Survival and Growth of Black Willow (*Salix nigra*), Silky Willow (*Salix sericea*), Silky Dogwood (*Cornus amomum*), and Virginia Sweetspire (*Itea virginica*) Live Stakes

by

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Abstract

Live stakes are a simple and inexpensive bioengineering solution to establishing riparian vegetation. Studies were conducted on the native species black willow (*Salix nigra*), silky willow (*Salix sericea*), silky dogwood (*Cornus amomum*), and Virginia sweetspire (*Itea virginica*) to investigate the effect of soaking in water prior to installation, to evaluate biomass differences among species, and to observe differences in survival attributed to season of harvest.

The experiment was conducted at Auburn University in Auburn, Alabama. Results suggest that live stakes collected in the dormant season and soaked do not consistently have significantly greater biomass or survival than those installed immediately after collection. Harvesting live stakes during the growing season is not recommended due to high mortality rates when compared with live stakes harvested in the dormant season. Results suggest the four species evaluated are able to survive and establish as live stakes when harvested in the dormant season. A combination of native species is recommended for live stake projects along streams to account for various conditions such as erosion and streambank degradation.

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Chapter 1 Literature Review

Water quality is a major focus in many urban areas, particularly the effects of nonpoint source pollution (Loague and Corwin 2005; Tang et al. 2005; Crawford et al. 2006; Cannon 2009; Zhang et al. 2011), which is the primary factor in the degradation of streams, rivers, lakes, and bays (U.S. EPA 2000a; Hunt et al. 2006). Maintainaince of stream health and water quality is critical for safe drinking water, protecting biodiversity and providing recreational opportunities (Finkenbine et al. 2007; Bingman et al. 2010; Pederson 2011).

According to the United States Enivironmental Protection Agency (U.S. EPA), nonpoint source pollution comes from many diffuse sources. Surface runoff and shallow sub-surface flows transport natural and man-made pollutants depositing them into water bodies (U.S. EPA 2010a). Nonpoint sources of pollution are more difficult to control than point sources due to unpredictable diffusion (Loague and Corwin 2005). This is in contrast to point sources, which are discrete conveyances such as man-made pipes or drains (Vigil 1996; U.S. EPA 2000b).

Watershed land use is directly linked to the source and type of nonpoint source pollution in streams (Schueler et al. 1991; Wang et al. 1997). For example, streams located near animal production farms may be vulnerable to nutrients and pathogens associated with animal waste (Tang et al. 2005). The introduction of pollutants such as metals, nutrients, and pathogens have been traced to recycling or trash centers, suburban lawns, commercial parking lots, and other urban land uses. Historically, an increase in erosion and sedimentation occurred during the early 1900s when lands in the U. S. were cleared of natural vegetation for agriculture, especially crop production (Trimble 2004; Stokes 2008).

Water quality in a stream may be improved by reintroducing native vegetation along the streambanks. These riparian buffers remove pollutants before they reach a waterway, help recharge groundwater, prevent soil erosion, and preserve or improve wildlife habitat (Wenger 1999; Lee et al. 2000; Lee et al. 2003; Lawler 2003; DesCamp 2004; Hoag 2009; Dosskey et al. 2010; Hunt and Lord 2006). Native plants are those that are indigenous to a region and possess traits that make them uniquely adapted to environmental factors such as climate, moisture, soil, flora, and fauna (Landis et al. 2003; DuBois et al. 2009). Various plants can improve water quality and manage the impact of pollution (Darris 2002; Pezeshki and Shields 2006; Grant et al. 2009).

1.1 Riparian buffers

Floodplains and lands adjacent to streams and rivers experience flooding and storm runoff seasonally, periodically, and due to climate and weather events. Plants in the floodplain and on stream and river banks are referred to as riparian or shoreline buffers and are accepted as an important natural mechanism to prevent and mitigate water pollution nationwide (Wenger 1999; Lee et al. 2000, 2003; Polyakov et al. 2005; Agouridis et al. 2010). The vegetation present in floodplains and streambanks plays an essential role in stream health and watershed function (Lowrance et al. 1984; Marden et al. 2005; Agouridis et al. 2010; Dosskey et al. 2010).

Vegetation in floodplains and on stream and river banks provides food and habitat that allows wildlife to hide or congregate in its cover (Schaff et al. 2003). The shade provided by a tree canopy allows for cooler water temperatures that improves dissolved oxygen potential in the stream water. High dissolved oxygen levels are required for some stream wildlife to thrive, particularly native fish and mussels (Schaff et al. 2003). Woody debris and leaves that fall from vegetation are the base of the food web in headwater streams, providing a source of food for aquatic animals (Schaff et al. 2003; Sotir and Fischenich 2003; Logar and Scianna 2005). A more constant temperature regime is another benefit recieved from the shade of riparian plants that allows in-stream biota to thrive in conditions that are less stressful (Brown and Krygier 1970).

Riparian plants can also minimize the introduction of pollutants entering a stream by physically slowing water and allowing solutes to settle (Agouridis et al. 2010; Gray and Sotir 1996). Vegetation decreases levels of dissolved pollutants entering a stream by assisting in the transformation of those pollutants into less harmful and in some cases beneficial byproducts (Licht and Isebrands 2005; Agouridis et al. 2010). For example, inorganic nitrogen may be assimilated by microbes or plants and converted into organic nitrogen instead of being transported to a stream where it may promote eutrophication (Wells 2002; NCCOS 2011).

Vegetation plays a critical role in soil stabilization and erosion control (Wells 2002). A streambank held together by roots is less likely to erode during water runoff events than one with no vegetation (Wells 2002). Additionally, native plants can improve soil quality through their deep root systems by shielding banks from erosive currents and contributing carbon from roots and leaves (Schaff et al. 2003).

Streambank restoration attempts to accelerate recovery of a degraded system by actively establishing riparian vegetation as the first step in rebuilding a forested corridor (Schaff et al. 2003). Conventional solutions to streambank erosion include rock rip rap and gabions, which involve the use of rocks, and boulders along water ways (Logar 2005). These are expensive to install and maintain and do not contribute to overall stream system integrity (NCSU 2006).

For riparian buffer plantings, it is best to use native, non-invasive plant species that are resistant to stress from periods of drought and flooding (DuBois et al. 2009; Greenshare 1999). The hardiness of native plants is due in part to their well-established root systems (Schaff et al. 2003). Additionally, native plants can be attractive aesthetically and are well suited for the "low maintanence" trend (DuBois et al. 2009; Richards and Richter 2010). Species selection may depend on color, texture or other aesthetically appealing attributes, but should also improve water quality and manage the impact of pollution (Polyakov et al. 2005; Beecham 2006; Sotir and Fischenich 2003).

There are four to five distinct zones outlined for establishing vegetation in riparian buffers (Schultz et al. 1997; Tjaden and Weber 1998; Fox et al. 2005). The first area, or zone, is along the toe of streambanks adjacent to water throughout the year. In this area, soil bioengineering, which is a stabilization technique that includes some plant material, is employed using a variety of technological solutions ranging from native plants to natural materials assembled by man to stabilize the streambank (Pennsylvania Department of Environmental Management 2006). The second area is above the toe of slope, but closest to the water. Here fast-growing trees and large shrubs are favored due to their extensive root systems, ability to provide woody and leafy debris, and shade (Lowrance et al. 2000; Fox et al. 2005; Dosskey et al. 2010). The *Salix* species is often recommended for this area of the riparian buffer (Schultz et al. 1997; Tjaden and Weber 1998; Li et al. 2006; Pezeshki and Shields 2006; Tilley and Hoag 2008).

Behind the fast-growing trees and large shrubs, there is a third area where it is recommended to plant slow-growing trees that are able to support nutrient cycling in the ecosystem (Schultz et al. 1997; Tjaden and Weber 1998;). Shade-tolerant shrubs can also be beneficial. Shrubs have multiple stems that slow flood water and minimize flood debris from entering agriculture fields. Planting a variety of tree and shrub species increases diversity and improves wildlife habitat (Tjaden and Weber 1998). Also, planting a mixture of species prevents loss of riparian benefits if one species does not thrive or fails to grow completely (Tjaden and Weber 1997). Finally, behind the slow-growing shrubs, a zone of native grasses and herbaceous, non-woody plants, such as clover, sunflower and milkweed, is recommended to slow water runoff and trap sediment (Schultz et al. 1997; Dosskey et al. 2010).

Problems may occur with establishing riparian vegetation during extreme weather conditions such as drought, trampling or grazing by wildlife or excessive sediment loads (Logar and Scianna 2005; Sotir and Fischenich 2003). According to regional cooperative extension services in partnership with the United States Department of Agriculture (USDA) National Resources Conservation Service (NRCS), planning is critical to the long-term success of a newly planted riparian buffer to support the local environment and improve water quality (Valdivia and Poulous 2008). Stakeholders and landowners should be invited to offer input in a stream improvement project (Brantley 2011). Many landowners are interested in riparian buffer solutions that have the greatest impact on erosion prevention, are easy to maintain, and are economically feasible.

One case study illustrating this point is Caney Branch in Baldwin County, Alabama. The Alabama Department of Enviornmental Management (ADEM) found that runoff from livestock grazing activities contributed to pathogen impairments of Caney Branch. Best management practices (BMPs) implemented included riparian buffers and livestock exclusion fencing that resulted in improved water quality. As a result, ADEM removed the 5-mile impaired segment of Caney Branch from the state's section 303(d) list of impaired waters in 2002 (U.S. EPA 2010b).

There are examples of native riparian buffers planted in floodplains and on stream and river banks that improve stream functions. Bott et al. (1985) found that gross primary productivity and community respiration increased with downstream direction following riparian planting. There is also indication that larger riparian zones in the headwaters (lower stream orders) are important for maintaining the biotic potential of streams (Ekness and Randhir 2007). In summary, with proper planning and vegetation selection, riparian buffer restoration can significantly improve water quality (Lowrance et al. 2000).

1.2 Soil bioengineering

There are several options in soil bioengineering for erosion control and water quality improvement (Tjaden and Weber 1999; Faber 2004). Fascines, or wattles, are used to protect stream banks for washout and seepage events (Tjaden and Weber 1999; Lewis 2000; Georgia Soil and Water Conservation 2011). A fascine is a long "sausage" like bundle of live dormant branches usually 3 to 6 meters long (Tjaden and Weber 1999; Lewis 2000; Faber 2004; Georgia Soil and Water Conservation 2011) (Figure 1). The branches are bound in an overlapping pattern and tied with natural twine with the basal ends all facing the same direction (Tjaden and Weber 1999). Species that root easily, such as *Salix*, are usually used for fascines. After the branches are bundled, they are placed in shallow trenches and held in place by dead stakes. One advantage to fascines is that they create terraces along steep slopes (Kraebel 1936; Sotir and Gray 1992; Lewis 2000). This reduces soil erosion and improves trapping of soil (Tjaden and Weber 1999). Lewis (2000) noted fascines do not perform well in high velocity water environments and can dry out quickly if the soil moisture is low. Another disadvantage is the labor and amount of plant material required for them to be successfully established (Lewis 2000). Lastly, fascines are recommended where there is only a moderate fluctuation in the water table (Tjaden and Weber 1999).

Brush mattresses are an alternative soil bioengineering practice. They provide an immediate decrease in erosion. After rooting and there is a longer term benefit for stream quality; however, installation of a brush mattress is labor intensive (Tjaden and Weber 1999; Faber 2004; Georgia Soil and Water Conservation 2011). The implementation of brush mattresses involves grading a slope and installing dormant stakes into a trench along the toe of slope and placing them in a crisscross pattern to lay along the streambank, creating a “mattress”. Soil is then spread over the branches to create a partial cover. Finally, strong fabric or wire is strung over dormant stakes to make a mesh-like covering to hold the mattress in place (Tjaden and Weber 1999; Napolitano and Owens 2007) (Figure 2). The final product slows water velocity, helps accumulate sediment, provides a strong network of roots and stems, provides a habitat for small animals, and helps in nonpoint source pollution control (Hollis and Fischerich 2001; Napolitano and Owens 2007).

Another soil bioengineering option for stream stabilization is the use of willow posts. Willow posts are 1.5 to 2.5 m long branches cut from trees with lateral branches removed. The basal ends are sharpened for ease of installation, half of the post is buried, and the damaged ends are removed (Shafer and Lee 2003). Willow posts help control streambank erosion by decreasing floodwater velocities with their foliage and binding soil together with their root system (Allen and Leach 1997; Derrick 1998; Shafer and Lee 2003; Illinois State Water Survey 2011). Moreover, Shafer and Lee (2003) noted posts are beneficial for a long period of time and provide canopy cover thereby improving stream habitat and decreasing water temperatures. The low cost and low maintenance provide an appealing alternative to other soil bioengineering practices; however, the installation is labor intensive. Other downfalls to post installation include the need to plant during the dormant season, moisture needs for establishment, and length of time for post establishment (Shafer and Lee 2003; Illinois State Water Survey 2011). Although willow posts and live stakes are similar, posts are larger and serve more as structural reinforcement while live stakes are smaller and have been described as live rebar.

Riparian restoration and enhancement efforts often call for the use of live stakes. Hoag (2009) noted that planting unrooted cuttings, such as live stakes, is the most common way to establish riparian woody species. Live stake plants are short-lived, fast-growing deciduous hardwood cuttings of dormant branches installed along streambanks that are typically 0.5 to 1 m in length and 1cm in diameter (Bir et al. 2002; DesCamp 2004; Logar 2005; Day et al. 2006; Greer et al. 2006; Li et al. 2006; Luna et al. 2006; Pezeshki and Shields 2006; Tilley and Hoag 2008) (Figure 3). Live stakes minimize erosion through promoting root growth that stabilizes and controls shallow mass movement of soil by binding particles together and removing moisture from the soil (Gray and Sotir 1996). Furthermore, live stakes become established more rapidly than seeds and are less likely to wash away (Oklahoma Water Resource Board 2006). These characteristics make the use of live stakes a cost-effective alternative to other bioengineering practices (Sotir and Fischenich 2003).

The successful establishment of live stakes has been documented. It is recommended that live stakes be harvested in the dormant season (Sotir and Fischenich 2003; Logar 2005; Gray and Sotir 1996). All side branches should be removed, the basal end should be cut at an angle for easier penetration into the soil, and tops should be cut square so there is a better surface for pounding into the soil (Bir et al. 2002; DesCamp 2004; Luna et al. 2006; Gray and Sotir 1996).

In some cases, cuttings become water stressed before they develop and lose the ability to grow a sufficient root system to help in erosion control (Edwards and Kissock 1975; Pezeshki and Shields 2006; Tilley and Hoag 2008). Previous practice indicates that stakes should not dry out before planting and it is recommended they be soaked in water for a minimum of 48 hours in a cool place away from direct sunlight before installation (Logar 2005; Tilley and Hoag 2008; Hall et al. 2010). Soaking of live stakes has been shown to increase survival and root/shoot growth of *Salix nigra* due to an increase in stem water content (Schaff et al. 2002, Tilley and Hoag 2008). Soaking has also been noted to decrease the mortality rate of *Salix* live stakes as long as they are planted directly after they are removed from the water (Schaff et al. 2002; Sotir and Fischenich 2003; Li et al. 2006; Pezeshki and Shields 2006).

Installation of live stakes on streambanks has proven effective for repairing eroded banks, adding support to the soil, and minimizing pollutants from entering streams (Sotir and Fischenich 2003; Luna et al. 2006; Hunt and Lord 2006). After establishment, live stakes can reduce nonpoint source pollution by intercepting sediment and attached pollutants that would normally enter the stream (Sotir and Fischenich 2003; Logar 2005). However, stakes must become established before erosion is slowed (DesCamp 2004; Agouridis et al. 2010). Also, stakes can dislodge and be swept downstream if not installed properly or if they have not rooted before a big rainfall event (Logar 2005).

Relatively few species are recommended for use as live stakes (King County 2011). Many riparian buffer restoration projects use black willow (*Salix nigra*) live stakes especially in the southeast (Greer et al. 2006; Li et al. 2006; Pezeshki and Shields 2006). Though the native *Salix* species are the primary species used for soil bioengineering and streambank protection, some dogwoods (*Cornus sericea, Cornus amomum*) are also acceptable species (Darris 2002).

Other shrubs that root easily have not been well evaluated and may be unlikely to outperform *Salix* species (Darris 2002). However, *S. nigra* has drawbacks such as creating a monoculture environment and having poor root strength (Simon and Collison 2001). Though several different species of live stakes have been used in practice, combinations of them have rarely been observed in the same experiment. The combination of multiple species of live stakes in one experiment is important because it is more likely the conditions will be more similar than repeating an experiment for each individual species (Day et al. 2006).

Furthermore, the use of multiple species is recommended as part of a riparian restoration best management practices (BMP) to minimize soil erosion and reduce nonpoint source water pollution (U.S. EPA 2003). Examples of other successful live stakes in the southeast include *Salix sericea, Itea virginica, Cornus amomum, Cephalanthus occidentalis, and Sambuccus canadensis* (Mitchell and Dyck 2000; Bir et al. 2002).

There is a lack of research on BMPs that minimize erosion and sedimentation, the response of water quality to streamside vegetation, and determining which species has a dominant influence on water quality (Dosskey et al. 2010). Moreover, the influence of initial live stake cutting size and potential interaction with soil moisture regimes has not been well documented and requires further research (Greer et al. 2006).

Salix nigra, S. sericea, I. virginica and *C. amomum* species were selected for investigation due to previous research and experience that indicates their potential to thrive in moist conditions, ability to be planted as a live stake, and potential for long-term viability.

1.3 Black willow (*Salix nigra*)

Salix species are pioneer, flood-tolerant species inhabiting areas around swamps and freshwater systems (Ferguson 1993; Greer et al. 2006; Stokes 2008). The *Salix* species are resilient and have been observed to resprout after being damaged by browsing (Pezeshki et al. 2005). They are economically important for timber and renewable energy and are able to survive even in nutrient poor soils where other species cannot (Ferguson 1993; Doty et al. 2009). *Salix nigra* is a colonizing floodplain species that grows quickly, thrives in full sun, and produces a root system capable of stabilizing streams (Schaff et al. 2003; Greer et al. 2006). Contrary to this, willows have been shown to have weak root strength (Simon and Collision 2001). *Salix nigra* has multiple stems and may grow to a height of 15.2 m at 20 years and up to twice that when mature. Sexual maturity is reached in as little as one year (Ferguson 1993). The *S. nigra* loses its numerous, thin leaves in winter and provides moderate shade in summer. It has a minimum rooting depth of 0.8 m with a medium tolerance to salinity. It performs best in fine to coarse texture soils that are moist with acidic to neutral pH. *Salix nigra* requires a minimum of 120 frost-free days per year, making it suitable as a riparian species from Wisconsin to Maine and south to Florida (USDA 2003; Stokes 2008).

The use of the *Salix* species as a live stake has been adopted by several agencies even with a survival rate as low as 40% (Schaff et al. 2003; Greer et. al. 2006; Pezeshki and Shields 2006). The low success rate has been linked to flooding, drought, vertical location on bank, soil texture, and soil fertility (Pezeshki et al. 1998; Schaff et al. 2003; Day et al. 2006; Greer et al. 2006; Li et al. 2006; Pezeshki and Shields 2006; Tilley and Hoag 2008). *Salix* species have been used in the past for controlling reed canarygrass (*Phalaris arundinacea*), an invasive, exotic plant in the Southeast, due to their ability to grow quickly in wetland environments (Ferguson

1993; Kim et al. 2006). In Australia, however, the *S. nigra* species is noted as an invasive exotic detrimental to riparian environments (Stokes 2008). More often, willows are highly recommended for water quality improvement and landscape rehabilitation (Kefeli et al. 2007; River Stewardship 2008). In particular, they have been used for live stake planting along streambanks, but there is a lack of data in the literature on differences between survival and biomass of soaked and non-soaked black willow live stakes.

1.4 Silky willow (*Salix sericea*)

Salix sericea is also recommended for use in stream restoration, but research on its survival and establishment is scarce in the scientific literature. *Salix sericea* is a tree that grows in swamps in the Southeast and is noted for its high production of the phenolic glycoside salicortin, which helps defend against herbivores (Orians et al.1999; Lower and Orians 2003). It is categorized as a rapidly growing tree that reaches a height of 3.6 meters (American Forests 2011). It is deciduous with multiple stems and thrives in sun or shade. It performs best in moderately acidic soils that are moist with fine to coarse texture. This species is found throughout the Eastern U. S. including Georgia and Alabama and commonly grows on the borders of lakes, streams, ditches, and other low areas (USDA 2003). Research on *S. sericea* has been in regard to genetics and there is little data available for live stake performance tests particularly dealing with biomass and growth (Orians et al. 1999).

1.5 Silky dogwood (*Cornus amomum*)

Cornus amomum is a wetland shrub that is known for its ability to improve surrounding wildlife habitats by providing a source of shade and food (Allen and Farmer 1977; USDA 2003).

It is resistant to damage during flooding due to its small resilient stems and the ability to resprout after damage (Hupp 1983). *Cornus amomum* can reach 1.8 to 3.0 meters in height and grows best in partial shade (USDA 2003). Rooting ability, even under harsh conditions is significant with this species (Chong and Hamersma 1996), which shows potential for use as a live stake. The shrub is upright and rounded, but the stems form roots when they come into contact with the ground, which creates thickets (Evans 2004; Yiesla 2011). *Cornus amomum* is adapted to the eastern U. S. from Wisconsin to Maine and south to Florida (USDA 2003). It performs best in medium to coarse textured soils that are moist, somewhat poorly drained, and moderately acidic to neutral (Dirr 1998; USDA 2006). Typically, it is recommended to establish *C. amomum* with other species, such as *Salix* species for riparian restoration (River Stewardship 2002; USDA 2003). On sites with streambanks that may become dry over the summer, it is recommended to use *C. amomum* closest to the water with willows above it. Survival is decreased in shaded environments with this species, therefore, more sunlight is recommended for better growth (Dirr 1998; Sanford et al. 2003). *Cornus amomum* has few problems with disease or insect pests (USDA 2006). Although it is recommended that *C. amomum* live stakes be soaked for 48 hours before planting for best results (DA Tree Store 2007), limited research data are available for this species survival and establishment from a live stake.

1.6 Virginia sweetspire (*Itea virginica*)

Itea virginica is a mound-shaped, slender-branched, shrub reaching a height of 0.9 to 2.4 m (Rhodus 2011). This species has a slow growth rate and is usually available in commercial nurseries in the ‘Henry’s Garnet’ cultivar (Rhodus 2011). *Itea virginica* is drought tolerant (Scheiber et al. 2008; Anderson et al. 2009) and in an irrigation study by Scheiber et al. (2008)

and Dylewski et al. (2011) noted non-irrigated plants were less dense than plants receiving constant irrigation. It grows well in full sun to full shade and is semi-evergreen in the southern part of its range (Dirr 1998; Rhodus 2011). It is found from Illinois to Pennsylvania and southward to Texas and Florida. *Itea virginica* has a medium green color with oblong and serrated leaves (Lauderdale 2010). It is aesthetically appealing with scarlet and mixed colors in the fall and white inflorescences in early summer (Dirr 1998; American Horticultural Society 2007; Scheiber et al. 2008; Rhodus 2011). In fact, *I. virginica* was selected in the top 75 most desirable shrubs by the American Horticultural Society (American Horticultural Society 2007).

Virginia Sweetspire performs best in soils that are moist, acidic, and fine to coarse in texture and is well suited to wooded stream banks (Rhodus 2011; Lady Bird Johnson Wildflower Center 2010). This species usually has an overall lower dry weight than other landscaping plants due to its size (Baz and Fernandez 2002). This species can extend past its intended space by peripheral suckers, which create a tangled colony (Rhodus 2011). *Itea virginica* was reported to be a good candidate in the removal of the herbicide oryzalin by phytoremediation (Baz and Fernandez 2002). Very little research has been conducted on the use of *I. virginica* as a live stake; however, based on its descriptions, has qualities that suggest a potential for success.

The objective of this project was to evaluate the survival and growth of four species of live stakes in order to assess their potential to reduce streambank erosion and improve stream functions. Because establishment of a variety of live stake species is poorly understood, the effect of 48 hours of soaking and seasonal installation on survival was observed.

Chapter 2 Materials and Methods

Four species were observed in this study: *C. amomum*, *I. virginica*, *S. nigra*, and *S. sericea.* Live stakes were cut from various locations on and around the Auburn University main campus in Auburn, Alabama. Straight, healthy branches with a diameter of approximately 1cm were selected (Bir et al. 2002; DesCamp 2004; Day et al. 2006; Greer et al 2006). Shears were used to cut the selected branches from the tree. Smaller branches and leaves were removed from each large branch and cut so all that remained was a straight, smooth stick (Bir et al. 2002; DesCamp 2004; Luna et al. 2006; Gray and Sotir 1996). Next, the branches were cut into several small live stakes that measure 1.5 m in length. The species *I. virginica* is a shrub, so each stake was cut to a length of 46 cm.

The basal end of all stakes were cut at a 45 degree angle to provide for easier planting and tops were cut flat (Bir et al. 2010; DesCamp 2004; Luna et al. 2006; Gray and Sotir 1996). This also eliminated confusion as to the correct end of the stake to soak and install. Immediately after being harvested, exactly one-half of each species (51 stakes) were placed in a bucket with basal ends submerged in water (Logar 2005; Tilley and Hoag 2008; Hall et al. 2010). Each species was bundled and labeled to avoid confusing similar looking stakes. Buckets containing the soaked stakes were placed in a cooler at 4°C for 48 hours before installation (Logar 2005; Tilley and Hoag 2008; Hall et al. 2010). As described by Logar (2005) non-soaked stakes were immediately installed by hand into constructed microcosms under an outdoor 60% woven shade cloth structure at the Paterson Horticulture Greenhouse Complex, Auburn, AL. A double layer of 6 mil clear polyethylene plastic was present to prevent rainfall from disrupting the microcosms. The top of the shade structure was 3.4 m tall sloping to 1.8 m along the short side. Plastic flagging was tied around each stake at the point where root collar diameter measurements were taken at the substrate surface to improve consistency (Schaff et al. 2003; Greer et al. 2006; Hall et al. 2010). Plants were watered tri-weekly and 13-13-13 fertilizer was added biweekly at a concentration of 50 mg/L to insure proper plant nutrition. PeaFowl fertilizer from Piedmont Fertilizer Inc. was used with 13% nitrogen, 13% phosphate, 13% potash, 5% sulfur, and 13% chlorine conent. If weeds became present they were removed and the plants were monitored closely for problems such as weather damage or insect effects (Hall et al. 2010).

Microcosms were constructed using Rubbermaid® (Atlanta, GA) plastic tubs with dimension of 48 cm in height, 86 cm length and 48 cm in width. Microcosms were filled with a mixture of 85% by volume sand (124 L), 10% top soil (15 L), and 5% organic matter (9 L) substrate. Ten drainage holes were placed along the sides .1 m from the bottom of the bucket, two each on the shorter sides and three each on the longer sides.

2.1 Dormant season planting

In both trials, live stakes were cut and installed in the dormant season before bud break. Trial 1 was conducted from March 2010 to December 2010 and trial 2 was conducted from February 2011 to November 2012. Stakes were installed into the media until only half of the stake was exposed aboveground (22.8 cm for *I. virginica* and 30.5 cm for the remaining species). A VWR digital caliper was used to measure the root collar diameter and height aboveground was recorded at time of planting.

Destructive biomass harvests occurred at three, six, and nine months after stake installation. At each harvest date, 20 stakes (10 soaked and 10 non-soaked) were collected for each species. Only stakes that were still living were harvested. Height and diameter were measured from only the stakes that were going to be collected. The measurements were taken from the point in contact with the substrate (marked with a flag) to the terminal bud. If a stake was no longer living, it was recorded as "dead." The stakes were collected from the media with as many roots as possible intact and rinsed gently with water to remove soil. Stakes were separated into stem, leaf, and root components and placed in labeled paper bags. The labeled bags were dried at 70°C for 48 hours. After 48 hours, or until a constant weight was achieved, the samples were weighed and the results recorded (Schaff et al. 2003; Greer et al. 2006).

2.2 Growing season planting

Live stakes were cut in July 2011 during the growing season. The same methods for live stake selection were used as in the dormant season experiment. Stakes were not destructively harvested during the growing season. Height, diameter at root collar, and survival were determined at three and six months by visual inspection for every stake (Schaff et al. 2003; Pezeshki and Shields 2006).

2.3 Data analysis

Microsoft Excel was used to consolidate the data. The statistical program SAS 9.2 was used to compare and analyze the data (SAS Institute Incorporated 2008, McLeod et al. 1986, Pezeshki et al. 1998, Schaff et al. 2002). This experiment was a split plot design by species. The proc GLM-factorial procedure was used to compare between treatments and within species.

Differences were analyzed with a $\alpha=0.05$ using Tukey-Kramer adjustment. The Proc univariate procedure was used to test for normality.

Chapter 3 Results

3.1 Comparison of live stake biomass among species

All species observed had 100% survival and became established during the dormant season harvest (figure 4-6). Means of each stake are in tables 1-3. P-values are found in tables 4-10 for the independent variable species. Table 1 includes data for all species at 3 months. Table 2 includes data for all species at 6 months. Table 3 includes data for all species at 9 months.

Non-soaked stake comparison

Itea virginica had a significantly less leaf, stem, aboveground , belowground, and total biomass than all non-soaked species at three months.

At six months, *I. virginica* had a significantly less leaf, stem, aboveground, belowground, and total biomass than all non-soaked species. *Salix nigra* had a significantly greater stem biomass than *C. amomum*, and *C. amomum* had a significantly greater belowground biomass than *S. nigra*.

Cornus amomum had a significantly greater leaf, belowground, and total biomasses than all species. *Itea virginica* and *S. nigra* had significantly less belowground biomass than all species, and *I. virginica* had a significantly less total biomass than all species.

The diameter of *I. virginica* was significantly less than all species at three and significantly less than *C. amomum* and *S. sericea* at six months. The height of *I. virginica* was significantly less than all species at three, six, and nine months.

Soaked stake comparison

At three months, soaked *S. sericea* stakes were significantly greater in leaf biomass than all species and *I. virginica* was significantly less in leaf biomass than all species. *Itea virginica* was significantly less in stem , aboveground, belowground, and total biomass than all other species.

Itea virginica was significantly less in leaf, stem, aboveground, belowground, and total biomass than all species at six months. *Salix nigra* had a significantly greater stem biomass than *C. amomum*. *Corus amomum* and *S. sericea* were significantly greater in belowground and total biomass than *S. nigra*.

At nine months, soaked *I. virginica* stakes had significantly less in stem, aboveground, and total biomass than all species. S. nigra had significantly less belowground biomass than *C. amomum* and *S. sericea* at nine months. The leaf biomass was significantly less for both soaked *Salix* species at nine months.

The diameter of *I. virginica* was significantly less than all species at three and six months. At nine months, the diameter of *I. virginica* was significantly less than *S. nigra*. The height of soaked *I. virginica* stakes was significantly less than all species at three, six, and nine months.

3.2 Treatment comparison

No species- treatment interaction existed for biomass or height any month for *C. amomum*, *I. virginica, S. nigra,* or *S. sericea*. P- values are found in AOV tables 4-8 and 10. There was a significant main effects interaction for diameter at 3 months (table 9).

3.3 Growing season harvest

Diameter, height, and survival were observed for the growing season harvest. Table 11 includes all growing season data. All species had a low survival rate compared to dormant season harvests, regardless of soaking treatment. Soaking *C. amomum* stakes resulted in a survival rate of 25% after three months compared to a 7% survival of non-soaked stakes. The total survival mean was 16.1% over both treatments for *C.amomum*. After six months, there was a 0% survival for both treatments.

Soaked stakes of *I. virginica* resulted in an 80% survival and a 78% non-soaked survival after three months. The total survival mean for both *I.virginica* treatments at three months was 78.7%. After six months the soaked *I. virginica* remained 80% alive and the non-soaked decreased to a 67% survival rate for a total mean of 73%. The *S. nigra* had a 40% soaked, 27% non-soaked survival after three months, with an overall species total of 33.3 %. By six months, the overall survival was 0% for *S. nigra*. *Salix sericea* had a 59% soaked, 71% non-soaked survival after three months, with an overall survival mean of 64.7%. Across both treatments, *S. sericea* had a 0% survival rate at six months.

Chapter 4 Discussion

4.1 Comparison of soaked and non-soaked species

Although a 48 hour soaking period has been suggested by commercial suppliers and previous research recommends some period of soaking' (Phipps et al. 1983; Schaff et al. 2002; Balch 2008) the data suggest this does not result in significant improvement in live stake survival or an increase in biomass for the species evaluated. Soaking stakes may not be required as long as immediate planting occurs at or below stream bankfull where they will receive a sufficient amount of water. Stakes in this study received adequate water immediately after collection which may have had the same effect as soaking for 48 hours. Treatment comparison of belowground biomass is presented in figures 7-10. Other research has shown an increase in survival, diameter, height, and biomass with a 14 day soaking period (Tilley 2008). Previous studies used a rooting hormone during the soaking period, which may have added benefits to live stake growth and survival. The high survival rate observed in the dormant season harvest suggests that rooting hormones may not be necessary in dormant season conditions.

4.2 Species preference

There is a lack of published data comparing species suitable for bioengineering, except for *S. nigra*, particularly comparing them at the same time and with the same parameters. Numerous field and greenhouse studies have been conducted with *S. nigra* and the results suggest it is a good option for live stake use (Greer et al. 2006; Li et. al. 2006; Pezeshki and

Shields 2006). In contrast, *S. nigra* did not consistently have significantly greater biomass than other species evaluated in this study. The root/shoot ratio of *s. nigra* was less than other species (table 12).

Though all species performed well in this experiment, *C. amomum* had a significantly greater belowground biomass than all species after nine months. At nine months, *S. sericea* had a biomass that was greater than *I. virginica* and *S. nigra*. *Itea virginica* consistently had less biomass, diameter, and height than other species. This trend is expected for a shrub such as *I. virginica* when compared to other species that are trees. However, it had a root/shoot ratio greater than both *Salix* species and similar to *C. amomum* (table 12).

The wide range of heights, diameters, and likely root tensile strength each species provides, gives all the more reason to support species diversity in riparian plantings. Every restoration project is different and requires its own analysis before implementation. Therefore, recommendations on live stake species can be determined by personal preference or site specific needs. A mixture of *C. amomum, I. virginica, S. nigra*, and *S. sericea* may be used to achieve an aesthetically appealing riparian corridor and to increase biodiversity along streams.

Several options in stakes exist as long as they are native, easily rooting woody cuttings (Descamp 2004; Sound Native Plants 2005). Species diversity of riparian vegetation has been shown to increase water quality, terrestrial wildlife, and biodiversity (Kauffman and Krueger 1984; Schelhas and Greenberg 1996; Bjornn and Reiser 2008). By ensuring new vegetation implementation has a wide range of shade, habitat and pollutant control capabilities, stream degradation can be slowed (Henry et al. 1999; Bir and Conner 2010).

4.3 Harvest timing

Dormant season planting showed a higher overall survival across all for species used in the experiment. These results confirm previous research on timing of live stake installation (Darris 2002; Shafer and Lee 2003; Sotir and Fischenich 2003; Logar 2005; Balch 2008.) Furthermore, a greater average height and diameter was present in the dormant season when compared with the growing season. Data strongly suggest that live stakes cut and planted in the growing season will experience high mortality rate for all species studied except *I. virginica*, Perhaps this is related to the ability of *I. virginica* to perform well in a drought environment (Dylewski 2011).

Chapter 5 Conclusion

The use of plants on streambanks to minimize erosion and reduce nonpoint source pollution can improve stream functions and promote conditions that assist a stream in maintaining long-term ecological integrity. This study evaluated the growth and survival of *Cornus amomum, Itea virginica, Salix nigra*, and *Salix sericea* live stakes that have the potential to help minimize streambank erosion, improve soil quality, provide habitat, and improve water quality when planted along riparian corridors. Plant species for this study were selected according to their regional adaptation, ability to thrive in soils that are moist and acidic with a variety of textures, and aesthetics.

The results suggest soaking for 48 hours before installation is not required as long as stakes do not dry out before planting and adequate moisture is maintained for establishment. Each of the species studied became established and had 100% survival when harvested in the dormant season and *C. amomum* and *S. sericea* had the greatest belowground and total biomass after nine months. A dormant season collection and installation is recommended for these live stake species based on low survival rates during growing season installation

Future studies may investigate root strength and performance in multiple field environments. Possible factors in future research may include variable time of soaking stakes, use of rooting hormone, and whether or not those factors affect growing season harvest results. Additionally, increasing length of observation time to 12 months may be a better indication of long-term live stake growth and survival. Lastly, future studies may also incorporate other native live stake species such as elderberry (*Sambucus canadensis*), button bush (*Cephalanthus occidentalis*), river birch (*Betula nigra*), sycamore (*Platanus occidentalis*) and nine bark (*Physocapus opulifolius*).

Results from this study will be provided to landowners and resource managers with recommendations for low cost, easy installation and maintenance solutions for streams and rivers. Species should be selected according to site specific needs such as shade tolerance or aesthetics. A variety of species is helpful in water quality and environmental quality improvement. The choice of using native plant species for riparian buffers may encourage landowners to use a “green” approach to address stream erosion that improves stream and riparian corridor quality and functions.

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Table 1. Dormant season means at three months of leaf, stem, aboveground, belowground, and total biomass, diameter and height. Soaked and non-soaked stake comparison observed among species. Significantly different *p*-values are less than α=0.05 and indicated with lower case letters. Biomass is in grams (g), diameter in millimeters (mm) and height in centimeters (cm).

	C. amomum†		*I. virginica*		*S. nigra*		*S. sericea*	
	NS	S	NS	S	NS	S	NS	S
Leaf	2.3a	1.9b	0.6b	0.9c	2.5a	1.9b	2.1a	2.7a
Stem	4.3a	3.5a	1.4b	1.5b	6.4a	11.0a	4.8a	3.8a
Aboveground	6.4a	5.7a	2.1b	2.6b	8.9a	13.1a	6.9a	6.9a
Belowground	7.9a	7.5a	2.2b	2.6b	7.3a	13.4a	7.0a	6.6a
Total	13.1a	13.9a	4.3b	5.2b	16.2a	25.4a	14.7a	14.4a
Diameter	6.4a	6.9a	4.4b	5.5b	7.0a	7.5a	6.4a	6.1a
Height	51.9c	49.7c	27.4d	27.3d	67.7a	66.7b	59.3b	77.9a

† Species are compared by soaking treatment across rows (non-soaked (NS) stakes are compared with each other and soaked (S) are compared with each other).

Table 2. Dormant season means at six months of leaf, stem, aboveground, belowground, and total biomass, diameter and height. Soaked and non-soaked stake comparison observed among species. Significantly different *p*-values are less than α=0.05 and indicated with lower case letters. Biomass is in grams (g), diameter in millimeters (mm) and height in centimeters (cm).

	C. amomum†		*I.virginica*		*S. nigra*		*S. sericea*	
	NS	S	NS	S	NS	S	NS	S
Leaf	13.2a	13.4a	8.0b	7.2b	13.5a	15.3a	12.3a	12.3a
Stem	18.4b	21.4b	6.8c	6.0c	25.9a	33.4a	20.8ab	25.8ab
Aboveground	30.0a	35.4a	15.8b	13.2b	31.3a	45.9a	34.8a	43.1a
Belowground	24.3a	36.7a	9.7c	7.6c	15.8b	13.3b	19.5ab	33.3a
Total	49.8a	73.0a	24.6b	20.8c	45.4a	39.8b	50.5a	63.8a
Diameter	10.2ab	11.1a	8.7ac	8.7b	12.5a	10.8a	10.2ab	10.5a
Height	109.9b	116.0b	57.5c	57.0c	116.8ab	139.1a	127.3a	137.0a

† Species are compared by soaking treatment across rows (non-soaked (NS) stakes are compared with each other and soaked (S) are compared with each other).

Table 3. Dormant season means at nine months of leaf, stem, aboveground, belowground, and total biomass, diameter and height. Soaked and non-soaked stake comparison observed among species. Significantly different *p*-values are less than α=0.05 and indicated with lower case letters. Biomass is in grams (g), diameter in millimeters (mm) and height in centimeters (cm).

	***C. amomum*†**		***I.virginica***		***S. nigra***		***S. sericea***	
	NS	S	NS	S	NS	S	NS	S
Leaf	8.2a	3.7ab	5.1b	5.8a	3.7b	2.1b	3.4b	1.9b
Stem	26.4b	25.9a	12.2c	9.5b	38.6a	30.0a	33.2ab	24.4a
Aboveground	32.8a	35.7a	16.0b	16.5b	44.8a	35.6a	38.4a	32.3a
Belowground	62.4a	63.5a	23.5c	31.6bc	24.5c	23.7c	42.8b	46.9ab
Total	107.1a	78.2a	41.0c	44.8b	75.1b	57.8ab	81.5b	77.5a
Diameter	18.6a	11.7ab	9.4c	10.3b	14.2b	12.7a	11.6b	11.5ab
Height	108.7c	106.8b	67.5d	65.5c	161.7a	147.3a	139.6b	202.1a

† Species are compared by soaking treatment across rows (non-soaked (NS) stakes are compared with each other and soaked (S) are compared with each other).

Table 4. Analysis of variance probability greater than F (Pr>F) for leaf biomass (g) over nine months.

	Source	**DF**	**SS**	**Mean Square**	**F value**	**Pr > F**
	Treatment	1	.00006	.00006	0	0.99
3 month	Species	3	66.62	22.20	17.10	< 0.0001
	Species*Treatment	3	7.18	2.40	1.84	0.14
	Treatment	1	58.93	58.93	1.25	0.26
6 month	Species	3	1315.83	438.61	9.28	< 0.0001
	Species*Treatment	3	140.86	46.95	0.99	0.40
	Treatment	1	94.49	94.48	3.17	0.08
9 month	Species	3	751.51	250.50	8.40	< 0.0001
	Species*Treatment	3	124.31	41.44	1.39	0.24

Table 5. Analysis of variance probability greater than F (Pr>F) for stem biomass (g) over nine months.

	Source	DF	SS	Mean Square	F value	Pr > F
3 month	Treatment	1	21.88	21.88	0.25	0.61
	Species	3	865.50	288.50	3.34	0.02
	Species*Treatment	3	146.64	48.90	0.57	0.64
6 month	Treatment	1	479.26	479.26	2.36	0.13
	Species	3	11268.44	3756.15	18.50	< 0.0001
	Species*Treatment	3	410.84	136.95	0.67	0.57
9 month	Treatment	1	1010.21	1010.21	2.77	0.10
	Species	3	17068.69	5689.56	15.63	< 0.0001
	Species*Treatment	3	228.78	228.78	0.63	0.60

Table 6. Analysis of variance probability greater than F (Pr>F) for aboveground biomass (g) over nine months.

	Source	DF	SS	Mean Square	F value	Pr > F
3 month	Treatment	1	33.98	33.98	0.36	0.55
	Species	3	1266.86	422.29	4.46	0.0051
	Species*Treatment	3	110.78	36.93	0.39	0.76
6 month	Treatment	1	874.34	874.34	2.28	0.13
	Species	3	20012.28	6670.76	17.37	< 0.0001
	Species*Treatment	3	859.74	286.58	0.75	0.53
9 month	Treatment	1	1102.85	1102.85	2.16	0.14
	Species	3	13601.34	4533.78	8.87	< 0.0001
	Species*Treatment	3	978.08	326.03	0.64	0.60

Table 7. Analysis of variance probability greater than F (Pr>F) for belowground biomass (g) over nine months.

	Source	**DF**	**SS**	**Mean Square**	**F value**	**Pr > F**
	Treatment	1	87.97	87.97	1.12	0.29
3 month	Species	3	1082.75	360.92	4.59	0.0044
	Species*Treatment	3	227.68	75.89	0.96	0.41
	Treatment	1	1566.78	1566.78	4.46	0.04
6 month	Species	3	12658.67	4219.56	12.01	< 0.0001
	Species*Treatment	3	2082.95	694.32	1.98	0.12
	Treatment	1	293.34	293.34	0.26	0.61
9 month	Species	3	56794.69	18931.56	16.89	< 0.0001
	Species*Treatment	3	682.91	227.63	0.20	0.89

Table 8. Analysis of variance probability greater than F (Pr>F) for total biomass (g) over nine months.

	Source	**DF**	**SS**	**Mean Square**	**F value**	**Pr > F**
	Treatment	1	231.29	231.29	0.69	0.41
3 month	Species	3	4578.70	1526.23	4.54	0.0046
	Species*Treatment	3	648.61	216.20	0.64	0.59
	Treatment	1	4781.96	4781.96	4.19	0.04
6 month	Species	3	49511.56	16503.85	14.45	< 0.0001
	Species*Treatment	3	4621.47	1540.49	1.35	0.26
	Treatment	1	403.76	403.76	0.20	0.65
9 month	Species	3	76242.46	25414.15	12.65	< 0.0001
	Species*Treatment	3	1765.14	588.38	0.29	0.83

Table 9. Analysis of variance probability greater than F (Pr>F) for diameter (mm) over nine months.

	Source	**DF**	**SS**	**Mean Square**	**F value**	**Pr > F**
	Treatment	1	0.82	0.82	0.14	0.71
3 month	Species	3	115.92	38.64	6.43	0.0004
	Species*Treatment	3	5.34	1.78	0.30	0.83
	Treatment	1	498.89	498.89	1.20	0.27
6 month	Species	3	3229.83	1076.61	2.59	0.05
	Species*Treatment	3	3724.51	1241.50	2.99	0.03
	Treatment	1	158.24	158.24	1.33	0.27
9 month	Species	3	766/28	255.43	1.96	0.12
	Species*Treatment	3	359.57	119.86	0.92	0.43

Table 10. Analysis of variance probability greater than F (Pr>F) for height (cm) over nine months.

	Source	DF	SS	Mean Square	F value	Pr > F
3 month	Treatment	1	305.95	305.95	1.05	0.31
	Species	3	40272.69	13424.23	46.13	< 0.0001
	Species*Treatment	3	2085.79	695.26	2.39	0.07
6 month	Treatment	1	3213.28	3213.28	2.96	0.09
	Species	3	137134.30	45711.43	42.17	< 0.0001
	Species*Treatment	3	2850.43	950.14	0.88	0.45
9 month	Treatment	1	5555.52	5555.52	0.67	0.41
	Species	3	261182.97	87060.99	10.46	< .0001
	Species*Treatment	3	39292.00	13097.34	1.57	0.20

Table 11
Growing season harvest survival. Soaked and non-soaked stake comparison for survival for three and six months. Results presented in number alive, number dead and percent alive. Bold values indicate a higher survival rate between species. Diameter and height are in (mm) and (cm) respectively.

			Alive	Dead	% Alive	AVG Caliper (mm)	AVG Height (cm)
3 month	*C. amomum*	Soaked	4	12	25	6.37	37.5
		Non-Soaked	1	14	7	6.30	37.0
		Total	5	25	16		
	I. virginica	Soaked	12	3	80	6.46	27.41
		Non-Soaked	14	4	78	5.86	27.50
		Total	26	7	78		
	S. nigra	Soaked	6	9	40	10.8	47.83
		Non-Soaked	4	11	27	11.1	49.25
		Total	10	20	33		
	S. sericea	Soaked	10	7	59	10.44	36.83
		Non-Soaked	12	5	71	9.16	37.40
		Total	22	12	64		
6 month	*C. amomum*	Soaked	0	16	0	0	0
		Non-Soaked	0	15	0	0	0
		Total	0	31	0		
	I. virginica	Soaked	12	3	80	6.85	29.60
		Non-Soaked	14	4	67	6.70	29.42
		Total	26	7	73		
	S. nigra	Soaked	0	15	0	0	0
		Non-Soaked	0	15	0	0	0
		Total	0	30	0		
	S. sericea	Soaked	0	17	0	0	0
		Non-Soaked	0	17	0	0	0
		Total	0	34	0		

Table 12. Root/Shoot ratio comparison over nine months.

	***C. amomum*†**		***I. virginica***		***S. nigra***		***S. sericea***	
	NS	S	NS	S	NS	S	NS	S
3 month	1.22	1.31	1.06	1	0.82	1.02	1.02	0.95
6 month	0.81	1.04	0.61	0.56	0.5	0.29	0.56	0.77
9 month	1.9	1.78	1.46	1.91	0.55	0.67	1.11	1.45

† NS is non-soaked stakes, S is soaked stakes

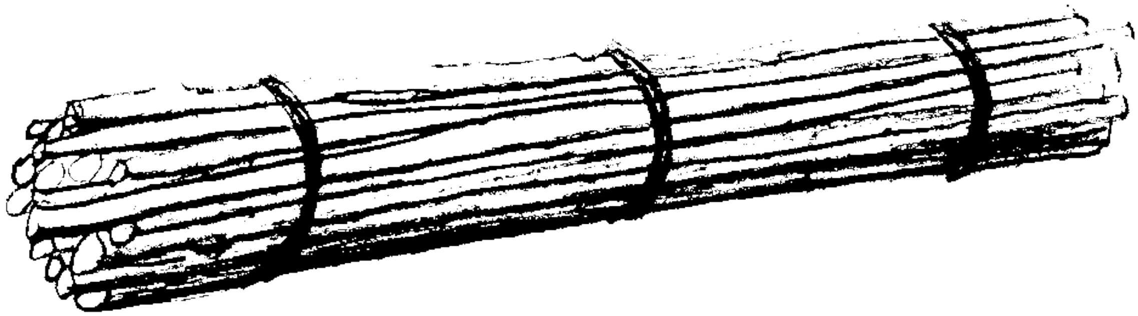

Figure 1. Fascine
http://www.sylvanative.com/bioengineering/bioengin.htm
Accessed April 19, 2012

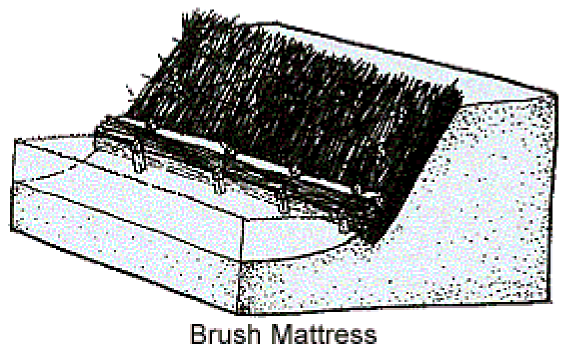

Figure 2. Brush mattress
http://www.anokanaturalresources.com/res_mgnt/lks_strms/brush_mattress.htm
Accessed April 14, 2012

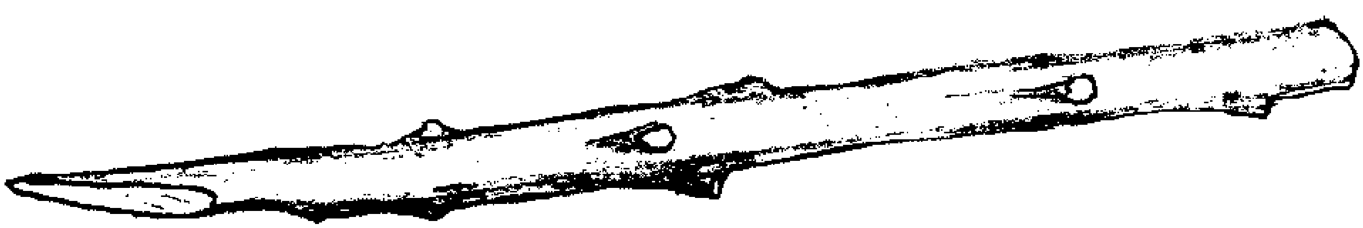

Figure 3. Live Stake
http://www.sylvanative.com/bioengineering/bioengin.htm
Accessed April 19, 2012

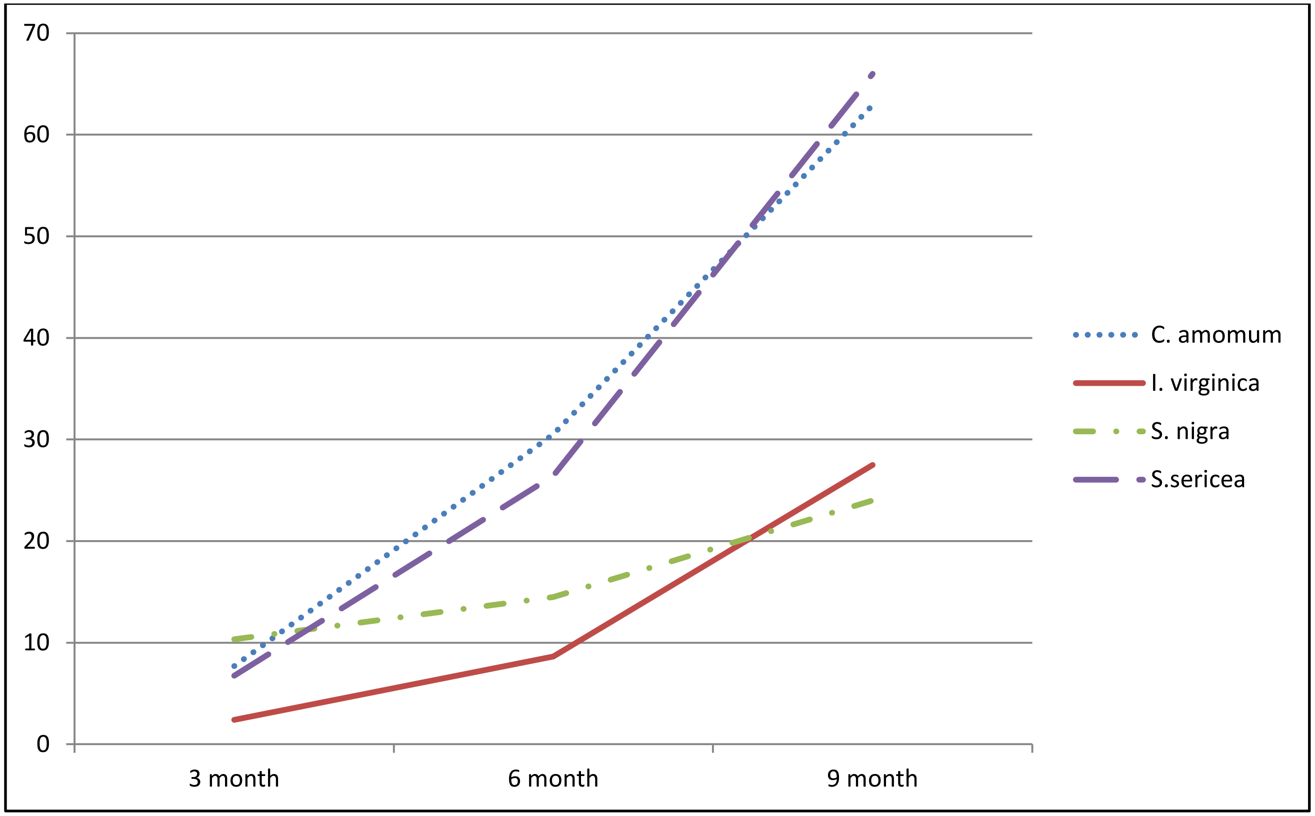

Figure 4. Change in belowground biomass (g) over time of the four species observed.

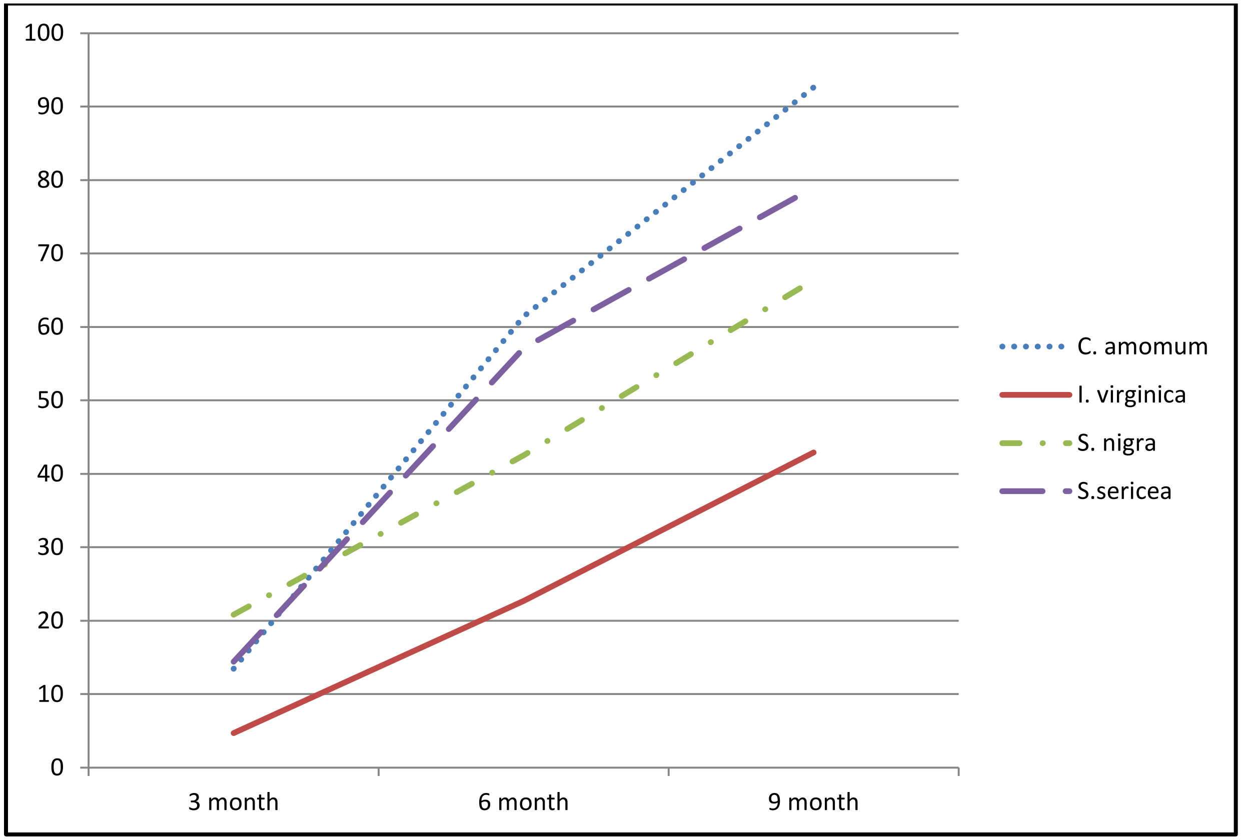

Figure 5. Change in total biomass (g) over time of the four species observed.

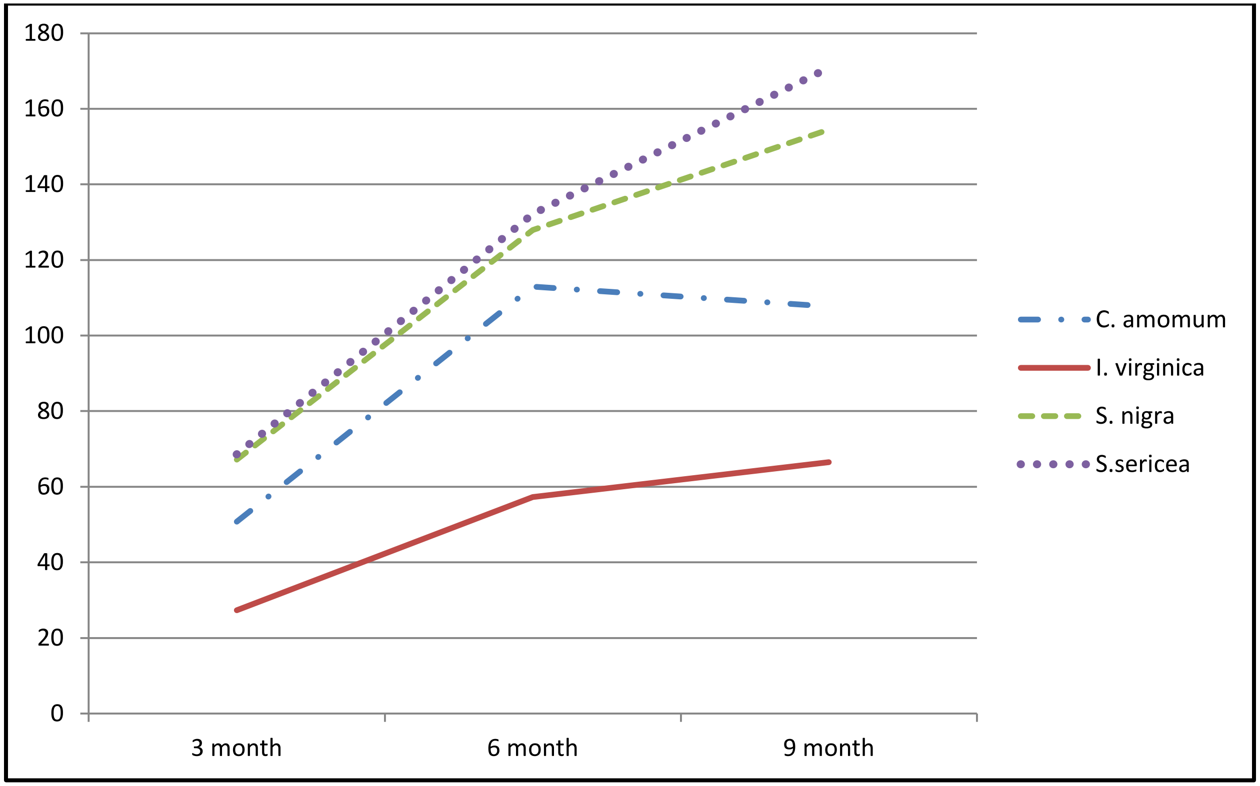

Figure 6. Change in height (cm) over time of the four species observed.

Figure 7. View of belowground root biomass of *Cornus amomum* at 9 months. Non-soaked stake is on the left and soaked stake is on the right.

Figure 8. View of belowground root biomass of *Itea virginica* at 9 months. Non-soaked stake is on the left and soaked stake is on the right.

Figure 9. View of belowground root biomass of *Salix nigra* at 9 months. Non-soaked stake is on the left and soaked stake is on the right.

Figure 10. View of belowground root biomass of *Salix sericea* at 9 months. Non-soaked stake is present on the left and soaked stake is on the right.

VITA

Alicia spent her childhood traveling the world as her parents were both US Air Force Officers. Alicia Erin Hunolt was born in Lubbock, Texas and has lived in Hawaii, Germany, Arkansas, Arizona, Rhode Island and Alabama. She attended German schools and was the fourth girl in history to play in the Little League World Series in 1999. She finished high school having been recruited by several colleges to play softball, but chose to attend The Naval Academy Preparatory School post high school as a Coast Guard Cadet Candidate, with plans to study environmental engineering the following year at the Coast Guard Academy. Due to injury and a delay in Academy entry, she was recruited to play Varsity softball at Auburn University, choosing to study chemistry and water quality. Choosing to stay at Auburn, due to the excellence in academic programs, Ms. Hunolt was awarded a Bachelors of Science in Environmental Science with a concentration in soil science in 2010. Invited to continue her studies at the graduate level, Ms. Hunolt was accepted into the College of Agriculture, Department of Agronomy and Soils, Fall 2010, and worked under Dr. Eve Brantley to water quality. She was awarded a Masters of Science in 2012 from Auburn University in Soils Science. Ms. Hunolt begins post-graduate study toward a Ph.D in Soils Science at Virginia Polytechnical and State University (Virginia Tech) in the Fall of 2012. Thank you to Dr. Brantley, all committee members, and fellow students for the time put into my success.