Survival and Growth of Four Floodplain Forest Species in an Upper Mississippi River Underplanting

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Abstract

Forest restoration efforts commonly occur in degraded ecosystems. For the floodplain forests of the Upper Mississippi River, the combination of aging canopy trees and expansion of invasive species such as reed canary grass (*Phalaris arundinacea* L.) can shift forested ecosystems to open meadows. Before this shift occurs, there may be opportunities to proactively underplant. Our study reports 2-year survival and growth of four tree species (swamp white oak (*Quercus bicolor* Wild.), silver maple (*Acer saccharinum* L.), hackberry (*Celtis occidentalis* L.), and sycamore (*Platanus occidentalis* L.) planted under a moderate canopy of silver maple (approximately 60 percent overstory cover) across three elevational gradients. Swamp white oak had high survival across all three of the elevational zones and showed limited effects by herbivory or insects. Growth and survival of sycamore and hackberry depended on the elevational zone; sycamore performed better on lower elevational sites and hackberry did better on higher elevational sites. Our results highlight the potential for underplanting in floodplain forests as a proactive restoration strategy, with consideration given to local site conditions.

Introduction

Anthropogenic expansion, utilization, and manipulation of the natural environment, which includes the intentional and unintentional introduction of nonnative species, have resulted in the development of a relatively new field of ecology and natural resource management—restoration (Galatowitsch 2012). While restoration has multiple subdisciplines (e.g., restoration ecology, restorative silviculture, and others), an overarching theme is management action focused on reestablishing composition, structure, and/or function of an ecosystem (Nunez-Mir et al. 2015). While some restoration efforts focus on restoring to some prior time period, often pre-European colonization, other restoration efforts also are couched under the broad theme of restoration that focuses on restoring ecosystem structure and/or function (but not necessarily individual species) in such a way that the restored ecosystem may be better adapted to future conditions (Stanturf et al. 2014).

Restoration efforts often focus on highly degraded ecosystems or ecosystems that have moved to a novel state (Hobbs et al. 2006). Numerous studies across multiple ecosystems note that restoration practices for ecosystems in these conditions often result in significant inputs of time and money, and these inputs may not guarantee immediate or long-term (> 5 years) success (Diagne et al. 2021, Fantle-Lepczyk et al. 2022, Hoffmann and Broadhurst 2016). To use resources more efficiently, basic knowledge of ecosystem function and response is important to avoid overinvestment in techniques that have little effect, or underinvestment in techniques beneficial to restoration success.

As opposed to the systems described above, some ecosystems may be considered degraded, but have not yet shifted to a novel state. These ecosystems may be affected by disturbances, but still maintain enough resistance or resilience to maintain ecosystem function (Millar et al. 2007). Such ecosystems are often not considered priorities for restoration, but may represent opportunities where restoration interventions could be applied in a more efficient way to increase resilience and maintain ecosystem function before a shift to a novel state (Dudney et al 2018).

Novel environmental conditions in the 19th through 21st centuries in the Upper Mississippi River (UMR) resulted from extensive land clearing; artificial river modifications culminating in the impoundment of the system via a series of locks and dams; expansion of native and nonnative invasive species; and increased hydrologic variability due to changes in regional weather patterns and land uses that have altered floodplain forest successional processes (Guyon et al. 2012, Cosgriff and Vandermyde 2019). Invasive species also may contribute to future shifts of these forests to alternate ecosystem states (Miller-Adamany et al. 2019). Forests that are highly resistant and resilient to current and future potential ecosystem shifts include healthy, mature overstory trees and newly regenerating individuals. When a disturbance does occur, mortality of overstory trees can be compensated through regeneration of individuals which will grow into the overstory. Forests with less resilience have potential to shift to a novel state. These forests may have an intact overstory or may have some mortality with invasive understory species establishing. Regeneration is limited under those conditions. Finally, forests that have shifted to a novel state have almost no overstory, no regeneration, and are dominated by a range of native and nonnative invasive herbaceous species. Often, the most visible examples of this shift from forest to an alternative state in the UMR are wet meadow habitats dominated by invasive reed canary grass (*Phalaris arundinacea* L.) occurring within historically forested areas (Bouska et al. 2020)

Researchers and managers have been exploring and testing multiple means for controlling the exclusionary, nonnative reed canary grass in the UMR to allow for the regeneration of native tree species (Adams et al. 2011, Thomsen et al. 2012, Clark and Thomsen 2020). Although short-term and highly intensive management options are available for controlling reed canary grass, seedlings face additional challenges due to the dynamic nature of the floodplain and increased pressure from herbivory. These factors can result in limited survival of the planted trees, and thereby limited success in restoring floodplain forest function (De Jager et al. 2013a). In addition, focusing restoration efforts on these invasive wet meadow sites may come at the expense of potentially lower cost interventions in forests that retain some components of a forested habitat but are on a potentially reversible trajectory towards a future ecosystem shift.

Challenges to regeneration in floodplains are well-documented from other systems, including invasive plants and browse pressure from small rodents, beavers (*Castor canadensis* Kuhl), and white-tailed deer (*Odocoileus virginianus* [Zimmerman]) (Guyon et al. 2012). Two historically important floodplain forest species in the UMR, American elm (*Ulmus americana* L.), and green ash (*Fraxinus pennsylvanica* Marsh.), face serious threats from pathogens and nonnative pests such as Dutch elm disease (caused by the fungus *Ophiostoma ulmi*) and emerald ash borer (*Agrilus planipennis* Fairmaire) (Nisbet et al. 2015, Ramano 2010). Even with control of competing vegetation and herbivory, regeneration treatments often fail in the UMR, indicating that other complicating factors, such as hydrologic variability, inadequate understanding of floodplain species silvics, and inappropriate stock types for artificial regeneration may also affect regeneration success (De Jager et al. 2019, Hammes et al. 2020).

Our overarching goal was to conduct an applied, *in situ* experiment to quantify how elevation (as a surrogate for hydrology) and herbivory influence the survival and growth of four different tree species established through artificial regeneration in a mature silver maple (*Acer saccharinum* L.) floodplain forest ecosystem with no well-established natural regeneration. Questions of interest were: (1) how does planted seedling survival and growth vary across gradients of hydrology in the UMR floodplain? and (2) how do survival and growth patterns vary across species and stock conditions? Data collected to address these questions can increase our basic understanding of the early growth dynamics of four understudied floodplain species, help match seedling species to environmental conditions to improve survival outcomes in restoration work, and aid in applied decision making related to floodplain forest restoration and management.

Methods

Regional Description and History

The UMR basin encompasses multiple forest ecosystems and ecotones from the headwaters of the Mississippi River beginning at Lake Itasca, MN, to its confluence with the Ohio River in Cairo, IL. Multiple indigenous tribes note locations of spirituality (e.g., Bdote at the confluence of the Minnesota River and Mississippi River in Minnesota and Trempealeau Mountain near modern-day Trempealeau, WI) (Anfinson 2003). These Tribes are the stewards of these ecosystems. Current ownership of these lands, especially in the Minnesota and Wisconsin portions of the navigable portion of the UMR, is primarily Federal, with small areas of State, municipal, Tribal, and privately owned land.

The U.S. Army Corps of Engineers (USACE) is the primary Federal agency responsible for management of UMR navigation and was the agency given authorization by the U.S. Congress to develop the lock and dam system in the 1930s (Nanda and Ports 2004). The USACE-St. Paul District manages the portion of the UMR that flows from the headwaters in northern Minnesota to Lock and Dam 10 at Guttenberg, IA. Most USACE lands in the St. Paul District, acquired to support development of the 1930s navigation project, along with substantial U.S. Fish and Wildlife Service (USFWS) ownership, are incorporated into the Upper Mississippi River National Wildlife and Fish Refuge. Land management is broadly defined in the context of a series of navigation pools and associated floodplains, with the area of impounded water upstream from the lock and dam being referred to as a navigation pool and numbered according to the number of the lock that impounds it.

Site Description

The study site is within the Kains Switch South (KSS) forest management site, a USACE site located on the western edge of the Mississippi River floodplain between river mi 668.2 and 670.3 within navigation Pool 9 (figure 1). The site is approximately 5 miles (8 km) south of New Albin, IA, and the Minnesota/Iowa border in Allamakee County, IA. The KSS encompasses 660.5 ac (267.3 ha) of USACE-owned lands and is within one of the largest contiguous tracts of floodplain forest of the USACE-St. Paul District.

The floodplain forest at KSS is representative of the broader UMR floodplain forest. Silver maple makes up almost 60 percent of the tree species' importance value on the site, with remaining species being primarily green ash, American elm, eastern cottonwood (*Populus deltoides* Bartr.), and black willow (*Salix nigra* Marshall) (figure 2). Average basal area in this forest is 148 ft^2/ac (34 m^2/km^2), with a quadratic mean diameter of 14.7 in (37.3 cm). Average annual inundation duration during the growing season for the site ranges from 0 to 101 days with a mean of 35 days (Van Appledorn et al. 2018). Areas higher in elevation (and with typically shorter inundation durations) generally have lower overstory density (approximately 50 to 100 ft^2/ac [approximately 11 to 23 m^2/km^2]). Boxelder (*Acer negundo* L.) and black walnut (*Juglans nigra* L.) are present in these areas. Green ash is a common component of the midstory and understory. Given the presence of the invasive emerald ash borer in the region, young ash will most likely be killed before reaching the forest canopy (Herms and McCullough 2014). Regeneration of other tree species is virtually nonexistent.

USACE forest management guidelines and priorities focus on maintaining important ecosystem functions, such as providing habitat for the numerous wildlife species of concern that are inhabitants or seasonal migrants of the floodplain forest or seasonal migrants (Guyon et al. 2012). Because many wildlife species of concern within these management areas are dependent on large forest tracts with relatively closed canopies and some large-diameter trees, maintenance of forest cover with large trees present is a management priority for the agency. Consideration of how these forests will regenerate and replace the current cohort of overstory trees present on the landscape, which are expected to reach natural senescence within the next 50 to 75 years, is important for long-term management at the landscape level. Canopy green ash mortality has accelerated forest canopy loss in discrete locations within the management area as well, necessitating an active management approach.

Experimental Design

We used elevation gradients as a surrogate for a suite of environmental conditions believed to influence forest composition and structure (e.g., soil moisture, nutrient availability, texture, and inundation regime). We divided the distribution of elevations at KSS into three quantiles and mapped these quantiles to identify high (highest elevation quantile: 626.5 to 628.5 ft [190.9 to 191.6 m]), intermediate (moderate elevation quantile: 624.5 to 626.5 ft [190.3 to 190.9 m]), and low (lowest elevation quantile: 622.5 to 624.5 ft [189.7 to 190.3 m]) elevational zones (figure 1). Within each of the three zones, locations with intermediate canopy coverage (approximately 60 percent closed) were identified using first-return light detection and ranging (lidar) data (Sattler and Hoy 2020), followed

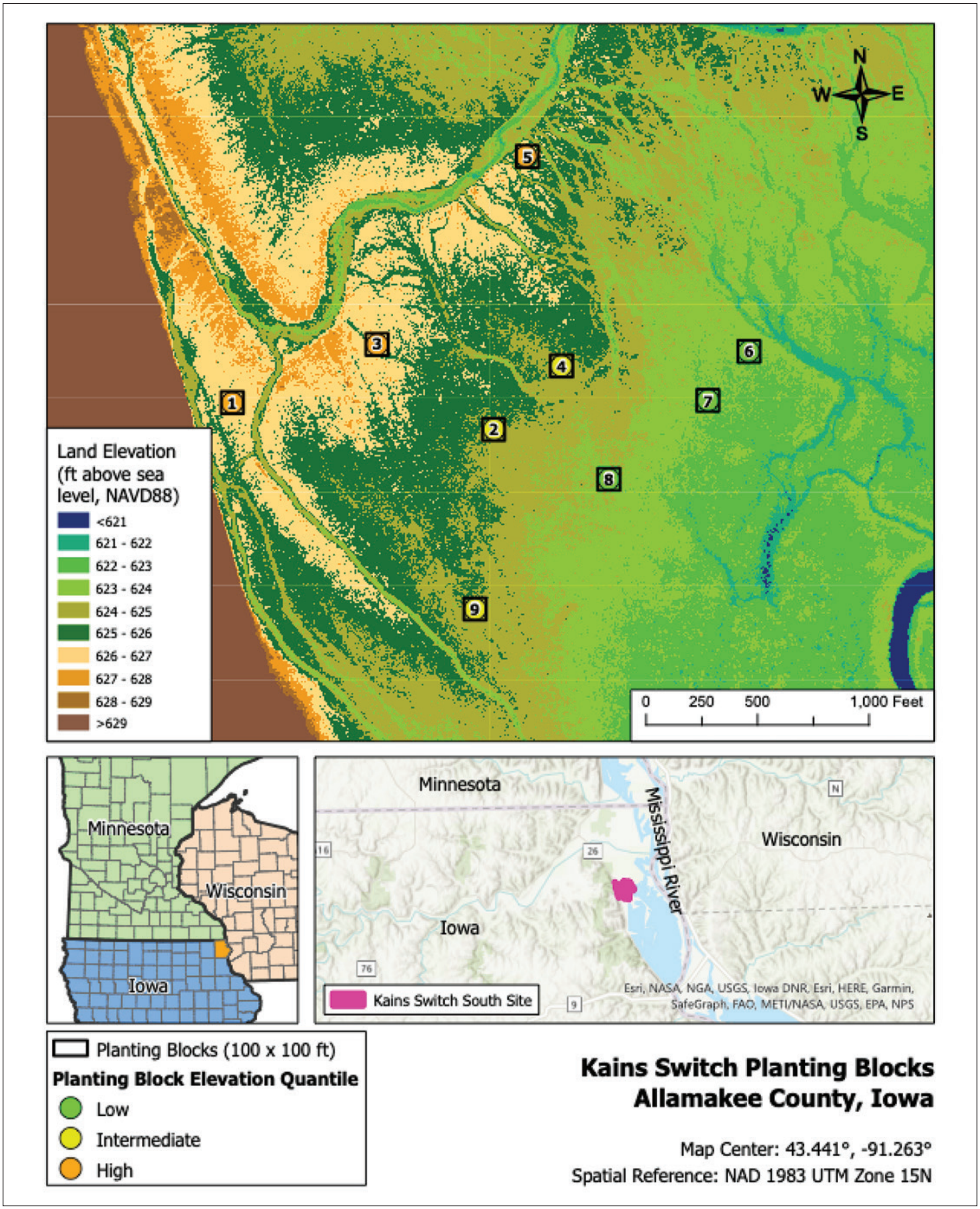

Figure 1. These maps show the Kains Switch South (KSS) planting study at various spatial scales. KSS is located along the Mississippi River near the borders of Iowa, Minnesota, and Wisconsin. Planting locations were located based on NAVD88 images and grouped into three elevational categories: low, intermediate, and high.

Figure 2. The floodplain forest ecosystem within Kains Switch South forest management area in northern Iowa consists of a mix of hardwood species. (Photo by Laura Reuling, 2021)

by on-site assessments to confirm canopy densities. The final plots were randomly selected from the set of viable locations identified during the on-site assessments. Plot size was 0.143 ac (578 m^2). Three plots that had similar overstory canopy coverage (approximately 60 percent overstory canopy) were selected within each zone, resulting in a total of nine plots (figure 3). Competing vegetation was present on most plots but was variable in composition and density; one of the highest elevation sites had high densities of reed canary grass, but wood nettle (*Laportea canadensis* L.), giant ragweed (*Ambrosia trifida* L.), and rice cutgrass (*Leersia oryzoides* L.) were more prevalent competitors across most sites.

Figure 3. Crews gridded out study plot locations early in the 2020 growing season before seedlings were planted. (Photo by Andrew Meier, 2020)

Figure 4. Each seedling was measured for height, as shown on this hackberry, shortly after planting in June 2020. (Photo by Andrew Meier, 2020)

Within each of the 9 plots, a total of 64 seedlings were planted in an 8 by 8 grid with 10- by 10-ft (3- by 3-m) cell sizes. containing 16 individuals representing each of the following species: swamp white oak (*Quercus bicolor* Willd.), silver maple, sycamore (*Platanus occidentalis* L.), and hackberry (*Celtis occidentalis* L.). Orientation of the grid was north/south. Species' cell assignments were randomly assigned, and placement within each cell was also random. Specific information on each species is listed in table 1.

Seedlings were planted May 21 and 22, 2020, by staff from the USACE and USFWS; staff received training on tree planting. Initial seedling measurements were collected 1 week later by staff at the University of Minnesota. Measurements included species, basal diameter, height, and notes regarding initial seedling vigor, health, and evidence of herbivory (figure 4). Each individual seedling (figure 5) was mapped within the plot to provide a detailed record for future measurements. During the 2020 and 2021 field seasons, field crews applied herbivory protection (PlantSkydd®) once annually in June. Later in the growing season (late June or early July), competing vegetation was controlled manually with a brush saw to maintain a free-to-grow condition. End-of-growing-season measurements (same as initial variables) occurred in September 2020 and October 2021. An additional survival assessment occurred in June 2021.

Data Summary

Percent survival, average height, and basal diameter growth were summarized by species, time period, and elevational zone. Linear regression was used to explore relationships between individual species diameter and height growth. A linear trend line was added to plotted data to visually determine positive, negative, or neutral trends. Data are publicly available (Windmuller-Campione et al. 2022b).

Table 1. Seedling stock size, nursery information, and average initial measurements with associated standard errors in parentheses for the four species planted at Kains Switch South. Size descriptions are nursery classifications and not field measured.

Species	Nursery size specifications	Nursery	Average basal diameter in (SE)	Average height in (SE)
Silver maple	21 to 30 in tall	Iowa Department of Natural Resources	0.37 (0.01)	29.3 (0.37)
Sycamore[1]	11 to 20 in tall	Iowa Department of Natural Resources	0.29 (0.01)	21.3 (0.29)
Hackberry	2 to 3 ft tall	Schumacher's Nursery (MN)	0.29 (0.01)	30.9 (0.35)
Swamp white oak	2-0 stock	Wisconsin Department of Natural Resources	0.50 (0.01)	39.6 (0.71)

[1] Sycamore stock were visually noted to be in poorer condition than other species.
1 in = 2.54 cm

Figure 5. This photo shows a sycamore seedling and surrounding understory vegetation on the study site after planting. (Photo by Andrew Meier, 2020)

Results

Survival

Survival varied across species, elevational zones, and measurement periods (figure 6). Swamp white oak seedlings had high survival across all three elevational zones with limited effects from browse and other disturbances. By October 2021, the high elevational zones had the highest percentage of healthy swamp white oak seedlings (61 percent). Although some mortality of sycamore occurred during the 2020 growing season, the high elevational zone had 70 percent, or 33 individual seedlings, still noted as healthy in October 2021. In the intermediate and low elevational zones, however, sycamore mortality increased during the 2021 growing season and a higher percentage of trees were dead by October 2021. Silver maple mortality was low in 2020 across all zones, but, similar to sycamore, silver maple mortality was substantially higher in the intermediate and high elevational zones in 2021. Hackberry had very low mortality in any measurement period in the intermediate and high elevational zones, but had substantial mortality in 2021 in the low elevational zone.

In general, the number of seedlings noted as healthy declined over the 2-year period, a pattern that was relatively consistent across species and elevational zones (figure 6). Swamp white oak and sycamore still had a high percentage of healthy individuals in October 2021. Silver maple had large decreases in the percentage of healthy seedlings across all three elevational zones starting in June 2021. A large proportion of silver maple seedlings were affected by browse. The browsing vector was not identified, but many silver maple seedlings showed substantial levels of insect defoliation earlier in the growing season, so ungulate browsing may not be the primary driver of defoliation on the site.

Growth

Seedling diameter and height growth varied across species, elevational zones, and time (figure 7). Over the two growing seasons, sycamore showed positive linear growth across the three elevational zones with some trees growing as much as 3.5 ft (1.1 m) in height and 0.3 in (0.76 cm) in diameter between June 2020 and October 2021 (figure 7). There were no obvious relationships between height and diameter growth across the three elevational zones for hackberry. Swamp white oak showed variable relationships between height and diameter growth across the three elevational zones with slight positives in the low and intermediate elevational zones and a slight negative relation in the high elevational zones. Although silver maple had positive linear relationships between diameter and height for both the high and the intermediate elevational zones, many of the height changes were negative due to browse (figure 7).

Discussion

Floodplain forests are a dynamic ecosystem (De Jager et al. 2019). Conditions across a management unit are not uniform (Windmuller-Campione et al. 2022a), and slight changes in elevation, which have nonlinear relationships with hydrology (Van Appledorn et al. 2021), can influence the short-term survival of planted seedlings. Among the four species and three elevational zones in this study, the number of healthy seedlings varied, highlighting the importance of quantifying microsite characteristics.

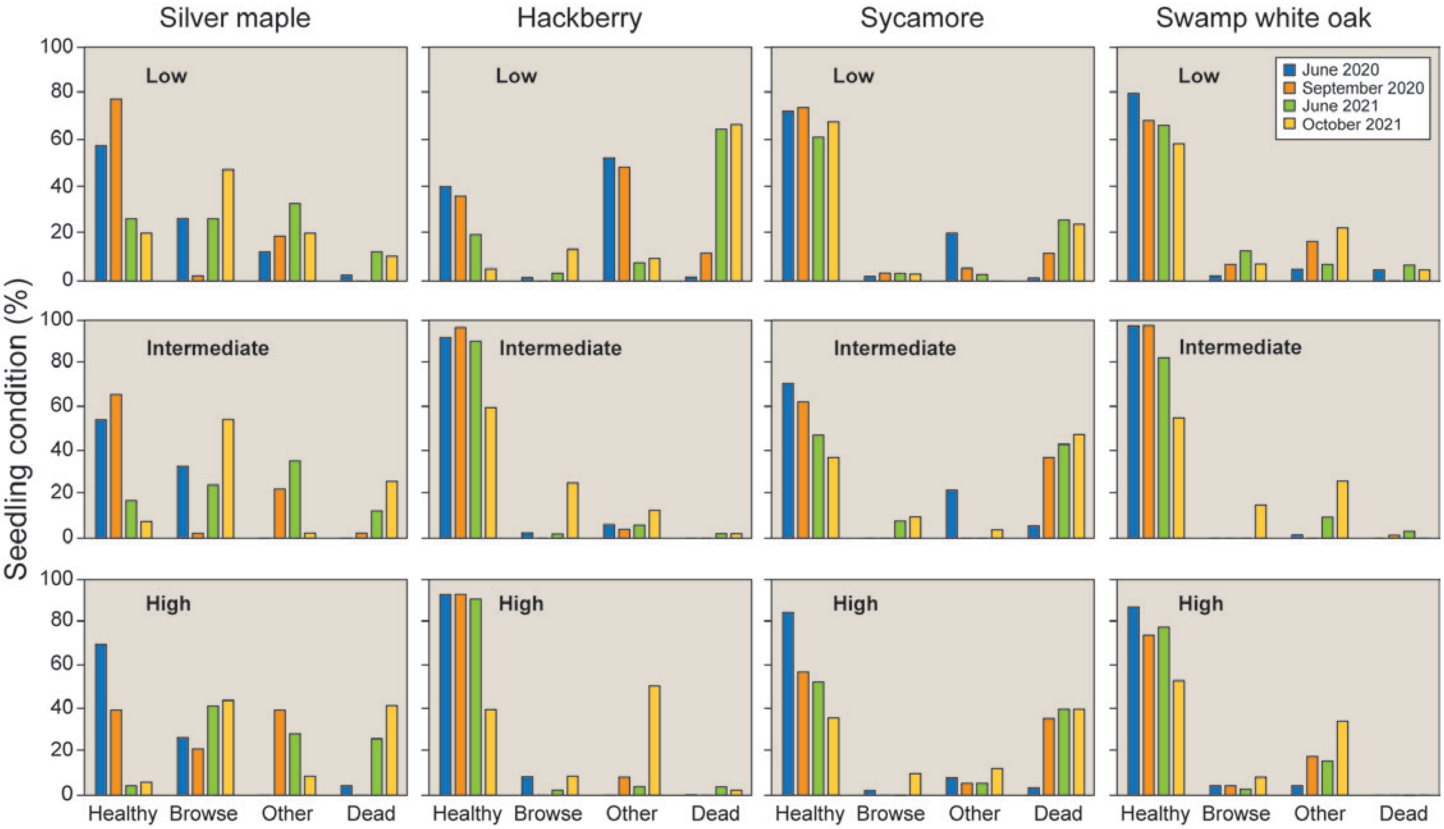

Figure 6. Seedling condition changed over time by elevational zone (low, intermediate, or high) and by species. The "Other" category included dieback, insects, wilt, or leaf drop.

Out of the four species planted, swamp white oak maintained the greatest healthy status and had the least impact from browse over the 2-year period (figure 6). PlantSkydd® was likely an adequate form of browse protection for this species, although we did not have an untreated control. Swamp white oak has emerged as a preferred choice for regeneration and restoration work within wet forested systems, both in floodplains and within wet black ash (*Fraxinus nigra* Marsh.) forests in the northern Lake States region (D'Amato et al. 2018, Hammes et al. 2020, Iverson et al. 2016). Early results from our study support the evidence that swamp white oak can survive under variable hydrological conditions including within low elevational zones (which had 60 percent of swamp white oak seedlings noted as healthy after 2 growing seasons). Height and diameter growth for this species, however, were limited during the 2 years (figure 7). Additional seasons of monitoring would be beneficial to fully understand the height and diameter growth potential of these seedlings because many oak species focus resources on root development during the first few years (Rogers 1990). This shift in resource allocation to a well-established root system could provide opportunities for underplanting, especially as overstory canopies of silver maple and cottonwood begin to reach maturity. Finally, given the already observed changes in the hydrologic regimes of the UMR (Guyon et al. 2012), the silvics of swamp white oak may allow this species to be more resilient to fluctuating water levels within and between growing seasons due to climate change (De Jager et al. 2013b).

The percentage of healthy silver maple seedlings was relatively low within all elevational zones (figure 6). Silver maple also suffered a high amount of insect damage which negatively affected height. Large cohorts of first-year silver maple natural regeneration can occur along the UMR, but additional research on silvics of silver maple as a seedling and sapling would be beneficial (Gabriel et al. 1990).

Hackberry and sycamore seedling survival and growth varied across elevational zones (figures 6 and 7). Sycamore is a common species occurring under varying conditions in floodplain forested systems (Bragg and Tatschl 1977). Hackberry performed best in the intermediate elevational zones, but had a large decrease in the number of healthy seedlings in the high elevational zone during the 2021 growing season. In other floodplain ecosystems, hackberry is considered a species common in higher elevations (Hale et al. 2008).

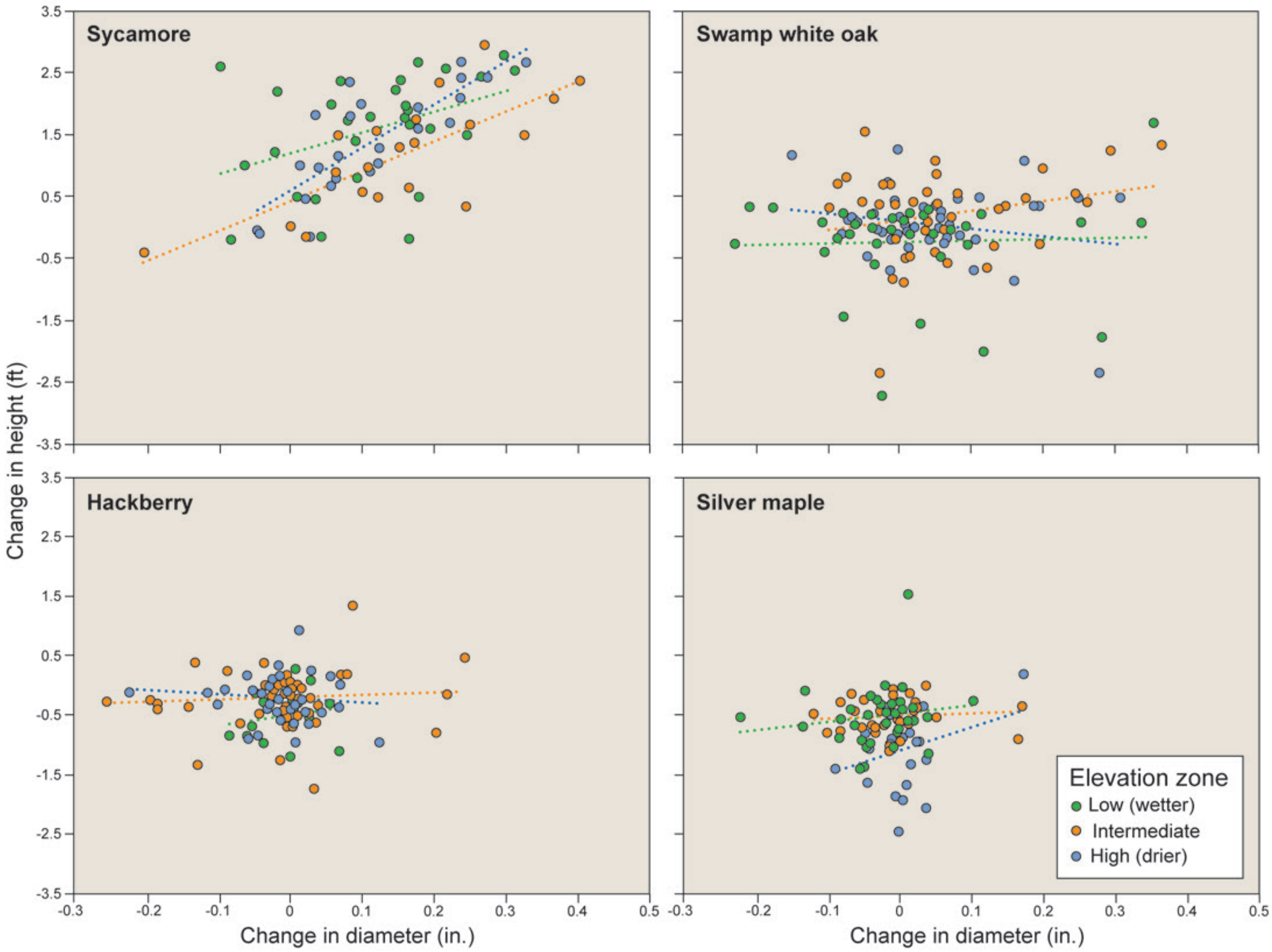

Figure 7. The relationship between changes in diameter and height between June 2020 and October 2021 varied by species and elevational zones.

An important caveat of our study is that these results represent just 2 years of data. During the establishment phase, planted or naturally regenerated seedlings are susceptible to impacts from the local environment and broader regional weather patterns (e.g., drought in 2021) (Oliver and Larson 1996). Additional years of monitoring and measuring would be useful to quantify seedling survival, growth, and development. Management actions that include artificial tree regeneration in floodplain forests cannot rely solely on early results to determine success or failure. In fact, assessments of planting success or failure would likely be more appropriate 3 to 5 years postplanting.

Regeneration is a key process within sustainable forest ecosystem management (Nyland 2016). Our short-term results highlight the importance of understanding the site when developing regeneration planting strategies. This study demonstrates that seedlings can be established under moderate light environments (60 percent overstory canopy) and across different elevational zones, providing opportunities for proactive restoration or underplanting to occur prior to canopy decline and the subsequent establishment of invasive species. In this study, understory vegetation was manually controlled with brush saws for 2 years. Accounting for the time and resources required for vegetation control could be important when considering the scale of planting. Even with this limitation, proactive underplanting may provide an opportunity for increased efficiency in resource utilization and the ability to treat greater areas. With underplanting, natural resource managers may consider multiple planting periods (e.g., planting at year 1, 3, and 5) compared with planting all at once to increase the potential of hitting recruitment windows with flooding. Longer term assessments of species' survival and growth would be beneficial especially given the multiple stressors that could affect seedling survival and growth in a floodplain forest environment.

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