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Eastern national parks protect greater tree species diversity than unprotected matrix forests

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ABSTRACT

Decline in tree species diversity is a widespread trend in eastern US forests, with implications for ecosystem functions and services, biodiversity and vulnerability to climate change and other stressors. While some impacts on diversity are widespread such as forest pests, forest management practices vary across the landscape. For example, forests in US national parks are managed to promote ecological integrity, develop under natural disturbance regimes, and are largely protected from timber harvesting. In this study we compared forests in 39 eastern US national parks with surrounding matrix forests to assess whether forest protection has led to differences in tree diversity patterns in parks. We calculated multiple alpha and beta diversity metrics using tree stem data. We examined alpha diversity metrics at the scale of the 7.31 m radius subplot and for an equal number of individuals, and examined beta diversity at multiple scales. This is the first study to compare tree diversity in protected lands with the surrounding forest matrix over such a large area of the US, and is only possible because of the 10+ years of data that are publicly available from US Forest Service (USFS) Forest Inventory and Analysis (FIA) and the National Park Service (NPS) Inventory and Monitoring (I&M) programs. Overall, results indicated that park forests have consistently greater alpha diversity. Park forests have higher tree species richness, particularly after the influence of the number of individuals was removed. Park forests also consistently had higher Shannon Evenness, lower McNaughton Dominance, and higher percentage of rare species. Beta diversity analyses also suggest that parks were less homogenous across sites, although results are exploratory due to differences in scale and small sample size. While a number of studies have documented higher diversity in protected areas, few studies have examined multiple diversity metrics or covered the large area of our study. Combining these results with a previous study, which found parks to have consistently greater structural complexity than surrounding forests, park forests may respond differently and potentially be more resilient to climate change and other stressors than unprotected forests, as there is a greater chance that some of the tree species or size cohorts present will persist through climate change. Continued monitoring is important to determine how forests respond to climate change and other stressors, and whether specific management actions, such as protecting more forests, translocating species, or altering management practices, are necessary to maintain forest biodiversity and function.

1. Introduction

Decline in tree species diversity at both local and regional scales is a widespread trend in eastern US forests (Schulte et al., 2007; Shields et al., 2007; Amatangelo et al., 2011; Nuttle et al., 2013; Thompson et al., 2013). Introductions of exotic pests and pathogens have resulted in direct loss of multiple tree species once common to the eastern forest, including American chestnut (*Castanea dentata*) and American elm (*Ulmus americana*) (Ellison et al., 2005; Loo, 2009). More recently, hemlock woolly adelgid (*Adelges tsugae*) has caused widespread decline

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and mortality of eastern hemlock (*Tsuga canadensis*) throughout much of its range (Vose et al., 2013). Additionally, emerald ash borer (*Agrilus planipennis*) is causing extensive mortality of ash species (*Fraxinus* spp.), functionally removing ash as a component of eastern forests within the continually expanding range of infestation (Flower et al., 2013).

Tree diversity has also been impacted by an overabundance of deer throughout the eastern US (Matonis et al., 2011; Nuttle et al., 2013; Côte et al., 2014). In the Great Lakes region, elevated deer browse pressure has severely impacted conifer regeneration, particularly for northern white cedar (*Thuja occidentalis*), eastern hemlock (*Tsuga canadensis*) and eastern white pine (*Pinus strobus*), leading to a loss of conifer species in the canopy and increased homogeneity in regional forest composition (Rooney and Waller, 2003; Côte et al., 2004; Salk et al., 2011; White, 2012). Reduced tree diversity has also been documented in the mid-Atlantic and Midwest regions, where forests once dominated by multiple species of oak (*Quercus* spp.) and hickory (*Carya* spp.) are being replaced primarily by American beech (*Fagus grandifolia*) and red maple (*Acer rubrum*) (Nowacki and Abrams, 2008; Nuttle et al., 2013). Termed 'mesophication', this pattern is widespread, with the combined impacts of fire suppression, deer overabundance, altered disturbance regimes and climate change considered the likely causes (Nowacki and Abrams, 2008; McEwan et al., 2011; Brose et al., 2013).

In eastern forests, such as oak-hickory and northern hardwood forests, stand-replacing disturbances are infrequent natural disturbances, with the composition in these forests driven more by frequent low intensity disturbances, environmental gradients and climate under natural conditions (Lorimer and White, 2003). However, historic patterns of land use and timber harvesting have led to local and regional declines in tree species diversity (Boucher et al., 2009; Thompson et al., 2013; Kern et al., 2017). Through centuries of land clearing and timber harvesting, northeastern forest composition has become more similar across the region, less coupled with climatic factors and environmental gradients, and more dominated by early to mid-successional species (Thompson et al., 2013). These patterns have been documented in similar forest communities in the Great Lakes region (Schulte et al., 2007; Hanberry et al., 2012). Modern-day harvesting practices can also contribute to patterns of tree diversity (Neuendorff et al., 2007; Shields et al., 2007; Boucher et al., 2009; Clark and Covey, 2012). For example, selection methods in northern hardwood forests have favored sugar maple (*Acer saccharum*) or American beech (*Fagus grandifolia*) regeneration over species that are less tolerant of shade, are sensitive to deer browse or that require exposed mineral soil or coarse woody debris to germinate (Nuttle et al., 2013; Kern et al., 2017). This has led to an overall decrease in tree diversity, including lower species richness and greater dominance of shade tolerant species, where applied (Neuendorff et al., 2007; Shields et al., 2007; Bolton and D'Amato, 2011; Kern et al., 2017). At the other extreme, even-aged management also tends to favor forests dominated by a few early successional species, such as quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera;* Schulte et al., 2005). Conversely, moderate intensity removals, such as shelterwood cutting, have been shown to maintain or enhance species diversity compared to other harvesting methods (Niese and Strong, 1992).

Higher tree diversity has been associated with greater ecosystem functions and services at local (Gamfeldt et al., 2013; Lefcheck et al., 2015) and regional scales (van der Plas et al., 2016), along with greater site productivity (Paquette and Messier, 2011; Vilá et al., 2013), and increased diversity of forest flora and fauna (Schmit et al., 2005; Hobson and Bayne, 2000; Barbier et al., 2008; Sobek et al., 2009). Higher tree diversity can also provide greater forest resilience, which is the capacity for ecosystems to absorb disturbance and change while maintaining similar ecosystem functions, composition and structure (Elmquist et al., 2003; Millar et al., 2007). For example, higher tree diversity can reduce impacts of insect herbivory (Jactel and Brockerhoff, 2007) and moderate the effects of environmental fluctuations (Aussenac et al., 2017). Moreover, in a changing climate, where species-specific responses are unknown, managing forests to promote tree diversity is a commonly suggested strategy for promoting forest resilience and adaptive capacity (Millar et al., 2007; D'Amato et al., 2011; Janowiak et al., 2014). The reasoning for this approach is that diverse forests will likely have a broader range of responses to stressors and climate change (i.e., response variability) than less diverse forests, and therefore be less vulnerable to rapid state shifts (e.g., conversion to grassland) and/or loss in ecosystem function (Millar et al., 2007). Given the importance of tree diversity, current trends of decline are of great concern to forest managers and conservationists (Schulte et al., 2007; White, 2012), and understanding the underlying causes are important to ensure that eastern forests remain diverse and able to adapt to climate change and other stressors over time.

While some impacts on diversity are widespread such as forest pests and pathogens, forest management practices vary across the landscape. For example, forests in US national parks are managed to promote ecological integrity, develop under natural disturbance regimes, and are largely protected from timber harvesting. Recent meta-analyses have found protected areas to preserve greater diversity than unprotected areas (Coetzee et al., 2014; Gray et al., 2015). However these studies only considered species richness and abundance in their comparisons, and datasets from eastern US forests were underrepresented or absent in the analyses. Data available from the US Forest Service (USFS) Forest Inventory and Analysis (FIA) program have been used in a number of studies to examine patterns and drivers of tree diversity across the eastern US (Canham and Thomas, 2010; Belote et al., 2011; Woodall et al., 2011; Siefert et al., 2013). However, the majority of forests monitored by USFS-FIA are not reserved from timber production (Oswalt et al., 2014; Miller et al., 2016), and forest management may have influenced the diversity patterns that were examined by these studies. The 10+ years of data available from the National Park Service (NPS) Inventory and Monitoring (I&M) program provide a unique opportunity to examine patterns of tree species diversity in forests that are managed for ecological integrity, and compare diversity patterns with unprotected forests using USFS-FIA data. Structural differences have already been documented between eastern national parks and surrounding unprotected forests, with parks consistently having greater structural complexity than surrounding forest lands (Miller et al., 2016). The observed structural differences are likely due to differences in management between parks and surrounding matrix forests. The question remains whether management differences have also influenced tree diversity patterns in park forests compared with surrounding matrix forests.

In this study we use a similar approach as Miller et al. (2016) to compare forests in eastern parks with surrounding matrix forests to assess whether the protection status of parks has led to differences in tree diversity patterns, and discuss the implications of observed patterns in the context of climate change vulnerability and adaptation. Our analysis incorporates multiple metrics of alpha and beta diversity and covers 39 national parks in the eastern US. This is the first study to compare tree diversity in protected lands with the surrounding forest matrix over such a large area of the US, and is only possible because of the 10+ years of data that are now publicly available from USFS-FIA and NPS I&M programs.

2. Methods

2.1. NPS site selection

The parks in this study represented a range of sizes, and included the following designations: National Battlefield (NB), National Battlefield Park (NBP), National Historical Park (NHP), National Historic Site (NHS), National Memorial (NM), National Military Park (NMP), National Monument (NMo), National Park (NP), National Recreation Area (NRA), National River (NR), and National Scenic River (NSR; Table 1). Parks were located across five NPS I&M regional