are still required to effectively design and implement short-term commercial plantations that prioritize biodiversity as a whole through advanced technologies and silvicultural practices, ultimately achieving the ecosystem services provided by biologically diverse, multifunctional planted forests.

5 Concluding remarks and future perspectives

In this thought-provoking article, I attempt to address the fundamental question of "*Will planting trees solve anything*". Through an appraisal of the relevant literature, I assert that the answer may indeed be affirmative, contingent upon the thoughtful design, implementation, and management (including silvicultural practices) of tree planting initiatives. I have identified two conflicting planting strategies that each require trade-offs between production and ecological goals: firstly, the adoption of short-rotation commercial plantations, driven by the market demands, which may inadvertently pose a threat to biodiversity conservation and environmental integrity, but can reduce pressure on existing natural forests; and secondly, the potential for ecological intensification and diversification of multifunctional planted forests to effectively achieve sustainable forest management and biodiversity conservation goals, though hindered by the urgency to meet market demands. In light of these conflicts, I emphasize that global change solutions must embrace the concept of biologically diverse, multifunctional planted forest ecosystems as a means to enhance the provision of ecosystem services through the regulation of both above- and below-ground biodiversity, as well as environmental integrity. To realize this vision, we must engage in further comprehensive global scientific research to inform global criteria for planting trees policy and practice.

Author contributions

AA: Conceptualization, Funding acquisition, Investigation, Resources, Software, Visualization, Writing—original draft, Writing—review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by Hebei University (Grant No. 521100221033).

Acknowledgments

I would like to express my gratitude to the editorial team at *Frontiers in Forests and Global Change* for inviting me to write an opinion and perspective article on a topical issue: *Conversations in: Will planting trees solve anything*. I greatly appreciate constructive comments from the Handling Editor (Jacqueline R. England) and reviewer which helped to improve the quality of this manuscript. I am thankful to Hebei University for the research support (Grant No. 521100221033). I created the graphical designs using the premium version of BioRender.com.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

References

Achim, A., Moreau, G., Coops, N. C., Axelson, J. N., Barrette, J., Bédard, S., et al. (2021). The changing culture of silviculture. *Forestry* 95, 143–152. doi: 10.1093/forestry/cpab047

Ali, A. (2023a). Biodiversity–ecosystem functioning research: brief history, major trends and perspectives. *Biol. Conserv.* 285, 110210. doi: 10.1016/j.biocon.2023.110210

Ali, A. (2023b). Linking forest ecosystem processes, functions and services under integrative social–ecological research agenda: current knowledge and perspectives. *Sci. Tot. Environ.* 892, 164768. doi: 10.1016/j.scitotenv.2023.164768

Bose, T., Hammerbacher, A., Slippers, B., Roux, J., and Wingfield, M. J. (2023). Continuous replanting could degrade soil health in short-rotation plantation forestry. *Curr. For. Rep.* 9, 230–250. doi: 10.1007/s40725-023-00188-z

Bowd, E. J., Banks, S. C., Strong, C. L., and Lindenmayer, D. B. (2019). Long-term impacts of wildfire and logging on forest soils. *Nat. Geosci.* 12, 113–118. doi: 10.1038/s41561-018-0294-2

Brancalion, P. H. S., and Holl, K. D. (2020). Guidance for successful tree planting initiatives. *J. Appl. Ecol.* 57, 2349–2361. doi: 10.1111/1365-2664.13725

Brown, S. E., Miller, D. C., Ordonez, P. J., and Baylis, K. (2018). Evidence for the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in high-income countries: a systematic map protocol. *Environ. Evid.* 7, 24. doi: 10.1186/s13750-018-0136-0

Cabon, A., Kannenberg, S. A., Arain, A., Babst, F., Baldocchi, D., Belmecheri, S., et al. (2022). Cross-biome synthesis of source versus sink limits to tree growth. *Science* 376, 758–761. doi: 10.1126/science.abm4875

Canelles, Q., Aquilué, N., James, P. M. A., Lawler, J., and Brotons, L. (2021). Global review on interactions between insect pests and other forest disturbances. *Landsc. Ecol.* 36, 945–972. doi: 10.1007/s10980-021-01209-7

Corlett, R. T. (2016). The impacts of droughts in tropical forests. *Trends Plant Sci.* 21, 584–593. doi: 10.1016/j.tplants.2016.02.003

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., and Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science* 361, 1108–1111. doi: 10.1126/science.aau3445

Duffy, J. E. (2009). Why biodiversity is important to the functioning of real-world ecosystems. *Front. Ecol. Environ.* 7, 437–444. doi: 10.1890/070195

FAO (2020). *Global Forest Resources Assessment* Rome: FAO.

FAO and UNEP (2020). *The State of the World's Forests (SOFO).* Rome: FAO and UNEP.

Feng, Y., Schmid, B., Loreau, M., Forrester, D. I., Fei, S., Zhu, J., et al. (2022). Multispecies forest plantations outyield monocultures across a broad range of conditions. *Science* 376, 865–868. doi: 10.1126/science.abm6363

Ferrier, S. (2020). Prioritizing where to restore Earth's ecosystems. *Nature* 586, 680–681. doi: 10.1038/d41586-020-02750-2

Fotis, A. T., Murphy, S. J., Ricart, R. D., Krishnadas, M., Whitacre, J., Wenzel, J. W., et al. (2018). Above-ground biomass is driven by mass-ratio effects and stand structural attributes in a temperate deciduous forest. *J. Ecol.* 106, 561–570. doi: 10.1111/1365-2745.12847

Gómez-González, S., Paniw, M., Blanco-Pastor, J. L., García-Cervigón, A. I., Godoy, O., Herrera, J. M., et al. (2022). Moving towards the ecological intensification of tree plantations. *Trends Plant Sci.* 27, 637–645. doi: 10.1016/j.tplants.2021.12.009

Hector, A., Joshi, J., Lawler, S., Spehn, E. M., and Wilby, A. (2001). Conservation implications of the link between biodiversity and ecosystem functioning. *Oecologia* 129, 624–628. doi: 10.1007/s004420100759

Lapola, D. M., Pinho, P., Barlow, J., Aragão, L. E. O. C., Berenguer, E., Carmenta, R., et al. (2023). The drivers and impacts of Amazon forest degradation. *Science* 379:eabp8622. doi: 10.1126/science.abp8622

Lefcheck, J. S., Byrnes, J. E. K., Isbell, F., Gamfeldt, L., Griffin, J. N., Eisenhauer, N., et al. (2015). Biodiversity enhances ecosystem multifunctionality across trophic levels and habitats. *Nat. Commun.* 6, 6936. doi: 10.1038/ncomms7936

Malhi, Y., Riutta, T., Wearn, O. R., Deere, N. J., Mitchell, S. L., Bernard, H., et al. (2022). Logged tropical forests have amplified and diverse ecosystem energetics. *Nature* 612, 707–713. doi: 10.1038/s41586-022-05523-1

Malkamäki, A., D'Amato, D., Hogarth, N. J., Kanninen, M., Pirard, R., Toppinen, A., et al. (2018). A systematic review of the socio-economic impacts of large-scale tree plantations, worldwide. *Glob. Environ. Change* 53, 90–103. doi: 10.1016/j.gloenvcha.2018.09.001

Mcewan, A., Marchi, E., Spinelli, R., and Brink, M. (2020). Past, present and future of industrial plantation forestry and implication on future timber harvesting technology. *J. For. Res.* 31, 339–351. doi: 10.1007/s11676-019-01019-3

Messier, C., Bauhus, J., Sousa-Silva, R., Auge, H., Baeten, L., Barsoum, N., et al. (2022). For the sake of resilience and multifunctionality, let's diversify planted forests! *Conserv. Lett.* 15, e12829. doi: 10.1111/conl.12829

Mori, A. S., Lertzman, K. P., and Gustafsson, L. (2017). Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. *J. Appl. Ecol.* 54, 12–27. doi: 10.1111/1365-2664.12669

Osuri, A. M., Gopal, A., Raman, T. R. S., Defries, R., Cook-Patton, S. C., and Naeem, S. (2020). Greater stability of carbon capture in species-rich natural forests compared to species-poor plantations. *Environ. Res. Lett.* 15:e034011. doi: 10.1088/1748-9326/ab5f75

Paquette, A., and Messier, C. (2010). The role of plantations in managing the world's forests in the Anthropocene. *Front. Ecol. Environ.* 8, 27–34. doi: 10.1890/080116

Pataki, D. E., Alberti, M., Cadenasso, M. L., Felson, A. J., Mcdonnell, M. J., Pincetl, S., et al. (2021). The benefits and limits of urban tree planting for environmental and human health. *Front. Ecol. Evol.* 9, 603757. doi: 10.3389/fevo.2021.603757

Poorter, L., Craven, D., Jakovac, C. C., Van Der Sande, M. T., Amissah, L., Bongers, F., et al. (2021). Multidimensional tropical forest recovery. *Science* 374, 1370–1376. doi: 10.1126/science.abh3629

Ranacher, L., Pollakova, B., Schwarzbauer, P., Liebal, S., Weber, N., and Hesser, F. (2021). Farmers' willingness to adopt short rotation plantations on marginal lands: qualitative study about incentives and barriers in Slovakia. *BioEnergy Res.* 14, 357–373. doi: 10.1007/s12155-020-10240-6

Reich, B. P. (2014). The world-wide 'fast-slow'plant economics spectrum: a traits manifesto. *J. Ecol.* 102, 275–301. doi: 10.1111/1365-2745.12211

Ruiz-Jaen, M. C., and Potvin, C. (2011). Can we predict carbon stocks in tropical ecosystems from tree diversity? Comparing species and functional diversity in a plantation and a natural forest. *New Phytolog.* 189, 978–987. doi: 10.1111/j.1469-8137.2010.03501.x

Schuldt, A., Assmann, T., Brezzi, M., Buscot, F., Eichenberg, D., Gutknecht, J., et al. (2018). Biodiversity across trophic levels drives multifunctionality in highly diverse forests. *Nat. Commun.* 9, 2989. doi: 10.1038/s41467-018-05421-z

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., et al. (2017). Forest disturbances under climate change. *Nat. Clim. Change* 7, 395–402. doi: 10.1038/nclimate3303

Silveira, F. A. O., Ordóñez-Parra, C. A., Moura, L. C., Schmidt, I. B., Andersen, A. N., Bond, W., et al. (2022). Biome Awareness Disparity is BAD for tropical ecosystem conservation and restoration. *J. Appl. Ecol.* 59, 1967–1975. doi: 10.1111/1365-2664.14060

Van Der Plas, F. (2019). Biodiversity and ecosystem functioning in naturally assembled communities. *Biol. Rev.* 94, 1220–1245. doi: 10.1111/brv.12499

Yuan, Z., Ali, A., Ruiz-Benito, P., Jucker, T., Mori, A., Wang, S., et al. (2020). Above- and below-ground biodiversity jointly regulate temperate forest multifunctionality along a local-scale environmental gradient. *J. Ecol.* 2020, 13378. doi: 10.1111/1365-2745.13378