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RESEARCH ARTICLE

Restoring hardwood trees to lake riparian areas using three planting treatments

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Lake riparian areas provide wildlife habitat for a wide variety of species. Residential development throughout such lakeshore areas of the United States has increased exponentially in recent decades. Awareness of the vulnerability and importance of lakeshore ecosystems has increased concurrently. Lakeshore habitat restoration projects have been implemented to mitigate some of the negative impacts of human shoreline development, and containerized (CT) trees are frequently one of the highest costs associated with such restoration projects. As an alternative, we tested the effectiveness of using dormant bare-root (BR) trees in restoration projects along two lakeshores in northern Wisconsin, U.S.A. In addition, we experimented using BR stock that was incorporated into gravel medium at a local nursery and planted later in the summer months. We monitored growth and survival of four native tree species in these three planting treatments over a 3–4-year period. CT red maple (*Acer rubra*), paper birch (*Betula paperifera*), and northern red oak (*Quercus rubra*) increased in size significantly faster than BR and/or gravel culture (GC) counterparts, whereas CT showy mountain ash (*Sorbus decora*) growth rates were similar to those of BR and GC stock. Mortality was generally low, but for those species/planting treatments with higher mortality (paper birch and red oak), CT trees were more likely to survive than BR or GC trees. Our results show that the success of deciduous BR and/or GC tree stock relative to CT trees is species dependent, and for some species, CT trees' higher growth rates and survivorship could offset their higher costs.

Key words: **bare-root trees, containerized trees, gravel culture trees, human development, lakeshores, wildlife habitat restoration**

Implications for Practice

- Gravel culture (GC) northern red oak stock and bare-root (BR) showy mountain ash stock experienced growth rates comparable to containerized (CT) counterparts. The growth rates of BR and GC red maple, BR northern red oak, and GC paper birch stock were lower than CT trees.
- Growth and survival varied between the two lakeshore sites, indicating complex site-specific effects on the success of different species and relative success of CT, BR, and GC planting treatments.
- High mortality occurred for BR northern red oak and GC paper birch. Many BR northern red oak trees that died in our study were larger in size, potentially from increased transplant shock that has been associated with larger trees.

Introduction

Lakeshores provide unique and critical habitat for a variety of wildlife taxa (Engle & Pederson 1998). Residential development on ecologically sensitive lakeshores can negatively impact plant and animal communities. For instance, such development has been shown to directly impact understory wildlife habitat in riparian areas (Racey & Euler 1983*a*,*b*; Clark et al. 1984; Elias & Meyer 2003; Haskell 2009), often because humans that inhabit lakeshores prefer a more parklike appearance with less understory vegetation diversity and structure (Macbeth 1992). This direct removal of understory habitat can negatively impact avian communities (Robertson & Flood 1980; Lindsay et al. 2002), small mammals (Racey & Euler 1982; Haskell 2009), amphibians (Woodford & Meyer 2003), and riparian and forest carnivores (Racey & Euler 1983*b*; Haskell et al. 2013).

Deciduous sapling trees are a critical component of lake riparian areas (Elias & Meyer 2003) because they provide quality habitat and food sources for a variety of birds and mammals (Martin et al. 1961; Goodrum et al. 1971; Ehrlich et al. 1998). For example, non-game bird species use deciduous habitat for nesting and foraging (DeGraaf & Yamasaki 2003), and deciduous trees provide habitat and food for ruffed grouse

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Author contributions: DEH, CRW, MWM designed the experiment; DEH preformed the field work; DEH and ALB analyzed the data and wrote the manuscript; CRW, DJF, MWM edited the manuscript; MWM secured funding for the experiment.

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(*Bonasa umbellus*; Blanchette et al. 2007), eastern wild turkeys (*Meleagris gallopavo*; Dickson 1992), and white-tailed deer (*Odocoileus virginianus*; Mooty et al. 1987).

In Vilas County, Wisconsin, U.S.A., lakeshore housing construction and development of recreational areas has increased dramatically in the past several decades (WDNR 1996; Radeloff et al. 2001; Schnaiberg et al. 2002; Gonzelez-Abraham et al. 2007). Vilas County is located within the Northern Highland Ecological Landscape (NHEL), which contains the third largest concentration of freshwater glacial lakes in the world (WDNR 2005). Increased development on NHEL lakeshores has led to increased awareness of the vulnerability and importance of lakeshore ecosystems. The Vilas County Land and Water Conservation Department offers a lakeshore restoration cost share program to private property owners, which requires participates to plant native trees at densities prescribed by Wisconsin Biology Technical Note 1: Shoreland Habitat (NRCS 2002). When planting trees in restoration projects, the most common practice is to use containerized (CT) trees, which are often one of the largest costs to property owners, lake managers, and restoration practitioners. As an alternative to CT trees, dormant bare-root (BR) trees can be used at half the cost due to reduced weight and associated ease of handling, which facilitates more cost-effective shipping from nurseries to restoration sites (Buckstrup & Bassuk 2000).

BR trees in the nursery and landscape industry have been used for decades and are commonly used in surface mine reclamation projects (Salifu et al. 2009; Wilson-Kokes et al. 2013), reforestation (Gardiner et al. 2005; Holmes & Webster 2014), stream and lake riparian restoration (Sweeney et al. 2002; Haskell 2009), and urban landscaping (Cool 1975; Vanstone & Ronald 1981; Buckstrup & Bassuk 2000). Many studies have compared BR stock to CT stock with mixed results (Grossnickle & El-Kassaby 2015). For example, Grossnickle and El-Kassaby (2015) reviewed 122 studies and found that 60.7% of studies reported higher survival for container stock, 14.8% reported higher survival for BR stock, and 24.6% reported similar survival between stock types. Sweeney et al. (2002) is one of few studies to compare seedlings of CT and BR plant stock on a lake riparian restoration site, and they reported no significant difference in survival over a 4-year period

BR trees are best planted between the periods of frost-free soil to bud break in the spring and leaf-fall to frozen soil in the fall, and such restrictive time frames are an impediment for those seeking to plant in the summer months. To resolve these problems, a relatively new technique was investigated by Starbuck et al. (2005) to extend the use of BR trees throughout the summer. Starbuck et al. (2005) used 6.4-mm-diameter (0.25 in) pea gravel as a temporary soil medium for storing trees for later planting. They attempted this "gravel culture" (GC) technique on green ash (*Fraxinus pennsylanica*) and northern red oak (*Quercus rubra*) and reported no mortality. In addition, Haskell et al. (in review) tested several native BR shrub species and conifer trees (commonly used in lakeshore restoration) in a culture of 2.5 mm (1 inch) diameter gravel from a local nursery and compared the growth and survival of these GC shrubs and trees to CT and BR shrubs and trees planted in the spring over a 3–5-year period. Their results revealed that plant growth and survival over time, for some species, varied among planting treatments.

GC planting could provide a cost-effective alternative to CT planting stock and extend the use of BR plants into the summer months. However, quantitative studies regarding the effectiveness of this technique for wildlife habitat restoration are lacking. In this study, our objective was to compare the relative success of dormant BR trees to CT trees and the relative success of GC trees to CT trees in restoration projects. To measure success, we planted trees from four native deciduous species typically used in NHEL lakeshore restorations and compared the relative growth and survival of those from BR and CT planting treatments and from GC and CT planting treatments.

Methods

Study Area

This project was conducted in the NHEL on two lakeshores (Fig. 1) in forested landscapes on deep sands with pitted glacial outwash in Vilas County, Wisconsin (Thwaites 1929). Vilas County encompasses a 2636 km^2 area along the state's northern border with the Upper Peninsula of Michigan, U.S.A. Glacial lakes cover approximately 16% of the county's area (WDNR 2005), and 53% of the area is in private ownership (Schnaiberg et al. 2002). The land cover is a mixture of bogs, northern wet forest, boreal forest, and northern dry to northern xeric forest (Curtis 1959). The daily mean ambient temperature is 3.4°C, ranging from −2°C in January to 10°C in July, and the mean annual precipitation is 80.25 cm (WDNR 2014*a*).

We conducted this project on Little St. Germain Lake (LSG [45°55′15.49″N, 89°27′23.64″W]) and Crystal Lake (46°00′11.69″N, 89°37′00.68″W) lakeshores. LSG is a drainage lake with a managed water level that drains into the Wisconsin River system. It has an area of 397 ha and a perimeter of 23.3 km. The majority of lakeshore is in private ownership with a housing density of 25.2 houses per linear km. LSG has several active vacation and fishing resort businesses that operate throughout the year. The lakeshores of Crystal Lake are publicly owned and are part of a recreational area that is comprised of modern campgrounds, picnic areas, and swimming beaches located in the Northern Highland-American Legion State Forest (NH-AL). Crystal Lake lakeshores have been managed as a public park since the mid-1940s (S. Peterson, superintendent NH-AL). Both lakes have been subjected to human development or high use in recreation, therefore making them excellent candidates for wildlife habitat restoration along the riparian area. Both sites had scattered mature trees but lacked woody understory layers (shrubs and saplings; unpublished data). Soils were low-nutrient sands (see Table S1, Supporting Information, for soil information of each lake). To reduce transplant and drought stress, an automatic irrigation system was installed on both sites.

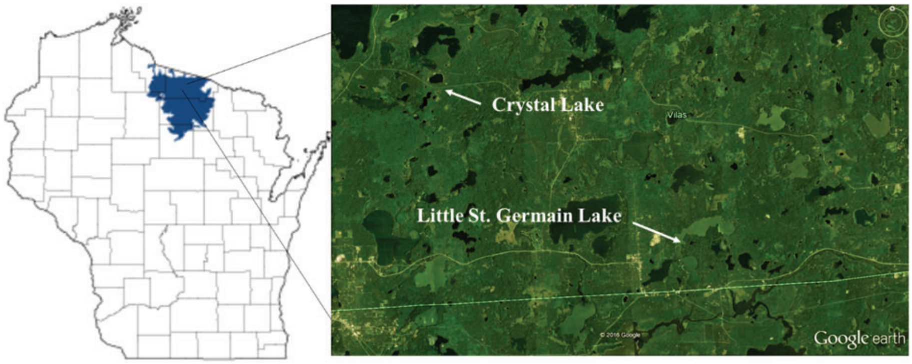

Figure 1. The Northern Highlands Ecological Landscape (http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&landscape=5) with location of restoration sites on Crystal and Little St. Germain Lakes within Vilas County, Wisconsin, U.S.A.

Plant Material

We planted four native tree species (northern red oak [*Quercus rubra*; USDA plant code QURU], red maple [*Acer rubra*; USDA plant code ACRU], paper birch [*Betula papyrifera*; USDA plant code BEPA], and showy mountain ash [*Sorbus decora*; USDA plant code SODE3]) and evaluated their suitability for rehabilitating wildlife habitat in degraded lake riparian areas. All species will hereafter be referred to by their USDA plant code (USDA NRCS 2016). Tree species were chosen for their site suitability and potential to provide food and habitat to wildlife. We planted 122 deciduous trees on the lakeshore of Crystal Lake in 2011 and 148 trees on LSG lakeshore in 2012 (Table 1). Each GC and BR tree was matched with a CT tree of the same species. Trees from each pair were planted ≤ 2 m of each other, and each tree was identified with a unique numbered metal tag. All BR/CT pairs were planted after frost left the ground and prior to bud break. All GC/CT pairs were planted after full leaf development, and CT species were delivered in 7–10-gallon nursery containers from local nurseries (July–August). All BR and GC roots were kept damp with wet oat straw when transported from nursery until planted, or if they were not planted within the day of delivery, the roots were submerged in water for not more than 12 hours. For each tree, 2–3 liters of compost were incorporated into the soil before trees were planted. Cedar mulch was placed around the basal area extending out 15 cm from base of trees at an approximate depth of 5 cm. All trees were contained within 2.4-m-high nylon fence to prevent herbivory (Haskell 2009) and irrigated as needed throughout the growing season for the duration of this project. All trees were planted within 10.8 m (35 ft) of the ordinary high water mark (WDNR 2014*b*, Chapter NR 115, https://docs.legis.wisconsin.gov/code/admin_code/nr/100/115.pdf). SODE3 BR/CT pairs were planted exclusively on Crystal Lake, and all GC/CT pairs were planted on Crystal Lake (Table 1).

Growth and Survival of Trees

To compare the relative growth of trees from different planting treatments, we measured the cylindrical volume of trees each summer over a 3–4-year period. To estimate volume, we first measured tree height (m) and canopy area (m^2). Height was measured from the soil surface to the highest point of the living tissue in its natural state. Tree canopy area (A) was determined by measuring the width of the canopy at its widest point (w_1) and the width of the canopy perpendicular to this point (w_2). The mean canopy radius was calculated using the two widths, which was used to calculate the circular canopy area (A) using the following equation:

$$A = \pi \left(\frac{w_1 + w_2}{4} \right)^2$$

Canopy area (A) was multiplied by height to obtain an estimate of cylindrical volume (m^3) for each tree (Bussler et al. 1995; Haskell et al. 2012).

In addition to volume, we measured tree diameter (mm) at 15 cm above the soil surface using digital calipers, and we recorded tree survival (alive or dead). For GC/CT pairs, all measurements were performed in late summer of the initial year of planting and repeated each summer for 4 years. For BR/CT pairs, measurements were similarly performed late in the summer of the initial year of planting but repeated each summer for only 3 years, with the exception of SODE3 pairs, which were measured for 4 years post-planting.

Statistical Analysis

We used a repeated measures mixed-model approach to determine whether changes in tree volume over time differed between planting treatments (i.e., BR vs. CT and/or GC vs. CT). Here, tree volume was used as the response variable, and model effects included planting treatment (a between-subject effect), growth year (a within-subject repeated effect), and a planting treatment × growth year interaction term as fixed-effects, plus each tree's unique ID number as a random effect (a subject variable). This type of mixed-model repeated measures allowed us to account for correlations between repeated observations made on the same tree (i.e., plant ID number recorded over multiple years) while also retaining individual trees in the model when one or more year's volume measurements were missing from the dataset as a result of sampling error or mortality (Wang &

Table 1. Number of bare-root (BR), gravel culture (GC), and containerized (CT) trees from four species planted on two lakeshores in Vilas County, Wisconsin, U.S.A., in 2011 and 2012. These species are native to the region, provide habitat for a wide variety wildlife species, and are commonly used on restoration projects.

				Treatment		
Lake	*Common Name*	*Scientific Name*	*USDA Plant Code*	*BR*	*GC*	*CT*
Crystal	Red maple	*Acer rubrum*	ACRU	—	22	22
	Paper birch	*Betula papyrifera*	BEPA	—	27	27
	Northern red oak	*Quercus rubra*	QURU	—	10	10
	Showy mountain ash	*Sorbus decora*	SODE3	13	—	13
LSG	Red maple	*Acer rubrum*	ACRU	30	—	30
	Paper birch	*Betula papyrifera*	BEPA	20	—	21
	Northern red oak	*Quercus rubra*	QURU	18	—	24

Goonewardene 2004). Separate mixed-effect models were run for each of the four species and for each planting treatment pair (i.e., BR vs. CT and GC vs. CT) for a total of seven models (SODE3 trees are only in the BR/CT treatments). A significant planting treatment × growth year interaction ($p < 0.05$) generally indicates that changes in volume over time were significantly different for CT trees relative to either BR or GC trees. To determine whether planting treatment influenced the odds of trees surviving to the third (BR/CT pairs) or fourth (GC/CT pairs) year, we used logistic regression models to calculate odds ratios for each of the four species in each planting treatment pair (i.e., BR vs. CT and GC vs. CT). Survival is not reported here for the first and second years of growth. All analyses were conducted in JMP version 12.1.0 (SAS Institute Inc., Cary, NC, U.S.A., 2015).

Results

Trees from most species and planting treatments experienced increases in volume over the 3 or 4-year growth period (Fig. 2, Table S2). For some species, CT trees experienced significantly greater increases in volume relative to BR and/or GC trees (i.e., a significant planting treatment × growth year interaction). CT ACRU trees experienced greater increases in volume relative to both their paired BR (interaction effect—$F_{[3,170.0]} = 4.89$, $p = 0.003$; Fig. 2A) and GC (interaction effect—$F_{[4,165.4]} = 8.74$, $p < 0.001$; Fig. 2B) counterparts over time. Although CT ACRU trees paired with BR stock had a larger initial mean volume at the time of planting relative to BR trees, these initial differences diverged dramatically during the second and third years of growth (Fig. 2A). Similarly, BEPA CT trees grew more rapidly than those in the GC planting treatments, shown by greater increases in volume (interaction effect—$F_{[4,171.2]} = 7.35$, $p < 0.001$; Fig. 2D). Conversely, BEPA CT stock matched with BR stock initially experienced positive growth, but began declining in volume between the second and third years of growth, while paired BR BEPA stock experienced slight declines in volume during the entire 3-year period (interaction effect—$F_{[3,105.3]} = 1.70$, $p = 0.172$; Fig. 2C). CT QURU stock in the BR/CT pairs appeared to initially begin growing at a faster rate than BR QURU trees and maintained a larger volume over the next 2 years (interaction effect—$F_{[3,106.3]} = 3.99$, $p = 0.010$; Fig. 2E). In some instances, BR and GC tree growth rates appeared to be very similar to that of CT trees. This was observed in GC/CT paired QURU trees (interaction effect—$F_{[4,66.1]} = 0.17$, $p = 0.950$; Fig. 2F) and BR/CT paired SODE3 trees (interaction effect—$F_{[4,88.8]} = 3.99$, $p = 0.938$; Fig. 2G), with all experiencing overall increases in volume over time respectively (Table S2).

The effects of planting treatment on stem diameter, in some instances, mimicked those of tree volume (Fig. 3, Table S3). For example, CT BEPA trees experienced significantly greater increases in stem diameter relative to those in the GC treatments (interaction effect—$F_{[4,131.0]} = 19.72$, $p < 0.001$; Fig. 3D). A similar significant interaction effect was observed for QURU trees in GC/CT pairs ($F_{[4,65.0]} = 6.10$, $p = 0.003$; Fig. 3F). BR QURU trees appeared to experience reduced average stem diameter during the first and second years of growth (Fig. 3E). However, this was due to high mortality of larger diameter trees from this treatment, where a mortality rate of 33 and 37.5% was observed in the first and second years of growth, respectively, which dramatically altered the mean stem diameter.

For some species, survival varied among planting treatments (Fig. 4). CT BEPA trees were more likely to survive to the fourth year than those in the GC treatment (odds ratio = 10.00, $p = 0.001$; Fig. 4B) and BR treatment (not significant—odds ratio = 5.00, $p = 0.125$; Fig. 4A). Similarly, CT QURU trees were significantly more likely to survive than those in BR treatments (odds ratio = 10.08, $p = 0.002$; Fig. 4A). For all other species and planting treatments, mortality was zero for one or both planting treatments (100% survival), and statistics could not be calculated (Table S4).

Discussion

The success of wildlife habitat restoration is influenced by the reliability and affordability of restoration practices. At our restoration sites, the primary goal of wildlife habitat restoration efforts was to establish an understory that creates habitat conditions favorable for wildlife. Our study is one of the first restoration projects to explore the use of GC to extend the planting window for BR tree saplings on restoration sites, which are

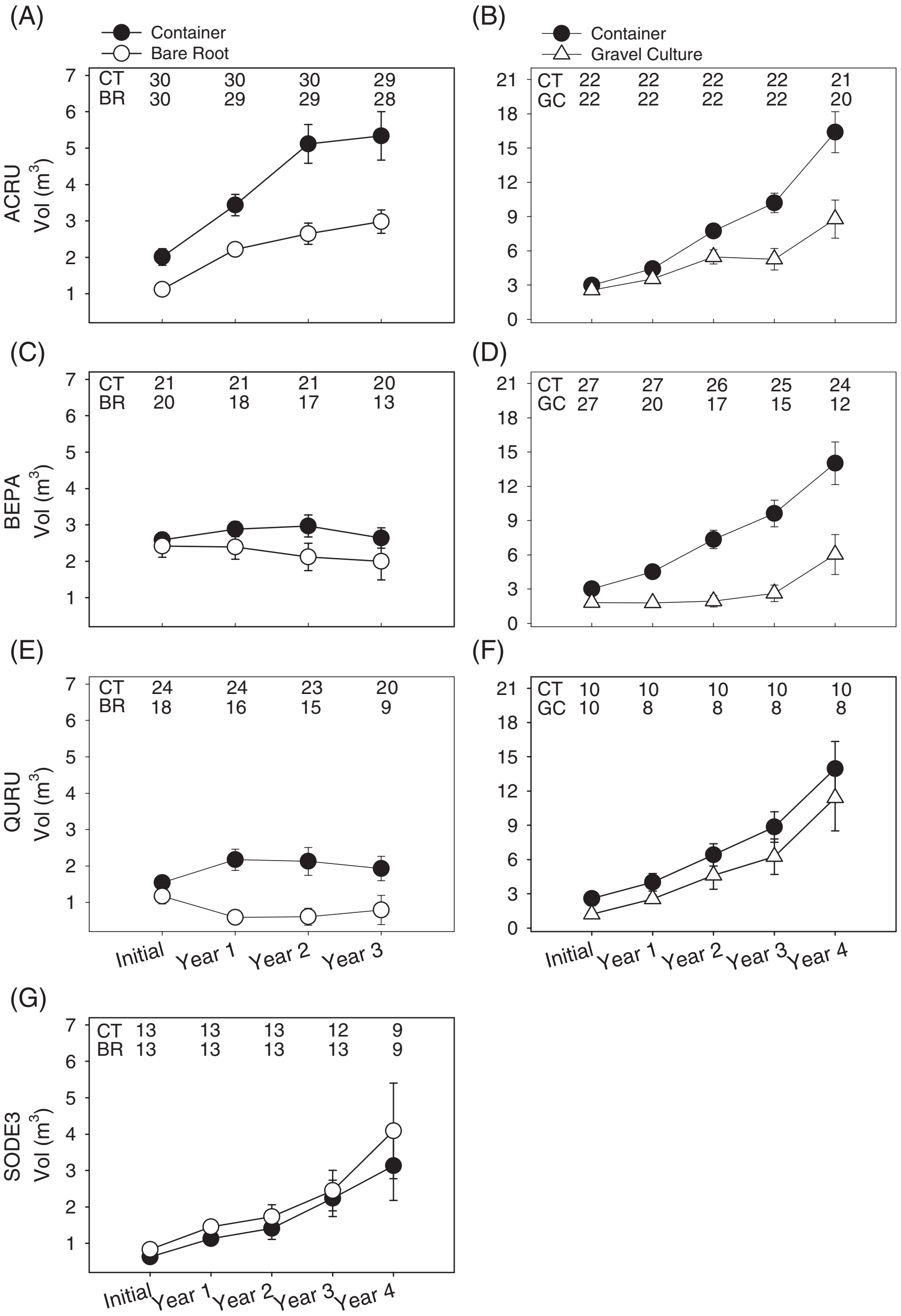

Figure 2. Results from repeated measure analyses showing the effects of planting treatment (BR vs. CT—left column; GC vs. CT—right column) on changes in mean tree volume ($m^3 \pm 1$ SE) over a 3 or 4-year period. Species include ACRU (A, B), BEPA (C, D), QURU (E, F), and SODE3 (G). Numbers above lines represent the total number of trees sampled for volume measurements for each planting treatment and growth year.

less expensive and easier to transport than similarly sized CT stock.

Our results show that for some species, BR and GC stock perform either equally well or more poorly relative to CT stock, and that these differences are dependent on species and planting treatment (i.e., BR vs. GC). For instance, GC *Quercus rubra* and BR *Sorbus decora* experienced growth rates (tree volume) comparable to the more expensive CT plants, while the growth rates of both BR and GC *Acer rubra* BR *Q. rubra*, and GC *Betula papyrifera* were slower than paired CT trees, indicating that the increased cost for CT trees may be justified for some species and depending on availability of BR and GC stock.

BR *Q. rubra* and both CT and paired BR *B. papyrifera* stock experienced a slight decline in volume over time, which may have been due in part to terminal shoot dieback and premature leaf senescence during the growing seasons.

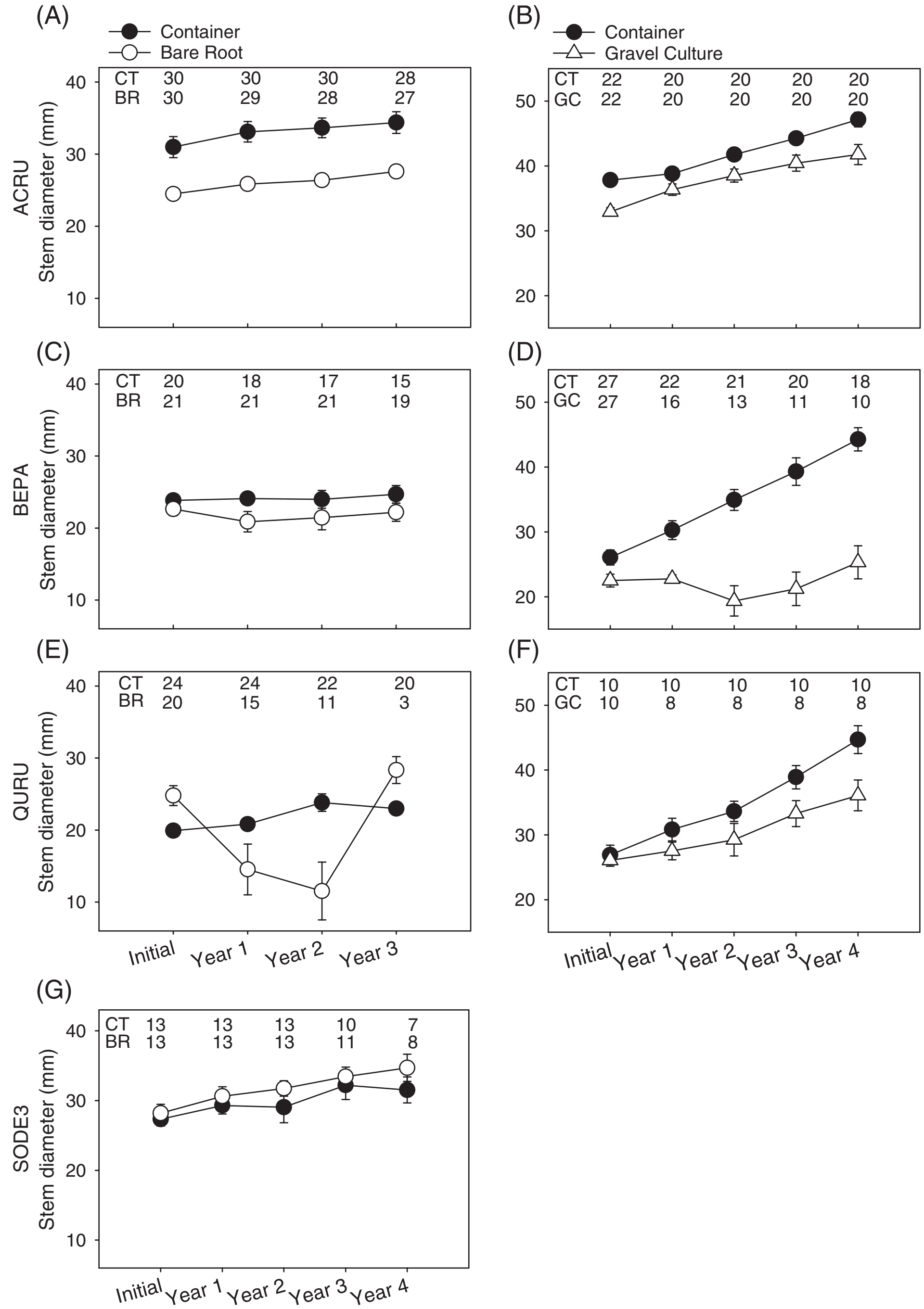

Figure 3. Results from repeated measures analyses showing the effects of planting treatment (BR vs. CT—left column; GC vs. CT—right column) on changes in mean stem diameter (mm ± 1 SE) over a 3- or 4-year period. Species include ACRU (A, B), BEPA (C, D), QURU (E, F), and SODE3 (G). Numbers above lines represent the total number of trees sampled for diameter measurements for each planting treatment and growth year.

Dieback and premature leaf senescence were also noted by Wilson et al. (2007) who observed significantly lower total biomass increases for *Q. rubra* BR compared to CT stock. Similarly, Cole et al. (1999) reported *B. papyrifera* BR trees were susceptible to top dieback caused by frost and winter temperatures, and aboveground stems were frequently killed to the ground and resprouted the following growing seasons. Top dieback occurred in 52% of *B. papyrifera* BR across treatments over their 5-year study (Cole et al. 1999). Interestingly, *B. papyrifera* GC and paired container stock performed much better in terms of volume growth in our study, indicating possible site-specific effects on volume growth (BR/CT pairs were planted on a different lakeshore; Table 1).

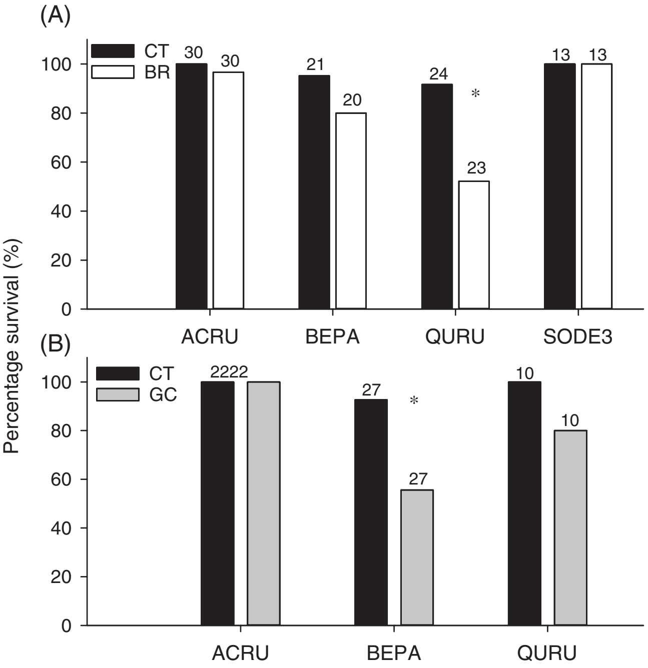

Figure 4. Percentage of containerized (CT) and bare-root (BR) trees from four species surviving to the third year of growth (A) and the percentage of CT and gravel culture (GC) trees from three species surviving to the fourth year of growth (B). Numbers above each bar represent the total number of trees initially planted and sampled for survival for each species and planting treatment. (* indicates pairings with significant differences $p < 0.05$).

Although trees from most species/planting treatment combinations experienced very little mortality, *Q. rubra* BR plant stock had the highest mortality (52%) in the third year and *B. papyrifera* GC stock had the highest mortality (56%) in the fourth year. Many of the *Q. rubra* trees that died in our study were of larger stem diameter, which could be related to increased transplant shock associated with larger diameter trees (i.e., smaller trees have been shown to experience relatively lower transplant shock and mortality; Struve et al. 2000). Starbuck et al. (2005) compared BR and balled-and-burlapped *Q. rubra* and *Fraxinus pennsylanica* trees that were placed into the pea gravel during the early spring months and transplanted in the summer, and they reported no mortality over their 3-year study. They also reported no significant difference in central leader and root elongation between trees and treatment after 3 years. However, their project was conducted at the Missouri Turfgrass Research Center under consistent environmental conditions rather than on restoration sites, which may indicate site-specific constraints for this technique.

Sweeney et al. (2002) compared seedlings of CT and BR plant stock on a lake riparian restoration site, and they reported no significant difference in survival over a 4-year period. However, when averaged across several treatments, they did report a significant difference in height after the first year between CT (+2.9 cm) and BR (−6.2 cm) seedlings, but this growth difference was reversed after 4 years (BR trees were taller than CT trees). In our study, GC *Q. rubra* stock and BR *S. decora* stock experienced growth rates similar to the paired CT stock. For restoration practitioners aiming to use these particular species/planting treatment combinations, such alternatives to CT stock may prove to be a cost-effective means of doing so and clearly warrant further investigation.

High mortality of *Q. rubra* BR stock in our study could be due to the vulnerability and sensitivity of trees during handling practices (e.g., lifting at nurseries, storage, transporting, and planting techniques; Grossnickle & El-Kassaby 2015). Johnson et al. (1984) reported that *Q. rubra* CT stock had greater new root development than BR stock (i.e., total new root length, number of new roots, new root dry weight). This could explain why we observed a lower mortality of *Q. rubra* CT stock which typically has lower shoot to root ratios, which can increase nutrient storage and resistance to drought conditions, thereby allowing trees to overcome planting stress (Grossnickle & El-Kassaby 2015). In addition, Wilson et al. (2007) reported *Q. rubra* BR suffered 25% mortality over one growing season, significant shoot die-back, and more variable growth. Furthermore, the root systems of *Q. rubra* container stock in their study had a larger number of first order lateral long roots and were significantly more fibrous than BR stock (Wilson et al. 2007). We did not measure tree roots for any of our planting treatments, and further research comparing the root systems of GC, BR, and CT stock used for habitat restoration on lakeshore may help to explain growth and mortality rates of these species.

The soils on our restoration sites were sandy with low-nutrient values (NRCS 1986; WDNR 2014*a*), which may be why CT stock generally performed better than GC and BR stock. All planting treatments in our study received supplemental water via automatic sprinkler systems, and we took precaution to minimize root desiccation during transporting and storage prior to planting. Nevertheless, container planting medium and root wads may retain moisture longer and have higher nutrient values, which could reduce transplanting shock (Grossnickle & El-Kassaby 2015). Other restoration projects have applied fertilizer to sites by various methods to stimulate growth and enhance establishment of plants (Casselman et al. 2006; Salifu et al. 2009). Applying fertilizer to lakeshores, however, may not be desirable because of the potential runoff into the lake. However, Salifu et al. (2009) used a technique called "nursery nutrient loading" on surface mine reclamation site. This technique entails applying high volumes of nitrogen to nursery seedlings biweekly prior to being transported to the restoration sites as BR plant stock (Birge et al. 2006). This approach aims to help plants build nutrient reserves in order to improve growth and survival and allow for quick establishment. Salifu et al. (2009) reported higher seedling field survival (>84%) for *Q. rubra* and *Quercus alba* (white oak) relative to nonfertilized seedlings. Consequently, this technique may be worth exploring for BR and GC stock on lakeshore restoration projects to bring growth rates and survival to levels closer to those observed in CT stock.

Our study and others reveal the importance of sampling across species and monitoring for an extended period of time. Planting of BR plants of some species may be extended throughout the summer months by using gravel as a medium.

Most tree species planted as BR and GC stock that were tested on this project experienced positive growth supporting their use in restoration projects. GC *Q. rubra* and BR *S. decora* demonstrated growth rates comparable to the more expensive CT trees. However, the growth rates of BR and GC *A. rubra*, BR *Q. rubra*, and GC *B. papyrifera* were slower than paired CT trees, indicating that the increased cost for CT trees may be justified for these species..

With the current interest in lakeshore restoration, this study provides valuable information to restoration practitioners, landowners, and agency personnel on practical restoration techniques that may aide in the restoration of lakeshore wildlife habitat. This study will aid in the design of effective programs for restoring trees and understory habitats to lakeshores.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Soil and site characteristics of two lakeshores in Vilas County, Wisconsin, U.S.A.
Table S2. Repeated measure results showing the effects of planting treatment.
Table S3. Repeated measure results showing the effects of planting treatment.
Table S4. Survival results showing the proportion of trees surviving to the third and fourth years of growth for CT/BR pairs and CT/GC pairs, respectively.

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