














RESPONSE OPEN ACCESS

Alleviating the Concerns About Pollen-Based Assisted Migration

David Chludil¹  | Curt Almqvist² | Mats Berlin²  | Arne Steffenrem³  | Steven E. McKeand⁴  | Jiří Korecký¹  | Jan Stejskal¹  | Jaroslav Čepel¹  | Fikret Isik⁴  | Debojyoti Chakraborty⁵  | Silvio Schueler⁵  | Torsten Pook⁶  | Christi Sagariya¹  | Milan Lstibůrek¹ 

¹Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic | ²Forestry Research Institute of Sweden (Skogforsk), Uppsala Science Park, Uppsala, Sweden | ³Division of Forest and Forest Resources, Innocamp Steinkjer, Norwegian Institute of Bioeconomy Research (NIBIO), Steinkjer, Norway | ⁴NC State University Cooperative Tree Improvement Program, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, North Carolina, USA | ⁵Department of Forest Growth, Silviculture and Genetics, Austrian Research Centre for Forests BFW, Vienna, Austria | ⁶Animal Breeding and Genomics, Wageningen University & Research, Wageningen, the Netherlands

Correspondence: Milan Lstibůrek (lstiburek@fd.czu.cz)

Received: 17 April 2025 | **Revised:** 6 May 2025 | **Accepted:** 7 May 2025

Funding: This work was supported by EEA/Norway Grants (2014–2021) and the Technology Agency of the Czech Republic.

Keywords: forest nurseries | forestry policy | gene flow | genetic diversity | heterosis | natural selection | phytosanitary risks | seed orchards

We appreciate the opportunity to respond to the concerns of O'Neill et al. (2025) regarding our recent opinion paper in *Global Change Biology* (Chludil et al. 2025). There, we proposed a novel approach to assisted migration (AM) in forest trees, shifting the focus from the conventional translocation of seeds or seedlings to the transfer of pollen. Specifically, we suggested using seed orchards (SOs) to collect pollen from source populations and produce seeds in target regions.

To frame our pollen-based approach, we began by outlining major challenges commonly associated with AM, drawing on a comprehensive review of scientific literature. This broader context was essential for situating our proposal within diverse perspectives in the field. While we understand O'Neill et al.'s (2025) reservations about the relevance of specific challenges, we maintain that the arguments we cited reflect legitimate, widely discussed issues. Therefore, in this response, we focus specifically on their concerns regarding pollen-based AM.

The authors identify the necessity of SOs in both source and target regions as a potential disadvantage. However, SO networks are often dense and widely distributed. In the European Union and Great Britain alone, 1503 SOs represent 40 species and hybrids (Chludil et al. 2025; section 4 and Figure 2). In Canada, 249 tree breeding programs with associated SOs have recently

been documented, covering 25 different species (Thomas et al. 2024; Table 1). The SO network is particularly dense in British Columbia and Quebec. Reid (2008; Table 1) reported 113 SOs in British Columbia, while Colas and Bettez (2013) stated 89 in Quebec. We stress that a substantial SO network is equally important for seed collection under conventional AM, as SOs typically consist of genetically tested genotypes, unlike forest stands.

To address the second concern, we acknowledge that pollen handling and controlled pollination can pose operational challenges. However, many SOs globally are already equipped for pollen-based AM, with control mass pollination (CMP) or supplemental mass pollination (SMP) routinely applied (Figure 1). These practices demonstrate the feasibility of implementing similar approaches elsewhere.

In response to the third concern regarding the potentially reduced efficiency of pollen-based AM, we contend that our simulations likely underestimate its potential adaptive response (Chludil et al. 2025; section 5). Due to a complex underlying genetic architecture, the adaptive response is not simply additive, even without heterosis. Moreover, as previously noted, our modeling did not incorporate several key benefits of pollen-based AM. For instance, pollen collection is unlikely to reduce

This is an open access article under the terms of the [Creative Commons Attribution-NonCommercial-NoDerivs](https://creativecommons.org/licenses/by-nc-nd/4.0/) License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2025 The Author(s). *Global Change Biology* published by John Wiley & Sons Ltd.

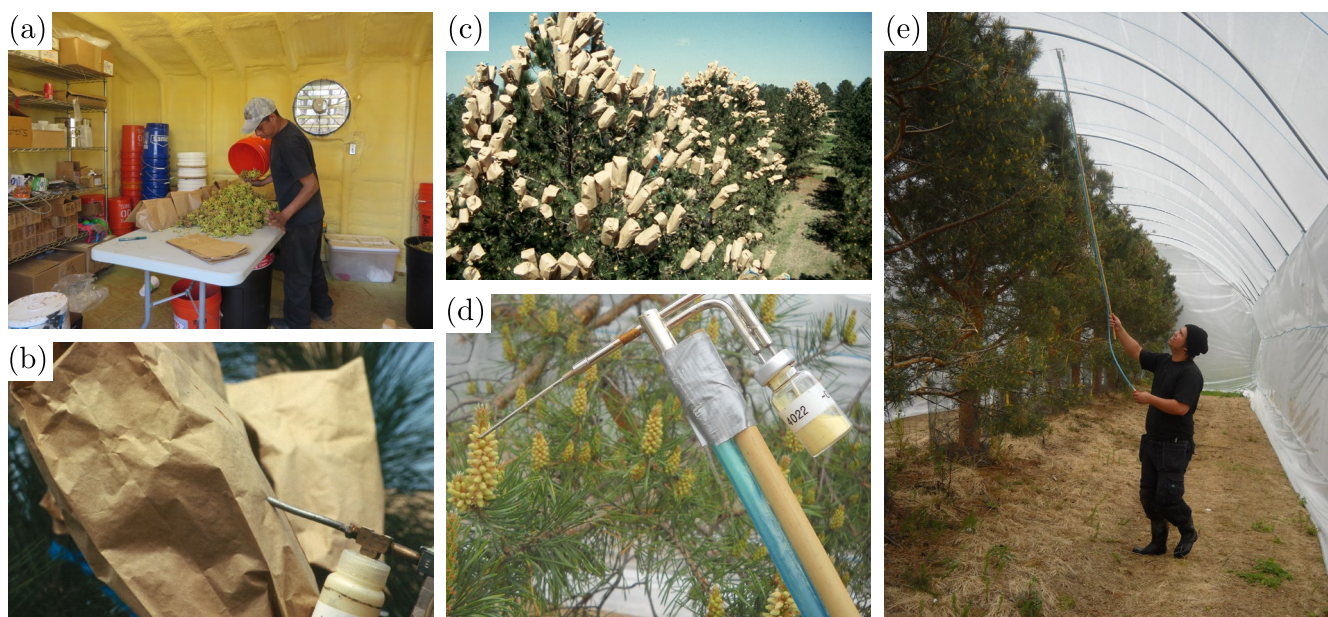


FIGURE 1 | Images (a–c) depict the process of controlled mass pollination (CMP) in loblolly pine (*Pinus taeda* L.) SOs in the southeastern United States. Over the past two decades, seedling production in this region has gradually shifted from open-pollinated to full-sib families produced through CMP. In the 2018–2019 planting season alone, an estimated 173 million CMP-derived full-sib seedlings were planted, representing approximately 21% of all loblolly pine seedlings planted across the southeastern United States. This trend is expected to grow as full-sib seedlings, which have a three- to fourfold price premium, offer substantial genetic improvements in timber production, stem form, wood quality, and stress resistance (McKeand et al. 2021). Images (d) and (e) show supplemental mass pollination (SMP) in Scots pine (*Pinus sylvestris* L.) SOs in Sweden, utilizing large isolation tents. Both CMP and SMP are employed to improve the genetic quality of seed crops through targeted crosses, reduced self-fertilization, and minimized pollen contamination, while enabling crosses between phenologically asynchronous parents and enhancing genetic diversity (Bridgwater et al. 1998; Funda et al. 2016). Key steps include pollen collection, extraction, and storage. Male strobili “catkins” are harvested in clusters shortly before natural pollen release. The pollen is extracted by drying the catkins in paper bags or boxes, see picture (a) for post-harvest handling before drying. In loblolly pine, two workers can harvest 22–28 L of catkins per hour, yielding up to 1.8 L of pollen after drying. Pollen for short-term storage is kept in a desiccator placed in a refrigerator, while long-term storage requires drying to 6% moisture and freezing at -15°C or colder. The main difference between CMP and SMP is isolation. CMP isolates strobili using bags (images b and c) (Heine et al. 2020), while SMP does not involve individual isolation. Although SMP is cheaper, its success rate is typically lower and more variable, particularly for loblolly pine, due to reduced pollen competitiveness and inconsistent strobilus development (Bridgwater et al. 1998). However, SMP success can exceed 75% with precise timing, targeting individual strobili, and utilizing advanced methods such as isolation tents, as shown in images (d) and (e) with Scots pine (Funda et al. 2016).

seed yield, thereby avoiding supply constraints that can affect conventional AM when the quality seed is in high demand in the source region. Controlled pollination also facilitates the rapid introduction of desirable haplotypes, enhancing adaptive traits such as pest resistance in the resulting reproductive material. Additionally, as noted in Chludil et al. (2025; section 4), pollen-based AM allows for the retention of locally adapted traits and favorable epigenetic effects of the maternal reproductive environment (Johnsen et al. 2005). This is especially significant given that, as O'Neill et al. (2025) have pointed out, not all relevant factors can be incorporated into AM transfer guidelines.

Author Contributions

David Chludil: conceptualization, investigation, writing – original draft, writing – review and editing. **Curt Almqvist:** visualization, writing – review and editing. **Mats Berlin:** visualization, writing – review and editing. **Arne Steffenrem:** writing – review and editing. **Steven E. McKeand:** visualization, writing – review and editing. **Jiří Korecký:** writing – review and editing. **Jan Stejskal:** writing – review and editing. **Jaroslav Čepel:** writing – review and editing. **Fikret Isik:** writing

– review and editing. **Debojyoti Chakraborty:** writing – review and editing. **Silvio Schueler:** writing – review and editing. **Torsten Pook:** writing – review and editing. **Christi Sagariya:** writing – review and editing. **Milan Lstibůrek:** conceptualization, visualization, writing – original draft, writing – review and editing.

Acknowledgments

The research leading to these results has received funding from the EEA/Norway Grants 2014–2021 and the Technology Agency of the Czech Republic.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors have nothing to report.

Linked Articles

This article is a Response to the Letter to the Editor by O'Neill et al., <https://doi.org/10.1111/gcb.70265>; regarding Chludil et al., <https://doi.org/10.1111/gcb.70014>.

References

- Bridgwater, F. E., D. L. Bramlett, T. D. Byram, and W. J. Lowe. 1998. "Controlled Mass Pollination in Loblolly Pine to Increase Genetic Gains." *Forestry Chronicle* 74: 185–189. <https://doi.org/10.5558/tfc74185-2>.
- Chludil, D., J. Čepl, A. Steffenrem, et al. 2025. "A Pollen-Based Assisted Migration for Rapid Forest Adaptation." *Global Change Biology* 31, no. 1: e70014. <https://doi.org/10.1111/gcb.70014>.
- Colas, F., and M. Bettez. 2013. *From Seed Collection to Seed Storage: A Quebec Review*. Tree Seed Working Group News Bulletin No. 58, 7–11. Canadian Forest Genetics Association.
- Funda, T., U. Wennström, C. Almqvist, B. Andersson Gull, and X.-R. Wang. 2016. "Mating Dynamics of Scots Pine in Isolation Tents." *Tree Genetics & Genomes* 12, no. 6: 112. <https://doi.org/10.1007/s11295-016-1074-z>.
- Heine, A. J., T. D. Walker, S. E. McKeand, J. B. Jett, and F. Isik. 2020. "Pollination Bag Type has a Significant Impact on Cone Survival in Mass Production of Controlled Pollinated Seeds in Loblolly Pine." *Forest Science* 66: 589–599. <https://doi.org/10.1093/forsci/fxaa013>.
- Johnsen, Ø., O. G. Dæhlen, G. Østreng, and T. Skrøppa. 2005. "Daylength and Temperature During Seed Production Interactively Affect Adaptive Performance of *Picea abies* Progenies." *New Phytologist* 168: 589–596. <https://doi.org/10.1111/j.1469-8137.2005.01538.x>.
- McKeand, S. E., K. G. Payn, A. J. Heine, and R. C. Abt. 2021. "Economic Significance of Continued Improvement of Loblolly Pine Genetics and Its Efficient Deployment to Landowners in the Southern United States." *Journal of Forestry* 119: 62–72. <https://doi.org/10.1093/jofore/fvaa044>.
- O'Neill, G., G. Howe, and S. Aitken. 2025. "Pollen Assisted Migration Faces Its Own Challenges." *Global Change Biology*.
- Reid, D. J. S. 2008. "British Columbia's Seed Orchard Program: Multi Species Management With Integration to the End User." In *Proceedings of a Seed Orchard Conference, Umeå, Sweden*, edited by D. Lindgren, 204–214. Swedish University of Agricultural Sciences.
- Thomas, B. R., M. Stoehr, S. G. Schreiber, et al. 2024. "Tree Improvement in Canada—Past, Present and Future, 2023 and Beyond." *Forestry Chronicle* 100: 59–87. <https://doi.org/10.5558/tfc2024-004>.