Preliminary Assessment of Climatic Sensitivity of Riparian Old-Growth Eastern Hemlock

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Eastern hemlock is a long-lived, slow growing climax species in North America currently undergoing a major decline in population due to a combination of effects derived from hemlock woolly adelgid (HWA) as well as changing climate patterns. Data was collected in an old-growth, riparian hemlock forest within the West Virginia University Research Forest to understand the effect of monthly climate factors (mean temperature, mean precipitation, and climate moisture index (CMI)) on hemlock radial growth. Results indicated that March mean temperature and May CMI of the current growth year are positively associated with hemlock growth whereas prior year summer conditions of each climate variable resulted in negative correlations. Spring temperature as well as winter precipitation of the current year also lessened hemlock growth. Many of the significant relationships ascertained by this study were well supported by other studies; however, increased June precipitation and CMI resulting in a reduction in growth may be explained by summer storm damage or root anoxia, resulting in lessened growth1, 2. Also, previous studies conducted south of the study area found winter precipitation to positively affect growth; this incongruence is explainable by differences in precipitation types and how heavy snow could contribute to hemlock damage2. Through the establishment of these relationships, it may be better understood how riparian, old-growth hemlock stands within central Appalachia will respond to changing monthly climate patterns.

Introduction

Eastern hemlock (Tsuga canadensis) is an important tree species found within the Northeast, Great Lakes, and Appalachian regions of the United States. It is noted for being an exceptionally long-lived foundational species, often taking hundreds of years to mature. Hemlock stands are unique in that they create a cool, moist microclimate that is conducive to deep organic soils associated with slowed decomposition[3]. The riparian nature of the stand examined in this report is consistent with eastern hemlock's favorability for the aforementioned climate conditions. The microclimate of hemlock, when paired with increased coarse woody debris retention derived from an old-growth structure, could allow for enhanced understory vegetation biodiversity[4].

Less than 1% of old-growth hemlock stands within the Appalachian region still exist[5, 6]. With the emergence of a deadly invasive insect, hemlock woolly adelgid (HWA), and changing regional climate, the decline of hemlock is expected to increase dramatically over the next century[7]. This depletion of a foundational species can significantly affect ecosystem function through altering forest carbon cycling, hydrology, and nutrient cycling; as well as by shifting species composition to better represent trees that are less sensitive to moisture stress (mesophytes)[3,8].

Current projections estimate that over the next century, the northeastern United States will see an increase of 2.9-5.3 degrees C in annual surface temperature with minimum winter temperatures expected to increase anywhere from 2.6 to 15.1 degrees C by 2081-2100[9]. This is significant in that HWA survivability is highly limited by winter minimum temperature[9]. Increased levels of CO_2 within the atmosphere have allowed for a projection of increased tree growth with hemlock displaying a change in gas exchange behavior[10]. Warming air temperatures associated with anthropogenic climate change have also been found to potentially increase hemlock radial growth; however, this effect is likely to be confounded by increased HWA activity associated with enhanced survival during winter months[1]. This appears to be most apparent in high elevation sites, as well as hemlock's northern range, due to spread of HWA being restricted by these low winter temperatures[11]. Hemlock found within the southern limit of its range appear to be most sensitive to moisture stress[2].

The key objective of this study is to examine the climatic sensitivity of a central Appalachian old-growth hemlock stand in proximity to a stream. Through utilizing hemlock cores and monthly climate data, this study aims to analyze climatic factors in relation to hemlock radial growth. This will give researchers a better understanding of how changing climate and pest invasion affect old-growth hemlock-hardwood stands within this region over the next century.

Methods

Field Sampling

Field data was collected in the West Virginia University Research Forest approximately 10 miles outside of Morgantown, WV at an elevation near 600 meters. Specifically, we sampled in the Hemlock Trail area - a stand of old-growth hemlock trees bisected by a stream. HWA has been detected at this site; however, the level of infestation is low. Inventory data was collected in August of 2019 with a total of five east aspect, 1/10th acre circular plots examined in this report. The plots were selected so that they were roughly at the same latitude, with a half-chain (1 chain = 66 feet) buffer from the stream, and at least a 3-chain buffer between plots. This study was considered to be preliminary as a limited number of plots were sampled.

Overstory data was collected at each plot by sampling trees ≥ 4" in diameter at breast height (DBH), or 4.5 feet. Within each plot, four eastern hemlocks were randomly selected, with an additional hemlock with the largest DBH selected for dendroclimatological analysis (for a total of five trees). Cores were taken at breast height on both northern and southern faces of each tree for a total of 10 cores per plot. Inventory data was then used to calculate trees per acre as well as basal (cross-sectional) area per acre values across diameter size classes.

Sample Processing

Cores were prepared for analysis by drying, mounting, and progressively sanding cores to 400 grit. Cores were then dated using the visual cross-dating approach known as the list method[12]. Cores were scanned at 2400 dpi and analyzed using the program "CooRecorder", a program used to measure the width of each annual ring, where measurements are saved into position files[13].

Statistical Analysis

Position files were then converted to rwl decadal files using the program "CDENDRO" so that ring width measurements could be further analyzed using program "COFECHA", a statistical program designed to determine cross-dating accuracy through establishing intercorrelation values between sample measurements[13, 14]. Ring width measurements were then standardized in program ARSTAN, using a 40-year cubic spline to eliminate growth variability due to tree aging or closed-canopy competition in order to create a residual chronology (autocorrelation removed) to be examined with climate variables[15].

Climate data was procured with PRISM climate group software to determine monthly climate variables for the geographic centroid (39.66053, -79.73631) of the study area[16]. Climate variables used in dendroclimatological (the science of using tree rings to reconstruct past climate) evaluation were maximum, minimum, and average monthly temperatures as well as monthly precipitation. These values were then used to calculate climate moisture index (CMI) through determining potential evapotranspiration (PET)[17]. CMI is a function of

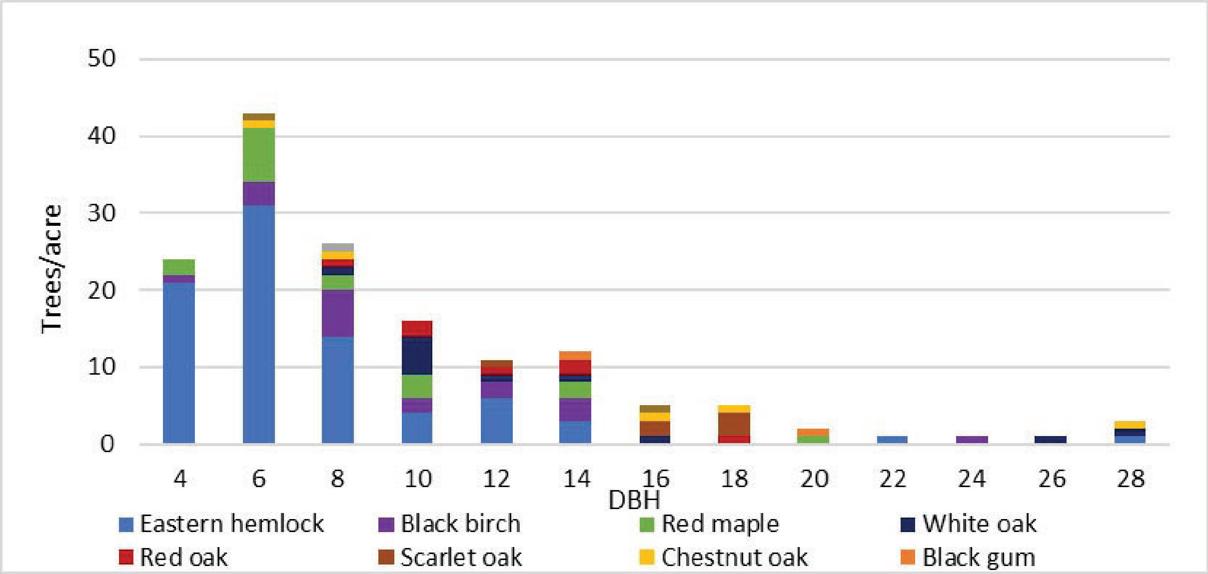

Figure 1: Diameter distribution of two-inch diameter classes.

monthly PET, precipitation, and elevation factors; this allows for concurrent analysis of these variables as an estimate of net water availability.

Using the program "DendroClim", we were able to analyze how mean temperature, precipitation, and CMI affected growth from August of the previous year to October of the current year[17, 18]. In doing this, correlation values between radial growth and each monthly climate variable could be examined; a significant positive value indicates increased annual hemlock growth due to favorable climate conditions. Due to the chronology sample size being 50 cores from 25 trees, it was possible to analyze climate variables from 1959 to 2019 which had an expressed population signal value greater than 0.85[19].

Results

Plot inventory data was used to determine that the study area had 300 trees per acre and a basal area of 182.5 ft^2/acre. On top of this, of the 150 trees sampled, 81 one of them were eastern hemlock (54%). Black birch and red

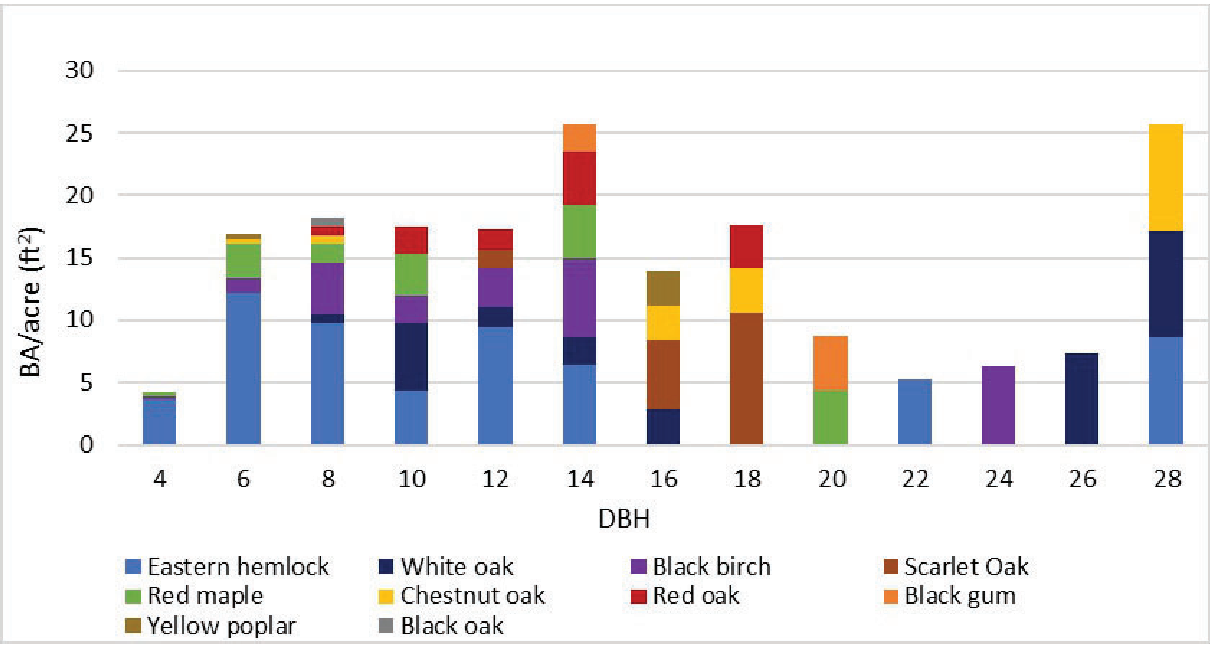

Figure 2: Basal area per acre (ft^2) by species.

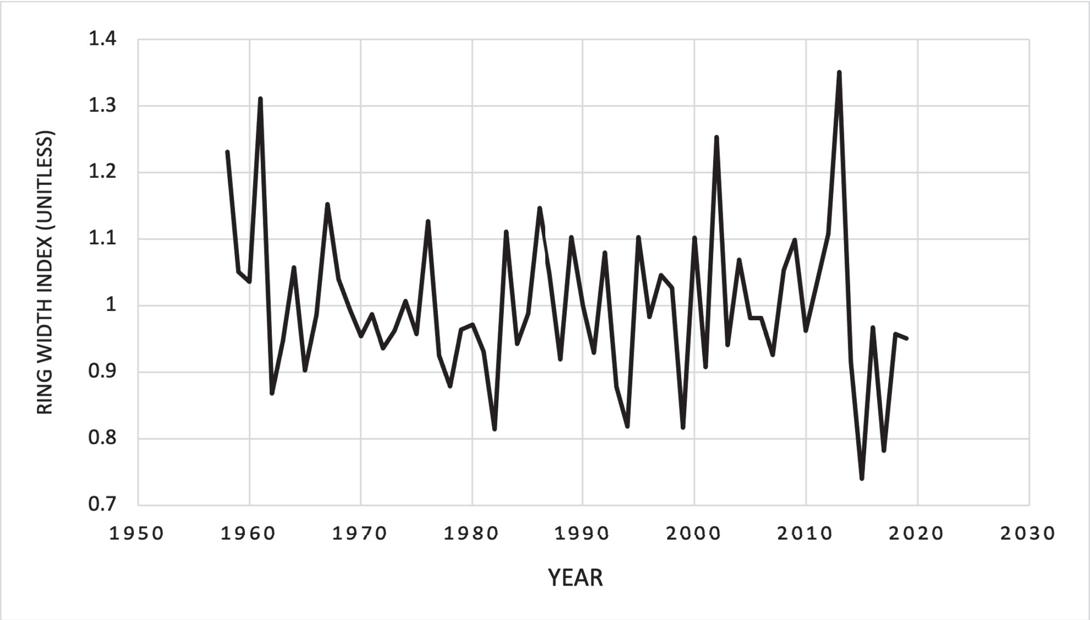

Figure 3: Standardized annual ring width chronology by year.

maple constituted 12% and 11% of the species composition, respectively. The rest of the stand was comprised of oak species (most notably, northern red oak, scarlet oak, and white oak) as well as small populations of black gum and yellow poplar. The diameter distribution of the stands was reverse-j in shape, which is characteristic of uneven aged h

emlock stands (Figure 1)[20]. *Figure* 2 displays per acre values of basal area (ft^2) of all tree species within the stand across two-inch diameter classes.

After running core samples through COFECHA, series intercorrelation was determined to be well within the acceptable range at 0.495, this indicates strong intercorrelation among samples. Using program ARSTAN, mean correlation between trees was determined to be 0.36 with an agreement with the population chronology of 0.931. Mean sensitivity of the chronology displayed a value of 0.187. *Figure 3* displays the relative annual ring widths over the growth-climate analysis period (1959-2019).

Figure 4 displays the monthly correlation values between radial growth and mean

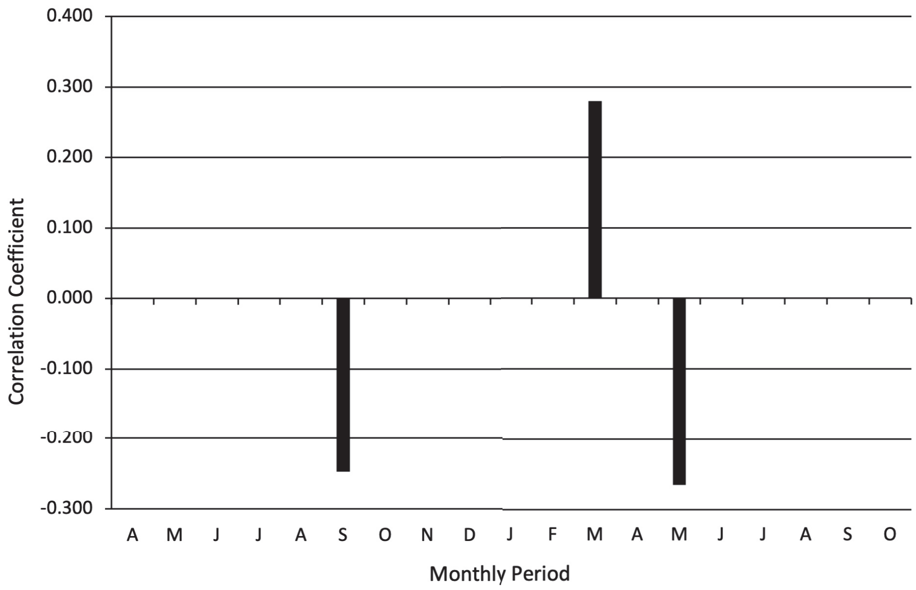

Figure 4: Correlation coefficients between radial growth and mean monthly temperature.

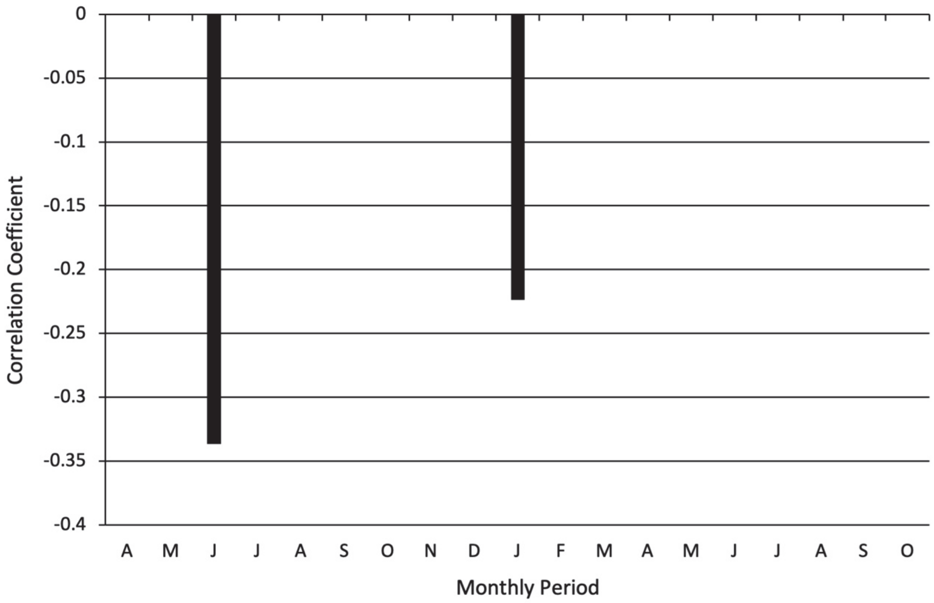

Figure 5: Correlation coefficients between radial growth and monthly precipitation.

monthly temperature of the previous and current year. Increased mean summer temperature was found to negatively impact hemlock growth with increased September temperature of the prior growing season and May temperatures of the current growing season correlating negatively at values of -0.25 and -0.26 respectively. Increased early spring temperature of the prior growing season correlated positively with a correlation of 0.28 in March.

Figure 5 shows the monthly correlation coefficients between annual radial growth and monthly precipitation of the previous and current year. Increased summer precipitation of the prior year was found to negatively impact hemlock growth at -0.34 correlation, while increased January precipitation also presented as a negative, significant correlation.

In *Figure 6*, previous and current year CMI values were analyzed with respect to hemlock radial growth. June of the prior year CMI values correlated negatively with growth at a correlation of -0.34; however, summer CMI values of the current year were found to be positively correlated (0.24) with growth.

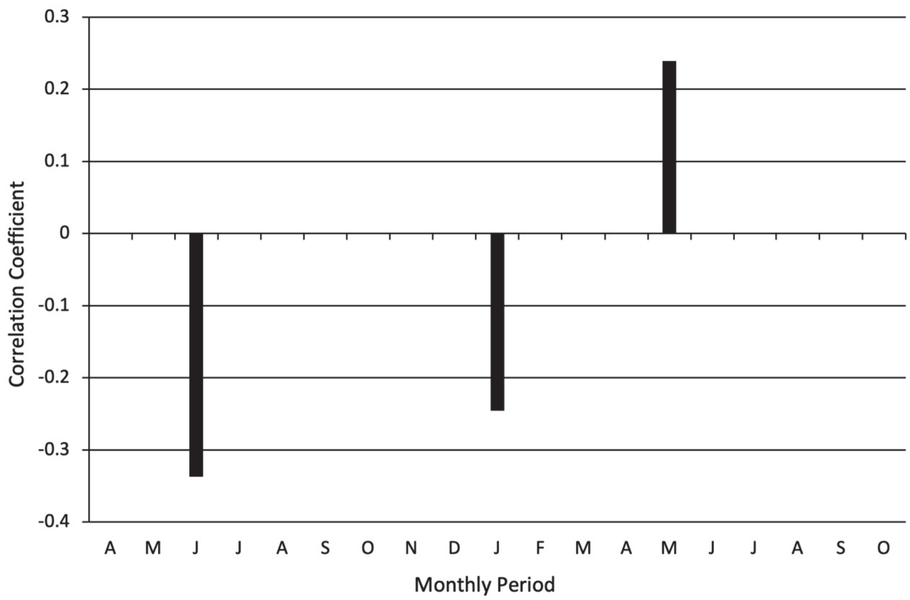

Figure 6: Correlation coefficients between radial growth and monthly climate moisture index (CMI).

Increased moisture availability in January of the current year was found to negatively correlate with radial growth (-0.24).

Discussion

Stand diameter was found to be reverse-j in distribution, which is in line with analysis of D'Amato et al.[20]. Further, a commonality between these studies can be drawn by considering both exhibited a greater range of representation among size classes as well as containing a high density of large trees. Meaning, this distribution is consistent with the complex structure of other old-growth hemlock stands brought about by gap-scale disturbance such as windthrow due to the shallow rooting nature of hemlock[21].

Species composition within the study area heavily favored eastern hemlock, accounting for 54% of all sampled trees. This is similar to other old-growth hemlock stands within northern West Virginia which exhibited a 60% hemlock representation in trees per acre[5]. Similarly, red maple and black birch exhibited 11% and 10%, respectively, in 2006[5]. This adds credence to the notion that hemlock stands within this region are likely to be replaced by these counterparts as red maple and black birch are already widely represented within the stand[3]. This has potential implications for carbon and nitrogen cycling rates as birch sequesters a greater amount of nitrogen (N) and less carbon (C) than hemlock with potential losses of 8% C uptake due to hemlock removal[11]. Organic mass has been found to be greater in hemlock plots than its mesophytic counterparts, perhaps due to a combination of hemlock microclimate and species biology[3]. Respiration rates are increased in birch stands, leading to potential implications for CO_2 source/sink dynamics[3].

Further, species composition within the study area indicates slow species composition shifts expected in riparian hemlock stands within central Appalachia[22]. HWA was first detected in northern West Virginia in 2002, where 4 years after infestation, hemlock stands within Cathedral State Park (CSP) had actually experienced an increase in hemlock representation by total tree count[5]. It is reasonable to deduce that the Hemlock Trail had not yet experienced a discernible change in hemlock density due to HWA invasion because of its riparian status and low level of infestation. This is inconsistent with many studies suggesting that hemlock mortality occurs within a timeframe of 4-10 years after infestation[23].

Significant positive radial growth relationships were determined in mean March temperatures (0.28) as well as in CMI in May (0.24) of the current year. A warmer early spring could allow for rapid utilization of stored resources through an early start in xylem tissue production in a season where moisture conditions are often favorable due to low evapotranspiration rates. Warm winter and spring temperatures positively correlating with short-term hemlock growth has also been found within old-growth hemlock stands by Bigelow et al.[1]. Heightened levels of CMI indicate greater water availability and thus, the results indicate that hemlock individuals exhibit increased growth due to greater water availability during early summer. These climatic factors are especially conducive to hemlock growth as the species tends to favor cool, humid sites[3].

However, significant negative growth relationships associated with elevated mean temperatures within the study area were determined in September of the prior year (-0.25) as well as May of the current year (-0.26). This may be an expression of moisture stress as the results indicate a positive correlation with May precipitation and CMI. A strong negative relationship has been found between hemlock growth and August of the prior year temperatures in southern hemlock stands[2]. A 2013 study conducted by Chhin et al. in northern, riparian white pine stands, found moisture stress derived from high mean summer temperatures negatively impacted growth[24]. With elevated temperatures within late summer months, drought stress may cause hemlock to reduce photosynthesis in order to limit stomatal conductance necessary for carbon uptake.

This study suggests that precipitation factors were only found to have negative growth relationships with hemlock. June precipitation of the prior year provided a strong negative relationship (-0.34) as did January of the current growth year (-0.22). This relationship with June precipitation is in opposition to prior studies suggesting that high summer precipitation positively impacted hemlock growth[1]. The findings also suggested that June CMI of the prior year (-.34). negatively impacted growth. This may be caused by wind damage enacted on hemlock crowns during storms or the over saturation of the soil profile leading to root anoxia.

Enhanced levels of January precipitation in the current year may result in greater damage caused by snow or frost, explaining the reduction of growth for the current year as hemlock will expend growth resources to recover from damage or needle loss. However, it is important to note that precipitation outside of this range could heighten or diminish this effect due to variability in precipitation type outside of central Appalachia; winter rain would not have the same damaging effect as a snowstorm. This may be supported by a prior study conducted on hemlock growth at the southern limit of its range in that February precipitation of the current year encouraged growth[2]. The effect of differing precipitation types could have implications for determining the future southern extent of hemlock's range as well as how hemlock may adapt to changes in late winter or early spring precipitation types. A study conducted in the Northeast found that warm January temperatures increase the risk of basal area increment decline by 45% in HWA infested sites[25]. Increased survivability of HWA due to higher winter temperatures may produce an interesting dynamic with this potential pattern of shifting precipitation types.

This study determined that riparian, old-growth hemlock respond positively in radial growth to warm early springs due an early start in the growing season when water demand is low. Increased moisture availability in May of the current growing season was also found to be beneficial to hemlock growth. However, it was found that hemlock within this site were negatively impacted by increased temperature in September of the prior growing season as well as in May of the current season which may be caused by increased moisture stress[24]. Increased summer and winter precipitation were also found to negatively impact hemlock growth, perhaps due to precipitation damage or root anoxia from oversaturated soils.

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Competing Interests

The author declares no competing interests.

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