New Forests
https://doi.org/10.1007/s11056-024-10064-8

Comparing performance of assisted migration seed sources of two oak species in a Minnesota red pine woodland

Brian J. Palik[1] · **Douglas N. Kastendick**[1] · **Josh Kragthorpe**[2]

Received: 1 April 2024 / Accepted: 13 August 2024

Abstract
Forest assisted migration (FAM) is the movement of tree species or genotypes to locations that are projected to be climatically suitable for future growth and survival. FAM can be an integral component of climate adaptation projects. An example of such a project is the Red Pine Adaptive Silviculture for Climate Change (Red Pine ASCC) experiment in northern Minesota, USA. The experiment includes planting seedlings of northern red oak and bur oak from two different seed sources south of the study area. The primary source for both species was central Minnesota, one seed zone south of the local zone. However, due to the number of seedlings needed, a secondary source was also used that included red oak from southwest Michigan and bur oak from eastern Iowa. Known planting locations and densities of the seed sources allowed comparison of survival and growth to assess if the primary seed sources out-performed the secondary sources. For both species, densities after five growing seasons were not significantly different between seed sources, suggesting similar survival. Heights and diameters of bur oak were nearly identical for the two seed sources, suggesting similar growth rates. For northern red oak, seedlings of the Minnesota seed source were taller and larger in diameter than the Michigan seed source, but differences were small. Our results suggest managers can be opportunistic when acquiring seedlings of these species for similar FAM projects.

Keywords Climate change · Adaptation · Bur oak · Northern red oak

✉ Brian J. Palik
brian.palik@usda.gov

[1] USDA Forest Service, Northern Research Station, 1831 E. Hwy 169, Grand Rapids, New York, MN, USA

[2] Department of Forest Resources, University of Minnesota, 2005 Upper Buford Cir, St. Paul, MN, USA

Published online: 21 August 2024

Introduction

Climate change is altering habitat suitability for native tree species in many regions (Hamann and Tongli 2006; McKenney et al. 2007). These changes have elevated calls for the use of assisted migration of species or genotypes to maintain productivity and functionality of forests (Williams and Dumroese 2013; Stanturf et al. 2014). This is termed forest assisted migration, hereafter FAM, to distinguish it from species rescue assisted migration, which may be done to bolster populations of a threatened species and not necessarily in response to climate change (Pedlar et al. 2012). For FAM to become an operational practice, such that its use is a routine part of forest management at the spatial scale characteristic of an organization (Palik et al. 2022), adequate numbers of desired seedlings need to be available for planting.

There are well recognized constraints on procurement of seedings in the numbers needed to operationalize FAM (Clark et al. 2023). These include a declining seed procurement network, a declining number of nurseries, and a lag in capacity of existing nurseries to produce needed stock. Nurseries only produce what they know they can sell and until recently they have not had the demand for stock and species for operational-scale FAM. For organizations interested in implementing FAM operationally, they may be forced to either delay plans until the seedling procurement bottleneck is resolved, or they may need to shop around from multiple nurseries to procure seedlings in adequate numbers for the project, potentially from seed sources that may be marginal in terms of being appropriate for their location.

This was the case for plantings of several hardwood tree species in the Red Pine Adaptive Silviculture for Climate Change (ASCC) project in northern Minnesota, USA. Red Pine ASCC was the first installation in the North American ASCC network (www.adaptivesilviculture.org), a suite of co-developed (scientists and managers), regionally-tailored demonstrations of approaches for integrating climate change adaptation into silvicultural planning and on-the-ground actions (Nagel et al. 2017). The study ecosystem for Red Pine ASCC is a red pine (*Pinus resinosa* Ait.) dominated woodland that also includes up to ten additional species of conifers and hardwoods (Wiechmann et al. 2022), including two species of oaks, northern red oak (*Quercus rubra* L.), and bur oak (*Q. macrocarpa* Michx.). Based on regionally-specific climate envelope models, both oak species are predicted to have increasing habitat suitability in the study region with climate change (Peters et al. 2020).

Survival and growth of novel species and genotypes of planted trees is one of the key metrics being evaluated in Red Pine ASCC (Muller et al. 2019). Planted seedlings are assessed systematically by following mapped individuals in a network of permanent sample plots. In these plots, the seed source was identified based on desired seed zones and was closely controlled, that is, only the target seed source was planted, usually a seed zone that was once or twice removed from the local zone. However, in the Red Pine ASCC project, entire treatment stands were planted in the areas outside of the measurement plots, necessitating the need for larger numbers of seedlings. To meet these planting numbers, we procured seedlings from multiple nurseries and seed sources, some of which were greater distances geographically and climatically than the desired (primary) seed collection zone. This provided an opportunity to compare performance of different seed sources for the same species, both growing within the same environmental conditions.

The objective of this study was to evaluate early performance of two contrasting seed sources of both northern red oak and bur oak growing under the same environmental conditions in the Red Pine ASCC experiment. For each species, the contrast was between a primary seed source, preferred based on its seed zone of origin, and a secondary seed source that was selected based on availability of seedlings in sufficient quantity (Fig. 1). We asked if there were significant differences in survival and growth of planted seedlings between two contrasting seed sources for each species, reflecting the influence of the seed zone of origin? Our goal is to provide natural resource managers with information that they can use to make decisions about expanding the use of opportunistic seed sources at operational scales for FAM projects.

Methods

Study site

The Red Pine ASCC study is on the Cutfoot Experimental Forest in north central Minnesota, USA (latitude 47º33'N, longitude 94º05'W). The region historically has a cold temperate climate with mean annual temperatures of 4º C, mean annual precipitation of 70 cm, and little topographic relief (Muller et al. 2019). Soils of the study area consist of excessively to well-drained loamy sands derived from glacial outwash (Adams et al. 2008). The study area is situated in the northern half of eastern seed zone 7 (Pike et al. 2020), which is defined by

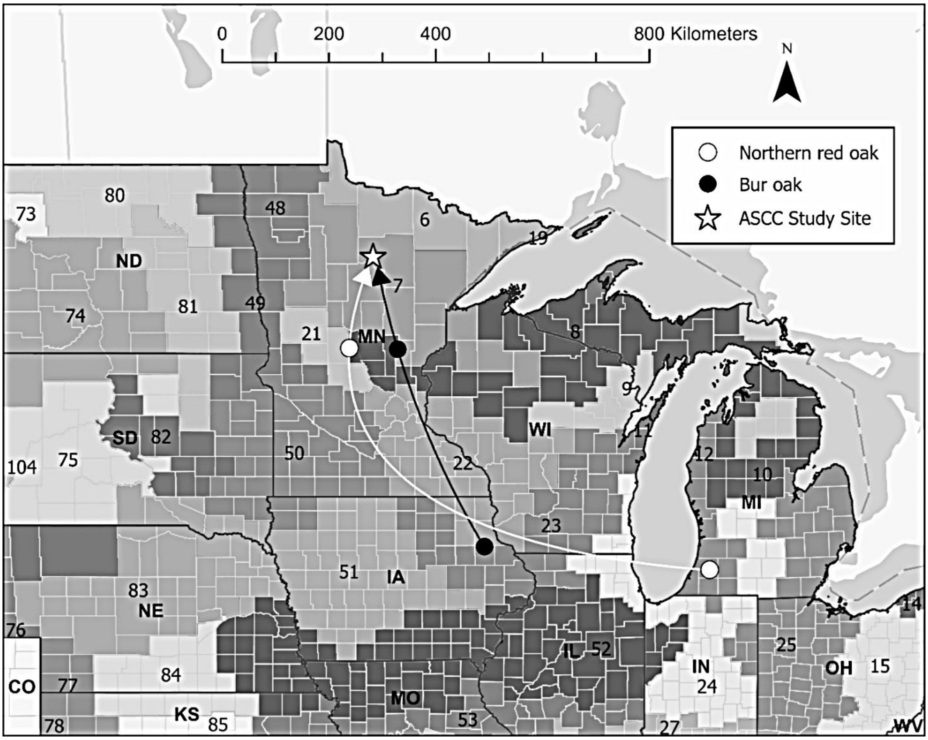

Fig. 1 Study site location and seed source locations for northern red oak and bur oak. Numbers are eastern seed zones (Pike et al. 2020), in the central US

an overlay of USDA 2012 plant hardiness zone 3b within ecological province 212 (Cleland et al. 2007). The 2023 update of the USDA plant hardiness zone map places the study area within the transition between 3b to 4a, as opposed to central 3b in 2012; it is unclear if this change will result in a future change in seed zone.

The forest is classified as northern dry mesic mixed woodland, based on the Minnesota native plant community classification system (Minnesota Department of Natural Resources 2003). At the time of study installation, forests were largely even-aged, dominated by a single cohort of red pine that regenerated following widespread logging and fires in 1918 (Muller et al. 2019). Overstory basal area (trees $\geq$ 12.7 cm diameter at breast height of 1.37 m) ranged from 32 to 41 m^2 ha^{-1}, with approximately 466 trees ha^{-1}, and a mean diameter of 31 cm. In addition to red pine, the overstory included eastern white pine (*Pinus strobus* L.), jack pine (*P. banksiana* Lamb.), paper birch (*Betula papyrifera* Marshall), balsam fir (*Abies balsamea* L.), white spruce *(Picea glauca* (Moech) Voss.), trembling aspen (*Populus tremuloides* Michx.), bigtooth aspen (*P. grandidentata* Michx.), northern red oak, bur oak, and red maple (*Acer rubrum* L.). Woody understory vegetation primarily consisted of hazel (*Corylus* spp.*)*, serviceberry (*Amelanchier spp.*), and native honeysuckle (*Lonicera spp.*).

Silvicultural treatment

The Red Pine ASCC design consists of four treatments replicated in five blocks, including passive, resistance, resilience, and transition treatments (Muller et al. 2019). Only the resilience treatment was used in the current study due to our ability to adequately sample primary and secondary seed sources for the two oak species planted at a known density. Details of the other treatments are described elsewhere (Nagel et al. 2017). The resilience treatment was harvested in winter 2014-15 using a variable density thinning approach. For this, 15–20% of the area of a stand was harvested in 0.2 ha gaps, 15–20% was left unharvested in 0.2 ha uncut patches, and the remainder of the stand was thinned to approximately 25 $m^2 ha^{-1}$. Resilience gaps were site prepared in summer 2015 using a harrow disc attached to a grapple skidder that exposed mineral soil and reduced competition from aggressive hazel clones by severing their root systems.

The gaps were planted in spring 2016 with five native tree species, including northern red oak, bur oak, eastern white pine, jack pine, and red maple (see Nagel et al. 2017). For the current study only northern red oak and bur oak were evaluated, based on our ability to sample adequate gaps in all five replicate stands for the two contrasting seed sources of each species (Table 1). Both oaks are common in the study ecosystem and both are projected to have increasing habitat suitability with climate change (Muller et al. 2019), further justifying our focus on these species. Unfortunately, we did not measure initial sizes of seedlings for both seed sources of a species at the time of planting, but we assume that seedlings were similar in initial height and diameter at that time, as they were all two-year-old (2 – 0) seedlings. While this assumption may not be accurate, it is size of seedlings at some later date after planting, for instance after five years as in this study, that is most useful for forest managers assessing regeneration success. Unlike initial sizes, we had exact measures of initial planting density. One hundred and fifty-eight seedlings of each species/seed source combination were planted in a gap (790 ha^{-1} for each species). Seedlings were planted on

Table 1 Seed source information for oak species planted in the Red Pine ASCC experiment

Species	Primary seed source			Secondary seed source		
	Geographic location[a]	Distance (km)[b]	Seed zone[c]	Geographic location[a]	Distance (km)[b]	Seed zone[c]
Northern red oak	Morrison Co MN; Pine Co MN	180 km S; 200 km SE	8 7	Van Buren Co MI	870 km SE	25
Bur oak	Mille Lacs Co MN; Todd Co MN	210 km SSE; 180 km S	8 21	Eastern Iowa	600 km SSE	22,23

[a]Geographic location is the finest scale information the supplying nursery had for a seed source. As noted, nurseries could not always distinguish between two counties in the seed lot or supply county level information for Iowa bur oak

[b]Distance and approximate azimuth from the center of the study area to approximate center of the geographic location of seed origin

[c]Eastern seed collection zone for the geographic location from www.easternseedzones.com (last accessed 01-29-2024)

approximately a 1.6×1.6 m spacing for the five species mentioned above, with every fourth and fifth seedling being one of the target oak species.

Seed source sampling

In summer 2020, in each stand, we selected two 0.2 ha gaps planted with the primary seed source and two gaps planted with the secondary source. In each gap, one 200 m^2 belt transect (50 m x 4 m) was centered in the gap and planted northern red oak and bur oak seedlings were tallied. The first ten individuals for each species were measured for size, including height and basal diameter in two perpendicular directions. This approach resulted in measured seedling being well distributed across gaps, with seedlings being located in every 10 m increment of the transect in most gaps and given the planting density, often approach the entire population in a transect.

Analysis

For each species and seed source combination, tallies were averaged among transects (one in each of two gaps) in a stand and scaled to a per hectare basis. Heights and diameters were averaged within a transect and then between the two transects in a stand for each combination. Stand-level means were used as replicates ($N=5$) for comparing density, diameters, and heights between seed sources for a species. These measures reflect survival and growth, but are indirect as we could not track individuals (for survival), nor did we have initial dimensions of seedlings (growth). Normality of the data distributions were tested using a Shapiro-Wilk test (normality rejected at $p \leq 0.05$), with all data sets passing this test. We used two-tailed paired t-tests to assess the null hypothesis that the mean of the paired differences equals zero in the population (rejected at $p \leq 0.05$).

Results

Seedling densities

Densities of seedlings were not significantly different between seed sources for either northern red oak (t=0.245; p=0.819) or bur oak (t=-1.090; p=0.337). Mean (+/- standard error) densities were nearly identical for northern red oak at 565 (68) and 535 (88) ha^{-1} for the Minnesota and Michigan seed sources, respectively (Fig. 2). For bur oak, densities were somewhat higher for the Iowa seed source at 565 (114) ha^{-1}, compared to the Minnesota seed source at 415 (66) ha^{-1}, but variability was also high for the former (Fig. 2). Assuming a planting density of 790 seedlings ha^{-1}, densities after five years suggest survival was similar (around 70%) for both seed sources of northern red oak, while survival for bur oak may was higher (around 72%) for the Iowa seed source compared to the Minnesota seed source (around 53%).

Seedling sizes

Basal diameters of seedlings were significantly different between seed sources of northern red oak (t=6.503; p=0.003), but not bur oak (t=-0.583; p=0.591). After five years, mean diameter of the Minnesota seed source of northern red oak was 9.95 (0.53) mm compared to 7.95 (0.45) mm for the Michigan seed source (Fig. 3). Basal diameters of bur oak averaged 9.25 (0.25) mm and 9.39 (0.17) mm for the Minnesota and Iowa seed sources, respectively (Fig. 3).

Heights of the seedlings after five growing seasons were not significantly different between seed sources for either northern red oak (t=2.389; p=0.075) or bur oak (t=0.004; p=0.997). Heights of the Minnesota northern red oak seed source averaged 79.5 (5.7) cm, compared to 66.9 (3.7) cm for the Michigan seed source (Fig. 4). Mean heights of bur oak were 72.0 (4.7) cm for the Minnesota seed source and 72.0 (3.0) cm for the Iowa seed source (Fig. 4).

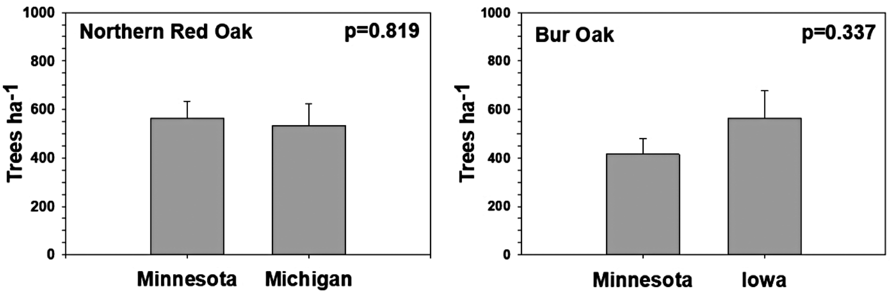

Fig. 2 Densities after five growing seasons of seed sources for two oak species planted in the Red Pine ASCC resilience treatments. Values are means ± standard errors; N=5

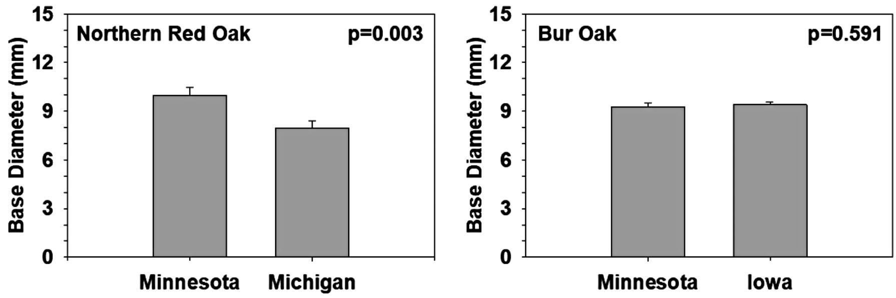

Fig. 3 Basal diameters after five growing seasons of seed sources for two oak species planted in the Red Pine ASCC resilience treatments. Values are means ± standard errors; $N=5$

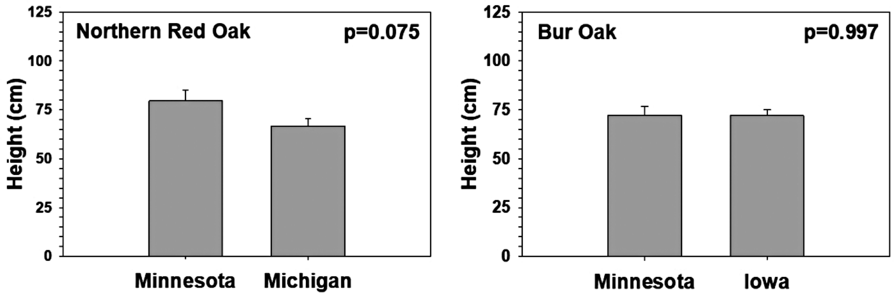

Fig. 4 Heights after five growing seasons of seed sources for two oak species planted in the Red Pine ASCC resilience treatments. Values are means ± standard errors; $N=5$

Discussion

For the operational-scale Red Pine ASCC experiment, our desire was to procure seedlings from a seed collection zone once removed to the south (Zone 8) of our study area (Zone 7), using the most recent eastern seed zone map (Pike et al. 2020). We found that securing adequate numbers of seedlings for even relatively common species like northern red oak and bur oak was not possible. At the time we began this study, we were only able to secure about half of the seedlings needed from a state nursery run by the Minnesota Department of Natural Resources. Consequently, the remaining seedlings were procured by shopping at different nurseries, with the additional seedlings of northern red oak coming from southwest lower Michigan, USA and for bur oak from eastern Iowa, USA. This presented an opportunity to examine differences in survival and size between the two contrasting seed sources for each species.

For both species, after five years, we found no significant differences in density between seed sources. As all seed sources were planted at the same density of 790 ha^{-1}, density at the time of sampling is an approximate measure of survival; northern red oak from both seed sources and bur oak from Iowa had approximate survival rates of at least 70%, while bur oak from Minnesota was just over 50%. In an earlier study, we reported on third-year survival of the two oaks using just the central Minnesota seed sources planted in the ASCC transition treatment (Muller et al. 2019). For this, survival was well over 90% for both species. There are several reasons for the differences between the current study and the results from Muller et al. (2019). First, we examined densities after five years compared to three, so mortality could have been higher because of the additional years. Second, the current study focused on seedlings planted in 0.20 ha gaps in the ASCC resilience treatment, compared to a higher light environment after an irregular shelterwood harvest in the ASCC transition treatment. Third, Muller et al. (2019) reported on survival by tracking known individuals over time in permanent study plots, compared to our estimates of survival using density comparisons which cannot track individuals. Finally, seedling survival in Muller et al. (2019) reflects replacement for mortality attributed to planting shock. That is, in Muller et al. (2019), seedlings that died between spring planting and late summer sampling were replaced in the population of tracked seedlings; we did not do this in the current study. Our results on density changes, as a surrogate for survival, better reflect responses after operational planting versus careful planting by researchers, as in Muller et al. (2019).

Another recent FAM study in northern Minnesota evaluated survival of northern red oak and bur oak (Etterson et al. 2020). In this study in northeastern Minnesota, USA, planting sites were at a similar latitude as our study site, but over 100 km to the east. A southern seed source in the study came from approximately the same latitude as our Minnesota sources, but they did not use the more refined eastern seed zone mapping to identify source locations, so it is difficult to compare directly to our results. The study reported over 95% survival for both species after three years, similar to Muller et al. (2019), with a southern source survival significantly higher than a local seed source for northern red oak and marginally higher for bur oak. The higher survival rates reported by Etterson et al. (2020) may reflect more careful planting for research purposes versus operational planting, as well as protection from whitetail deer browsing and annual competition control around planted seedlings, neither of which were employed in this study. Another study in southeastern Ontario, Canada examined seed sources of northern red oak from a comparative distance south as our study, although the actual latitude was several hundred km south of our study sites (Pedlar et al. 2024). This study, which included northern red oak seed sources from Pennsylvania, Tennessee, and Kentucky, USA, found similar survival after 10 years as we did after five years.

We did not measure growth of seedlings directly, since we did not have starting sizes of known individuals in the operational planting examined in this study. We assume that seedlings within a species were similar in height and diameter at the time of planting, as they were all two-year-old seedlings. This assumption may not be correct, but we felt justified in taking this approach, as it is seedling size over time after planting that is a primary metric of interest to forest managers for assessing regeneration success. With this assumption in mind, there was a difference in pattern of size between seed sources for the two species. Northern red oak seedlings from the central Minnesota seed source were significantly taller, by 14 cm, and had greater stem base diameter by 2 mm, after five years, compared to the southern Michigan seed source. A potential explanation for the height differences is that the seedlings from the Michigan seed source may have had higher tissue nitrogen concentrations, thus making them more likely to be browsed (George and Powell 1977; Gill 1992). Bur oak heights and diameters between the two seed sources were virtually identical.

Etterson et al. (2020) reported mixed results on growth rates in their FAM study. Their northern red oak seed source from central Minnesota had faster height and diameter growth than the local seed source, while the opposite was the case for bur oak. For northern red oak planted in southern Ontario, Canada, Pedlar et al. (2024) reported over two-fold greater height by year 10 of a local seed source, compared to seed sources from east central and southeastern US. If the results of Pedlar et al. (2024) are generalizable, it may be that the small but significantly greater height of our central Minnesota northern red oak seed source will increase overtime compared to the southern Michigan seed source.

Etterson et al. (2020) report that there is little known about the adaptive capabilities for species with limited commercial value, which in Minnesota includes the oak species we examined. Both bur oak and northern red oak have large geographic distributions, ranging from southern Manitoba CA to south Texas USA for bur oak, and southern Ontario, CA to central Alabama, USA for northern red oak. In theory, populations of species with such wide north-south ranges will consist of a gradient of ecotypes that are adapted to local climate, including temperature (Aitken et al. 2008; Frelich and Toot 2018). Given that temperatures in all seasons have been increasing in northern Minnesota over the last several decades (Handler et al. 2014), it may not be surprising that the southern seed sources of both species we examined appear to be surviving and growing similarly. A caveat of our approach is that while our seed zones differed in climate and ecological province by definition (Pike et al. 2020), we did not measure seedling morphological or physiological parameters that would reflect actual genotypic differences among the seed sources and provide a mechanistic understanding survival and growth.

Guidance for management

In our study, both species of oaks we examined are components of dry-mesic woodlands and forests in northern Minnesota (Minnesota Department of Natural Resources 2003), although both are nearing the northern extent of their range in our study area. With climate warming, the expectation is substantial increases in habitat suitability based on climate envelop models (Peters et al. 2020), presumably with habitat becoming increasingly favorable to more southern ecotypes. Foresters may be interested in management to increase the establishment and abundance of these ecotypes, but it is unclear if adapted ecotypes will migrate naturally at a rate that keeps pace with climate change (Corlett and Westcott 2013), hence the importance of FAM. Our results suggest that for our northern Minnesota study site, there is little short-term risk of poor performance for either northern red oak or bur oak seedlings from the next southern seed zone, or even from seed zones that were 600–900 km southeast of our study area.

Acknowledgements We thank the Chippewa National Forest for logistic support of the ASCC project. We also thank Shawn Linder for support with measuring seedlings. We thank three anonomous reviewers for helpful comments to improve the manuscript. The USDA Forest Service Northern Research Station provided financial and logistic support for this project.

Author contributions BP, DK, JK conceptualized the study, DK, JK conducted fieldwork, BP wrote the original and revised manuscript, DK, JK reviewed and editing the manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

References

Adams MB, Loughry L, Plaugher L (2008) Experimental forests and ranges of the USDA Forest Service. USDA Forest Service General Technical Report NE-321, Revised
Aitken SN, Yeaman S, Holliday JA, Wang T, Curtis-McLane S (2008) Adaptation, migration or extirpation: climate change outcomes for tree populations. Evol Appl 1:95–111
Clark PW, D'Amato AW, Palik BJ, Woodall CW, Dubuque PA, Edge GJ, Hartman JP, Fitts LA, Janowiak MK, Harris LB, Montgomery RA (2023) A lack of ecological diversity in forest nurseries limits the achievement of tree-planting objectives in response to global change. Bioscience 73:575–586
Cleland DT, Freeouf JA, Keys JE, Nowacki GJ, Carpenter CA, McNab WH (2007) Ecological subregions: Sections and subsections for the conterminous United States. USDA Forest Service General Technical Report WO-76D
Corlett RT, Westcott DA (2013) Will plant movements keep up with climate change? Trends Ecol Evol 28:482–488
Etterson JR, Cornett MW, White MA, Kavajecz LC (2020) Assisted migration across fixed seed zones detects adaptation lags in two major north American tree species. Ecol Appl 30:e02092
Frelich LE, Toot R (2018) Accelerated migration of bur oak ecotypes for climate resilience. Report to the Legislative-Citizen Commission on Minnesota Resources (www.lccmr.mn.gov/projects/2015/finals/2015_08f_accelerated_migration_of_bur_oak_frelich_and_toot.pdf; accessed 04 March 2024)
George JF, Powell J (1977) Deer browsing and browse production of fertilized American elm sprouts. Rangel Ecol Management/Journal Range Manage Archives 30:357–360
Gill RMA (1992) A review of damage by mammals in north temperate forests: 1. Deer. Forestry: An International Journal of Forest Research 65: 145–169
Hamann A, Tongli W (2006) Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology 87:2773–2786
Handler S, Duveneck MJ, Iverson L, Peters E, Scheller RM, Wythers KR, Brandt L, Butler P, Janowiak M, Shannon PD, Swanston C, Barrett K, Kolka R, McQuiston C, Palik B, Reich PB, Turner C, White M, Adams C, D'Amato A, Hagell S, Johnson P, Johnson R, Larson M, Matthews S, Montgomery R, Olson S, Peters M, Prasad A, Rajala J, Daley J, Davenport M, Emery MR, Fehringer D, Hoving CL, Johnson G, Johnson L, Neitzel D, Rissman A, Rittenhouse C, Ziel R (2014) Minnesota forest ecosystem vulnerability assessment and synthesis: a report from the Northwoods Climate Change Response Framework project. USDA Forest Service General Technical Report NRS-133. 228 p
McKenney DW, Pedlar JH, Lawrence K, Campbell K, Hutchinson MF (2007) Potential impacts of climate change on the distribution of north American trees. Bioscience 57:939–948
Minnesota Department of Natural Resources (2003) Field guide to the native plant communities of Minnesota: The Laurentian Mixed Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey and Natural Heritage and Nongame Research Program, St. Paul, MN USA
Muller JJ, Nagel LM, Palik BJ (2019) Forest adaptation strategies aimed at climate change: assessing the performance of future climate-adapted tree species in a northern Minnesota pine ecosystem. For Ecol Manag 451:117539
Nagel LM, Palik BJ, Battaglia MA, D'Amato AW, Guldin JM, Swanston CW, Janowiak MK, Powers MP, Joyce LA, Millar CI, Peterson DL (2017) Adaptive silviculture for climate change: a national experiment in manager-scientist partnerships to apply an adaptation framework. J Forest 115:167–178
Palik BJ, Clark PW, D'Amato AW, Swanston C, Nagel L (2022) Operationalizing forest-assisted migration in the context of climate change adaptation: examples from the eastern USA. Ecosphere 13:e4260
Pedlar JH, McKenney DW, Aubin I, Beardmore T, Beaulieu J, Iverson L, O'Neill GA, Winder RS, Ste-Marie C (2012) Placing forestry in the assisted migration debate. Bioscience 62:835–842
Pedlar JH, McKenney DW, Allen DJ (2024) Effect of tree species and seed origin on climate change trial outcomes in Southern Ontario. New Forest 55:63–79
Peters MP, Prasad AM, Matthews SN, Iverson LR (2020) Climate change tree atlas, Version 4. USDA Forest Service and Northern Institute of Applied Climate Science (https://www.nrs.fs.fed.us/atlas; accessed 04 March 2024)
Pike C, Potter KM, Berrang P, Crane B, Baggs J, Leites L, Luther T (2020) New seed-collection zones for the eastern United States: the eastern seed zone forum. J Forest 9:444–451
Stanturf JA, Palik BJ, Dumroese RK (2014) Contemporary forest restoration: a review emphasizing function. For Ecol Manag 331:292–323
Wiechmann LJ, Curzon MT, Palik BJ (2022) Response of natural tree regeneration to climate adaptation treatments in *Pinus resinosa*-dominated forests. For Ecol Manag 523:120499
Williams MI, Dumroese RK (2013) Preparing for climate change: forestry and assisted migration. J Forest 111:287–297