Climate Adaptation Treatment Impacts Adaptability of Natural Regeneration in Red Pine-dominated Ecosystems

Lewis J. Wiechmann, Miranda T. Curzon, and Brian J. Palik[1]

Abstract.—Climate change may require foresters to adapt management in order to maintain healthy, functional forests. We present the effects of experimental climate adaptation treatments on species diversity and adaptability of natural tree regeneration 5 years following implementation in red pine-dominated ecosystems in north central Minnesota. Treatments included resistance, resilience, and transition. Each adaptation treatment increased tree species diversity and richness over the passive control treatment. The transition treatment resulted in the greatest adaptability, quantified as a composite index that integrated disturbance response and life history traits. Our results suggest the transition treatment positively impacted recruitment of native tree species that are adapted to future climate conditions as intended, including species such as northern red oak, red maple, and black cherry. The implication is that natural regeneration can be an important factor in achieving climate adaptation objectives.

INTRODUCTION

Increasingly, forest managers face the challenge of regenerating tree species under current conditions that are also able to adapt to a range of anticipated climate conditions in the long term. In the Great Lakes region of the United States and Canada, warmer temperatures, along with reductions in growing season precipitation, are anticipated to reduce habitat for many tree species, such as red pine (Swanston et al. 2018). Models also predict an increase in abundance and range for other species expected to become more competitive under the projected future climate conditions, such as red maple and northern red oak (Iverson et al. 2019). To address the challenges posed by these changes, the Adaptive Silviculture for Climate Change (ASCC) long-term study site at the Cutfoot Experimental Forest in north central Minnesota, USA, is assessing the impacts of three climate adaptation approaches (resistance, resilience, and transition) and a "no action" passive control treatment in red pine-dominated forest ecosystems (Nagel et al. 2017). Five years following treatment implementation, we evaluated how these climate adaptation approaches have influenced natural regeneration and the understory woody community in terms of species abundance, community composition and diversity, and whether silviculture can be used to encourage natural regeneration of species that are more adaptable to future climate.

METHODS

Natural regeneration of trees and shrubs was sampled within 170 plots from May to August 2019 across the entire study area (200 ha), including all five replicates of the four treatments. The passive treatment served as the study control, representing a no action approach to management. The resistance treatment consisted of a stand-wide thinning to a residual basal area of approximately 25 $m^2 ha^{-1}$. For the resilience treatment, 15 to 20 percent of each stand was harvested in 0.2-ha gaps and scarified with a harrow disc. Another 15 to 20 percent of each stand was reserved in 0.2 ha-"skips" (not harvested), and the remaining 60 to 70 percent was thinned to

[1] Research Associate (LJW), and Assistant Professor (MTC), Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA; Research Ecologist (BJP), USDA Forest Service, Northern Research Station, Grand Rapids, MN. MJW is corresponding author; to contact, email wiechmlj@iastate.edu.

a residual basal area of 25 $m^2\ ha^{-1}$. The transition treatment involved harvesting 0.2-ha gaps across 15 to 20 percent of each stand while the remainder of the stand was thinned to an average of 15 m^2 ha^{-1} with scarification applied throughout. While artificial regeneration is part of the resilience and transition treatments, we did not include it in our study.

Species density, frequency, and biomass estimates calculated from field measurements were then used to calculate a species relative importance index at the stand-scale. Using previously published species-specific adaptability scores based on a composite of life history and disturbance response traits (Matthews et al. 2011) and the relative importance index, we calculated a community weighted mean of adaptability for natural tree regeneration within each stand. Species richness and diversity (as defined as the Shannon Diversity Index; H') were also calculated for each stand. Differences in species diversity, species richness, abundance of individual species, and adaptability of the regenerating tree community relative to the passive treatment were then tested with analysis of variance.

RESULTS

All climate adaptation treatments differed from the passive control treatment in terms of tree species diversity and richness. Total woody species diversity (including shrub and tree regeneration) also differed among treatments ($F=6.42$, $p=0.008$), but only resilience differed from the passive control. The change in relative importance of individual species (from the passive control treatment) varied among treatments as well. This includes black cherry[2], which was more abundant in resistance, resilience, and transition treatments (Fig. 1). Lastly, change in relative adaptability from the passive control varied significantly among treatments ($F=7.138$, $p=0.017$), with mean adaptability of the transition treatment exceeding means observed for both resilience and resistance (Fig. 2).

DISCUSSION

Natural regeneration is an important component of sustainable forest management, key to ensuring productive forest ecosystems for future generations, particularly when resources are unable to support artificial regeneration. Therefore, knowing what species establish naturally following the types of adaptation treatments we examined, including those that combine overstory manipulation with site preparation (e.g., scarification), will inform strategies and implementation. Although planting seedlings may be a more predictable way to regenerate stands adapted for future conditions, our results suggest relying on natural regeneration may be a viable option. Each of the climate adaptation treatments we tested (resistance, resilience, and transition) increased naturally regenerated tree species diversity and richness relative to the passive control, while offering different benefits (e.g., woody species diversity versus adaptability) in terms of climate adaptation.

Greater species diversity will likely increase ecosystem resilience to future disturbance (Webster et al. 2018), in part because of associated increases in response diversity, the variability in tolerances to different stressors or disturbances with potential to cause change among species with similar functions (Elmqvist et al. 2003). The resilience treatment resulted in the greatest difference in overall woody species diversity from the three other treatments; however, mean adaptability of the regenerating tree community was greatest within the transition treatment. Soil scarification, combined with lower residual basal area and varied structure across the transition treatment may have aided in the recruitment of species scoring higher on the adaptability index, including several hardwood species (e.g., red maple, northern red oak, and black cherry) in this historically pine-

[2] Scientific names of tree species listed: red pine (*Pinus resinosa*); black cherry (*Prunus serotina*); red maple (*Acer rubrum*); northern red oak (*Quercus rubra*).

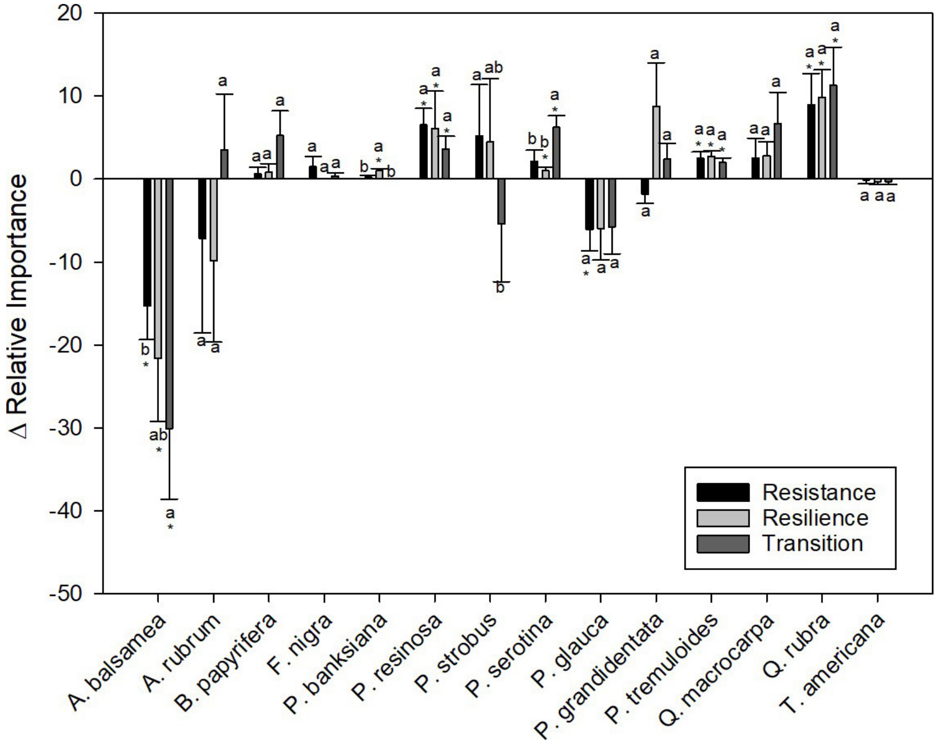

Figure 1.—Change (Δ) in relative importance of natural regeneration compared to the passive control. Bars with different lower-case letters are statistically different. An asterisk indicates a significant change from the passive treatment (p <0.1). Error bars indicate a 68 percent confidence interval around the estimate. Scientific names of tree species listed on the x axis: balsam fir (*Abies balsamea*); red maple (*Acer rubrum*); paper birch (*Betula papyrifera*); black ash (*Fraxinus nigra*); jack pine (*Pinus banksiana*); red pine (*Pinus resinosa*); eastern white pine (*Pinus strobus*); black cherry (*Prunus serotina*); white spruce (*Pinus glauca*); bigtooth aspen (*Populus grandidentata*); quaking aspen (*Populus tremuloides*); bur oak (*Quercus macrocarpa*); northern red oak (*Quercus rubra*); basswood (*Tilia americana*).

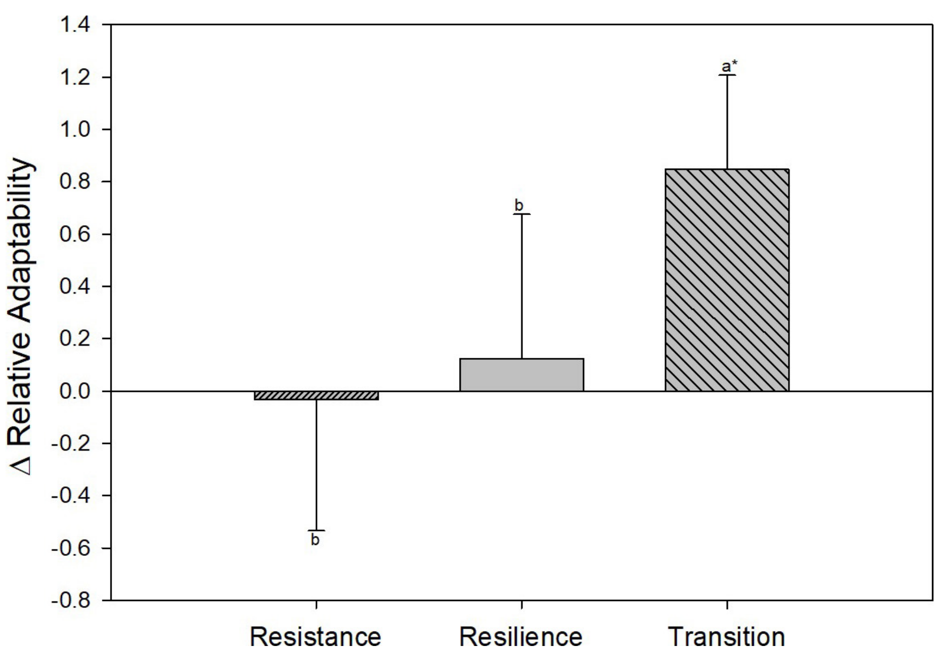

Figure 2.—Change (Δ) in relative adaptability compared to the passive control. Bars with different lower-case letters are statistically different based on Tukey-adjusted pairwise comparisons (p <0.1). An asterisk indicates a significant change from the passive control (p <0.1). Error bars indicate a 68 percent confidence interval around the estimate.

dominated ecosystem. Results indicate that the resilience and transition treatments are moving stands toward greater representation of future-adapted tree species. Our work suggests that climate adaption objectives may be achieved through natural regeneration in addition to or in lieu of artificial regeneration when financial or time resource constraints exist.

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