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Dendroecological Potential of Appalachian Riverscour Woodland Trees

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Abstract: Appalachian riverscour woodlands are intermittently flooded areas along high-energy rivers characterized by exposed bedrock and poorly developed sandy soils, high plant diversity, and scattered and stunted trees. These sites can be negatively impacted by dam construction and alterations to river hydrology, trampling associated with riverside recreation activities, and non-native species. In West Virginia, little is known about the development of riverscour woodlands or the growth and hydroclimate sensitivity of associated tree species. In this exploratory study, our objectives were to evaluate our ability to crossdate riverscour woodland trees (i.e., assign accurate calendar years to annual growth rings) as well as determine stand structure and tree establishment patterns at one site along the New River in Fayette County, West Virginia. In addition, for two species, *Ulmus americana* and *Diospyros virginiana*, we examined annual growth trends and relationships between tree growth and monthly hydroclimate, including streamflow, precipitation, and Palmer Drought Severity Index (PDSI). Seventy-three percent of all ring-width measurement series were crossdated, but results were mixed across species. Most trees were less than 50 years old and no trees established before the late 1940s. Both *U. americana* and *D. virginiana* were highly sensitive to April–August hydroclimate, but differed in response to previous year moisture availability. These findings provide new direction for the use of riverscour woodland trees in future dendroecological studies.

Keywords: New River; riverscour; dendrochronology; hydroclimate; American elm; persimmon

Introduction

Appalachian riverscour plant communities are characterized by intermittent flooding, exposed bedrock, and poorly developed sandy soils (Vanderhorst *et al*. 2007; Wolfe *et al*. 2007). These riparian communities, found along high-energy rivers such as the Gauley, New, Potomac, and Tygart in West Virginia, are relatively small in area and fragmented (WVDNR 2022a). Like other insular plant communities, these sites harbor high levels of biodiversity relative to the surrounding landscape (Cartwright and Wolfe 2016). Interactions between underlying bedrock, channel landforms, and the frequency and intensity of scouring determine community succession by controlling the amount and type of sediments available for plant establishment, growth, and persistence (Nilsson and Svedmark 2002; Podniesinski *et al*. 2010; Perles *et al*. 2022). Riverscour prairies, for example, are dominated by warm season grasses such as *Andropogon gerardii* Vitman (big bluestem) and *Panicum virgatum* L. (switchgrass) with deep root systems that withstand scouring and drought conditions, while woodlands of scattered and stunted *Platanus occidentalis* L. (American sycamore), *Betula nigra* L. (river birch), and *Ulmus* (elm) species develop where disturbance is less frequent or where tree establishment sites are sheltered from high-velocity streamflow or flood debris (Vanderhorst *et al*. 2007). Regardless of successional stage, site quality can be negatively impacted by multiple factors including dam construction and alterations to river hydrology, trampling associated with recreation activities (e.g., boating, fishing), and periodic establishment of non-native invasive species (WVDNR 2022a). While there have been efforts to describe and monitor riverscour plant communities in the context of these drivers of change (e.g., Wolfe *et al*. 2007; Perles *et al*. 2022), no studies have evaluated the potential use of riverscour woodland trees for dendroecological analysis.

Dendrochronology has been used to examine ecosystem change and tree growth response to climate and hydrology at several bottomland and floodplain sites in eastern North America (e.g., Copenheaver *et al*. 2007; Anderson and Mitsch 2008; White and Smith 2015; Saladyga *et al*. 2020). These dendroecological studies provide historical context for floodplain management and species conservation by evaluating riverside tree establishment, mortality, growth, or sensitivity to changing hydroclimatic conditions. For example, recent mortality of *Quercus palustris* Münchh. (pin oak) was found to be linked to prolonged flooding at one bottomland site in the Meadow River watershed in Greenbrier County, West Virginia (Saladyga *et al.* 2020). Others have identified species-specific responses to variation in the local hydrologic regime in Virginia (Copenheaver *et al.* 2010), Ohio (Dudek *et al*. 1998) and Illinois (Mitsch and Rust 1984), while slight changes in floodplain elevation have also been shown to influence the climate sensitivity of riparian tree species (Copenheaver *et al*. 2007). Each of these studies demonstrates the application of dendrochronology in bottomlands or along reservoir shorelines, but none have investigated tree growth dynamics in riverscour communities subjected to intermittent scouring and drought conditions.

In this exploratory study, we first describe the composition and structure of one riverscour woodland site located along the New River in Fayette County, West Virginia (Fig. 1A). We then examine multiple characteristics of tree establishment, growth, and hydroclimate sensitivity. Specifically, our objectives were to: (1) describe tree species composition and stand structure at the study site, (2) assess our ability to crossdate multiple species (i.e., assign accurate calendar years to annual growth rings), (3) determine tree age and establishment patterns, (4) evaluate annual growth trends in selected species, and (5) examine relationships between monthly hydroclimate and tree growth. The results of this study will provide new insights for the use of riverscour woodland trees in future dendroecological studies with an aim to inform the management and conservation of these dynamic riparian plant communities.

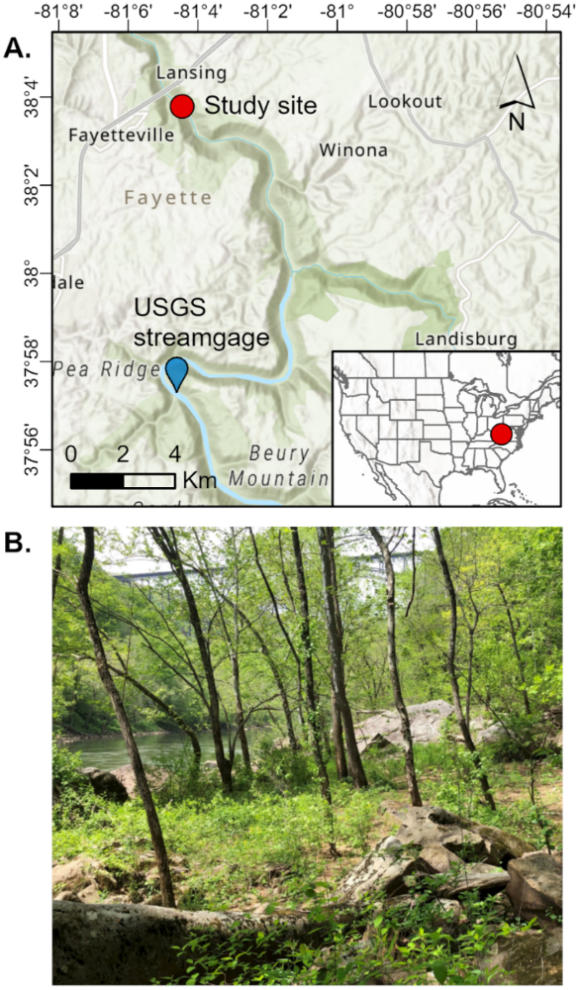

Figure 1. Riverscour woodland study site. Location of the study site within New River Gorge National Park & Preserve and the USGS streamgage (03185400) at Thurmond (A). View of the study site looking west toward the New River Gorge bridge (B).

Materials and Methods

Study Site

The 0.3-ha (120 m x 25 m) study site is located along the New River approximately 350 m upstream of the Fayette Station bridge within New River Gorge National Park & Preserve (38°3'46" N, 81°4'25" W) (Fig. 1A). The site stretches the distance been two West Virginia Natural Heritage

Program vegetation plots (NERI.358 and NERI.359) that were last surveyed in September 2003. The area is underlain by the Pottsville-New River (sandstone) formation and soils are sandy, well-drained, and slightly acidic and exposed bedrock is common (WVDNR 2019) (Fig. 1B). Both plots are classified as New River Sycamore – River Birch Riverscour Woodland (WVDNR 2022b), while other tree species include *Diospyros virginiana* L. (common persimmon), *Fraxinus pennsylvanica* Marsh. (green ash), and *Ulmus americana* L. (American elm) (WVDNR 2019). A variety of herbs and grasses are present in the area, including *Conoclinium coelestinum* (L.) DC. (blue mistflower), *Lysimachia ciliata* L. (fringed loosestrife), *Solidago juncea* Ait. var. juncea (early goldenrod), *A. gerardii*, *Chasmanthium latifolium* (Michx.) Yates (river oats), *Tripsacum dactyloides* (L.) L. (eastern gammagrass), and the exotic invasive *Microstegium vimineum* (Trin.) A. Camus (Japanese stiltgrass) (WVDNR 2019). The climate is temperate, with an average annual temperature of 11.5°C and monthly temperatures ranging from 0.0°C in January to 21.9°C in July (1991–2020) (NOAA 2023). Average annual precipitation is 121.4 cm, with monthly totals ranging from 7.7 cm in October to 13.7 cm in July (1991–2020) (NOAA 2023).

Hydroclimate Data

We obtained monthly discharge (hereafter “streamflow”) data for the New River at Thurmond, West Virginia (1982–2022) (USGS 2023). This streamgage station is located 21 km upstream from the study site (Fig. 1A) and 64 km downstream of the Bluestone Dam. We also obtained monthly precipitation data for Fayette County, West Virginia (1940–2022) and monthly Palmer Drought Severity Index (PDSI) data for West Virginia Climate Division 4 (1940–2022) from the National Oceanic and Atmospheric Administration’s Centers for Environmental Information (NOAA 2023). The streamflow and precipitation datasets are direct measurements of local hydrologic conditions, while PDSI is an index of regional net surface soil moisture with values ranging from -4 (extreme drought) to +4 (extremely wet) (Palmer 1965; Alley 1984). Annual time series of these data indicate a gradual increase in moisture availability since the 1940s (Fig. 2).

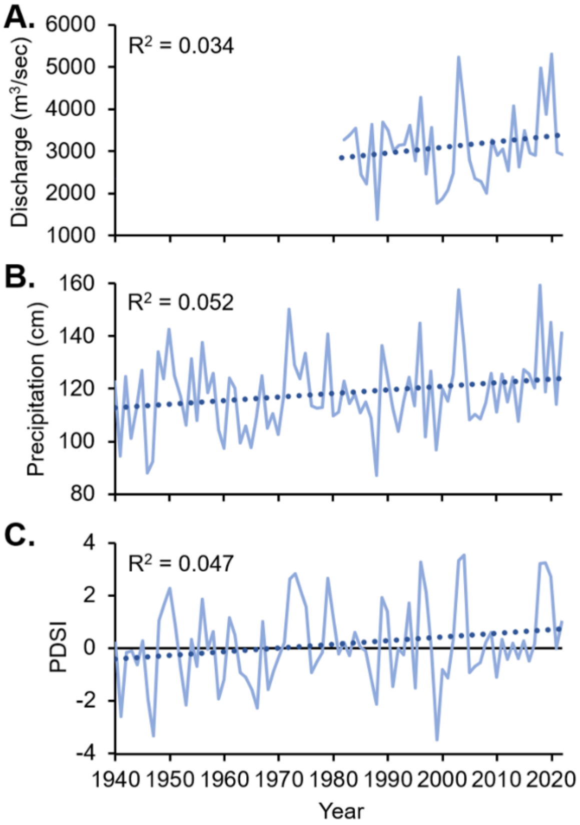

Figure 2. Annual hydroclimate data. New River total discharge (“streamflow”) at Thurmond, West Virginia (1982–2022) (A). Total precipitation for Fayette County, West Virginia (1940–2022) (B). Average Palmer Drought Severity Index (PDSI) for West Virginia Climate Division 4 (1940–2022) (C). A linear regression trend line is shown for each time series.

Field Methods

In May 2022, we established five point-quarter transects perpendicular to the river (Mueller-Dombois and Ellenburg 1974; Piao *et al.* 2009). This plot-less method of data collection assumes that trees are randomly distributed throughout a study area. Transect length (13–18 m) and spacing between transects (10–30 m) varied depending on accessibility and width of the riverscour plant community. A random number generator was used to locate one sampling location along each transect that was divided into four quadrants. At this location, the closest tree to the center point in each quadrant was identified to species and its diameter at breast height (DBH; minimum of 7.5 cm), status (live or dead), distance to the center point, and any notable features (e.g., stem damage, vine) were recorded (n = 20). These transect-based data were used to calculate average DBH (± 1 standard deviation) and stem density (trees/ha) for the site.

We collected two core samples from each of the point-quarter transect trees at the lowest possible height above ground. In addition, we selectively sampled trees outside of plots in an effort to increase sample size for the most abundant species. The total number of trees sampled was limited to fewer than 35 per our research and collecting permit issued by the National Park Service (NERI-2022-SCI-0007).

Tree-Ring Dating and Analysis

Tree cores were air dried, mounted, and then sanded until cells were clearly visible under magnification (Speer 2010). We visually crossdated (Schweingruber *et al.* 1990) and then scanned core samples using a high-resolution (3200 dpi) flatbed scanner (1200XL, EPSON, Suwa, Japan) (Fig. 3). We used the image analysis software CooRecorder 9.8.1 (Larsson 2016) to measure annual rings to the nearest 0.01 mm and each measurement series (i.e., core sample) was statistically crossdated using the program CDendro 9.8.1 (Larsson 2016). All dating was quality checked using the program COFECHA (Grissino-Mayer 2001).

To visualize stand structure and establishment patterns, we graphed the relationship between DBH and tree age for all species sampled at the study site. If a core sample did not include pith, we estimated tree age using the pith estimator tool in CooRecorder 9.8.1 (Larsson 2016). Trees with an estimated pith year that added more than 10 years to the inner ring were excluded from the graphical representation. We did not attempt to model diameter-tree age relationships due to limited sample size.

We used the program ARSTAN (Cook 1985) to develop residual annual ring-width indices for *U. americana* and *D. virginiana;* the two species with 10 or more measurement series that were each at least 20 years long. Raw ring-width measurements were standardized using the negative exponential growth model to remove age-related growth trends (Cook 1985). The resulting ring-width indices have a mean of 1.0 and represent annual growth variation at the site. We report two common chronology statistics for both species: series intercorrelation (i.e., average Pearson's correlation coefficient for individual measurement series when compared to all other dated series) and average mean sensitivity (i.e., average interannual ring-width variability for all dated series). Finally, we used correlation analysis to assess the relationship between *U. americana* and *D. virginiana* growth during the common period (1988–2021), when there was a sample depth of at least five series in both chronologies. For both species, we identified notable years of below- or above-average growth as those more than one standard deviation from the index mean during this time period.

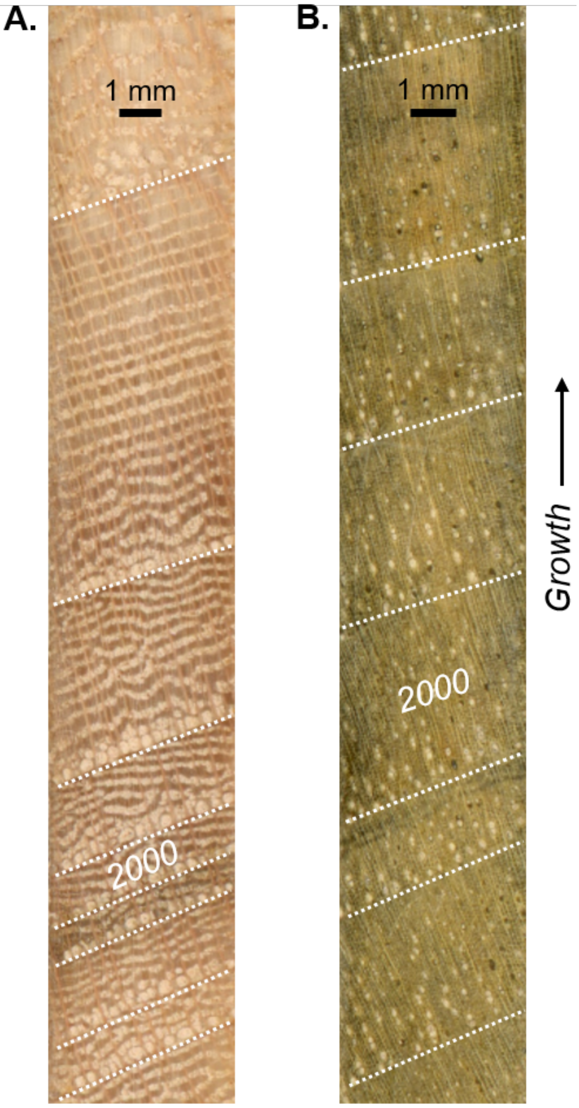

Figure 3. Scanned images of example tree core samples. *Ulmus americana* (A). *Diospyros virginiana* (B). Annual growth-ring boundaries are highlighted for visual interpretation. Note the relatively narrow (1999) and wide (2003) rings in both samples.

Hydroclimate-Tree Growth Analysis

We examined relationships between monthly hydroclimate (i.e., streamflow, precipitation, and PDSI) and the *U. americana* and *D. virginiana* annual ring-width indices from 1988 to 2021.

Pearson's correlation coefficient was calculated for each month of hydroclimate data during an 18-month window beginning in the previous May and ending in October of the current growing season. We used the residual ring-width indices in the correlation analysis because these lacked significant temporal autocorrelation (Copenheaver *et al.* 2007; Kincaid 2017; Saladyga *et al*. 2020). Statistically significant relationships between monthly hydroclimate and tree growth were identified as those that exceeded the 95% confidence interval ($p < 0.05$).

Results

Species Composition and Stand Structure

All trees observed in point-quarter transects were living at the time of data collection (n = 20). *U. americana* and *D. virginiana* occurred most frequently, while eight other tree species were observed, including the exotic invasive *Ailanthus altissima* (Mill.) Swingle (Tree-of-heaven) (Table 1). Average DBH was 23.5 ± 9.7 cm and stem density was 370 trees/ha. Six trees (30%) supported vine growth (*Toxicodendron radicans* (L.) Kuntze (eastern poison-ivy) and *Celastrus orbiculatus* Thunb. (oriental bittersweet)) and external structural damage was present on the stem of four trees (20%).

Table 1. Number of trees systematically (transect) and selectively (target) sampled by species. Also shown are the total number of measurement series and proportion that were dated.

Tree species	Transect/ target trees	Total series	Dated series (%)
Acer rubrum	1/0	2	100.0
Acer saccharinum	1/0	2	50.0
Ailanthus altissima	1/0	2	100.0
Catalpa speciosa	1/0	2	100.0
Diospyros virginiana	5/7	24	66.7
Liriodendron tulipifera	2/0	4	100.0
Oxydendrum arboreum	1/0	2	100.0
Platanus occidentalis	2/4	12	41.7
Robinia pseudoacacia	1/0	2	100.0
Ulmus americana	5/2	14	92.9

Crossdating Assessment

We collected core samples from a total of 33 trees, including 20 point-quarter transect trees and 13 trees that were selectively sampled across the study site (Table 1). We successfully crossdated 73% of all measurement series, but success rate varied by species (Table 1). For example, only 42% of the *P. occidentalis* and 67% of the *D. virginiana* series could be dated due to heart rot, structural damage (particularly in recent growth years), and/or indistinguishable growth rings in some samples. We were more successful with tree species that had less structural damage, including, for example, *U. americana*, *Acer rubrum* L. (red maple), and *Liriodendron tulipifera* L. (tulip tree) (Table 1).

Tree Age and Establishment

We plotted tree age against DBH for 25 trees with pith or estimated pith year (Fig. 4). We were not able to estimate pith year for eight trees due to substantial heart rot. Most trees (64%) were less than 50 years old. These trees, including all *D. virginiana*, had a DBH between 8 and 28 cm, with the exception of a fast-growing *Catalpa speciosa* Warder ex Engelm. (northern catalpa), which had a DBH of 38 cm (Fig. 4). Tree species with individuals more than 50 years old included *U. americana*, *P. occidentalis*, *L. tulipifera*, *A. rubrum*, and *A. saccharinum* L. (silver maple), each with a DBH between 17 and 43 cm (Fig. 4). Eight trees (32%) established in the late 1940s-1950s, while the remainder established during subsequent decades between the 1960s and 2000s.

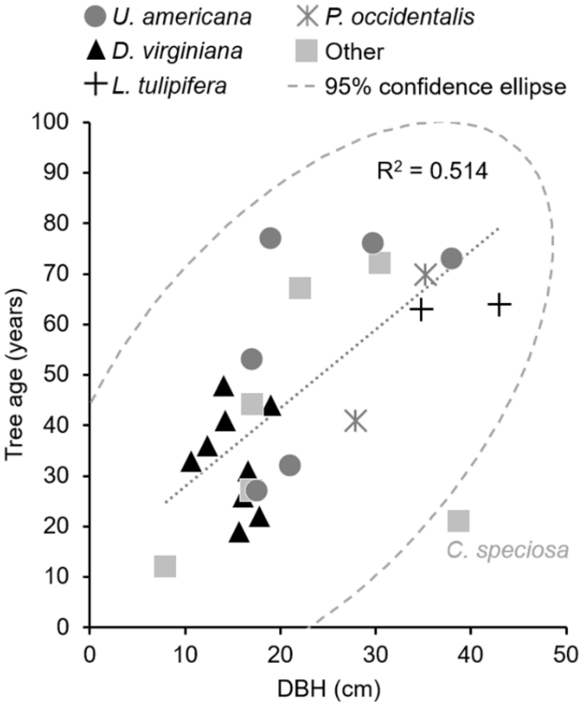

Figure 4. Relationship between diameter at breast height (DBH) and tree age (n = 25). "Other" includes *Acer rubrum* (1), *Acer saccharinum* (1), *Ailanthus altissima* (1), *Catalpa speciosa* (1), *Oxydendrum arboreum* (1), and *Robinia pseudoacacia* (1). The linear regression trend line excludes the outlier and is for display purposes only.

Tree-Ring Chronologies

Annual ring-width chronologies were developed for *U. americana* (1948–2021) and *D. virginiana* (1975–2021) (Table 2, Fig. 5). Raw ring-width measurements were, on average, slightly wider and more variable in *U. americana* (2.04 ± 1.23 mm) compared to *D. virginiana* (1.78 ± 0.50 mm) during the full chronology periods. There was, however, a marked increase in *U. americana* average ring width since 2003 (3.05 ± 0.72 mm) compared to prior years (1.35 ± 0.74 mm) (Fig. 5). The two ring-width indices were significantly correlated (r = 0.62, p < 0.001) during the common period (1988–2021). During this time, notable years of below-average ring-width index values common to both species included 1988, 1999, 2005, and 2021, while 2003 was the only notable above-average growth year shared by both species.

Table 2. Descriptive statistics for the *Ulmus americana* and *Diospyros virginiana* annual ring-width chronologies.

Statistic	*Ulmus americana*	*Diospyros virginiana*
Samples (trees/measurement series)	7/13	8/11
Mean series length (years)	46.0	27.0
Series intercorrelation	0.44	0.43
Average mean sensitivity	0.36	0.35
Full chronology period	1948–2021	1975–2021
Measurement series ≥ 5	1958–2021	1988–2021

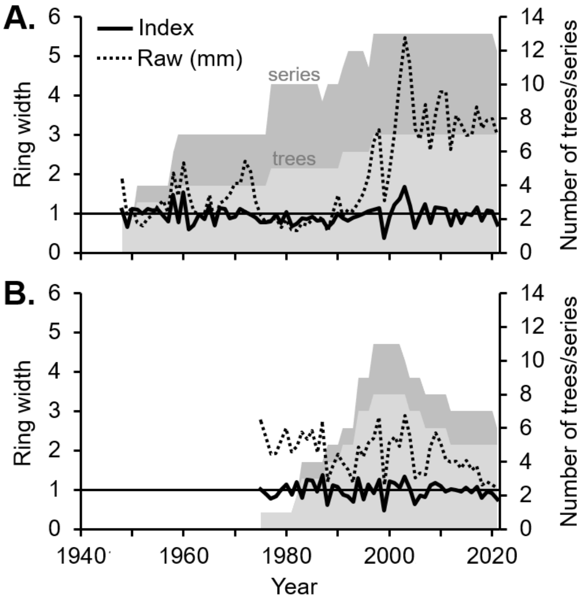

Figure 5. Annual ring-width chronologies and sample depth (trees and measurement series). *Ulmus americana* (A). *Diospyros virginiana* (B).

Hydroclimate-Tree Growth Relationships

We identified statistically significant (p < 0.05) relationships between *U. americana* growth and spring, summer, and early fall monthly hydroclimate variables (Fig. 6A). Specifically, April and June–July streamflow, May–June and previous year July precipitation, and April–October PDSI were positively correlated with *U. americana* growth. Significant (p < 0.05) correlations between *D. virginiana* growth and hydroclimate were also identified (Fig. 6B). August streamflow, May–July precipitation, and April–August PDSI were positively correlated with *D. virginiana* growth, while previous year June streamflow and PDSI were negatively associated with tree growth.

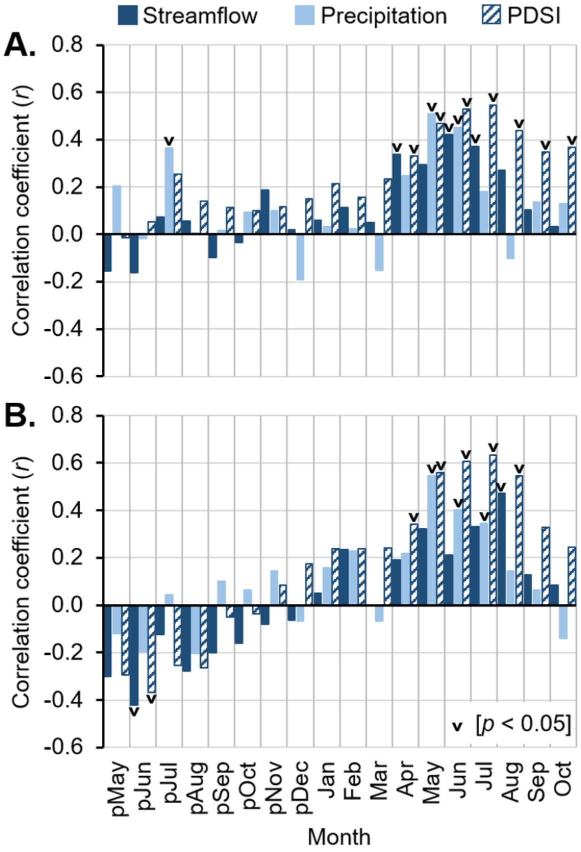

Figure 6. Relationships between monthly hydroclimate and annual tree growth for 1988–2021. *Ulmus americana* (A). *Diospyros virginiana* (B). Analysis included previous May through current growing season October hydroclimate variables.

Discussion

This exploratory study provides new insights into the establishment, growth, and hydroclimate sensitivity of riverscour woodland trees. Our results indicate that multiple species, particularly *U. americana* and, to a lesser extent, *D. virginiana*, can be used to examine ecological changes in these dynamic riparian plant communities. We dated approximately three-quarters of all ring-width measurement series, with the remainder having heart rot, structural damage, or, in some cases, indistinguishable growth rings. We attribute these difficulties to injuries caused by blunt force trauma from by rocks, logs, and other floating debris carried by occasional flood waters. Although we could not date many of the *P. occidentalis* samples, we are encouraged by the work of other researchers who have done so in different riverine contexts (e.g., Oswalt and King 2005; Anderson and Mitsch 2008). This abundant and relatively long-lived species has the potential to supplement other growth records (i.e., *U. americana*) and improve our understanding of riverscour ecology.

The oldest trees at the site established in the late 1940s and early 1950s. Although sample size was limited, this timing coincides with the construction of the Bluestone Dam, which became operational in 1949 and has since served to reduce flood risks in the Lower New River Basin and Ohio Valley (USACE 2023). While flood control measures benefit human communities and industry, riparian plant communities in watersheds with regulated flow volumes are particularly vulnerable to biodiversity loss (Johnson 2002). A mid-20th century decrease in flood frequency and severity or a change in its timing may have created conditions needed for tree establishment and persistence leading to woodland succession at some riverscour sites. Additional study sites and sample depth would be necessary to assess this hypothesis, however, which is complicated by the absence streamflow data for the relevant stretch of the New River before dam construction. Also, the lack of dead wood at these riverscour sites limits our ability to supplement or extend records of tree establishment and plant community succession.

In addition to assessing the timing of tree establishment, we examined annual growth trends in *U. americana* and *D. virginiana*. These ring-width chronologies provide baseline information for two underrepresented species in the tree-ring literature (Grissino-Mayer 1993; ITRDB 2023). Average mean sensitivity values were within an acceptable range for crossdating (Speer 2010), and series intercorrelation values would likely improve if additional measurement series were available. There was significant correlation between both ring-width indices during the common period (1988–2021) and both species responded similarly to regional drought (e.g., 1988 and 1999) and pluvial (2003) conditions (NOAA 2023). For *U. americana*, the marked increase in raw ring-width since 2003 suggests that an analysis of growth release (or suppression) events might be appropriate (Lorimer and Frelich 1989). With a larger sample size, this analysis could be used to infer the timing and severity of disturbance events possibly linked to changes in the flood regime. Dating injuries or anatomical variation preserved in the growth rings of *U. americana* and other longer-lived riverscour tree species might also provide a record of past disturbance (e.g., Meko and Therrell 2020). Furthermore, riparian populations of *Ulmus* species at the New River Gorge are, at present, unaffected by Dutch elm disease. Future sampling and analysis of *U. americana* would ensure an archive of the growth record before it is lost to disease; an approach that has been recommended for other tree species threatened by invasive pests or pathogens (Hessl and Pederson 2013).

Our analyses of hydroclimate-tree growth relationships indicate that tree growth at the study site is moisture-limited. There were, however, some differences in hydroclimate sensitivity observed for *U. americana* and *D. virginiana*. During the core growing season (April–August), streamflow was more consistently associated with *U. americana* growth, while precipitation and PDSI were more strongly associated with growth in *D. virginiana*. This difference in hydroclimate sensitivity between species is possibly due to differences in tree age and diameter (Trouillier *et al.* 2019); young, small-diameter *D. virginiana* may be more sensitive to changes in surface moisture compared to older, larger-diameter *U. americana*. In addition, previous year June streamflow and PDSI were negatively associated with *D. virginiana* growth, indicating a possible threshold in antecedent moisture availability or lingering effects of flood damage. Similar to previous studies (Mitsch and Rust 1984; Dudek *et al.* 1998; Copenheaver *et al.* 2010; Saladyga *et al.* 2020), the above results suggest that changes in river hydrology and regional moisture availability have species-specific impacts that likely change over time. These initial findings should be used to guide further investigations of hydroclimate sensitivity in riverscour trees, particularly in the context of flood control and a regional wetting trend (Kutta and Hubbard 2019).

Conclusions

In summary, we have demonstrated that multiple riverscour tree species, including *U. americana*, *D. virginiana*, and others can be used for dendroecological analysis. While some limitations exist, our results provide initial assessments of tree age and establishment patterns in a riverscour woodland as well as the growth and hydroclimate sensitivity of two underrepresented species in the tree-ring literature. Furthermore, this exploratory study provides new information that can be used to inform future research aimed at the management and conservation of a unique riparian plant community in West Virginia.

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