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Twenty Years of Structural Change, Including Tornado Damage, in Southern Disjunct Eastern Hemlock Stands

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ABSTRACT

Eastern hemlock (*Tsuga canadensis*) is projected to experience shifts in suitable habitat distribution in response to climate change. Models predict the southern boundary of eastern hemlock will remain geographically stable, but that eastern hemlock will decline in dominance and abundance along the boundary. In 2003 and 2013, 10 disjunct eastern hemlock stands on the southernmost portion of the Cumberland Plateau in Alabama were surveyed to characterize the vertical structure and diameter distributions of eastern hemlock. This work represents the third survey over 20 years and provides more complete insight into the stand dynamics of these disjunct stands. No trends were common among all stands, but there was a general decrease in the number of canopy eastern hemlock from 2013 to 2023. Despite the loss of canopy dominance, the majority of stands experienced an increase in the number of stems in the larger diameter classes. We expect these stands to remain viable and predict no shift in the southern range limit of the species. If, however, climate change effects begin to manifest in the stand structure or a severe disturbance occurs, eastern hemlock may lose dominance and be unable to regenerate. In 2021, an EF1 tornado obliterated one stand, and removed all canopy stems from another. Although the hemlock woolly adelgid (*Adelges tsugae*) is perhaps the most well-known threat to eastern hemlock, non-species specific disturbances have the potential to be equally as devastating to these disjunct populations.

Key words: Alabama, *Tsuga canadensis*, forest structure, plant demography, wind disturbance

INTRODUCTION

Climate change has prompted the modeling and mapping of potential range shifts based on suitable habitat for many tree species (Iverson et al. 2008; Matthews et al. 2011). Species distribution models predict the expected spatial distribution of suitable environments for tree species under different climate change scenarios (Guisan and Thuiller 2005; Elith and Leathwick 2009; Iverson et al. 2019; Peters et al. 2020; Climate Change Atlas 2023). The eastern hemlock (*Tsuga canadensis* L.) models suggest a shift in suitable habitat distribution in response to emissions scenarios, although the southern boundary is expected to remain relatively stable geographically, despite a potential decrease in abundance and/or dominance (Climate Change Atlas 2023).

Eastern hemlock populations at the southern species boundary are descended from stands that first developed during the late Pleistocene and early Holocene as the climate warmed and glaciers retreated (Williams et al. 2004). Continued warming throughout the early Holocene caused a subsequent range contraction of eastern hemlock into the Appalachian Highlands (Williams et al. 2004; Potter et al. 2012). Despite the range contraction, eastern hemlock populations were able to remain on sites with favorable microenvironmental conditions along the southern portion of its range. The

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native range of eastern hemlock extends from Quebec and Ontario, Canada, south to Georgia and Alabama, U.S.A. Across this range, eastern hemlock stands exhibit a variety of structural characteristics and unique genetics (Potter et al. 2012; Myers et al. 2015). Disjunct stands are common in the southern and western range extents, and the characteristics of some disjunct stands have been studied (e.g., Harper 1943; Friesner and Potzger 1944; Segars et al. 1951; Oosting and Hess 1956; Bormann and Platt 1958).

Despite relative geographic isolation, disjunct stands remain vulnerable to the nonnative, invasive, hemlock woolly adelgid (*Adelges tsugae* Annand; HWA), as HWA can spread through avian and anthropogenic dispersal (Hart 2008). Eastern hemlock has experienced a significant decline primarily caused by the outbreak of HWA (McClure 1991; Letheren et al. 2017; Ellison et al. 2018). The HWA has contributed to the classification of eastern hemlock as a near-threatened species by the International Union for Conservation of Nature (Farjon 2013). The combined threats of anticipated climate change and HWA spread warrant continued monitoring of eastern hemlock stands, but especially disjunct stands.

In 2003 and 2013, Hart and Shankman (2005) and Myers et al. (2015), respectively, sampled and reported on all known eastern hemlock stands (10 in total) at the southern range limit of the species on the Cumberland Plateau in Alabama, U.S.A. They recorded forest vertical layers and diameter distributions for eastern hemlock stems, and Myers et al. (2015) examined changes in structure between the two sampling periods. Our objectives were to resurvey these stands to document further changes and attempt to locate additional eastern hemlock stands previously not quantified. We characterized the structure of these stands in the same manner of Hart and Shankman (2005) and Myers et al. (2015) and made inferences as to their continued viability. As these stands exist as relicts of past climatic conditions, monitoring climate-stand dynamics patterns will be paramount to their preservation.

MATERIALS AND METHODS

Study Area

Our study took place in Fayette, Jefferson, and Walker counties, Alabama, on the southernmost part of the Cumberland Plateau, immediately upstream of the Fall Line separating the Cumberland Plateau and Coastal Plain (Fenneman 1938). The southern terminus of the Cumberland Plateau generally coincides with the southern range limit of eastern hemlock (Shankman and Hart 2007). Here, eastern hemlock stands are disjunct and often restricted to areas directly adjacent to stream margins or along incised tributaries. All stands sampled in this study range in elevation from 110 to 125 m above mean sea level (Hart and Shankman 2005). The linear extent of our stands ranges from 50 to 600 m, with most stands ranging from 200 to 300 m. Stands are generally restricted to within 50 m of stream margins, and eastern hemlock stems beyond this point are generally restricted to understory positions. Eastern hemlock dominates the canopy of some stands but is entirely absent from the canopy in others. Other overstory species include American beech (*Fagus grandifolia* Ehrh.), white oak (*Quercus alba* L.), northern red oak (*Quercus rubra* L.), chestnut oak (*Quercus montana* Willd.), southern red oak (*Quercus falcata* Michx.), red maple (*Acer rubrum* L.), tulip-poplar (*Liriodendron tulipifera* L.), loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), and bigleaf magnolia (*Magnolia macrophylla* Michx.). Stands occur almost exclusively on steep slopes, where shallow soils overlie sandstone of the Hartselle formation. Lichens and bryophytes cover the sandstone, and larger vegetation (including eastern hemlock) establishes in crevices in the rocks. In addition to water from nearby streams, moisture is also available to plants during typically drier months in the form of springs and seepage through the permeable sandstone (Lacefield 2000). Although HWA has not yet been observed in Fayette, Jefferson, or Walker counties, it was found to the northeast on ornamentally-planted eastern hemlock in DeKalb County, Alabama, in June 2020 (Alabama Cooperative Extension System 2021).

Data Collection and Analysis

In the fall and winter of 2023, we sampled 10 eastern hemlock stands previously sampled in 2003 and 2013 and reported by Hart and Shankman (2005) and Myers et al. (2015) respectively. During our sampling, we also located and sampled a previously undocumented stand in Fayette County. Of the 11 stands, six are in Fayette County along the Sipsey River (stands 1, 2, 3, 4, 5, and 11), three in Walker County along Blackwater Creek (stands 6, 7, and 10), and two in Jefferson County along Village Creek (stands 8 and 9; Figure 1). Of the two Jefferson County stands, only one was sampled, as a recent wind disturbance prohibited sampling of the other stand, and we were unable to locate any eastern hemlock stems in the catastrophically disturbed stand. Though we did not sample the stand, we opted to include it for continuity in the event the stand has observable eastern hemlock during a future sampling effort. During our sampling, we also periodically checked eastern hemlock stems for HWA presence.

In each sampled stand, we recorded all eastern hemlock stems. Following the methods of Hart and Shankman (2005), we classified stems as residing in one of four forest layer categories: (1) <1.5 m in height, seedlings; (2) ≥1.5 m in height but not in a canopy position, understory; (3) shared canopy position, codominant; and (4) unshared canopy position, dominant. In addition to forest layer categories, we placed each stem into one of four diameter size classes based on diameter at breast height (1.37 m above the ground; dbh): (1) <4 cm dbh; (2) 4–20 cm dbh; (3) 20–40 cm dbh; and (4) >40 cm dbh. We also recorded the substrate in which eastern hemlock seedlings were present, and noted our visual observations of co-occurring species in the understory, midstory, and overstory.

We compared our 2023 data to the 2013 and 2003 datasets to quantify changes in eastern hemlock abundance, vertical structure, and diameter structure over the 20-year observation period. Further, we compared our demographic changes to temperature, precipitation, and Palmer Drought Severity Index (PDSI) data from 1993–2023 to infer climatic drivers of stand dynamics. To illustrate the influence of wind disturbance, Figure 1 also shows tornado paths since 1993 within 3 km of the stands (FEMA 2023).

RESULTS AND DISCUSSION

Eastern Hemlock Stem Abundance

Eastern hemlock stem abundance ranged from 27 individuals in a stand to 353 individuals in a stand in 2003 (Hart and Shankman 2005), from 30 to 313 individuals in a stand in 2013 (Myers et al. 2015), and from 58 to 676 individuals in a stand in 2023 (Figure 2). Stand 11, in Fayette County, was not previously sampled, but contained a relatively high number of stems (507), second only to stand 6 in Walker County (676). Eastern hemlock stands in Jefferson County experienced a decrease in stem abundance for both stands. Eastern hemlock stands in Fayette and Walker counties did not exhibit a unanimous increase or decrease in stem density from 2013 to 2023, nor was there a general pattern across all counties. Of the 10 previously sampled stands, six exhibited an increase in stem density and four a decrease in stem density. The greatest percent increase (450%) occurred in stand 7, which had 46 recorded eastern hemlock stems in 2013 and 253 in 2023. The stand with the greatest negative change (–100%) was stand 9.

Stand 9 had only 62 and 59 stems in 2003 and 2013 respectively, but no stems were recorded during our 2023 sampling. We observed clear evidence of a recent catastrophic wind disturbance in stand 9 and the nearby stand 8. Tornado records (FEMA 2023) show an EF1 tornado path between these stands in 2021. Stand 9 was in the stand initiation phase of stand development (Oliver and Larson 1996) following the 2021 tornado. The density of young stems combined with a high amount of coarse woody debris made extensive sampling prohibitive, but we found no eastern hemlock stems during our exploration of the stand location. It is possible there were eastern hemlock stems that we did not observe and that could be documented at a later sampling date, when the stand has further developed. Stand 8 also exhibited a decrease in stem abundance (-42%) from 252 stems

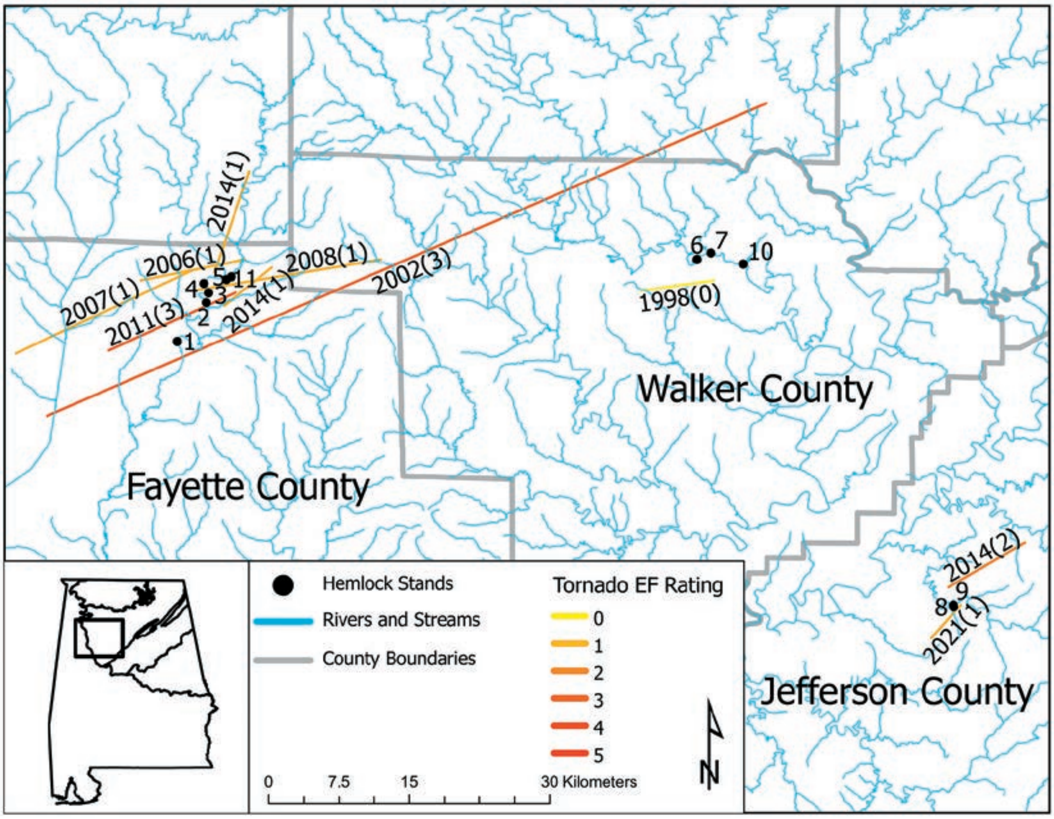


Figure 1. Disjunct eastern hemlock (*Tsuga canadensis*) stands in Fayette, Walker, and Jefferson counties, Alabama, USA, at the southern range limit of the species, coincidental with the physiographic boundary of the Cumberland Plateau and the Coastal Plain. Tornado paths since 1993 within 3 km of the stands are shown, along with their magnitude. (Esri 2023; FEMA 2023)

in 2013 to 147 stems in 2023. Although eastern hemlock in stand 8 did not experience the complete removal observed in stand 9, all canopy stems were removed. The six codominant and three dominant stems recorded in 2013 were uprooted or snapped following the 2021 tornado. Further, stand 2 also showed evidence of wind disturbance. The canopy height was comparably low (ca. 15 m) and there were multiple downed canopy eastern hemlock stems. Downed stems had lost their fine branches, and bark was generally present, but loose. The most recent recorded tornado in the area was of EF1 magnitude and occurred in 2016, but it is also possible an unrecorded wind event caused the observed damage.

Although the HWA is arguably the most notorious threat to eastern hemlock through its range, none were found during our sampling. The HWA has not yet reached Fayette, Walker, or Jefferson counties, yet two stands experienced complete removal of all canopy stems as a result of wind disturbance. Since 1993, 10 tornados have occurred within 3 km of the stands documented here (FEMA 2023; Figure 1). A single, F0 tornado occurred in Walker County in 1998. Jefferson County experienced the aforementioned 2021 EF1 tornado and an EF2 tornado in 2014. Fayette County experienced seven tornados: one of F1 magnitude that occurred in 2006, four of EF1 that occurred in 2007, 2008, 2014, and 2016, one of F3 magnitude that occurred in 2002, and one of EF3 magnitude in 2011.

In a chronology of eastern hemlock stems within these stands, Hart et al. (2010) documented

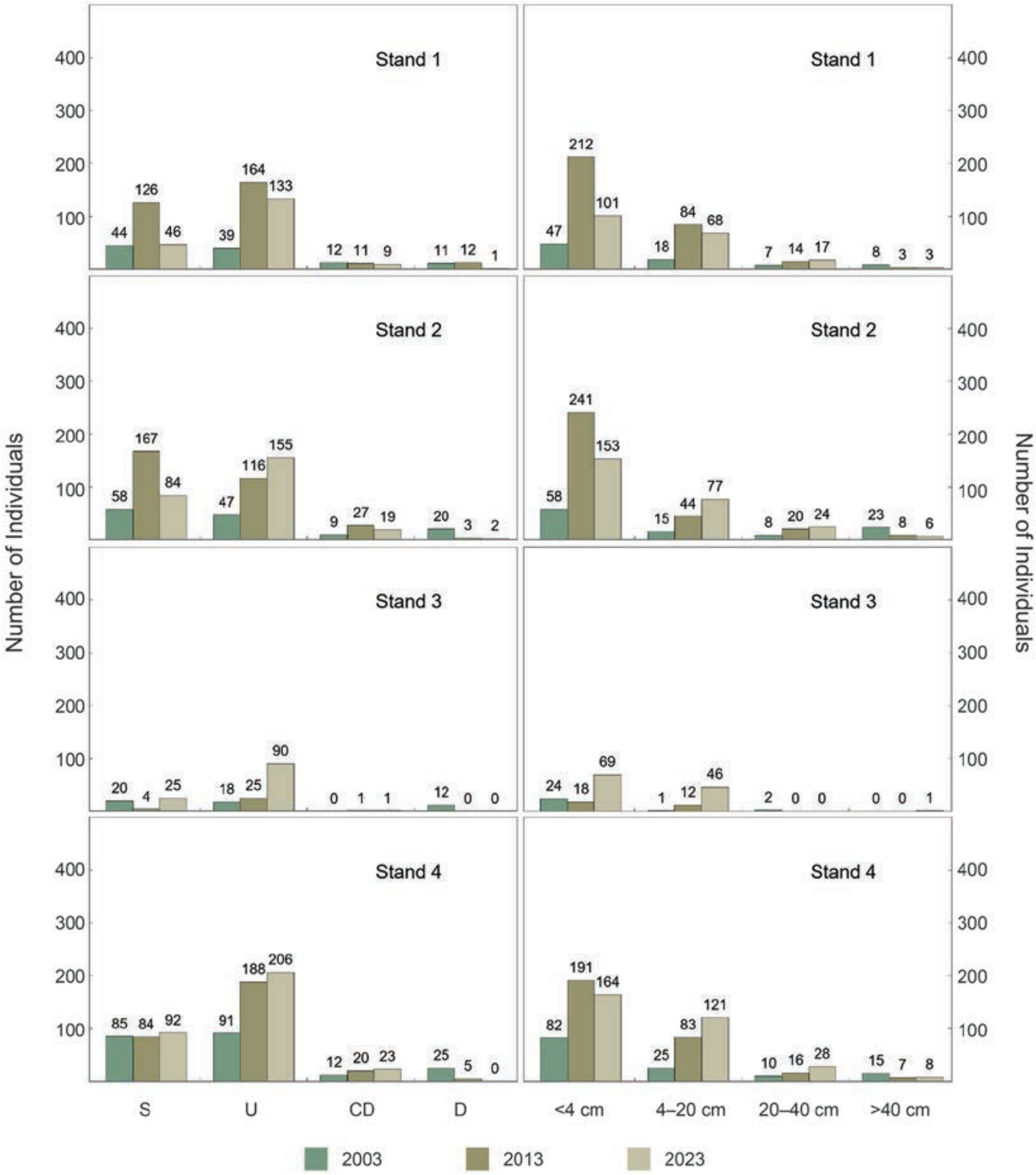
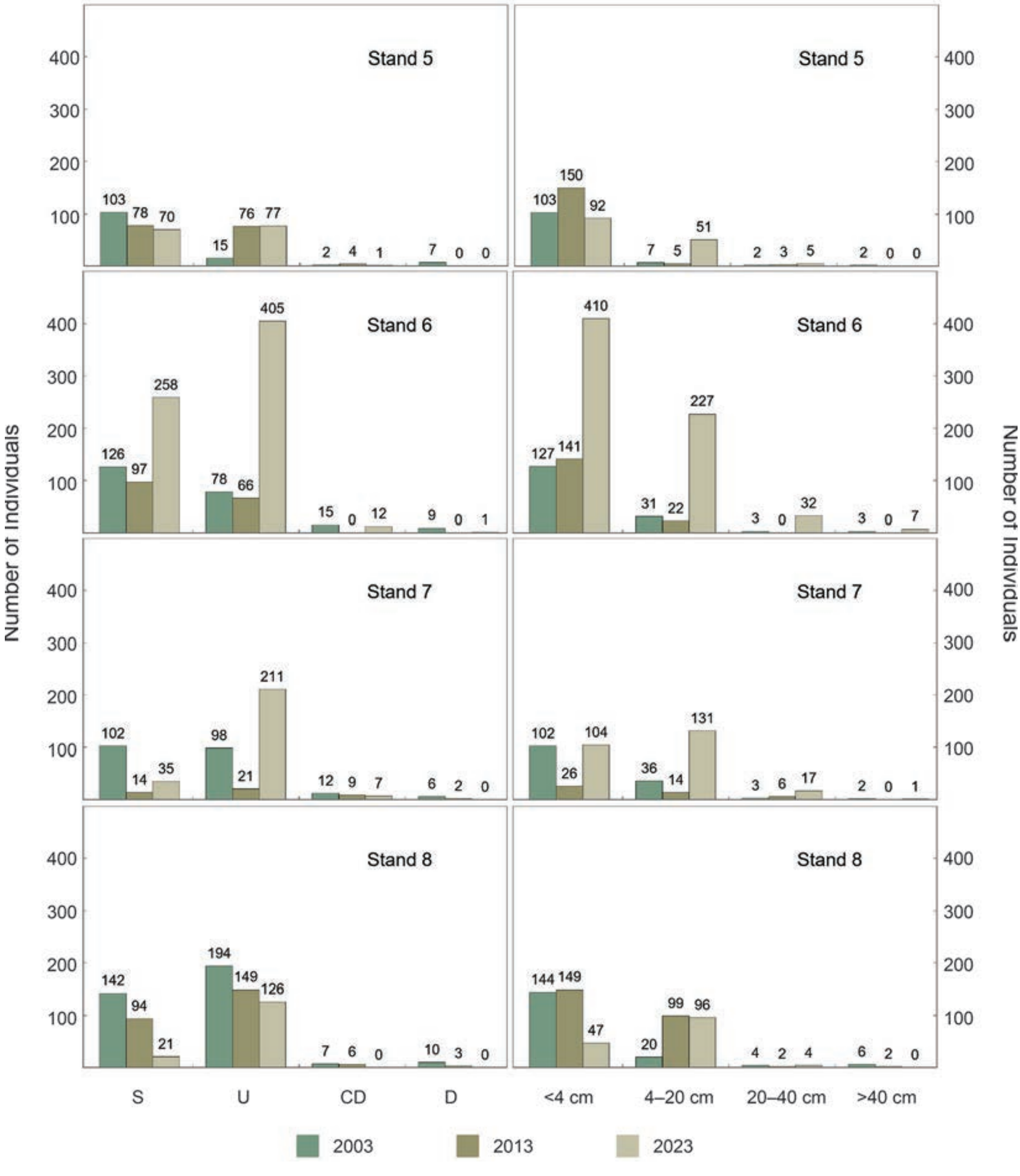


Figure 2. Vertical class distribution and diameter at breast height distribution for eastern hemlock (*Tsuga canadensis*) stems in 11 disjunct stands in Fayette, Walker, and Jefferson counties, Alabama, at the southern range limit of the species. Vertical classes are S (seedling; <1.5m in height), U (understory; ≥1.5 m in height but not in a canopy position), CD (codominant; shared canopy position), and D (dominant; unshared canopy position).



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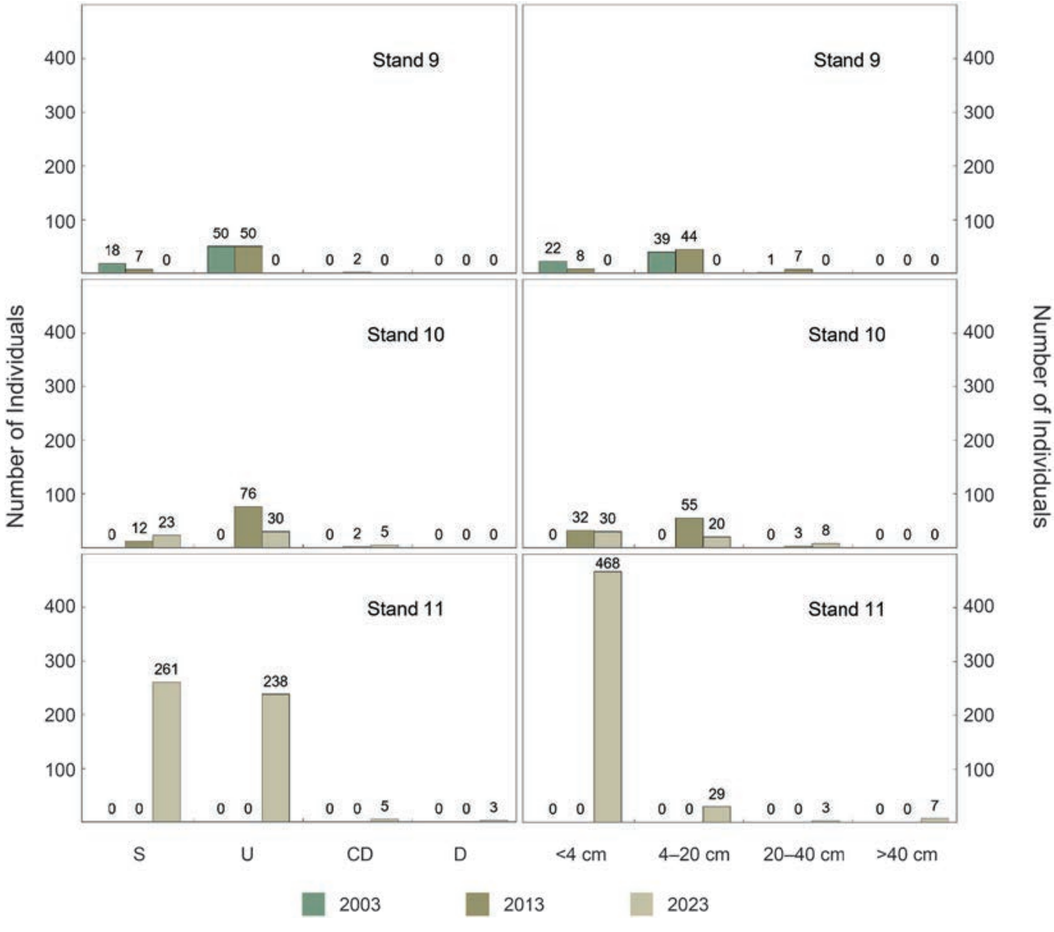

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several increases in radial growth that were likely unrelated to climate. Indeed, the oldest documented release events in 1920, 1929, 1946, were coincident with tornados in 1917 (F3, F4), 1920 (F4), 1926 (F3), 1928 (F2), 1944 (F2), and 1945 (F2) that occurred in Fayette, Walker, or Jefferson counties (NWS 2024). Certainly, these tornados might be unrelated to the radial growth increases, but they demonstrate the frequency of tornadic events in the counties. Hart et al. (2010) also observed increased growth in 1961, 1970, and 1990. For the 1961 and 1990 release events, there are three coincident tornados within 3 km of the stands: a 1957 F4 tornado in Walker County, a 1961 F3 tornado in Fayette County, and a 1990 F1 tornado in Jefferson County (FEMA 2023).

At its southern range limit, eastern hemlock stands exist as disjunct relicts of its historical range (Hart and Shankman 2005; Hart et al. 2010), now restricted to areas where specific microclimate conditions sustain previously established stands. Catastrophic and intermediate-severity disturbances such as tornados can remove canopy eastern hemlock stems. Indeed, windthrow is a common occurrence in many eastern hemlock stands (Davis et al. 1996), and is the dominant natural disturbance in the area (Hart and Shankman 2005). Further, although forest disturbances such as wind events have yet to be conclusively linked to climate change, some trends indicate a connection

(Knutson et al. 2010). It is possible that the already dominant disturbance type could increase in both frequency and severity. If insufficient advance reproduction exists, or if disturbance is severe enough, eastern hemlock may lose dominance and be unable to regenerate.

Vertical Structure

Except for tornado-impacted Jefferson County stands, eastern hemlock was present in the canopy of every stand sampled. Stands 3 and 5 of Fayette County however, had only one codominant eastern hemlock stem each. Canopy-dominant eastern hemlock were observed in three of the Fayette County stands and one of the Walker County stands. Common canopy species included American beech, white oak, northern red oak, chestnut oak, southern red oak, red maple, tulip poplar, loblolly pine, Virginia pine, and bigleaf magnolia. Black cherry (*Prunus serotina* Ehrh.), post oak (*Quercus stellata* Wangenh.), and shortleaf pine (*Pinus echinata* Mill.) were also observed in the canopy, though more rarely. Stands 6 and 10 exhibited an increase in canopy eastern hemlock stems from 2013 to 2023, stand 3 experienced no change, and the remaining stands had a decrease in the number of canopy eastern hemlock. The observed increase in stand 6 was a result of a sampling error in 2013, in which a portion of the stand was not sampled. Stand 6 has the greatest length of our sampled stands, and extends from Blackwater Creek upstream into a tributary. Myers et al. (2013) did not sample the stand area along the tributary. Although no canopy stems were recorded in 2013, Hart and Shankman (2005) recorded 15 codominant and nine dominant eastern hemlock, compared to our 2023 sampling which found 12 codominant and one dominant stems. The increase in canopy stems for stand 10 is attributable to canopy recruitment of understory stems. Stand 11 contained three canopy-dominant stems, the highest number recorded in the 2023 sampling.

Stands 1, 8, 9, and 10 experienced a decrease in understory eastern hemlock stems from 2013 to 2023. The greatest decrease (other than stand 9, -100%) occurred in stand 10 (–61%), which decreased from 76 stems to 30. Remaining stands experienced an increase in understory stems. The greatest increase occurred in stand 7 (905%), which increased from 21 understory stems to 211. Compared to the 98 understory stems recorded in 2003, this increase would be less drastic, at only 115%. The increase could be attributed to the production of a larger seed crop between 2013 and 2023. Eastern hemlock regeneration is typically considered episodic, occurring when good seed crops and low moisture stress coincide (Bormann and Platt 1958). Eastern hemlocks produce large seed crops every 2–3 years (Hett and Loucks 1976; Rooney and Waller 1998). Combined with favorable PDSI following a 2016 drought (Figure 3), a large seed crop could have germinated, established, and grown to understory size in the years between sampling. Common midstory species included American beech, American holly (*Ilex opaca* Aiton), sweetgum (*Liquidambar styraciflua* L.), red maple, American hornbeam (*Carpinus caroliniana* Walter), and bigleaf magnolia. Less common were oaks (*Quercus* spp.), pines (*Pinus* spp.), and mountain laurel (*Kalmia latifolia* L.). Stands 3 and 10 had no notable midstory. Common understory species included mountain laurel (present on all stands except stand 9), American holly, *Vaccinium* L. spp., and American hornbeam. Less common understory species included eastern red cedar (*Juniperus virginiana* L.) and eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch) Additionally, Chinese privet (*Ligustrum sinense* Lour.) was abundant in stand 8. The ubiquity of mountain laurel in these stands can be attributed to its competitive success in abiotic conditions required by eastern hemlock: high understory insolation, moss and deadwood substrates, and moist, acidic mineral soil (Chapman 1950; Kurmes 1961; Huebner et al. 2014). In response to increases in light, mountain laurel can exhibit increased growth, photosynthetic capacity, and water use efficiency (Kurmes 1961; Lipscomb and Nilsen 1990). Mountain laurel could increase in abundance when sexually mature eastern hemlock (typically >20–40 years old; Hough 1960; Ruth 1974; Goerlich and Nyland 1999) do not produce sufficient seed crops or if seed sources are removed entirely with the loss of canopy eastern hemlock. Mountain laurel could form a dense thicket, a “laurel hell,” and inhibit regeneration of other woody plant species. Indeed, stands 1 and 2 contained dense thickets of mountain laurel, often necessitating crawling through mountain laurel to adequately count seedling and understory eastern hemlock stems.

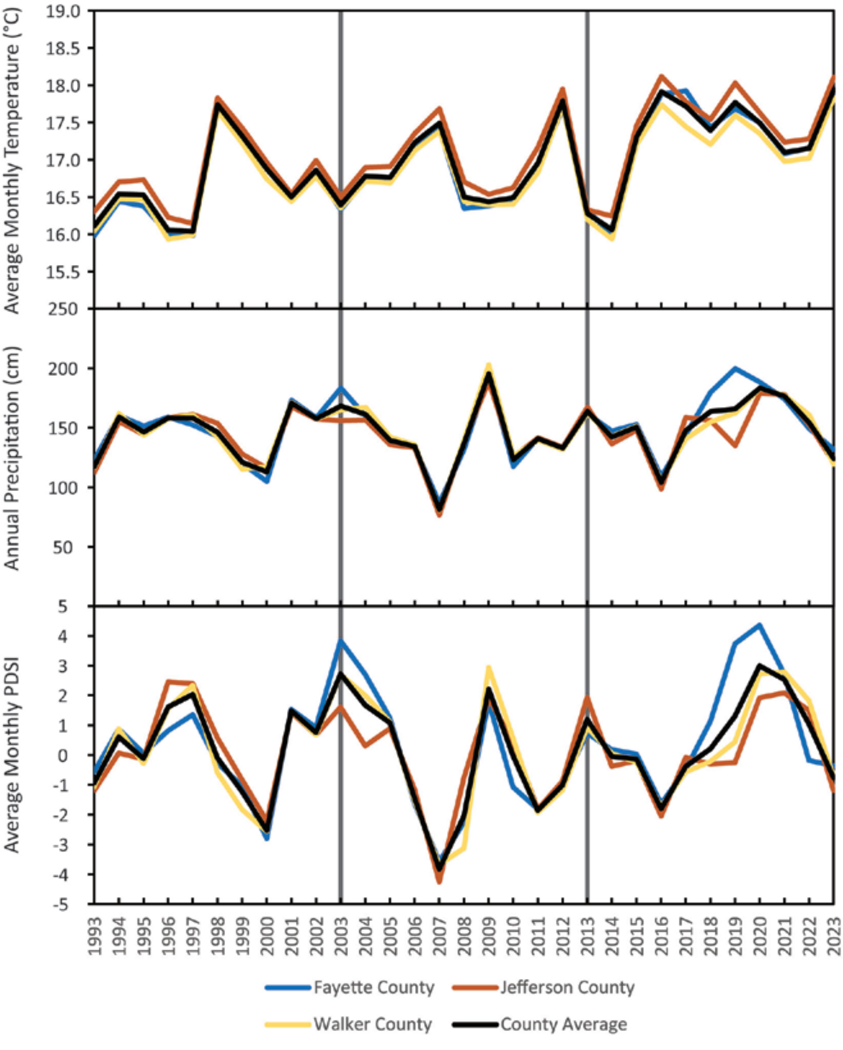

Figure 3. Average monthly temperature, annual precipitation, and average monthly Palmer Drought Severity Index for Fayette, Walker, and Jefferson counties, Alabama.

Eastern hemlock seedlings exhibited no general patterns across all stands. Eastern hemlock stands in Jefferson County were the only stands to experience a unanimous change (in the negative direction). Other ground flora was not common, but stands 5 and 11 did contain some grasses and ferns. Stands 11 and 6 had the greatest number of recorded seedlings, 261 and 258 respectively. The greatest decrease in seedling abundance (other than stand 9) occurred in stand 8 (–78%), decreasing from 94 seedlings in 2013 to only 21 in 2023. The greatest increase occurred in stand 3 (525%), increasing from four seedlings in 2013 to 25 seedlings in 2023. Eastern hemlock germination is facilitated by substrates such as mosses and coarse woody debris in advanced stages of decay (Friesner and Potzger 1944; Bormann and Platt 1958; Brown et al. 1982; Mladenoff and Stearns 1993; Rooney and Waller 1998). Moss substrate was observed in small amounts in five stands and was estimated to be 20% of ground cover in stand 8. Eastern hemlock seedlings were found on moss in each of these stands. We also observed eastern hemlock seedlings among pine and hardwood litter. Understory eastern hemlock outnumbered seedlings in every stand except for stand 11, which contained 261 seedlings and 238 understory stems. We suspect the number of recorded eastern hemlock seedlings is lower than the actual number of seedlings present on the sites as eastern hemlock seedlings can be difficult to locate depending on the substrate, but the trends in observed seedling abundance from one sampling period to the next provide insight into seed production and germination over time.

Diameter Structure

Stand diameter distributions generally exhibited a reverse J-shaped curve, indicating a regenerating stand (Nyland 1996). Stands 7 and 8 however, had fewer stems in the <4 cm dbh size class than the 4–20 cm dbh size class. For stand 7, this difference was relatively small (26%), and could be attributed to a large seeding event and growth of stems into the lower end of the 4–20 cm dbh size class in the time between sampling years. It is likely that more restrictive dbh size classes would provide more detailed insight into the structure of this stand, but our size classes were chosen for direct comparison to those of Hart and Shankman (2005). Stand 8 however, has more than twice the number of stems in the 4–20 cm dbh size class compared to the <4 cm dbh size class. The number of stems in the <4 cm dbh size class dropped to one-third of the 2013 sampling, but the number of stems in the 4–20 cm dbh size class remained roughly the same. Although nine canopy stems were recorded in 2013, none remained following the 2021 tornado (including the two stems >40 cm dbh). At least two stems grew into the 20–40 cm dbh size class, but these stems remain in the understory. The complete lack of eastern hemlock stems in the canopy is concerning, but it is expected that eastern hemlock will persist in the understory, given its shade tolerance. Nonetheless, this stand is perhaps most likely at risk for the complete loss of eastern hemlock.

The number of recorded stems <4 cm dbh decreased in seven stands from 2013 to 2023. For stands 1, 2, 4, and 5, this is partially attributable to recruitment to larger dbh size classes, as each of these stands had increases in the number of stems in larger dbh size classes from 2013 to 2023. Any recruitment that might have occurred in stands 8 and 9 is obfuscated by the 2021 tornado. Stand 10 had some stems recruit into the 20–40 cm dbh size class, but lost stems from 2013 to 2023 in the 4–20 cm dbh size class. With the exception of the 20–40 cm dbh size class for stand 3 (no stems recorded in the two most recent sampling years), stands 3, 6, and 7 show an increase in every dbh size class from 2013 to 2023. The >40 cm dbh size class experienced increases in each of these stands, as well as stand 4. Loss of stems >40 cm dbh could be attributed to localized weather events (such as tornados) or senescence. Although the oldest stem previously recorded in these stands was only 211 years old (relatively young for eastern hemlock), there could have been much older stems that were unable to be properly aged because of rotten centers (Hart and Shankman 2005). No direct comparisons or recruitment inferences can be made for stand 11, as this stand was not sampled in previous years. However, this stand contained 7 stems >40 cm dbh.

The 20–40 cm dbh size class had an increase in stems in all but stands 3 (no stems recorded in the two most recent sampling years) and 9 (no recorded stems in any dbh size class). Hart and Shankman (2005) found dbh and age of eastern hemlock (sampled from many of these sites) to be significantly and positively correlated. Eastern hemlock stems of this size have likely reached sexual maturity and can produce seed, indicating every stand has the potential to persist.

Conclusion

Myers et al. (2015) observed a general decrease in eastern hemlock seedling and canopy tree abundance from 2003 to 2013 but noted that these stands were still viable. We observed no unanimous trends in seedling abundance. Seedling trends could be influenced by the recency of seed crops and conducive climatic factors such as relatively moist and cool conditions. Seed crops produced from roughly 2016 to 2022 under favorable climatic factors could have resulted in more germination and subsequent seedling establishment, compared to stands without productive seed crops during this same time.

Of the 10 previously sampled stands, seven had a decrease in the number of canopy stems. We attribute this loss of canopy stems to localized disturbance and senescence. Larger canopy eastern hemlock are particularly vulnerable to wind disturbance, as many of them are established on thin soils and exposed bedrock. However, four of the 10 stands had an increase in the number of stems >40 cm dbh. Although there may be general loss of canopy presence throughout the stands, eastern hemlock is still recruiting into the largest size class, despite being at its range limit. Further, seven stands exhibited an increase in the number of stems 20–40 cm dbh. Even in instances where eastern hemlock has been removed from the canopy or restricted to size classes <40 cm dbh, stems are reaching sexual maturity and can produce seed crops.

Like Myers et al. (2015), we consider these stands to be viable, and suspect they will persist in the absence of catastrophic disturbance (with the exception of stand 9, which was catastrophically disturbed). Although disjunction provides some safety from the HWA, distance inhibits new seed sources when sexually mature trees are removed. We detected no HWA in our sampling, but observed evidence of wind disturbance in three of the 11 stands. Stand 8 experienced a loss of all canopy eastern hemlock, and stand 9 was catastrophically disturbed, to the point it had returned to the stand initiation phase of development. Sampling stand 9 was prohibitive, and we were unable to verify the total absence of any eastern hemlock stems.

Concerning genetic variation of these stands, it is likely they are genetically differentiated and contain unique alleles compared to eastern hemlock stands in the interior, contiguous range. Although Potter et al. (2012) did not sample the stands in our study area, they did sample eastern hemlock in the Bankhead National Forest, in Lawrence County, Alabama. Eastern hemlocks here exhibited a unique allele and were one of the most genetically distinct populations sampled. Eastern hemlock stands in our study area could represent another genetically distinct cluster of stands. Unfortunately, disjunction can increase the risks of inbreeding and population extirpation under additional forest stressors at the range limit (Potter et al. 2012). Genetic sampling of these stands would help inform their monitoring and preserve genetic diversity of the species.

We located an additional, previously-unsampled stand with a large number of eastern hemlock stems. Other undiscovered stands may exist, but we suspect no stands exist further south than those documented here. Disjunct stands such as these exist as relicts of the past, restricted to favorable microsites, somewhat sheltered by distance from the HWA but still vulnerable to other, non-species-specific forest disturbances. With the exception of stand 9, we consider each stand to be viable. Continued monitoring of these stands is imperative to quantify stand dynamics, especially in response to climate change effects and forest disturbance.

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