Impacts of Historic Disturbance on Drought Response of Aspen-dominated Forest

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Abstract.—Water limitation is expected to have greater impact on forest growth in the Lake States region in the future, and management may have long-term impacts on how forests respond to this and other potential stressors. We examined the response of aspen-dominated forest growing on droughty, sandy soils to a regionwide drought that occurred in 2012. During July 2018, we stem-mapped, measured, and cored overstory trees across nine replicated treatments at the Long-Term Soil Productivity (LTSP) study installation at Huron-Manistee National Forest in lower Michigan, USA. Annual biomass growth, reconstructed from cross-dated tree ring widths, was used to calculate indices of resistance and resilience and evaluate drought responses at tree and stand scales. Our results indicate little to no direct impact of organic matter removal or compaction on stand-scale growth responses to the 2012 drought, but species, tree size, and density (neighborhood crowding) did influence resistance and resilience.

INTRODUCTION

The Long-Term Soil Productivity (LTSP) study was founded in 1989 to examine the effects of soil disturbance, specifically impacts related to compaction and the removal of organic matter on forest soils and biomass production (Powers et al. 2005). In addition to basic questions about sustaining forest productivity over time, the LTSP study design provides a robust experimental framework for addressing additional questions about management impacts, including whether the severity of initial, stand-replacing disturbance might impact forest response to future disturbance and stress.

Resistance and resilience are commonly used to measure ecological responses to disturbances or other stressors such as drought (Grimm and Wissel 1997). For this study, resistance was defined as the ability of a stand or individual tree to maintain growth during a drought event and resilience as the ability to return to predrought growth rates (Kohler et al. 2010). Previous work has demonstrated that management has potential to influence these responses in other forest types (Kohler et al. 2010, D'Amato et al. 2013), but less is known about aspen-dominated forest ecosystems. The purpose of this study was to address the following research questions related to aspen systems' response to drought at a LTSP site on the Huron-Manistee National Forest: (1) How do soil compaction, organic matter removal, and their potential interaction impact stand-level forest growth response to drought, and (2) How are individual trees responding to drought given factors such as size, species, and crowding in addition to treatment effects.

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METHODS

The study site is on the Huron-Manistee National Forest in northeastern lower Michigan, USA. Forest stands were dominated by quaking aspen[2] and bigtooth aspen with lesser components of red maple, northern red oak, and white pine prior to harvest in early 1994. Soils at the Huron-Manistee site are acidic and relatively infertile, having developed from outwash sands and composed of 93 percent sand, 6 percent silt, and 1 percent clay (Slesak et al. 2017, Stone et al. 1999).

The impacts of two factors, organic matter removal and compaction, were examined by fully crossing three levels of each, resulting in nine treatments. Levels of organic matter removal included stem-only harvest, whole-tree harvest, and whole-tree plus forest floor removal. Levels of compaction included no additional, moderate (up to 15 percent increase in bulk density), and heavy (up to 30 percent increase in bulk density) (Stone et al. 1999). Each experimental treatment was replicated three times for a total of 27 treatment plots, each 1 acre in area. Sampling for the present study occurred June to August 2018. All live and dead trees greater than 4 inches in diameter at breast height (d.b.h.) that occurred within 0.12-acre circular plots (41.3 ft radius) centered in the existing treatment plots were stem-mapped. Data recorded for each tree included species, crown class, and d.b.h. In addition, increment cores were collected from all living trees greater than 4 inches d.b.h. within a 26 ft radius of each plot center so that neighborhood data could be calculated for all cored trees.

Tree cores were mounted, cross-dated, and measured. Then, annual woody biomass growth was estimated using reconstructed diameters for each year prior to 2018 and allometric biomass equations (Perala and Alban 1993). Estimates of drought response were based on methods described by Kohler et al. (2010). Resistance was quantified as the ratio of growth during drought (2012) to mean annual growth during the 5 years preceding drought (2007–2011). Resilience was the ratio of mean annual growth during the 5 years following drought (2013–1017) to mean annual growth during the 5 years preceding drought. Differences among treatments in stand-level resistance and resilience were tested using analysis of variance (ANOVA). The influence of treatments, tree size, crowding, and species on the drought resistance and resilience of individual trees was assessed using linear mixed effects models.

RESULTS

Our work suggests that treatments (varying combinations of compaction severity with organic matter removal) did not impact drought resistance or resilience at tree- or stand-scales. However, species responses varied and the effect of tree size and neighborhood crowding (related to density) on drought response also varied among species.

Larger trees were generally less resistant to drought than smaller trees (bigtooth aspen was an exception) (Fig. 1). Relative to northern red oak, species that were significantly less resistant to the 2012 drought included red maple, red pine, white pine, bigtooth aspen, and quaking aspen (Fig. 1).

[2] Scientific names of tree species listed in this paper: quaking aspen (*Populus tremuloides*); bigtooth aspen (*Populus grandidentata*); northern red oak (*Quercus rubra*); red maple (*Acer rubrum*); red pine (*Pinus resinosa*); white pine (*Pinus strobus*); black cherry (*Prunus serotina*); bur oak (*Quercus macrocarpa*); paper birch (*Betula papyrifera*); balsam fir (*Abies balsamea*).

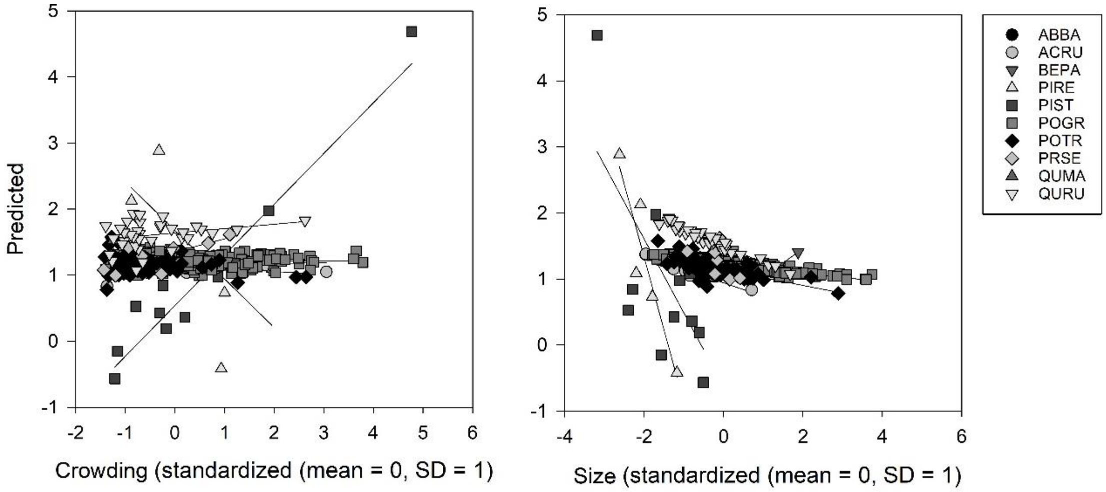

Figure 1.—Plots showing the effects of the interaction between crowding and species and between size and species on drought <u>resistance</u>. Abbreviations: balsam fir (ABBA), red maple (ACRU), paper birch (BEPA), red pine (PIRE), white pine (PIST), bigtooth aspen (POGR), quaking aspen (POTR), black cherry (PRSE), bur oak (QUMA), and northern red oak (QURU).

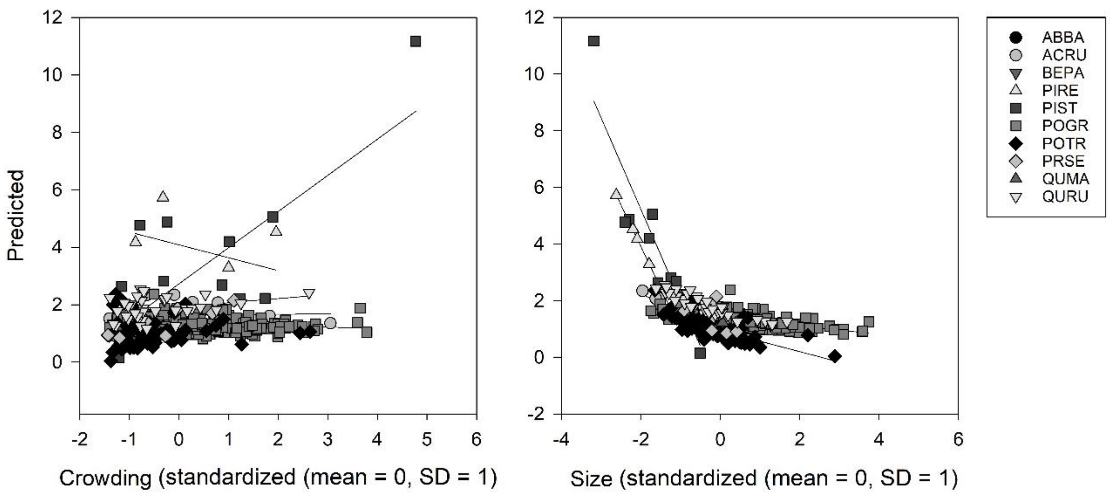

Figure 2.—Plots showing the effects of the interaction between crowding and species and between size and species on drought <u>resilience</u>. Abbreviations: balsam fir (ABBA), red maple (ACRU), paper birch (BEPA), red pine (PIRE), white pine (PIST), bigtooth aspen (POGR), quaking aspen (POTR), black cherry (PRSE), bur oak (QUMA), and northern red oak (QURU).

Northern red oak was more resilient to drought than red pine, white pine, and quaking aspen. Larger trees were significantly less resilient to drought regardless of species, particularly red pine, white pine, and bigtooth aspen (Fig. 2). Crowding negatively affected drought resistance in most species, but generally increased resilience, especially in white pine.

DISCUSSION

Previous studies at this site have shown whole-tree harvest negatively impacts stand-scale aboveground live woody biomass, particularly aspen biomass, compared with conventional, stem-only harvest (Curzon et al. 2014, Curzon et al. 2020). Despite the clear impact of whole-tree harvest on stand productivity, our results suggest that neither whole-tree harvest nor increased compaction directly impacted stand-level response to a drought occurring 18 years later. It is possible that the young age of the stands may have influenced responses as tree age is known to affect climate-growth relationships. Potential recovery from forest tent caterpillar (*Malacosoma disstria*) defoliation during a recent outbreak (2008–2010) may have also influenced our ability to quantify the response of quaking and bigtooth aspen to drought as both response indices quantified (resistance and resilience) rely on comparisons of diameter growth during, after, and prior to the drought year.

As observed in other forest types, tree size influenced drought response in these forests as did neighborhood conditions. Trees in more crowded neighborhoods, or those with a greater density of neighboring trees (with larger and closer trees weighted more heavily) generally exhibited less resistance to drought as expected based on observations in other forest types (Bottero et al. 2017, D'Amato et al. 2013). However, crowding generally had a positive influence on the resilience of individual trees to drought, meaning that the ratio of post-drought growth to predrought growth was higher in trees within denser neighborhoods.

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