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Investigating Native Bamboo Practices for Reservoir Conservation and Habitat Restoration

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INVESTIGATING NATIVE BAMBOO PRACTICES FOR RESERVOIR CONSERVATION AND HABITAT RESTORATION

by

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Reservoirs are an important resource for both humans and wildlife. They provide drinking water, recreational opportunities, wildlife habitat and more. A major issue land managers face on reservoirs is shoreline erosion leading to water quality impairments, sedimentation, and habitat loss. Traditionally, riprap has been used to mitigate this issue, but is costly and has limited ability to provide habitat. A promising measure to mitigate shoreline erosion and provide habitat is the establishment of giant cane [*Arundinaria gigantea* (Walt.) Muhl], on shorelines. Giant cane, a bamboo species native to southern Illinois and the southeastern United States, forms monodominant stands called canebrakes. Where canebrakes exist soil stabilization occurs, water quality increases, and habitat is utilized by multiple faunal species. Canebrakes are considered critically endangered habitat for several animal species and regrettably have been reduced to only 2% of their historical extent due to land conversion and loss of traditional burning practices by Native Americans. Giant cane rehabilitation and restoration has been a goal of the US Fish and Wildlife Service and Illinois Department of Natural Resources and is identified as a Critical Species in the Illinois Wildlife Action Plan. Many locations could benefit from cane restoration, especially riparian areas and reservoir shorelines. Research has been conducted on the successful propagation of giant cane, but little is known of the establishment and restoration on shorelines. And thus, this study examined factors that affect the survival and growth of giant cane propagules on shorelines of two southern Illinois reservoirs (Cedar Lake and Kinkaid Lake) in Jackson County, Illinois to successfully establish canebrake habitat and mitigate shoreline erosion.

This study consisted of three replications at three different locations (sites) on each of the two reservoirs. Giant cane transplants were planted along two elevations (30 per elevation) at each site, the beach ~20 cm above the normal reservoir pool and upslope (US) about 1 meter above beach transplants. Initial growth (height of the tallest culm and number of culms) was collected prior to transplanting to be used as factors. Survival, height of the tallest culm (cm), number of culms, and amount of spread (cm) were collected following each of the three growing seasons after planting. Canopy cover (%) was collected after the second growing season on Kinkaid Lake and soil properties (bulk density, texture, and nutrients) were measured on both reservoirs after the third growing season.

Key takeaways were 1) significantly greater survival occurred among transplants in the US position (43.8% for the US vs 3.3% for the beach for Cedar Lake and 82.2% for the US vs 67 for the beach for Kinkaid Lake), 2) elevations with lower bulk density and greater organic matter trended toward greater rates of height and culm density and 3) initial height and number of culms had a positive influence on culm density and height after 3 growing seasons. The major takeaway was that much of the mortality was due to shoreline erosion of beach transplants that were missing and washed away.

For greater survival, transplants of giant cane should be planted up slope from the beach and the normal pool elevation. It is important to plant outside of the zone which may experience regular flooding and/or wave action from boat traffic or winds. For long term growth, looking at soil parameters may be advantageous. Though giant cane has been shown to grow in various soil conditions, this study did see increased spread and number of culms where organic matter was

greater and bulk density lower. Larger transplants should be favored to aid in greater future growth and establishment. The findings of this study can help guide the efforts of land managers in the successful establishment of giant cane on reservoir shorelines.

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CHAPTER 1

INTRODUCTION

Reservoirs provide multiple services to both humans and wildlife. "Reservoirs are important resources for recreation, water supply, flood control, and wildlife habitat, but these benefits are impacted by water quality degradation," (Severson et al. 2009, 208). A major contributor to water quality degradation is shoreline erosion. Shoreline erosion can lead to land management issues such as lake filling, degraded water quality (due to siltation), and a reduction in both shoreline and upland habitat for flora and fauna (Gersbacher 1937, Keddy 1983, Severson et al. 2009). Traditionally, riprap has been used at the interface between shorelines and water bodies to reduce erosion but lacks the ability to provide a significant source of habitat for both flora and fauna and can be costly (Severson et al. 2009).

The establishment of giant cane [*Arundinaria gigantea* (Walt.) Muhl.], on shorelines is a promising management technique to mitigate shoreline erosion and provide habitat. Giant cane a bamboo native to the southeastern United States, has been shown to be an effective riparian buffer species providing multiple ecosystems services (Dattilo 2005, Schoonover et al. 2005, Schoonover et al. 2006). Being a leptomorphic bamboo, cane as a perennial woody grass produces above ground stems or culms from spreading or running belowground rhizomes. Giant cane forms dense mats of rhizomes underground with fine roots that hold soil aggregates tightly. Where giant cane forms monodominant stands known as canebrakes, soil stabilization occurs, water quality is improved, and habitat is provided and utilized by multiple faunal species (Dattilo 2005, Platt et al. 2013, Schoonover et al. 2005, Schoonover et al. 2006).

Canebrakes are considered critically endangered habitat and have been reduced to only 2% of their historical extent due to land conversion and loss of traditional burning practices by

Native Americans (Noss et al. 1995, Platt and Brantley 1992, Platt and Brantley 1997, West 1934). Giant cane rehabilitation and restoration has been a goal of the United States Fish and Wildlife Service and Illinois Department of Natural Resources, and it is identified as a critical species by the Illinois Wildlife Action Plan (IDNR 2005).

Research has been conducted on the successful propagation and field establishment of giant cane, but little is known of the successful establishment of transplants on shorelines. And thus, this research aims to determine factors effecting establishment of giant cane transplants on shorelines of two southern Illinois reservoirs, Kinkaid Lake and Cedar Lake, for the purpose of shoreline stabilization, water quality improvement and wildlife habitat.

CHAPTER 2

LITERATURE REVIEW

Historical Context

There are four bamboo species in the *Arundinaria* genus native to the southeastern United States including giant cane [*A. gigantea* (Walt.) Muhl], hill cane (*A. appalachiana)*, Tallapoosa cane (*A. alabamensis*) and switchcane (*A. tecta)* (Platt and Brantley 1997, Triplett et al. 2006, Triplett 2023). This study focuses on the species giant cane, native to the study area in southern Illinois. Giant cane is an important component of bottomland and riparian forest ecosystems ranging from southern Maryland, west to southern Ohio, Indiana, Illinois, and Missouri, south to central Florida, and west to Texas (Marsh 1977; Simon 1987). Xeric conditions to the west and cold temperatures to the north limit its range (West 1934). "In southern Illinois, giant cane occurs only in sporadic patches, primarily along riparian corridors" (Blattel et al. 2005, 302), but historically was more prevalent.

Cane is described in the literature of early European explorers traversing the North American continent, where extensive canebrakes (large monodominant stands of cane) were noted on the landscape preceding their rapid removal by colonizers (Platt and Brantley 1997). Documented inside *In the Louisiana Canebrakes*, Theodore Roosevelt (1908) noted "the canebrakes stretch along the slight rises of ground, often extending for miles, forming one of the most striking and interesting features of the country" (pp. 47). Preceding European settlement, Native Americans had a profound impact on the environment, and as a result the often described "vast wilderness" of the United States may be somewhat of a misnomer. Platt and Brantley (1997) explain, European settlers describing extensive canebrakes were looking upon the likely result of abandoned Native American agricultural fields and results of their burning practices.

Native Americans positioned their fields of corn in alluvial habitats where floodwaters would keep soils fertile with their villages positioned nearby (Delcourt et al. 1993, Doolittle 1992). Throughout the Southeast, many riverine corridors were modified to support the agricultural demands of high populations of Native Americans (Delcourt et al. 1993, Platt and Brantley 1997). Additionally, canebrakes were maintained near villages for construction material, weapons, a food source, and other cultural purposes. Within fifty years of contact with Europeans, Native American populations dropped drastically due to disease, with estimates of an eighty to ninety percent population drop, resulting in an abandonment of many agricultural fields (Delcourt et al. 1993, Dobyns 1983). Subsequently, canebrake expansion into abandoned agricultural fields likely occurred quite rapidly (Platt and Brantley 1997). Canebrake expansion into these abandoned sites is well documented (Platt and Brantley 1997).

While once relatively plentiful, it is estimated that the extent of canebrakes has been reduced to only 2% of their natural range due to anthropogenic influences such as agricultural land conversion, urban development, and altered fire regimes, and where it does occur, patches are small and isolated (Noss et al. 1995, Platt and Brantley 1992, West 1934). This attests to its critically endangered habitat status (Noss et al. 1995, Platt and Brantley 1992, West 1934). Due to its ecosystem services and limited range, many natural resource agencies are interested in the restoration of these habitats. In fact, the Cypress Creek National Wildlife Refuge in southern Illinois, as well as other members of the Cache River Wetlands Joint Venture Partnership, have focused on cane restoration within the Cache River Watershed to improve habitat and diversity and cane is a recommended species to be planted in riparian areas for the lower Midwestern United States (Schoonover and Williard 2003). Rehabilitation and restoration of canebrakes has been a goal of the U.S. Fish and Wildlife Service and Illinois Department of Natural Resources and giant cane has been identified as a critical species by the Illinois Wildlife Action Plan (IDNR 2005).

Ecological/Morphological Context

Giant cane is a member of the *Poaceae* family and is a temperate perennial woody grass. Giant cane forms dense monodominant stands called canebrakes. Theodore Roosevelt (1908) notes in *In the Louisiana Canebrakes*, "it is impossible to see through them for more than fifteen or twenty paces, and often for not half that distance," providing a description of the dense canebrakes of the past (pp. 47).

There are three main parts to the plant including the culms (aboveground structure reaching 2-9 meters in height), rhizomes (belowground stems spreading many meters horizontally), and roots. At each node of the rhizomes are buds that have the potential to become either a new culm or rhizome. Growing season for canebrakes occurs from spring through mid-summer, with culms reaching their full height and diameter in one year but continuing to branch out at the nodes in subsequent years, each culm living an average of 5-10 years (Hughes 1951, Marsh 1977).

Propagation

Cane flowers for about a month and produce seeds, but these events are sporadic, averaging 30–100-year intervals, and some studies suggest the seed is largely not viable (Hughes 1951). However, more recent observations found greater success with seed viability (Gagnon and Platt 2008b). Cane spreads primarily asexually by rhizomes and a single rhizome may spread as far as 6.1 m in one growing season (Marsh 1977). Because flowering events are so sporadic, propagation of giant cane has been the focus of several studies through the use of rhizomes. Zaczek et al. (2009) discovered that transplanting bare rhizome sections directly in the field or rhizome sections initially grown in a greenhouse setting were both ecologically and operationally feasible methods of propagating giant cane for large-scale canebrake restoration. Zaczek et al. (2003) found that rhizomes with at least ten internodes with the distal end partially exposed to sunlight produced more culms than those with fewer internodes and buried without sun exposure. Though earlier studies suggest rhizome lengths of 45-60 cm for propagation (McClure 1993), Zaczek et al. (2003) found a 76% success rate in culm production in smaller rhizome sections planted with a mean length of 25.9 cm (+/- 0.25 cm), potentially increasing planting stock and providing easier planting operations. Schoonover et al. (2011) suggests rhizome sections of about 30 cm in length for greenhouse grown stock and regards rhizome source to be an important factor in propagation success, suggesting the use of a known viable growing stock or to test a source prior to restoration efforts.

In July 2008, a giant cane nursery was established at Southern Illinois University to sustainably harvest rhizomes for research and restoration and identify the factors necessary in developing a giant cane nursery (Dalzotto 2013). This nursery has allowed for multiple studies to be conducted on management and propagation of giant cane at Southern Illinois University and provided a source of rhizomes for this study.

Management Considerations

Research has been conducted to look at the role of disturbance on canebrakes and resulting management considerations. Though giant cane is known to grow in a wide range of conditions, there are conditions it has been found to favor. Canebrakes can handle a range of environmental conditions but tend to be sparse in distribution under full canopy cover. Cirtain et al. (2009) found that giant cane responds positively to canopy thinning with increased number of shoots and their diameter. Gaps in the canopy as a result of disturbance allow more light to reach the understory vegetation increasing potential for growth (Cirtain et al. 2009). Removing overstory vegetation may increase the vigor of existing canebrakes under forest canopy.

Research suggests giant cane has a preferred soil moisture regime. Much of the historical record of canebrakes locate them exclusively to areas directly adjacent to streams (Cirtain et al. 2004). Cane can survive in moist soils but cannot survive inundation for prolonged periods of time (Platt and Brantley 1997). Cirtain et al. (2004) examined the effects of moisture regimes on giant cane seedling growth in a lab setting and demonstrated, though cane could survive flood and drought, well-drained soils provided the best conditions for growth. Griffith et al. (2009) found that giant cane growth and establishment favors well drained, coarse textured soils.

As it grows most vigorously in full sun, cane depends on disturbances such as fire, wind, or inundation to maintain vigor and stimulate growth (Gagnon 2009). Where disturbance is lacking, canebrakes decline and encroachment of competing vegetation will occur (Gagnon 2009). Historic canebrakes can serve as indicators of recurrent fires due to the strong association between fire and canebrake-like stand structure (Gagnon 2009). Fire is a disturbance that can be implemented through prescribed burning and frequency of fire has varying effects. Cane is quite flammable and burns hot. During a fire, the aboveground culms are killed, but they can quickly resprout from rhizomes, and increases in density and spread may occur (Gagnon and Platt 2008a, Zaczek et al. 2010). Gagnon et al. (2013) recommends a fire frequency of three to eight years for open canopy stands of cane and suggests this may be a year too frequent for forest-grown stands of cane. This is similar to a former recommendation by Hughes (1966) to burn every five to ten years with seven being optimal.

Ecosystem Services

Canebrakes are known to provide multiple ecosystem services and play significant roles in riparian zones. Giant cane forms a dense mat of rhizomes underground with fine roots that hold the soil together tightly. This mat increases soil porosity and infiltration, reducing the negative effects of overland flow. Schoonover et al. (2005 and 2006) compared remnant giant cane and forest riparian vegetative buffers from agricultural settings and found that both were excellent buffers against nutrients (nitrate, ammonium, and phosphate) and sediment load over short distances (3.3-10 m), though giant cane was a slightly better buffer, reducing significant sediment and nutrient loads at 3.3 m vs 6.6 m for forest buffers. Both studies associated the effectiveness of the cane buffer with high infiltration rates, litter layer thickness, and culm density (Schoonover et al. 2005, Schoonover et al. 2006). The underground mat of rhizomes, fast growth, aboveground surface roughness, and resprouting ability of giant cane makes it an excellent species to stabilize banks, provide habitat, and serve as a riparian buffer (Dattilo et al. 2005, Singh et al. 2019, Platt et al. 2013).

Canebrakes provide significant habitat for wildlife. Many mammals, birds, reptiles, and insects take advantage of this habitat, favoring the high density of culms (Dattilo et al. 2005). Platt et al. (2013) report 70 vertebrate species (5 reptiles, 36 birds, and 29 mammals) occurring in canebrakes. These canebrakes are considered critical habitat for several species, such as bamboo specialists of which six butterfly species exist, and important habitat for bears, swamp rabbit, Swainson’s warbler (*Limnothlypis swainsonii*), and several more species (Platt et al. 2013, Yarrow and Yarrow 1999). They provide forage/browse, a den/nesting site, cover, and other beneficial services.

Reservoir Management

Reservoirs, constructed through damming of streams and waterways or excavating depressions, serve as important resources for both humans and wildlife. They provide a source for drinking water, flood control, recreational activities such as fishing and watercraft activities, habitat for wildlife and more. These artificial impoundments account for 94% of all impoundments in Illinois (Severson 2007). In the southern half of Illinois, reservoirs are an important source for municipal water supply due to insufficient groundwater availability (Severson 2007). Managers of reservoirs face multiple challenges in ensuring the integrity of their reservoir is maintained. A natural impoundment may have a lifespan of thousands or millions of years, but due to higher susceptibility to sedimentation and eutrophication, artificial impoundments have a much shorter lifespan of 100 years or less (Severson 2007). Due to anthropological control structures, the water level fluctuations of reservoirs are generally significantly greater than natural impoundments (Hayes et al. 2017). The reservoir is considered full when the pool elevation matches the normal pool, also known as the conservation pool. Normal pool is the height above sea level of the spillway. Typically, the engineering plans for the development of a reservoir establish a certain volume of water necessary for the purpose of that reservoir be it municipal water supply, flood control, etc. Average rainfall, frequency of drought conditions, and expected average daily usage are all considerations that help determine the volume necessary for a reservoir's purpose. Necessary depth is then determined once expected acreage of the reservoir is determined.

Major contributors to the degradation of reservoirs are sedimentation and eutrophication. Compared with natural impoundments which receive input through groundwater, lakes and reservoirs which receive input through overland flow have a higher rate of sedimentation in general (Severson 2007). Sedimentation is a natural process but can be accelerated by human activity such as boat traffic, resulting in an increase in shoreline erosion. Shoreline erosion can result in underwater shelves and vertical bank faces that slough off over time (Severson et al. 2009). Shoreline erosion leads not only to sedimentation, but water quality impairments and habitat loss as well, posing a threat to the many services reservoirs provide (Severson 2007, Severson et al. 2009). Aquatic macrophytes, important in producing oxygen, trapping sediment, stabilizing soil, and providing habitat as well as primary production energy in the littoral zone, are adversely affected by high rates of erosion and sedimentation and therefore can decline (Severson 2007). Impairments in photosynthesis, respiration, growth, reproduction, and feeding can be seen because of sedimentation as well as destruction of habitat for aquatic life (Severson 2007). Sediments accumulating in reservoirs lead to loss of storage capacity, impacting local water supplies (Holdren et al. 2001). Another challenge in managing reservoirs is eutrophication, caused by excess nutrients in a water body, typically nitrogen and phosphorus, leading to increased primary production and potentially large algal blooms that can result in hypoxic waters (IEPA 1978a, Severson 2007). Excess nutrients can make their way into reservoirs via shoreline erosion, overland flow from neighboring agricultural operations, and urban settings.

Traditionally, riprap has been placed at the interface between shorelines and water bodies to reduce erosion, but this can be costly and doesn't provide significant habitat for wildlife (Severson et al. 2009). Bioengineering methods like fiber rolls, willow fences, and plant rolls can provide some habitat benefits but high wave stress may make them unsuitable (Severson et al. 2009). The successful establishment of giant cane on reservoir shorelines presents a promising management technique to mitigate shoreline erosion and sedimentation, improve water quality, and promote a critically endangered habitat.

Research has been conducted on the successful propagation of giant cane and establishment in former agricultural fields and along streams (Schoonover et al. 2011, Zaczek et al. 2009, Zaczek et al. 2010), but nothing has been documented about the establishment of cane transplants on reservoir shorelines. This research explored the feasibility of establishing giant cane transplants on reservoir shorelines for the purpose of shoreline stabilization, water quality improvement and wildlife habitat. This study examined the role of culm height and number of culms prior to planting, elevation above conservation pool, canopy cover, and soil factors on the survival and growth of giant cane on shorelines of two southern Illinois reservoirs, Kinkaid and Cedar Lake.

CHAPTER 3

OBJECTIVE

The objective of this study was to identify factors affecting the establishment of giant cane transplants on reservoir shorelines. Specific null hypotheses tested in this study at two reservoirs include: 1) there is no effect of the elevation above normal pool on transplant survival and growth, 2) initial transplant height and number of culms has no effect on transplant survival and growth, 3) forest canopy cover is not related to cane transplant survival and growth, 4) soil characteristics are not related to cane transplant survival and growth.

CHAPTER 4

METHODOLOGY

Study Area

Two southern Illinois reservoirs within Jackson County, Cedar Lake (area of approx. 7 km^2) and Kinkaid Lake (area of approx. 11 km^2), were chosen for this study. Cedar Lake is located just 11 km south of Carbondale, Illinois and Kinkaid Lake is located 27 km northwest from Carbondale. Both are located within the Big Muddy Watershed which covers an area of approximately 6,100 km^2. Neither reservoir has shoreline development of homes or similar structures.

Cedar Lake was dammed in 1974 for the purpose of supplying municipal water to residents of Carbondale, IL and the surrounding area and serves other purposes such as fishing, canoeing/kayaking, and other recreation. Normal pool elevation for this reservoir is 132.00 meters. The maximum depth of the reservoir is roughly 17 meters. The reservoir spillway is approximately 16.5 meters across and made of engineered blocks called ArmorFlex® (Contech Engineered Solutions LLC, 2024). There is a 10-horsepower boat motor limit on the reservoir. All research sites on Cedar Lake were located on lands managed by the City of Carbondale.

Kinkaid Lake was dammed in 1968 for recreation, a public water supply, and irrigation. Normal pool elevation for this reservoir is 128.02 meters. The maximum depth is roughly 24 meters. The reservoir spillway is approximately 76.2 meters across and has a concrete formation. Motor limits are not in place, but speed limits exist for boats being 80 kilometer/hour during the day and 40 kilometer/hour from sunset to sunrise. Research sites located on Kinkaid Lake are managed by both the Illinois Department of Natural Resources (IDNR) and the U.S. Forest Service.

Site Locations

Prior to planting, potential site locations were chosen. Locations were determined based on edaphic characteristics such as shoreline slope and shape, soil depth without near-surface bedrock, as well as limited overhead vegetative cover. A gradual shoreline slope was desired, but there were few sites with this characteristic as most locations had a steeply cut bank. Permission was obtained from land managers of each respective reservoir and site prior to planting. Permission was granted to begin cane transplanting operations on Cedar Lake in the fall of 2018. The permitting process for Kinkaid Lake took longer, and thus permission to transplant was granted in the spring of 2019.

Transplant Preparation

Two sources of giant cane from the SIU cane nursery (putatively at least 2 different genotypes), Bellrose Gate and F2 that were originally collected from locations in southern Illinois, were selected and harvested during the spring of 2018. Rhizome propagules were dug up to produce in-leaf containerized transplants to be planted on the shorelines of both reservoirs. These different sources were chosen to encourage cross pollination in the post-establishment future in case of a flowering event and were not used as independent variables in this study. After harvesting, bare rhizomes were stored in a refrigerator ~35 degrees Fahrenheit or 1.7 degrees Celsius in plastic bags to maintain moisture prior to potting that occurred between April 6 and May 7, 2018 in D40 Deepots (Stuewe and Sons, Tangent Oregon) in a mix of Berger BM1 nutrient holding potting mix (Berger, Saint-Modeste, Quebec). Approximately 1000 rhizome sections ~ 25 cm long with 3 or more live buds and no visible damage or discoloration were selected and potted similar to procedures described by Dalzotto (2013) and Nesslar (2018). Approximately 3 cm or more of each rhizome was left exposed to light above the potting medium to encourage culm growth. Each transplant was marked with a plastic ID tag reflecting their source and individual ID series number. Transplants were grown in accordance with established practices in the SIU Horticultural Research Center greenhouses. The transplants were transferred to a lathe house to harden off in September 2018.

Initial measurements of the plants were taken before transplanting on shorelines. This included number of culms and height of the tallest culm above the planting media surface using a meter stick to the nearest cm on October 23, 2018. These measurements were to be used as factors in the statistical analysis.

This study consisted of three replications (planting sites) at three different locations (sites) on each reservoir. None of the planting sites were located behind riprap that were established along some shoreline areas. Two elevations were planted, the beach and upslope (US). The beach plantings were located approximately 20 cm above the normal pool at each site. Because of variable terrain, US plantings were established at variable elevations directly above the beach-planted cane.

Most of the banks along and directly above the beach locations were eroded and sloughed, with steep vertical angles. Most were not suitable to transplant giant cane at a fixed elevation across all sites. Thus, where the banks were too steep, the transplants at US elevations were primarily located at more horizontal flattened locations either on bank tops and back approximately 15 cm away from the edge of a steep slope or on more gradual slopes at elevations as listed below.

Upon returning to Cedar Lake on October 23, 2018, the current reservoir pool level was ascertained to determine its elevation relative to the normal pool in order to establish beach and bank top elevation transplant locations. Three site locations, C1, C2, and C3, were chosen. See

Table 4-1 for site GPS coordinates and Figure 4-1 for mapped locations. At each site, using a TopCon® auto level and stadia rod, individual planting spots were marked with pin flags 20 cm in elevation above the normal pool horizontally along the beach 50 cm apart with 30 locations in total (15 of each source). US elevations varied based on slope steepness, more horizontal areas, and vegetation present at each site. Above the beach planting spots, the 30 US treatment planting spots were delineated at higher elevations along the bank top with pin flags also placed ~50 cm apart. Along both beach and US elevations, 15 cm long wooden surveyors' stakes were placed adjacent to every fifth pin flag to aid in location of the transplants in future measurements. Using the TopCon® auto level and stadia rod, US planting spots were determined to have a mean elevation (± standard deviation) above the beach elevation of 98.1±15.7 cm at site C1, 105.4±21.2 cm at site C2, and 102.6±20.7cm at C3. Where vegetation, often trees or shrubs, were already present at the potential planting spot, the location was offset to the side to allow for an obstruction free planting zone without disturbing the existing vegetation.

At each site, after individual planting spots were determined, a planting bar (approx. 8 cm wide, 2 cm thick, and 25 cm deep) or hand trowel was used to dig a hole just large enough for the transplant. The transplant was carefully removed from the D40 Deepot and planted in the hole, without removing the potting mix medium, and voids were filled with mineral soil. Additionally, mineral soil was used to cover the top surface of the plug to ensure the potting mix was not exposed to the air in order to aid in moisture retention. Each individual's original ID tag remained with the planted transplant to identify the individuals during subsequent data collection. All propagules were mapped at the time of transplanting for source and individual ID. Vegetation, including trees, were not altered, or removed during planting.

Permits from the IDNR for this research arrived later than those from the U.S. Forest Service and City of Carbondale and so planting operations on Kinkaid Lake began later than those on Cedar Lake. On May 13, 2019, upon returning to Kinkaid Lake, the current reservoir pool level was determined relative to the normal pool. Three site locations were selected to be planted at the beach and bank top, K1, K2, and K3. See Table 4-1 for site GPS coordinates and Figure 5.2 for mapped locations. Site K1 was located on land managed by the IDNR. Sites K2 and K3 were located on land managed by the U.S. Forest Service. The order of operations followed suite with those at Cedar Lake. Using a TopCon® auto level and stadia rod, at each site, the 30 beach planting spots were located 20 cm above the normal pool and 50 cm apart and marked using pin flags and wooden stakes at every fifth pin flag in total (15 of each genotype). US planting spots were determined to have a mean elevation (± standard deviation) above the beach elevation spots of 63.0±0.0 cm at site K1, 89.5±35.0 cm at site K2 and 80.0±11.8 cm at K3. The containerized cane stock was transplanted as described above at Cedar Lake. Following transplanting, the planting spots were mapped, recording the sources and individual ID number.

Table 4-1 GPS coordinates and description of planting sites on each reservoir.

Reservoir	Site	GPS Coordinates
Cedar Lake	C1	37.65599, -89.26888
Cedar Lake	C2	37.65678, -89.26717
Cedar Lake	C3	37.67248, -89.28179
Kinkaid Lake	K1	37.81034, -89.41920
Kinkaid Lake	K2	37.79622, -89.44113
Kinkaid Lake	K3	37.80042, -89.46240

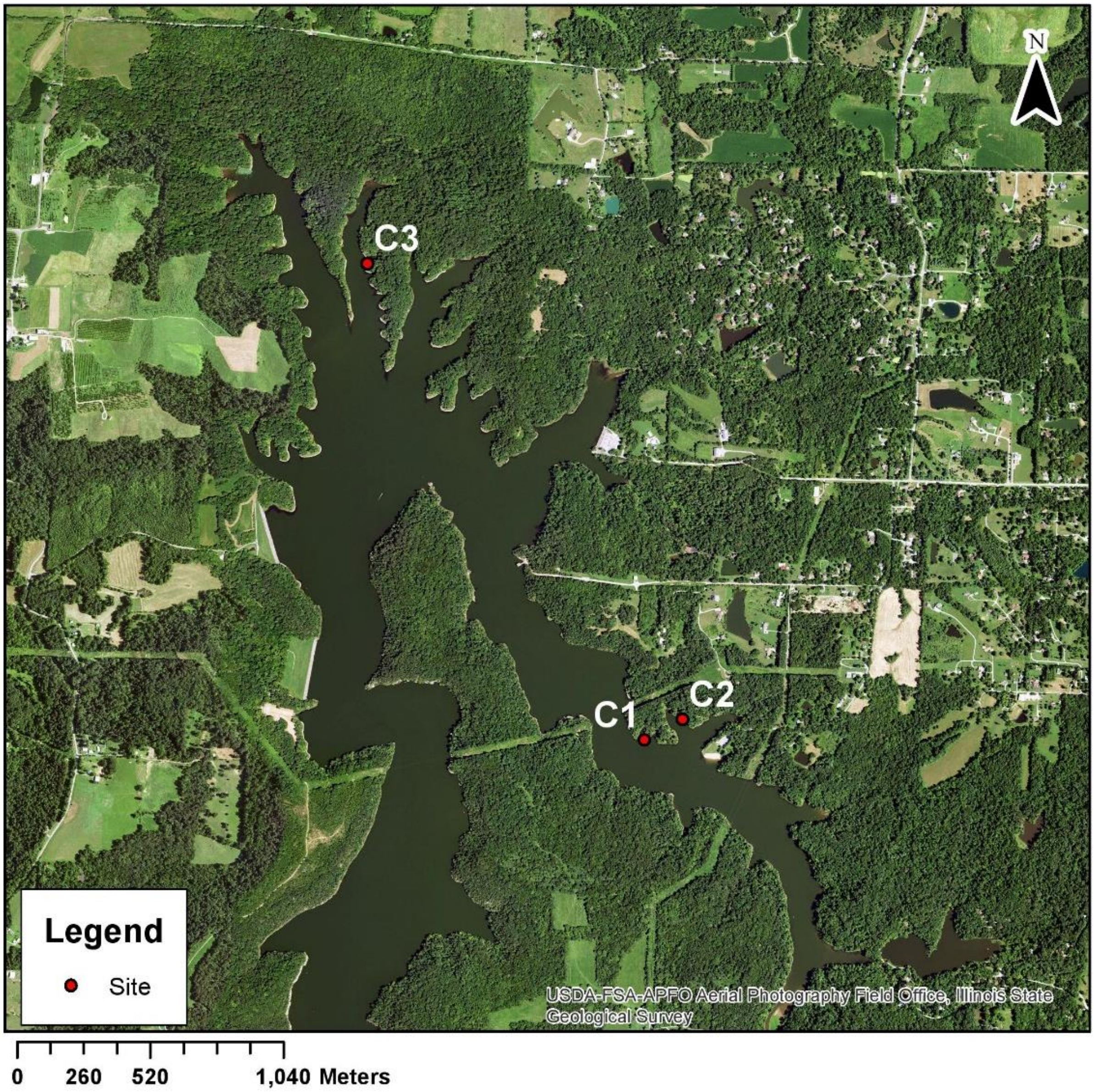

Figure 4-1 Map of Cedar Lake, Jackson County Illinois with site locations indicated in red.

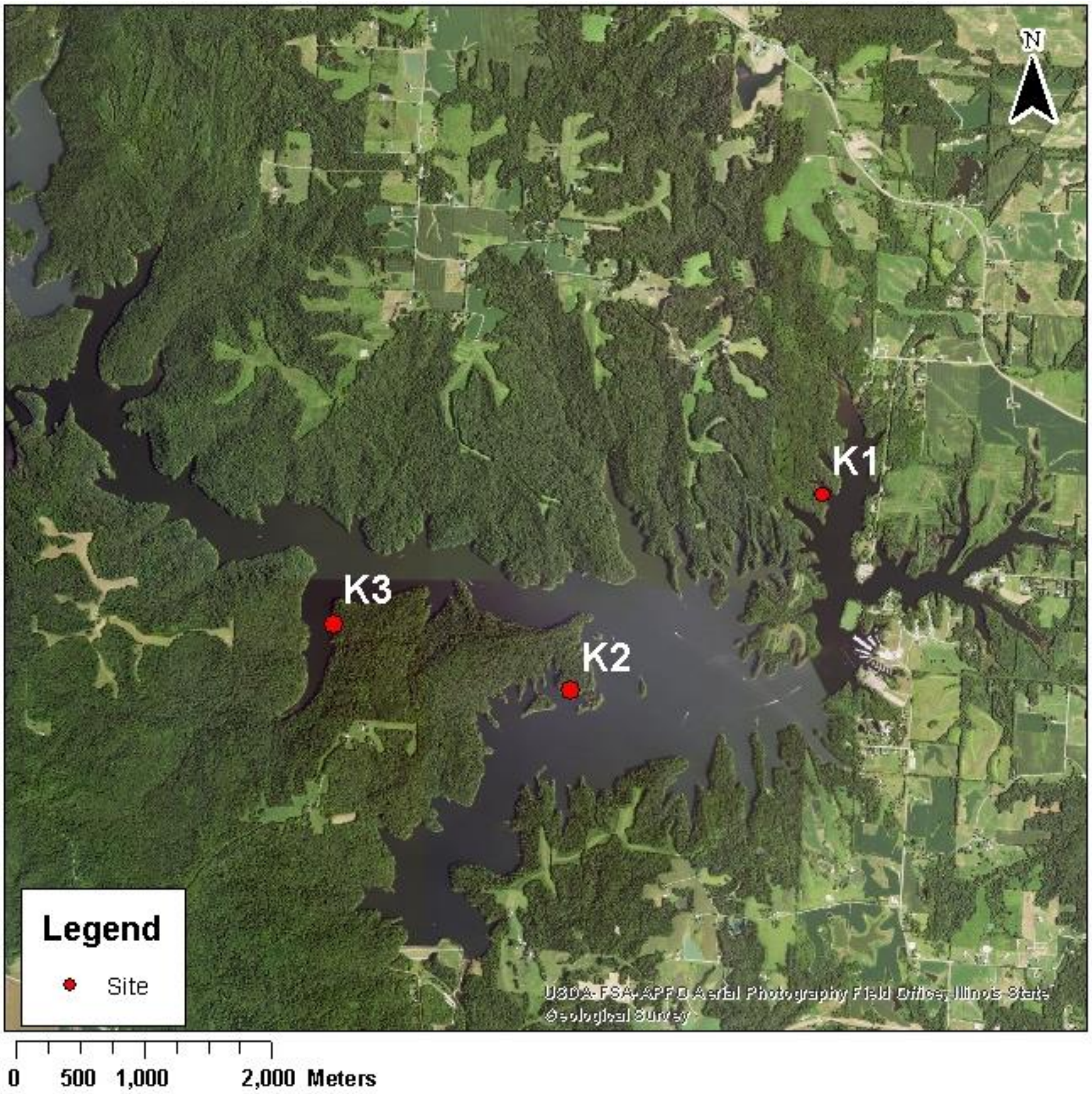

Figure 4-2 Map of Kinkaid Lake, Jackson County, Illinois with site locations indicated in red.

Physical Site Characteristics

Soils at sites on Cedar Lake are Menfro silt loams, Menfro-Wellston silt loams, and Hickory-Menfro silt loams (Web Soil Survey). See Table 4-2 for soil descriptions and their respective sites. Sites on Cedar Lake were not as protected from wave action as Kinkaid Lake, as they were not located in no wake zones, and only site C3 was tucked into a cove, somewhat perpendicular to the typical boat lane travel. Site C1 is in a small cove and has an approximate aspect of 199^{o}. Site C2 is in a small cove with a drainage in the middle of the site that was unfavorable for planting. The transplants were planted on either side of the drainage along their respective elevations (beach and US). This site has an approximate aspect of 195^{o}. Site C3 is located in a small cove with an approximate aspect of 320^{o}.

Soils at sites on Kinkaid Lake include Menfro silt loam and Menfro-Wellston silt loam (Web Soil Survey). See Table 4-2 for soil descriptions and their respective types. Sites on Kinkaid appeared to be more protected from the erosive forces of boat traffic, either by residing in no wake zones and/or being tucked into a cove perpendicular to the main reservoir travel lanes, where wave action did not directly hit those shorelines. Site K1 was located in a cove away from the main lake body and boat traffic and have an approximate aspect of 154^{o}. Site K2 is located in a cove within a no wake zone, with an approximate aspect of 200^{o}. Site K3 is located in a cove within a no wake zone, with an approximate aspect of 35^{o}.

Table 4-2 Soil Data Collected from the USDA Web Soil Survey Interactive Map (2021).

Reservoir	Site	Soil Description
Cedar Lake	C1	Menfro silt loam, 18-25% slopes
Cedar Lake	C2	Menfro-Wellston silt loams, 35-70% slopes
Cedar Lake	C3	Hickory-Menfro silt loams, 18-35% slopes
Kinkaid Lake	K1	Menfro silt loam, 10-18% slopes, severely eroded
Kinkaid Lake	K2	Menfro silt loam, 10-18% slopes, severely eroded
Kinkaid Lake	K3	Menfro-Wellston silt loams, 18-35% slopes

Post-Transplanting Vegetative Data Collection

Data collected on transplants following shoreline planting was collected during the dormant season to easily distinguish giant cane, whose leaves remain green in the dormant season, from other vegetation, especially herbaceous grasses. Data collection of individual transplants occurred during the dormant season following each of the first three following growing seasons after planting referred to as Season 1, Season 2, and Season 3. Cedar Lake transplants were measured on May 22, 2020, April 15, 2021, and December 3, 2021. Kinkaid Lake transplants were measured on June 1, 2020, May 7, 2021, and November 30, 2021. Data collection consisted of measurements of survival, height of tallest culm (HTC) in cm, number of culms (NC), and spread or distance (cm) of the farthest culm from the original transplant or ramet on each site. Survival data included finding the transplant with green tissues (alive), finding the transplant with no green tissues (dead), and not being able to locate the transplant (missing). Missing transplants were separately recorded for Season 1 and 2 and were recorded collectively with the "dead" category in Season 3 data. Height was measured to the nearest ½ cm using a meter stick from the soil surface to the top of the uppermost live node on the culm. Spread was measured to the nearest ½ cm using a meter stick from the original ramet to the base of the farthest culm. A few transplants were reported dead or missing at one measurement and reported as live at another later measurement. This could be a result of culm dieback and growth from another section of the rhizome later or the data collector being unable to locate any sign of living (green) tissues from a transplant at a previous measurement period. Average tree canopy cover (%) was collected on July 14, 2021, and measured using a spherical densiometer, on Kinkaid Lake only, to determine if canopy had an influence on survival and growth after Season 2. Measurements using the spherical densiometer were taken at six locations along each of the beach and bank top elevations equidistance apart. Spherical densiometer readings were taken in each cardinal direction at each location along each elevation and averaged across the elevation at each site for an average canopy cover. Canopy cover was measured once during the summer, to gain some insight into the effects of canopy cover on the growth and survival of transplants.

Soil Data Collection

Soil samples were collected on May 10, 2022, on both reservoirs for each site and elevation. A compact slide hammer with a core volume of 181 cm^3 was used to collect 2 soil samples per elevation, per site, at a depth of 10 cm. These were collected to be analyzed for bulk density (BD). The samples were weighed (g) upon returning to the campus lab. They were then oven dried at 105 °C for 48 hours and oven dry weight (g) was recorded. Weight of the sample (g) was divided by the core volume to determine BD (g/cm^3) for each sample. The difference in grams between original weight and oven dry weight was noted to determine soil moisture (%).

A metal soil probe was used to collect 5 soil samples from the upper 15.24 cm of soil for a composite soil sample. One composite soil sample was collected per elevation, per site. Soil composites were allowed to air dry for 6 days then ground and sifted through a no. 10 (2 mm X 2 mm) mesh screen to remove any rocks and large debris using a DC-5 Dynacrush Soil Crusher from Custom Laboratory Equipment Inc. Each sample was then separated by weight into a 50 g sample and a 120 g sample.

The 50 g samples were used to analyze soil texture (percent sand, silt, and clay) using the Bouyoucos Hydrometer Method (Dane & Topp, 2002). Each of the 50 g samples were placed in a dispersing cup and filled with 100 ml of distilled water and 10 ml of normal (1 N) sodium hexametaphosphate. They were left to soak in this solution for 15 minutes. The dispersing cup was then placed in a mixer for 10 minutes. Afterwards, the contents of the dispersing cup were put into a sedimentation cylinder with deionized water added to total a 1 l solution. The cylinder was shaken and set to rest for measurements taken with a hydrometer at 40 seconds (% silt and clay reading) and two hours (% clay reading). The temperature was collected with a glass thermometer at both the 40 second reading and 2 hour reading to adjust for the calibration of the hydrometer (for every 1° C away from 20° C ±0.2 g/l). The 120 g samples were collected and sent to Brookside Soil Testing Laboratories (New Bremen, OH) to be analyzed for nutrient content.

Table 4-3 Timeline of Activities. HTC=height of the tallest culm. NC=number of culms.

Date	Activity
October 23, 2018	Initial transplant measurements of HTC and NC collected.
October 23, 2018	Collected pool elevation on Cedar Lake. Determined locations of transplants and planted them in designated locations for all sites on Cedar Lake.
May 13, 2019	Collected pool elevation on Kinkaid Lake. Determined locations of transplants and planted them in designated locations for all sites on Kinkaid Lake.
May 22, 2020 Season 1	Measurements of transplant survival, HTC, NC, and spread collected on Cedar Lake.
June 1, 2020 Season 1	Measurements of transplant survival, HTC, NC, and spread collected on Kinkaid Lake.
April 15, 2021 Season 2	Measurements of transplant survival, HTC, NC, and spread collected on Cedar Lake.
May 7, 2021 Season 2	Measurements of transplant survival, HTC, NC, and spread collected on Kinkaid Lake.
July 14, 2021	Measurements of canopy cover collected using a spherical densitometer on Kinkaid Lake.
November 30, 2021 Season 3	Measurements of transplant survival, HTC, NC, and spread collected on Kinkaid Lake.
December 3, 2021 Season 3	Measurements of transplant survival, HTC, NC, and spread collected on Cedar Lake.
May 10, 2022	Soil samples collected on both reservoirs for each elevation and site.

Statistical Analysis

The primary interest that guided the statistical analysis was to determine which of the factors (elevation above normal pool, initial transplant morphology, or soils) affected survival and growth after 3 growing seasons. Canopy cover after two growing seasons was also considered as a factor on Kinkaid Lake. Chi-square analysis was performed to determine if survival of cane transplants was independent of reservoir after three growing seasons, Season 3. Percent survival and means and standard errors of growth parameters (HTC, NC and amount of spread) were calculated for each Season on each reservoir by elevation. Chi-square analysis was used to determine if there was an association between cane transplant survival for Season 3 and elevation for each reservoir.

For Cedar Lake, survival was very low for each of the Seasons for beach-planted stock, so further statistical analyses on survival and growth parameters were performed on the US transplants only for that reservoir. Logistic regression was used to test if height of the tallest culm (HTC) of a transplant at the TOP predicted survival of US transplants for Season 3. Chi-square analysis was used to determine if survival of US transplants for Season 3 was associated with number of culms (NC) of a transplant at the time of planting (TOP), categorized into either 1 or 2+ culms. Linear regression was used to test if HTC at the TOP predicted HTC, NC, or amount of spread of US transplants for Season 3. Independent t-tests were used to test if NC at the TOP predicted HTC, NC, or amount of spread of US transplants for Season 3.

The following tests were run on Kinkaid Lake data. Chi-square analysis was used to determine if survival for Season 3 depended on NC of a transplant at TOP, categorized into 1 or 2+ culms. Logistic regression was used to determine if HTC of a cane transplant at the TOP predicted survival for Season 3.

An independent t-test was used to determine if HTC at the TOP varied by elevation and chi-square analysis was used to determine if NC at the TOP differed by elevation. An independent t-test was used to identify if mean growth parameters varied by elevation for Season 3. Independent t-tests were also used to determine if mean growth parameters for Season 3 varied by NC of a transplant at the TOP, categorized into 1 or 2+ culms. Linear regression analysis was used to determine if HTC at the TOP predicted growth parameters for Season 3.

An independent t-test was used to identify if canopy cover varied significantly by elevation. Logistic regression analysis was used to test if canopy cover predicted survival for Season 3. Correlation analysis was used to determine if there were relationships between canopy cover and growth parameters for Season 3.

Soil parameters were analyzed to determine if there was an influence on transplant survival or growth parameters. Bulk density (BD), organic matter (OM), pH, and Calcium (Ca) were the soil parameters of focus. For a full list of soil parameters for each reservoir by site and by elevation, see Appendix A and B. Kruskal-Wallis nonparametric tests were used to determine if there were significant differences among soil parameters between sites and a Mann-Whitney nonparametric test was used to determine if soil variables were different by elevation. Correlation analysis was used to determine relationships between soil parameters, mean survival, and mean growth parameters.

A Shapiro-Wilk normality test was performed for HTC, NC, and amount of spread on each reservoir. Variables failing to meet normality were log or square root transformed in an attempt to meet normality. A significance level of α=0.05 was used in all analyses. Levene's test for equality of variance was performed to determine if equal variances were assumed for each of the independent t-tests. Welch test was reported where equal variances were not assumed. All analyses were run using SPSS Statistics software (IBM SPSS Statistics Armonk, NY).

CHAPTER 5

RESULTS

Both Reservoirs

After the first growing season, mean survival of transplants varied from a low of 5.7% at the Cedar Lake beach elevation to 86.7% at the Kinkaid Lake US elevation (Table 5-1). Subsequently, survival changed little after growing seasons 2 and 3 at each lake by elevation location.

The low survival of beach transplants at Cedar Lake was, in a large part, due to nearly 2/3 of the transplants recorded as missing (Table 5-2) apparently from primarily being washed away due to shoreline erosion. In comparison, for US transplants, less than 2.2% were considered missing after either of the first two growing seasons. At Kinkaid Lake, an analogous but not as extreme result occurred with 26.1% to 21.6% of the beach transplants missing over seasons 1 and 2, respectively, while only 1.1% of US transplants were missing over that time.

As after Seasons 1 and 2, Season 3 survival on the beach elevation of Cedar Lake was much lower than on Kinkaid Lake (3.3% vs 67.0%) and survival of the US elevation on Cedar Lake was about half the survival reported on Kinkaid Lake (43.8% vs 82.2%). An association between reservoir and survival after 3 seasons was observed, $x^2(1)=91.56$, $p=<0.001$. Thus, analyses of the effect of transplanting elevation above normal pool on survival and growth parameters were separately performed for each reservoir.

Table 5-1 Survival percentage of giant cane transplants at each lake by elevation above normal pool over time. (US=upslope)

Reservoir	Elevation	# of Cane Transplants	Survival Percentage Season 1	Season 2	Season 3
Cedar Lake	Beach	87	5.7	2.3	3.3
	US	89	48.3	48.3	43.8
Kinkaid Lake	Beach	88	63.6	64.8	67.0
	US	90	86.7	82.2	82.2

Table 5-2 Fate (Percentage Alive, Dead, or Missing) of transplanted giant cane at each lake by elevation above normal pool over time. (US=upslope) after each of the first two growing seasons.

Lake	Elevation	# of Cane Transplants	Alive (%)		Dead (%)		Missing (%)	
			Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Cedar	Beach	87	5.7	2.3	31.0	35.6	63.2	62.1
	US	89	48.3	48.3	49.4	50.6	2.2	1.1
Kinkaid	Beach	88	63.6	64.8	10.2	13.6	26.1	21.6
	US	90	86.7	82.2	12.2	16.7	1.1	1.1

Cedar Lake

On Cedar Lake, a significant association between elevation and survival was observed, $x^2(1)=39.466$, $p<0.001$, with greater survival on the US than the beach (Table 5-1). As mentioned earlier, since survival was so low for beach transplants, besides basic means and standard errors, further statistical analysis at Cedar Lake was confined to US transplants.

For US transplants, HTC of a transplant at the TOP did not significantly predict Season 3 survival ($p=0.220$). Season 3 survival of US transplants was not associated with NC at the TOP ($p=1.000$). Mean HTC of a transplant slightly decreased, and mean NC slightly increased between the TOP and Season 3 and mean amount of spread increased between Season 1 and Season 3 for both beach and US transplants (Table 5-3). For those US transplants, HTC at the TOP was not found to be a significant predictor of HTC, NC, or amount of spread for Season 3 ($p=0.197$, $p=0.823$, and $p=0.248$ respectively). For those US transplants, HTC, NC, and amount of spread were not significantly different by NC at the TOP for Season 3 ($p=0.297$, $p=0.967$, and $p=0.628$ respectively).

Table 5-3 Means and standard errors of growth parameters (Height of the Tallest Culm in cm (HTC), Number of Culms (NC), and Spread) in cm at the time of planting and for Season 1, Season 2, and Season 3 of surviving transplants by elevation on Cedar Lake.

Time	Time of Planting		Season 1		Season 2		Season 3	
Variable	Beach	Upslope	Beach	Upslope	Beach	Upslope	Beach	Upslope
n	87	89	5	43	2	43	3	39
HTC (cm)	32.22 ±1.25	33.93±1.39	21.60±5.45	29.12±2.35	32.25±4.75	28.33±2.19	22.00±9.07	32.87±3.12
NC	1.31±0.06	1.30±0.06	1.00±0.00	1.60±0.15	1.00±0.00	1.58±0.12	1.67±0.67	2.15±0.30
Spread (cm)	NA	NA	0.00±0.00	1.35±0.64	0.00±0.00	2.63±0.71	3.33±3.33	7.62±2.11

Kinkaid Lake

On Kinkaid Lake, a significant association between elevation and survival was observed, $x^2(1)=5.425$, $p<0.020$, with greater survival on the US than the beach (see Table 5-1). HTC of a transplant at the TOP did not significantly predict Season 3 survival ($p=0.48$). Season 3 survival was not associated with NC at the TOP ($p=0.77$).

HTC at the TOP and NC at the TOP did not differ by elevation ($p=0.949$ and $p=0.180$ respectively). Growth was evident over time as mean HTC of a transplant and mean NC tended to increase between the TOP and Season 3 and mean amount of spread tended to increase between Season 1 and Season 3 for both beach and US transplants (Table 5-4). After 3 growing seasons, mean HTC, NC, and amount of spread was statistically greater on the beach than the US (see Table 5-5).

Table 5-4 Means and standard errors of growth parameters (Height of the Tallest Culm in cm (HTC), Number of Culms (NC), and Spread) in cm at the time of planting (TOP) and for Season 1, Season 2, and Season 3 by elevation on Kinkaid Lake. US=Upslope.

Time	Time of Planting TOP		Season 1		Season 2		Season 3	
Variable	Beach	Upslope	Beach	Upslope	Beach	Upslope	Beach	Upslope
n	88	90	56	78	57	74	59	74
HTC (cm)	34.48±1.21	34.59±1.27	38.45±1.85	36.59±1.52	41.78±2.11	39.05±1.76	60.52±3.16	48.95±2.67
NC	1.25±0.05	1.18±0.05	2.11±0.16	1.76±0.12	4.75±0.59	2.42±0.20	5.47±0.59	3.05±0.24
Spread (cm)	NA	NA	3.29±0.62	2.12±0.40	9.81±1.62	5.64±1.07	20.42±2.56	11.26±1.51

Table 5-5 Differences between elevations on growth parameters (height of the tallest culm (HTC), number of culms (NC), and amount of spread) for Season 3 on Kinkaid Lake.

	Beach		Upslope					
	$\bar{x}$	SE	$\bar{x}$	SE	Df	t	P	Cohen's d
HTC Season 3	60.52	3.16	48.95	2.67	131	2.812	0.006	0.49
NC Season 3	5.47	0.59	3.05	0.24	131	3.933	<0.001	1.07
Spread Season 3	20.42	2.56	11.26	1.51	98	2.681	0.009	0.93

Transplants with only 1 culm when compared to those with multiple culms at the TOP did not differ after 3 growing seasons for HTC (t(29)=-1.37, p=0.183, d=-0.366) ($\bar{x}$ =52.49 cm vs $\bar{x}$ =61.29 cm, respectively) nor spread (t(98)=-0.18, p=0.854, d=-0.045) ($\bar{x}$ =14.26 cm vs $\bar{x}$ =21.35 cm, respectively). However, NC after Season 3 was greater from transplants that had multiple culms at the TOP compared to those with only 1 culm at TOP (t(29)=-2.24, p=0.033,d=-0.629) ($\bar{x}$ =6.04 vs $\bar{x}$ =3.68, respectively).

HTC at the TOP was not found to be a significant predictor of NC (p=0.672) or amount of spread (p=0.576) for Season 3, however, it was found to be a positive predictor of HTC (p=0.006) for Season 3 (Table 5-6) accounting for only 5% of the variation.

Table 5-6 Regression Analysis Summary for Height of the Tallest Culm (HTC) at the Time of Planting (TOP) predicting HTC, Number of Culms (NC) and Amount of Spread for Season 3.

Variable	B	95% CI	β	T	P	R^2
(Constant)	36.28	[23.12, 49.45]		5.45	<0.001	0.050
HTC	0.51	[0.15, 0.87]	0.24	2.81	0.006	
(Constant)	1.97	[1.54, 2.40]		9.12	<0.001	0.001
NC	-0.002	[-0.01, 0.01]	-0.04	0.42	0.672	
(Constant)	1.23	[.98, 1.48]		9.91	<0.001	0.003
Spread	-0.002	[-0.01, 0.01]	-0.06	0.56	0.576	

CI=Confidence interval for B

Canopy Cover did not differ by elevation (t-test, p=0.096, $\bar{x}$ =81.73 vs. $\bar{x}$ =90.05 for beach and US respectively). Canopy cover was not found to be a significant predictor of survival for Season 3 (p=0.558). Canopy cover was not correlated with HTC, NC, or amount of spread for Season 3 (p=0.467, p=0.502, and p=0.109 respectively).

Due to low survival on beach planted transplants on Cedar Lake, statistical analyses involving soils were conducted for Kinkaid Lake only. See Appendix A and B for a full list of soil parameters measured for both reservoirs. When looking at soils, mean BD did not differ among sites on Kinkaid Lake (H(2)=0.73, p=0.694) and averaged 1.05 g/cm^3 overall. However, bulk density was greater on the US elevation (mean=1.25 g/cm^3) than the beach (mean=0.84 g/cm^3) (p=0.016). Mean OM, pH, and Ca did not differ among sites (H(2)=3.53, p=0.171, H(2)=0.857, p=0.651, H(2)=2.9, p=0.867, respectively) on Kinkaid Lake and averaged 3.89%, 5.2, and 1317.67 mg/kg (respectively) overall. OM, pH, and Ca did not differ by elevation (p=0.376, p=0.050, p=0.050, respectively) on Kinkaid Lake either.OM averaged 2.59% on the US and 5.18% on the beach. The pH averaged 4.7 on the US and 5.7 on the beach. The Ca averaged 843 mg/kg on the US and 1792.33 mg/kg on the beach. Correlation analysis between soil parameters and survival and growth parameters revealed relationships between NC for Season 3 and OM (see Table 5-7).

Table 5-7 Pearson correlations for soil parameters, mean survival, and mean growth parameters for Season 3. Values indicate Pearson's Correlation Coefficient. BD= Bulk Density, OM= Organic Matter, Ca= Calcium, HTC= Height of the Tallest Culm, and NC= Number of Culms

Variables	Survival	HTC	NC	Spread
BD	0.668	-0.184	-0.754	-0.703
OM	-0.447	0.393	0.909*	0.803
pH	-0.761	0.544	0.740	0.795
Ca	-0.706	0.505	0.769	0.805

*Correlation is significant at the 0.05 level (2-tailed).

CHAPTER 6

DISCUSSION

The focus of this research was to aid in the development of management recommendations for establishing giant cane on reservoir shorelines. The discussion will focus on factors that significantly influenced survival and growth of giant cane transplants.

Survival between each reservoir was quite different and also varied between elevations at each reservoir. Perhaps the most significant finding was that the cause of mortality mainly appeared to result from transplants being eroded away from beach planting spots from shoreline erosion or from stressful growing conditions such as extended flooding/inundation after rain events. Similar responses have been noted in other studies on giant cane (Andrews et al. 2011) where mortality of cane occurred as a result of frequent flooding when planted along a stream. Several studies mention giant cane is not well adapted to grow in flooded landscapes and tends to grow on well-drained ridges along floodplains, sometimes called secondary bottoms, where the species is not exposed to prolonged inundation (Griffith et al. 2009, Platt and Brantley 1997, Shoemaker 2018).

Shoreline erosion was apparent and varied by reservoir and by elevation as evidenced by transplants that were no longer locatable and missing from their planting spots primarily at beach locations especially at Cedar Lake by Season 1. After two growing seasons, few transplants were missing in the US position for either lake (1.1%). The mortality of beach-planted giant cane on Cedar Lake after the second growing season appears to be mainly the result of shoreline erosion and being washed away as there were almost twice as many transplants missing as those present but dead (62.1% vs. 35.6%). On Kinkaid Lake, the difference between transplants missing and present but dead after the second growing season was less pronounced, but greater a percentage was missing (21.6% vs. 13.6%), respectively. This was likely influenced by the effects of shoreline erosion from boat and wind propagated waves in combination with fluctuating water levels that occurred after some rainstorm events.

There were almost three times as many transplants missing and apparently washed away on the beach at Cedar Lake as compared to Kinkaid Lake (62.1% vs. 21.6 %) and over twice as many present but dead on Cedar Lake as compared to Kinkaid Lake (35.6% vs 13.6 %) after the second growing season. This may be a result of 1) different exposure to boat or wind propagated waves and/or 2) difference in reservoir size in relation to its individual watershed and spillway length, allowing for water levels to return to normal pool after flooding events at different rates. Also, since Cedar Lake was planted October of 2018, the transplants were subjected to longer exposure to potential flooding and shoreline erosion compared to those at Kinkaid Lake which were planted in May of 2019.

On Cedar Lake, sites were more exposed to boat traffic than Kinkaid Lake sites. There are few “no wake zones” around Cedar Lake sites, which can provide extra protection from boat-propagated wave action (Bilkovic et al. 2019). The shoreline along Cedar Lake sites appeared to be more undercut above the beach elevation and below the US elevation than Kinkaid Lake, likely due to more exposure to boat and wind propagated wave action. On Kinkaid Lake, sites were either tucked into a cove, with a shoreline behind a point of land separating the site from the non wake-regulated main lake body or within no wake zones at a distance of at least 152 meters from the main lake.

The size of the reservoir in relation to its individual watershed in addition to its spillway length also likely contributed to differences in exposure to inundation/flooding and erosion from wave action. When looking at watersheds specific to each reservoir, Cedar Lake’s ratio of reservoir to watershed area is approximately 1:13, while Kinkaid Lake's ratio of reservoir to watershed area is approximately 1:9, therefore Cedar Lake is receiving overland and subsurface flow from a greater area of land relative to its size as compared to Kinkaid Lake. Kinkaid Lake's spillway is also much wider than Cedar Lake's spillway (approx. 76.2 meters vs. 16.5 meters across). The greater land surface within its watershed and shorter length of spillway likely contribute to water levels returning to normal at a much slower rate on Cedar Lake as compared with Kinkaid Lake.

Daily records on lake water level fluctuation were obtained for Kinkaid Lake between the dates of 5/13/2019 (planting date) and 10/25/2021 (after the third growing season). Multiple flooding events occurred following planting on Kinkaid Lake with some events reaching the beach elevation (see Table 6-1). No flooding events reached the US elevation. Though daily records on water fluctuations were unobtainable for Cedar Lake, observations indicated that water level rise appeared to be greater/higher than Kinkaid Lake and tended to drop more slowly and be flooded for longer periods. These flooding events likely contributed to mortality from extended periods of inundation and may have caused flood-related erosion, contributing to missing transplants along beach elevations.

Table 6-1 Summary of average periods (in days) of flooding events, range of flooding event duration (in days), number of days where the lake level reached the beach elevation, and maximum flood level (in centimeters) on Kinkaid Lake.

Year	Average Flooding Event Duration (in days)	Range of Flooding Event Duration (in days)	# Days Flooding Above Beach Elevation	Maximum Flood Level (cm above normal pool)
2019	4	1 to 9	2	20
2020	6	1 to 16	12	46
2021	10	1 to 26	15	37

On Cedar Lake, as discussed, survival was much greater on the US compared to the beach after three growing seasons (43.8% vs. 3.3%) due to apparent shoreline erosion and likely inundation-caused mortality. Due to low survival, only the US transplants were considered for further analysis. Factors measured in this study revealed little evidence for influence on survival or growth. Survival was not associated with NC at the TOP and was not predicted for by HTC at the TOP. Growth (HTC, NC and amount of spread) was not predicted by HTC at the TOP and did not differ by NC at the TOP.

Further investigation was performed for Kinkaid Lake on both the US and beach. Survival differences between the US and beach were much less pronounced compared to Cedar Lake (82.2% vs. 67.0%) but nonetheless significantly different. The major difference in survival between elevations appears to be the result of missing transplants likely due to shoreline erosion. There was a large difference in missing transplants between the US and beach after the second growing season (1.1% vs. 21.6% respectively). Those differences by elevation in transplants after the second growing season that were present but dead was less pronounced (16.7% for the US vs. 13.6% for the beach).

Survival was not influenced by light on Kinkaid Lake (ranging from 73-99% canopy cover). However, canopy cover by elevation did not vary greatly (81.73% vs 90.75% on the beach and US, respectively). Survival was not associated with NC at the TOP nor HTC at the TOP. No correlation was found between soil parameters and survival. This isn't surprising as other studies have noted quite variable soil parameters among established canebrakes and may indicate a generalist behavior when it comes to certain soil parameters (Griffith et al. 2009, Singh et al. 2018).

Another factor related to flooding that may have reduced survival for some of the present but dead transplants was the presence of aquatic vegetation that for the most part appeared to be some type of filamentous algae. The algae occasionally would be deposited on top of the transplants after some flooding events receded. The algae deposits covering the cane apparently blocked sunlight and may have damaged the cane foliage resulting in reduced photosynthetic capacity. At Kinkaid Lake this occurred only for the beach transplants because flooding never overtopped the US transplants. It is unknown whether flooding overtopped the US transplants at Cedar Lake because the hydrologic data was unobtainable.

Mean growth on Kinkaid Lake after 3 growing seasons was greater on the beach elevation than US. It is not clear why growth was greater on the beach. Of the factors looked at in this study, bulk density differed by elevation (ranging from 0.53-1.14 g/cm^3 on the beach and 1.13-1.34 g/cm^3 on the US), but no correlation was found between bulk density and growth. According to the USDA Natural Resource Conservation Service (2008), for soils that are silty, in general, bulk densities below 1.40 g/cm^3 are ideal for plant growth and above 1.65 gm/cm^3 restrict root growth. All soils for this study fell within the ideal bulk density range. Though no correlation was found, increased bulk density does tend to restrict root growth and may limit aboveground biomass.

The NC at the TOP had a positive influence on NC after three growing seasons ($\bar{x}$ =6.04 for 2 or more culms at the TOP vs $\bar{x}$ =3.68 for 1 culm at the TOP) and HTC at the TOP was a positive predictor on HTC after three growing seasons (p=0.006). Besides using in-leaf transplants as in this study, planting bare rhizomes may also be effective and less costly at establishing giant cane as has been demonstrated in previous field studies (Zaczek et al. 2009, Schoonover et al. 2011)

Though other studies regard light as an important factor contributing to growth of giant cane (Cirtain et al.2009), canopy cover was not found to be a significant factor limiting or contributing to growth. This could be because canopy cover was generally high (73-99%) overall. More open conditions may have resulted in greater growth. Of the soil variables tested, OM was the only metric to have an influence on growth. OM ranged from 2.44%-10.02% across elevations at different sites and had a positive influence on NC after the third growing season. Site K2 on the beach elevation had the most organic matter (10.02%) of all sites and elevations on Kinkaid Lake and had the highest NC and amount of spread after three growing seasons. This site also, unsurprisingly, had the lowest bulk density (0.53 gm/cm^3) which is typical with higher rates of OM and tends to improve conditions for plant growth (USDA NRCS 2008).

CHAPTER 7

CONCLUSION

As natural resource professionals become more interested in the restoration of giant cane, it becomes increasingly critical that research examines important factors playing a role in establishment in different locations and ecosystems. Several studies have looked at factors that influence giant cane's survival and growth in field planting and along streams and rivers, but none have focused on successful establishment on reservoir shorelines. Preparing transplants for this study relied on the findings of past studies which looked at growing giant cane in greenhouse settings in preparation for restoration projects (ex. using bare rhizomes and planting with at least one bud exposed to sunlight). This study then examined factors which then may influence transplants following placement along reservoir shorelines.

Establishing giant cane on reservoir shorelines has the potential to provide several ecosystem services. As mentioned previously, Schoonover et al. (2005 and 2006) found giant cane to be an effective buffer against nutrient and sediment load over short distances (as low as 3.3 m) due to high infiltration rates, thick layers of leaf litter and the high densities of culms in established canebrakes. The underground matt of rhizomes provides a dense network of roots that holds soil together tightly (Dattilo et al. 2005, Platt et al. 2013, Singh et al. 2019) which should assist with shoreline erosion mitigation and thereby improve water quality and wildlife habitat. In addition to improving aquatic wildlife habitat as a buffer and through shoreline stabilization, canebrakes provide terrestrial wildlife habitat where established for several wildlife species, which utilize the dense culm structure (Dattilo et al. 2005 and Platt et al. 2013).

Management Implications

For greater survival, transplants of giant cane should be planted upslope from the beach and the normal pool elevation. It is important to plant outside of the zone which may experience regular flooding and/or wave action from boat traffic or winds. This should decrease chances of transplants being washed away during the establishment period and mortality in place due to inundation. If possible, obtain hydrologic data about typical maximum flood levels and refrain from transplanting cane in that zone.

Plant cane transplants on stable slopes or flat-topped benches, especially if exposed to significant wave action from winds or boat traffic. It is recommended that cane be planted in coves that are more protected from wind and boat propagated wave action. Observations did indicate giant cane may spread towards the beach from higher elevations over time once established. Cane, when transplanted to beach elevations, may spread upslope but survival can be poor, especially for sites that are more exposed to shoreline erosion and on lakes that experience extended flooding periods above the normal pool, and thus it is not recommended to plant at the beach. Though not discussed here, shoreline aspect should be considered as well, considering that, depending on the region, some shoreline aspects are potentially more protected from wind-propagated wave action than others.

For long term growth, considering soil parameters may be advantageous. Though giant cane has been shown to grow in various soil conditions, this study did see increased spread and number of culms where organic matter was greater and bulk density lower. When choosing between sites, land managers should favor those that exhibit these features. If using in-leaf transplants, land managers should favor those with greater initial height of the tallest culm and number of culms as this was shown to result in greater height and densities of culms over time.

Though genotype was not in the focus of this study, transplanting at least two different genotypes when establishing giant cane along shorelines should be considered, in order to encourage cross pollination during flowering events. Though it spreads locally primarily through underground rhizomes, there is potential for water-facilitated spread of viable seed of greater distances which may result in establishing canebrakes along reservoir shorelines and downstream from the reservoir. Rhizome sections do have the potential to dislodge and asexually reproduce by fragmentation and establish on lakeshores downstream as well.

The time of year for transplanting is another factor which was not discussed in detail here, but greater survival was seen on Kinkaid Lake where transplants were planted in May of 2019 as compared to Cedar Lake which was planted in October of 2018. Transplanting in the spring or closer to the start of the growing season may prove advantageous as this should stimulate new root growth sooner and provide conditions to become better established prior to the dormant season. Transplants which were planted on Cedar Lake were not provided an opportunity to establish through a growing season prior to being exposed to boat and wind propagated wave action and flood events which may result in transplants being washed away. Also, if rip rap has been installed on the shoreline, planting cane upslope from it should help in establishment and limit loss of transplants through shoreline erosion.

Future studies should consider measuring rates of erosion on shorelines where canebrakes are established as compared to those without canebrake establishment. The benefit of wildlife habitat in canebrakes is apparent, but it is unclear how rates of erosion may differ. Considering thinning of canopies on reservoirs where giant cane is planted or canebrakes exist could also provide insight into best management practices for canebrakes on reservoir shorelines.

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APPENDIX A

BULK DENSITY, SOIL TEXTURE AND SOIL MOSTURE

Appendix-1. Bulk density (BD), soil texture (%), and soil moisture (%) for sites by elevation on each reservoir.

Reservoir	Site	Elevation	Bulk Density	% Sand	% Silt	% Clay
Kinkaid	1	US	1.337873	19.2	58.4	22.4
	1	Beach	0.859475	31.6	46	22.4
	2	US	1.283895	33.6	46	20.4
	2	Beach	0.531105	29.6	56.4	14
	3	US	1.134061	14	66.4	19.6
	3	Beach	1.136271	12.8	61.6	25.6
Cedar	1	US	1.086243	56	25.6	18.4
	1	Beach	1.410967	75.6	16	8.4
	2	US	1.200276	34.4	51.2	14.4
	2	Beach	1.47989	19.6	58	22.4
	3	US	1.18884	41.2	48	10.8
	3	Beach	1.493757	65.2	24	10.8

APPENDIX B

CHEMICAL SOIL ANALYSIS

Appendix-2. Chemical soil analyses performed by Brookside Laboratories for sites by elevation on each reservoir.

Reservoir	Site	Elevation	pH	OM (%)	Ca (mg/kg)	TEC (meg/200 g)	Mg (mg/kg)	K (mg/kg)	Bray I P (ppm)
Kinkaid	1	US	4. 9	2.78	961	16.96	310	86	2
	1	Beach	5. 7	3.09	1666	16.23	327	59	3
	2	US	4. 7	2.56	648	11.87	162	74	5
	2	Beach	5. 9	10.02	2175	17.17	233	57	18
	3	US	4. 6	2.44	920	13.56	53	55	20
	3	Beach	5. 4	2.44	1536	19.13	415	69	11
Cedar	1	US	5. 3	2.74	1252	13.90	176	63	5
	1	Beach	6. 3	1.49	1155	9.34	222	56	6
	2	US	4. 9	2.06	791	11.47	121	63	5
	2	Beach	5. 5	1.2	1221	18.65	625	60	2
	3	US	5	2.07	571	7.73	78	41	3
	3	Beach	5. 9	1.22	888	8.77	236	42	4

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