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Decadal changes in tree range stability across forests of the eastern U.S.

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ABSTRACT

The monitoring of tree range dynamics has emerged as an important component of adaptive responses of forest management to global change scenarios such as extreme precipitation events and/or invasive species. Comparisons between the locations of adults versus seedlings of individual tree species using contemporary forest inventories is one tool widely used to assess the status of tree ranges in light of these changing conditions. With the consistent remeasurement of standard forest inventory plots across the entire eastern US occurring since the 2000s, the opportunity exists to evaluate the stability of tree ranges of focal species across a decade. Using said inventory, the northern range margins of tree distributions were examined by comparing differences (Holm-Sidak adjusted p-value = 0.2) in the 95th percentile locations of seedlings to adults (i.e., trees) by 0.5 degree longitudinal bands over nearly 10 years and by categories of canopy disturbance (i.e., canopy gap formation) for 20 study species. Our results suggest that range margins are stable for 85% of study species at both time one and at remeasurement regardless of canopy disturbance. For the very few species that had a significant difference in seedlings and adults at their range margins, there was nearly a 0.4 degree difference in latitude with seedlings being farther south irrespective of disturbance. Our findings of tree range stability across forests of the eastern US indicate a general propensity towards range contraction, especially for study species forecasted to lose range and located on disturbed sites, which may present substantial hurdles for adaptive management strategies focused on maintaining and enhancing forest ecosystem resilience in the context of global change and associated rapid climate change.

1. Introduction

Global change poses serious threats to future delivery of forest ecosystem services where changing climate (Stenseth et al., 2002; Bonan et al., 2008), land use (Metzeger et al., 2006), and economies (Woodall et al., 2012) coupled with invasive species (Holmes et al., 2009) and browse impacts (Russell et al., 2017) may reduce the extent and health of forest ecosystems (Trumbore et al., 2015). The distribution of tree species is a primary driver of current and future forest extent and condition (i.e., provisioning of ecosystem services; Gamfeldt et al., 2013). Tree species define patterns of biodiversity in a given region, which in turn strongly affect levels of forest productivity and resilience in the face of global change (Botkin et al., 2007; Paquette et al., 2011). Furthermore, the adaptive response of forest managers to global change is in part limited for endemic tree species especially in areas where natural regeneration is the traditional method of regenerating forest stands (Oliver and Larson, 1996) following disturbance or harvest activity, including numerous forest types in the eastern United States (Oswalt et al., 2014). Accurately gauging the dynamics of tree ranges in the context of forest disturbance (Liang et al., 2017) is critical for informing appropriate pathways for adapting current forest management activities in response to global change (D'Amato et al., 2011; Messier et al., 2013; Nagel et al., 2017).

Tree ranges have shifted for millennia (Clark et al., 1998; Davis and Shaw, 2001; McLachlan et al., 2005). However, the major question for resource management is if the rate of tree migration will keep pace with expected rates of climate change (Loarie et al., 2009) and other noted forcing factors of global change (Bertrand et al., 2011; Iverson and McKenzie, 2013; Vanderwel and Purves, 2014). Research suggests tree ranges may be contracting for certain species while at best migrating at a pace slower than that of expected climate change. In one of the first range margin examinations of forest tree species in the eastern US, Zhu et al. (2012) found evidence that range margins were not migrating northward as would be expected given climate change hypotheses.

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Recent results from Sittaro et al. (2017) suggest tree ranges will not be able to track the rate of expected future warming. Liang et al. (2017) emphasize that not only is climate change a driver of range margin dynamics but also interspecific competition and disturbance as the attributes of forest canopies are important controlling factors on related tree regeneration (Dobrowski et al. 2015). Fei et al. (2017) found that changes in precipitation might be causing a westward shift of certain eastern US tree species as opposed to poleward migration in response to increased moisture availability over the past few decades. When expected changes in tree ranges are combined with the influence of forest pests and pathogens, even more serious hurdles to tree range movement emerge (Thuiller et al., 2008, Rogers et al., 2017). Overall, refined monitoring techniques coupled with continuous monitoring are needed to ensure conservation of forest ecosystems in a future of expected global change.

In the forests of the eastern US, the trajectory of tree monitoring techniques has greatly evolved over time from Little's (1971) seminal work delineating tree ranges in the United States to a myriad of contemporary refinements and approaches. Before the advent of remote sensing technologies (e.g., Landsat) and consistent continental-scale forest inventories (e.g., Bechtold and Patterson 2008), the quantification of tree ranges was often limited to a delineation of individual tree-species presence based on inconsistent inventories and subjective botanical descriptions summarized at coarse spatial scales (e.g., county). Although certainly adequate for basic understanding of tree species distributions, these early techniques afforded little ability to monitor tree ranges let along enable quantitative analyses. The adoption of more consistent forest inventories in concert with publicly available digital databases enabled the statistical modeling of tree ranges with the production of dynamic tree atlases (e.g., Prasad et al., 2007, Iverson et al., 2008), which in turn informed conservation and management efforts (e.g., Iverson and McKenzie, 2013, Nagel et al., 2017). In addition to these region-wide analyses, elevational studies have greatly refined the understanding of tree species migration (e.g., Walther et al., 2005, Lenoir et al., 2009; Kelly and Goulden, 2008). In an effort to refine tree range monitoring beyond the modeling of tree distributions and elevational studies, Woodall et al. (2009) used a nationally consistent inventory to compare the distributions of seedlings versus adults as an indicator of tree range shifts. Zhu et al (2012) built upon this work by more fully evaluating the range margins of seedlings versus adults in the context of climatic variables with Woodall et al. (2013) incorporating attributes of forest canopy disturbance in the range analyses. More recent work by Sittaro et al. (2017) and Liang et al. (2017) highlight the utility of these tree range metrics and related analyses in monitoring tree ranges in the context of global change.

Much of this prior work has been conducted in the eastern United States. It is an optimal study location given the consistent region-wide forest inventory that has been conducted for nearly 20 years (Bechtold and Patterson, 2008) in concert with a relatively diverse temperate forest and biophysical conditions (Oswalt et al., 2014). Perhaps most importantly, the remeasurement period has nearly doubled from earlier studies allowing greater statistical detection of changes in range margins combined with refined mapping. Therefore, the goal of this study was to quantify the decadal changes in range margins of major tree species in the eastern US employing the techniques used in Woodall et al. (2013) but with the important lengthening of the remeasurement period and improved mapping for visual interpretation. Specific objectives were (1) to evaluate the stability of northern range margins of selected eastern U.S. tree species by comparing latitudinal occurrences of trees and their associated seedlings by individual species at 0.5-degree lines of longitude in eastern U.S. forests across a decade-long remeasurement period and (2) to determine if said range stochasticity is influenced by forest disturbance (i.e., canopy gaps) with implications for evaluating forest ecosystem resilience and adaptive management responses.

Table 1
Study tree species common/Latin name, number of subplot observations, and forecasted change in conterminous U.S. suitable habitat (percent area) under a future Hadley Low (B1) climate scenario (see Prasad et al., 2007-ongoing). Species were assigned to one of two groups: (1) species with forecasted range loss or minimal expansion, (2) species with substantial forecasted range expansion.

Common name	Latin name	Observations	Habitat change (%)
Species with range loss or minimal expansion			
Sweet birch	*Betula lenta*	1709	−11.5
American beech	*Fagus grandifolia*	4267	−7.6
Sourwood	*Oxydendrum arboreum*	868	−7.1
Black cherry	*Prunus serotina*	8001	2.2
White oak	*Quercus alba*	6174	10.0
Scarlet oak	*Quercus coccinea*	1458	−23.9
Chestnut oak	*Quercus prinus*	1802	8.0
Northern red oak	*Quercus rubra*	6921	−0.1
Black oak	*Quercus velutina*	4512	13.5
American basswood	*Tilia americana*	2330	−10.7
Species with substantial range expansion			
Eastern redcedar	*Juniperus virginiana*	2845	66.9
Shortleaf pine	*Pinus echinata*	1230	57.6
Slash pine	*Pinus elliottii*	166	110.4
Longleaf pine	*Pinus palustris*	139	77.2
Bitternut hickory	*Carya cordiformis*	1916	85.3
Eastern redbud	*Cercis canadensis*	1176	62.0
Water oak	*Quercus nigra*	1646	74.3
Post oak	*Quercus stellata*	2137	67.4
Black locust	*Robinia pseudoacacia*	974	62.5
Winged elm	*Ulmus alata*	2515	142.6

2. Methods

As the methods in this study are largely derived from Woodall et al. (2013), methods will be succinctly summarized with detailed notes of divergence along with inclusion of new inventory data. Please refer to Woodall et al. (2013) for details unless otherwise noted below.

2.1. Study tree selection

As noted by Woodall et al. (2010), the selection of tree species in tree range shift analyses influences results, leading Woodall et al. (2013) to develop a list of 20 species for evaluation of tree range shift hypotheses in eastern forests. In short, this list only includes species with distributions largely contained within the conterminous US and with abundant observations in the seedling and overstory layers. The same tree list from Woodall et al. (2013) was used in this study along with Prasad et al.'s (2007) future potential tree habitat models under the low emission Hadley climate scenario (B1) as a conservative future (Table 1). The use of Woodall et al.'s (2013) tree species list allows not only comparison with prior study results but continued monitoring of this important ecosystem attribute across the eastern US.

2.2. Data

Nationally consistent forest inventory data from the USDA Forest Service's Forest Inventory and Analysis program (FIA; Bechtold and Patterson, 2005) served as the basis for this study. FIA applies a nationally consistent sampling protocol using a quasi-systematic design covering all ownerships in the entire nation with plots remeasured every 5–7 years in the eastern U.S. (Bechtold and Patterson, 2005). The multi-phase inventory is based on an array of hexagons assigned to separate interpenetrating, non-overlapping annual sampling panels. The first phase involves land area stratification while the second and third phase involves measuring field plots for trees and forest health indicators (e.g., soils), respectively. The focus of our study was the second phase of the inventory when permanent sample plots are visited