ABSTRACT

TRUE, SARAH LOUISE. The Biology and Control of Beach Vitex *(Vitex rotundifolia)* and Common Reed *(Phragmites australis)*. (Under the direction of Dr. Robert J. Richardson).

Beach vitex [*Vitex rotundifolia* (L.f.)] is a perennial woody shrub native to Hawaii and countries of the Pacific Rim. Beach vitex thrives on coastal sand dunes and was introduced into the southeastern United States for use as an ornamental and dune stabilizing plant. Today, however, it is considered a noxious weed and invasive species due to its aggressive spread and competition with native flora and fauna. Field and greenhouse studies were conducted from 2006 through 2008 to evaluate the efficacy of selected herbicides and mixtures on beach vitex. In one experiment, beach vitex control at 1 month after treatment (MAT) was greatest with glyphosate and glyphosate plus imazapyr (73% to 84%) and at 12 MAT, control increased to 90 and 94%, respectively. Control with triclopyr mixtures was less than 36% at 1 MAT and less than 11% at 12 MAT. In a second experiment, at 1 MAT glyphosate, imazapyr, and metsulfuron controlled beach vitex 66 to 82%. Control with aminopyralid, imazamox, and penoxsulam was less than 50%. At 8 MAT greatest control was observed with glyphosate and imazapyr (83 and 90%, respectively). Control levels with other treatments were significantly lower at 19 to 52%. In a greenhouse study at 3 weeks after treatment (WAT), control was 37 to 68% with glyphosate and 41 to 76% with imazapyr. At 5 WAT, control was 34 to 87% with glyphosate and 48 to 95% with imazapyr. Dry weight was 4.47 to 5.00 g in glyphosate treatments and 3.50 to 6.18 in imazapyr treatments as compared to the

nontreated dry weight of 6.93 g. The absorption and translocation of glyphosate in beach vitex was evaluated with cut stem and foliar applications. Plants were treated with a prepared ^{14}C-glyphosate solution and harvested at 6, 24, 48, 92, and 196 hours after treatment (HAT). In beach vitex cut stems, time of harvest was not significant indicating that all absorption and translocation occurred within the first six hours after treatment. The greatest amount of herbicide recovered remained in the stump (348,408 DPM). A moderate amount translocated to the first root section (14,572 DPM) and a minimal amount translocated to root segments greater distances from the stump (1,657 and 617 DPM for second 10 cm of roots and end roots, respectively). In foliar treatments, the greatest recovered herbicide remained in the treated leaf at 17,828 DPM. Recovered ^{14}C-glyphosate in other plant parts did not differ and ranged 1,222 to 4,300 DPM. At 6 and 24 HAT, 2,081 to 2,825 DPM were recovered. Greater amounts of 6,432 to 9,661 were recovered at 48 to 196 HAT. Translocation of the applied herbicide was generally low with both application methods. Another invasive plant common to coastal areas of the southeastern United States is common reed [*Phragmites australis* ((Cav.) Trin. ex Steud.)]. Often referred to as Phragmites, this perennial emergent aquatic grass is spread worldwide. Field studies were conducted in 2006 and 2007 to evaluate efficacy of selected herbicides on Phragmites. At 12 to 16 WAT, Phragmites was controlled at least 93% with imazapyr at either 1.25 or 2.5% v/v, and at least 73% with glyphosate at the same rates. At 47 to 66 WAT, control by glyphosate and imazapyr was equivalent and at least 88%. Phragmites was controlled with triclopyr at initial ratings (at least 79%), but control was less than 13% at 47 to 66 WAT due to extensive regrowth. Control with 1.25% v/v imazamox did not exceed 51% and control with 0.45% v/v penoxsulam did not exceed 23% at any rating.

The Biology and Control of Beach Vitex *(Vitex rotundifolia)* and
Common Reed *(Phragmites australis)*

by
Sarah Louise True

A thesis submitted to the Graduate Faculty of
North Carolina State University
In partial fulfillment of the
Requirements for the degree of
Master of Science

Crop Science

Raleigh, North Carolina

February 4, 2009

APPROVED BY:

Robert Richardson
Committee Chair

Joseph Neal

David Jordan

Kurt Getsinger

BIOGRAPHY

Sarah Louise True grew up in Wilmington, NC. She received her B.S. degree in Biological Sciences from North Carolina State University, with a minor in Environmental Science. While completing a coastal management summer internship, she realized the need for control of invasive plant species in order to conserve native species. She went on to work towards a Masters degree in Weed Science under Dr. Rob Richardson. During her graduate career, Sarah has been involved in the Aquatic Plant Management Society, the South Carolina Aquatic Plant Management Society, the Weed Science Society of North Carolina, the Northeast Weed Science Society, and the Beach Vitex Task Force. Sarah is planning on continuing her education in Weed Science through a PhD program under Dr. Rob Richardson.

ACKNOWLEDGEMENTS

I would like to thank David Nash for introducing me to the study of invasive plant species, and for the constant support he has given me. I would also like to especially thank Dr. Rob Richardson for accepting me as a graduate research assistant, encouraging and believing in me, and providing a great environment to further my education. I would like to thank my other committee members, Dr. Joe Neal, Dr. Kurt Getsinger, and Dr. David Jordan, for their dedicated assistance throughout my graduate career. Thanks to all the NC State folks who helped with my field and greenhouse research. Those include Andrew Gardner, Amanda West, Rory Roten, Wes Everman, Steve Hoyle, Jenny Johnson, and Jared Whitaker, as well as others. Thanks to the Beach Vitex Task Force for your insight and support. Finally, a big thanks to all of my family and friends, without whose love and support I could not have made it this far.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

AN INTRODUCTION TO THE BIOLOGY AND CONTROL OF BEACH VITEX (*Vitex rotundifolia*) AND COMMON REED (*Phragmites australis*)

ABSTRACT

Beach vitex [*Vitex rotundifolia* (L.f.)] is a perennial woody shrub native to Hawaii and countries of the Pacific Rim. Beach vitex thrives on coastal sand dunes and was introduced into the southeastern United States for use as an ornamental and dune stabilizing plant. Today, however, it is considered a noxious weed and invasive species. Beach vitex spreads aggressively due to prolific seed production, long runners that root at multiple nodes, and reproduction via stem fragmentation. It outcompetes native dune plant species and dominates dune ecology. The dense mats interfere with native water bird and loggerhead sea turtle (*Caretta caretta* L.*)* nesting and hinder expensive beach renourishment projects. Due to these concerns, aggressive eradication programs are being conducted in North and South Carolina. Another invasive plant common to coastal areas of the southeastern United States is common reed [*Phragmites australis* ((Cav.) Trin. ex Steud.)]. Often referred to as Phragmites, this perennial emergent aquatic grass is spread worldwide. It thrives in wetland and riparian areas of fresh, salt, or brackish waters and aggressively spreads through these areas forming dense monocultures by its extensive rhizome system. As

a result, native ecosystems are severely changed with great impacts to native flora and fauna. Control recommendations for Phragmites typically include foliar herbicide applications of glyphosate or imazapyr. Mowing and burning have also been evaluated alone or in combination with foliar applied herbicides for maximum effect. In Phragmites as well as beach vitex management programs, monitoring and retreating is very important due to the plants' prolific natures.

BEACH VITEX

Biology and Ecology. Beach vitex [*Vitex rotundifolia* (L.f.)] is a perennial woody shrub that thrives on coastal sand dunes (WHO 1998). It is native to Hawaii and countries of the Pacific Rim including China, Japan, Taiwan, Thailand, Indonesia, Malaysia, Papua New Guinea, Philippines, Australia, Fiji, and New Caledonia (USDA 2008). *Vitex rotundifolia* has many common names, but is mainly called beach vitex or sometimes roundleaf chastetree in the continental United States. It has been placed in both the *Lamiaceae* and *Verbenaceae* families, but is now accepted in *Verbenaceae* (Figure 1.1) (USDA 2008). There are approximately 250 Vitex species worldwide (Wu et al. 1994), with two commonly found in nurseries: chastetree (*V. agnus-castus* L.) and Indian three leaf vitex (*V. trifolia* L.) (Olsen and Bell 2005).

Beach vitex is a deciduous shrub, with prostrate, creeping stems that root at nodes. Branchlets are tomentose and tetrangular with procumbent stems (Westbrooks 2007). Leaves are typically simple but can be trifoliate; sessile or short petiolate; obovate or circular; 2.5 to 5 cm long by 1.5 to 3 cm wide; and abaxially velvety to silky tomentose while adaxially pale grayish-green (Wu et al. 1994). The leaf margin is entire with the base attenuate to round (Wu et al. 1994). Flowers are terminal thyrses ranging from 3 to 10 cm long and 1 to 2.5 cm wide (Wu et al. 1994). The calyx is cup shaped and 4 to 5 mm, slightly two lipped, and five denticulate with the outside silky tomentose and glandular and the inside glabrous (Wu et al. 1994). The corolla is anywhere from a purplish mauve to lilac blue and slaverform (Wu et al. 1994). The outside is silky tomentose and glandular with villous hairs in the tube and the lower half of anterior lobe of lower lip (Wu et al. 1994). The stamens and style are exerted while the ovary is globose, glabrous, and densely glandular (Westbrooks 2007). beach vitex fruits have a persistent calyx, are hard, spherical, non-fleshy and about 5 mm in diameter (Cousins et al. 2006). In September through October, the fruit color changes from green into yellow and reddish, and when mature the fruit is bluish-black (Westbrooks 2007). Fruits have four compartments that hold one seed each but all four are not always present (Cousins et al. 2006).

In its native range, beach vitex has been studied for many different uses. One study found that beach vitex fruits have a diterpene called rotundifuran that is a potential chemo-preventative and chemotherapeutic agent (Ko et al. 2001). Another found that an aqueous extract of the fruits may help regulate immediate-type allergic reactions (Shin et al. 2000). It has also been found that a flavonoid from beach vitex fruits, casticin, showed inhibition against human lung and colon cancer cells (Ono et al. 2002). beach vitex has also been evaluated as a source of functional food, with fruit and stem being analyzed for carbohydrate, protein, and fat ratios (Lee et al. 2008). In Korea, beach vitex fruits have been used for headaches and upper respiratory infections, and certain allergies (Shin et al. 2000). In Japan, beach vitex fruits are also used for colds, migraines, and eye pain (Ono et al. 2002). In Hawaii, beach vitex is referred to as pohinahina or kolokolo kahakai and is widely used as an ornamental for landscaping and also for lei making (Bornhorst and Rauch 2003).

Introduction into the Southeast Coastal United States. The introduction of beach vitex into the United States has been attributed to the J.C. Raulston Arboretum in Raleigh, NC (Olsen and Bell 2005). In 1985, the U.S. National Arboretum sponsored a plant collecting expedition to the Republic of Korea. Dr. J.C. Raulston, then director of the Raleigh arboretum, took part in this expedition and the details are recorded in the newsletters of the J.C. Raulston Arboretum (Olsen and Bell 2005).

Olsen and Bell (2005) reported that beach vitex was introduced to the United States by the U.S. National Arboretum as long ago as 1955. Beach vitex was then introduced at least six more times (Olsen and Bell 2005). By 1978, beach vitex was growing in the JCRA, but was still rare in North America and not available for sale in 1985 (Olsen and Bell 2005). After the 1985 expedition, beach vitex began to be recommended and sold for southeastern United States coastal landscapes, before any known research was done to determine its potential invasiveness in these areas (Olsen and Bell 2005). Its attractiveness and proposed use for dune stabilization seemed a perfect fit for North and South Carolina coasts at that time, however it is now considered an exotic invasive species in these areas.

In the mid 1990s, the U.S. Army Corps of Engineers became concerned with the invasive nature of beach vitex on South Carolina beaches (Westbrooks and Madsen 2006). Gresham and Neal (2004) conducted greenhouse trials and recorded field observations to evaluate the invasive potential of beach vitex. They found that areas where beach vitex was present were thus dominated, with 73 to 84% of all plant stems being beach vitex. Native species including sea oats [*Uniola paniculata* (L.)] and beach grass [*Ammophila breviligulata* (Fernald)] comprised only 2.8 to 12.4% of the stems (Gresham and Neal 2004). Marsh pennywort [*Hydrocotyle umbellate* (L.)] and cord grass [*Spartina patens* (Aiton) Muhl.] were also present only in small amounts. Soil surface light levels were greatly reduced due to the dense cover of established beach vitex in these areas. Only 2.3 to 10.7% of light reached the soil surface (Gresham and Neal 2004). Average vitex growth in these areas was 33 cm in vertically and 188 cm horizontally, with a maximum runner length of 330 cm (Gresham and Neal 2004). beach vitex seed production also lends to its invasive threat. On these same areas, Gresham and Neal (2004) also reported an average of 2,730 fruits per square meter, with a maximum of 5,580 fruits per square meter. Each fruit produces on average 1.25 viable seeds (Cousins et al. 2006). A University of Hawaii at Manoa Extension publication describes beach vitex as a wind and salt tolerant groundcover that thrives in sandy soils, but does well over a large range of elevations and soils (Bornhorst and Rauch 2003).

In areas of beach vitex establishment few other species are present, and those species found under the mass of vitex do not outcompete it (Gresham and Neal 2004). Plants like marsh pennywort, cord grass, sea oats, and beach grass cannot compete in beach vitex stands due to lesser height, stature, or reproductive vigor (Gresham and Neal 2004). beach vitex has also been shown to release allelopathic compounds into the surrounding soil as well as compounds that cause the soil to be hydrophobic (Gresham and Neal 2004). Cousins et al. (2009) found that the sand under areas of beach vitex was significantly hydrophobic. This hydrophobicity is caused by cuticular alkanes from beach vitex leaves and fruits, and persists in the sand for at least three years after removal of beach vitex (Cousins et al. 2009).

The high potential for beach vitex spread is due to prolific seed production, long runners that root at multiple nodes, and reproduction via stem fragmentation (Gresham and Neal 2004). These reproductive methods allow dissemination by humans, animals, and even floating (Gresham and Neal 2004). beach vitex was once found on an undeveloped beach 2.6 km from the closest planted population (Gresham and Neal 2004). Based on native habitat and hardiness, beach vitex can grow in eastern coastal zones as far north as Rhode Island, south to Florida and west to Texas, as well as on the entire west coast from California to Washington (Olsen and Bell 2005).

In 2006, Randy Westbrooks and John Madsen estimated in the Beach Vitex Federal Regulatory Weed Risk Assessment that approximately 5.7 ha of North and South Carolina's coastline was infested with beach vitex. Approximately 125 sites have been found in South Carolina, averaging 280 square m each (Westbrooks and Madsen 2006). Survey results of beach vitex populations on the North and South Carolina coast by the Beach Vitex Task Force from 2004 to 2008 are shown in Figure 1.2. Beach vitex has also been found in Alabama, Georgia and Florida (Maddox 2008, Suiter personal communication).

If left unmanaged, beach vitex would negatively affect the North and South Carolina coast. It outcompetes native dune species, including the federally threatened seabeach amaranth [(*Amaranthus pumilis* (Raf.)]. Dense mats interfere with native waterfowl and sea turtle nesting (Brabson 2006; Westbrooks and Madsen 2006). Large multimillion-dollar beach renourishment projects can also be affected by beach vitex growth (Westbrooks and Madsen 2006). In addition, beach vitex is not as efficient at trapping windblown sand to build dunes as some native dune plant species (Anonymous 2008b). The extensive fibrous root system of sea oats is better suited for dune stabilization than beach vitex (SCNPS 2004). The soil seed bank of beach vitex is persistent and will repopulate cleared areas (Cousins et al. 2006). All of the aforementioned impacts yielded an overall pest risk potential of “high” in the USDA-APHIS risk assessment model (Westbrooks and Madsen 2006). This model has been used to determine if a plant species should be quarantined in the United States and listed as a state or federal noxious weed.

The Board of the North Carolina Department of Agriculture ruled that *Vitex rotundifolia* will be added to the Class B Noxious Weed List in North Carolina. Effective February 1, 2009, the sale or distribution of beach vitex will be prohibited throughout the state, and the movement of beach vitex, or articles that may be infested with, is prohibited from counties where it is quarantined. These North Carolina counties include Brunswick, Carteret, Currituck, Dare, Hyde, New Hanover, Onslow and Pender counties. (Iverson, R., personal communication 2009)

Beach Vitex Control. The South Carolina Beach Vitex Task Force was formed in 2003, consisting of federal, state, and local agencies. In 2005, North Carolina joined the task force, making it the Carolinas Beach Vitex Task Force. This group operates under the mission of early detection, prevention, rapid assessment, rapid response, and restoration of the Carolinas Coast (Anonymous 2008b).

Little published information is available regarding beach vitex control. Gresham (2006) recommends a 10% (v/v) glyphosate solution to cut stems followed by replanting native species two weeks later. In other research, glyphosate (25% + 1% adjuvant + 1% dye v/v) with a cut and paint treatment, imazapyr (10% v/v plus MSO 1% v/v) with a hack and squirt treatment, and triclopyr (20% v/v plus bark oil 1% v/v) with a basal paint treatment were evaluated (Anonymous 2008a; Gresham, C. personal communication 2008). None of the three treatments provided complete control, but control ratings with glyphosate and imazapyr were higher than with triclopyr (Anonymous 2008a).

Table 1.1 shows a list of herbicides recommended for beach vitex and similar species. Application rates vary by method, including hack and squirt, foliar spray, basal bark, and cut stem (Maddox 2008). An important aspect of beach vitex eradication involves disposal of vegetative material. Due to high vegetative fecundity, all pieces must be removed and disposed of properly (Maddox 2008).

The beach vitex population on Jekyll Island, GA has been greatly reduced due to a unique control program (D. Suiter, personal communication January 2009). beach vitex was introduced to this area after hurricane Hugo when a local oceanfront homeowner brought in and planted six beach vitex plants from SC. Over the next nine years beach vitex spread to an area totaling 0.3 ha. Recently, 10 to 12 volunteers gathered and removed much of the above ground vegetation and applied picloram to cut stems. All removed plant material was placed between layers of black plastic and left to dry for six months. A follow up application of picloram was applied the next year. At one year after treatment (YAT) there was a 75% reduction in beach vitex, and at 2 YAT there was a 90 to 95% reduction. The site will be monitored and managed in future years, but few seedlings or spread of beach vitex has been found.

Picloram, however, may not be a suitable option for other areas. It is considered moderately to highly persistent in the soil environment, with a soil half-life ranging from 20 to 300 days, and averaging 90 days (Kamrin 1997). This could cause poor reestablishment of native species after beach vitex removal. Picloram is soluble in water, and as a result has the potential to be very mobile in the soil water column with greatest leaching potential in sandy soils (Kamrin 1997; Senseman 2007). These characteristics lead to a high risk of groundwater contamination with picloram (Kamrin 1997). It is regulated as a restricted-use pesticide largely due to off-target movement and phytotoxicity concerns (Senseman 2007).

COMMON REED

Biology and Ecology. Common reed, [*Phragmites australis* ((Cav.) Trin. ex Steud.)] commonly referred to as Phragmites, is a perennial emergent aquatic grass in the Poaceae family (Aulbach-Smith and de Kozlowski 1996). It has annual, upright and thick hollow culms that can grow to 6 m (Mal and Narine 2004). The culms are ridged and not shiny (Weakley 2008). Phragmites stems can be 0.4 to 1 cm in diameter with internodes 10 to 24 cm long (Mal and Narine 2004). The leaves are distichous, blue-green to green, smooth, flat, and long-attenuate (Aulbach-Smith and de Kozlowski 1996). Blades are lanceolate and linear with overlapping sheaths, are opposite, and taper to a long thin point (Mal and Narine 2004). Each leaf can be 1 to 5 cm wide by 15 to 60 cm long (Anonymous 1997; Uva et al. 1997). Phragmites flowers from July to October with a tawny, brown, purplish or silver densely branched terminal panical that can be over 30 cm long (Aulbach-Smith and de Kozlowski 1996; Mal and Narine 2004). The spikelets have long silky hairs that become silvery and silky with age (Aulbach-Smith and de Kozlowski 1996). In winter, areas of rigid Phragmites stems persist and continue to show seedheads (Uva et al. 1997).

Seed production and germination can be rare and variable in many populations of Phragmites (Mal and Narine 2004). Viable seeds are seldom produced (Uva et al. 1997). The extensive rhizome system is the main method of reproduction, with widespread aerenchymatous tissue that supplies oxygen, and roots that grow from the perennial rhizomes and submersed shoots (Mal and Narine 2004). Phragmites rhizomes are scaly, thick, and long (Uva et al. 1997).

Phragmites is classified as a "cryptic" invader because it cannot be easily identified as native or introduced (Saltonstall 2002). There is a native form of *Phragmites australis* [(Cav.) Trin. ex Steud. *Ssp. americanus*], which grows in freshwater marshes and is rare (Weakley 2008). This haplotype has been displaced from New England and has greatly decreased in numbers in other parts of the country, as the introduced aggressive haplotype dominates (Saltonstall 2002). The invasive haplotype is considered one of the most profuse plant species in coastal wetlands of the U.S. (Blossey 2002). The presence of Phragmites is often considered as a sign of wetland disturbance (Blossey 2002). The two haplotypes can be distinguished by DNA sequencing (Saltonstall 2002).

Phragmites is found in almost all of the United States (USDA 2008), and has a near-worldwide spread (Weakley 2008). It grows in fresh, salt, and brackish wet areas, including marshes, stream and lake banks, drainage ditches, and roadsides (Mal and Narine 2004). It withstands salt and alkaline waters and can grow in still or flowing water (Uva et al. 1997). Phragmites distribution and abundance in the United States has greatly increased over the past 150 years (Saltonstall 2002). It aggressively takes over wetland and riparian areas, while severely out competing native species (Weakley 2008). Invasion of Phragmites reduces floral and faunal biodiversity, altering the structure and function of the ecosystem (Chambers 1999; Mozdzer et al. 2008).

Phragmites can grow as much as 4 cm per day, both above and below ground (Shay and Shay 1986). The rapid stem and rhizome growth of Phragmites plus its persistent shading and aggressive takeover of space combine with deadly root secretions to eliminate other plants and form monocultures (Haslam 1971; Rudrappa et al. 2007). On much of the eastern U.S. coast, Phragmites is replacing the dominant native plant

Spartina alterniflora (Loisel.) (Able and Hagan 2000). The shift from *S. alterniflora* to Phragmites is shown to have a negative effect on larval and small juvenile fish (Able and Hagan 2000). The displacement of native plants, including *S. alterniflora,* indicative of a Phragmites stand is partly caused by gallic acid (Rudrappa et al. 2007). Gallic acid was found to be the active ingredient in Phragmites root exudates that are rhizotoxic (Rudrappa et al. 2007). In gallic acid treated plants, increased levels of reactive oxygen species were noted (Rudrappa et al. 2007). Root exudates from the invasive haplotype of Phragmites produced greater rhizotoxicity than native Phragmites haplotype exudates (Rudrappa et al. 2007).

Phragmites Control. Phragmites management has included herbicides, cutting, burning, and de-watering (Mal and Narine 2004). Mozdzer et al. (2008) found that an imazapyr foliar application (2 to 5% v/v) was more effective when applied early season than late season and was more effective than glyphosate (2% v/v). Selective grass herbicides commonly used in ornamental and turf management (clethodim, fenoxaprop, fluazifop, dithiopyr, MSMA, and sethoxydim) did not control Phragmites in greenhouse studies (Derr 2008a). Monteiro et al. (1999) found that cutting or mowing in the fall prior to a spring herbicide application improved the control of Phragmites. Isopropylamine (2.9 kg ai/ha) and trimesium (2.6 kg ai/ha) salts of glyphosate were similar, but application at 2.5% v/v rather than 2% v/v provided greater control (400 and 320 L/ha, respectively) (Monteiro et al. 1999). Ailstock et al. (2001) found that Phragmites treatment with glyphosate or glyphosate plus burning, "greatly reduced Phragmites abundance and increased plant biodiversity." However, the authors considered re-establishment to be likely due to the prolific nature of Phragmites rhizomes (Ailstock et al. 2001). Virginia Tech Cooperative Extension recommends foliar treatment of Phragmites with EPA registered glyphosate rates (Barnes 2003). Kay (1995) found that wipe on applications of imazapyr or glyphosate did not provide sufficient control. Control of Phragmites by mowing plus glyphosate application was shown to have no effect on the microinvertebrate and fish populations in a tidal marsh in Connecticut (Fell et al. 2006). No matter what control method is used, Phragmites needs to be monitored and retreated for subsequent years to combat regrowth (Derr 2008a, Derr 2008b, Ailstock et al. 2001, Monteiro et al. 1999, Barnes 2003).

Derr (2008b) evaluated postemergent herbicides for Phragmites control, with treatments in summer and fall. In field and greenhouse studies, glyphosate (2% v/v) and imazapyr (1% v/v) reduced Phragmites growth. In field trials regardless of summer or fall application, imazapyr controlled Phragmites 93% and control with glyphosate was 82% the following summer. Imazapyr and glyphosate treatments can be applied foliarly in summer, while Phragmites plants are smaller and easier to spray, versus fall when Phragmites is much taller (Derr 2008b). Fosamine treatments controlled 68% of Phragmites 7 MAT, and 43% 10 MAT (Derr 2008b).

In another study, Derr (2008a) evaluated Phragmites responses to mowing and herbicide application. Glyphosate at 2.24 kg/ha controlled Phragmites greater than 1.12 kg/ha glufosinate (96 vs. 71% control, respectively). Among mowing treatments, mowing every two weeks resulted in 93% Phragmites control 4 MAT, while mowing every four or eight weeks provided less control at 81 and 69%, respectively. At 12 MAT, plots that were mowed every two, four, and eight weeks had similar control levels. Mowing may be a control option for sites where chemical options are undesirable.

Turner and Warren (2003) evaluated the proportion of U.S. east coast native *Spartina alterniflora* to the invasive *P. australis* when Phragmites was treated intermittently or continuously. They reported that *Spartina* cover increased after herbicide application, but regained dominance when applications were stopped (Turner and Warren 2003).

Biocontrol research has also targeted Phragmites. In the United States, 26 herbivores feed on Phragmites, only five of which are native (Tewksbury et al. 2002). In Europe, over 170 herbivores feed on Phragmites including such species as stem boring moths in the *Archanara* and *Arenostola* families, and the chloropid fly *Platycephala planifrons* (Fabricius) (Tewksbury et al. 2002). The chloropid fly was found to have generally low attack rates in its native range (a max of 29%), but could still be a successful Phragmites biocontrol method if is used early in the season and can escape natural enemies (Hafliger et al. 2005). A restoration project evaluated increasing sulfide levels in Phragmites marshes to levels similar to those found in smooth cordgrass marshes as a means of control (Howes et al. 2005). This did not kill Phragmites plants, but did put them under stress (Fell et al. 2006). Mechanical control methods may have good control results but are impractical in large stands of Phragmites. When Phragmites stems are manually broken or cut and submersed in water, population size is greatly reduced (59 to 90% reduction) the following year, (Smith 2005).

LITERATURE CITED

Ailstock, M.S., C.M. Norman, and P.J. Bushman. 2001. Common reed *Phragmites australis*: Control and effects upon biodiversity in freshwater nontidal wetlands. Restoration Ecology. Vol. 9. p. 49-59.

Anonymous. 1997. Common Wetland Plants of North Carolina. Raleigh, NC: NC Department of Environment, Health, and Natural Resources, Division of Water Quality. Available Online: http://h2o.enr.state.nc.us/esb/Wetplant/ grassframe.htm. (Accessed July 2008)

Anonymous. 2008a. Ordinary People, Extraordinary Change: Saving Sea Turtles on the Carolina Coast. Latitude by BASF. Available online: http://www.vmanswers.com/magazines.aspx?pid=1602 (Accessed June 2008).

Anonymous. 2008b. Carolinas Beach Vitex Task Force Website, hosted by North Inlet-Winyah Bay National Estuarine research Reserve. Available online: www.beachvitex.org (Accessed January 2009).

Aulbach-Smith, C.A. and S.J. de Kozlowski. *Aquatic and Wetland Plants of South Carolina.* Columbia, SC: South Carolina Department of Natural Resources, 1996. p. 87.

Barnes, V.P. 2003. Identification and control of common reed (*Phragmites australis*) in Virginia. Virginia Extension publication. Available Online: http://www.ext.vt.edu/pubs/weeds/427-101/427-101.pdf. (Accessed August

2008).

Blossey, B. 2002. Native to North America or introduced or both? Ag Web, Cornell University, Ithaca, NY. Available online: http://www.invasiveplants.net/Phragmites/phrag/natint.htm (Accessed January 2009).

Bornhorst, H.L. and F.D. Rauch. 2003. Native Hawaiian plants for landscaping, conservation, and reforestation. University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources, Cooperative Extension Service.

Brabson, B. 2006. Beach vitex task force: How one person can make a difference. 8th Annual Southeast Exotic Plant Council Symposium. Available Online: http://www.se-eppc.org/SEPPCSymposiumProgram2006fin.pdf (Accessed June 2008).

Chambers, R.M., L.A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquatic Botany. Vol. 64. p. 261-273.

Cousins, M.M., C.A. Gresham, M.B. Riley, and T. Whitwell. 2009. Beach dune sand hydrophobicity due to the presence of beach vitex (*Vitex rotundifolia* L.f.). Journal of Agriculture and Food Chemistry. Vol. 59. p. 409-415.

Cousins, M., T. Whitwell, and J. Briggs. 2006. Viability of beach vitex (*Vitex rotundifolia*) seed: and invasive coastal plant. SNA Research Conference. Vol.

51. p. 417-419.

Derr, J.F. 2008a. Common reed (*Phragmites australis*) response to mowing and herbicide application. Invasive Plant Science and Management. Vol. 1. p. 12-16.

Derr, J.F. 2008b. Common reed (*Phragmites australis*) response to postemergence herbicides. Invasive Plant Science and Management. Vol. 1. p. 153-157.

Fell, P. S. Warren, and A.E. Curtis. 2006. Short-term effects on macroinvertebrates and fishes of herbiciding and mowing *Phragmites australis*-dominated tidal marsh. Northeastern Naturalist. Vol. 13. p. 191-212.

Gresham, C. 2006. Identifying and managing beach vitex. Clemson University Extension Home and Garden Information Center. Available Online: http://hgic.clemson.edu/pdf/hgic2315.pdf (Accessed May 2008).

Gresham, C. and A. Neal. 2004. An evaluation of the invasive potential of beach vitex (*Vitex rotundifolia*). Bell W. Baruch Institute of Coastal Ecology and Forest Science. Clemson University. Georgetown, SC. In publication.

Häfliger, P., M. Schwarzlaender, and B. Blossey. 2005. Biology of *Platycephala planifrons* (Diptera: Chloropidae) and its potential effectiveness as biological control agent for invasive *Phragmites australis* in North America. Biological Control. Vol. 34. p. 302-311.

Haslam, S.M. 1971. Community regulation in *Phragmites communis* Trin. I.

Monodominant stands. Journal of Ecology. Vol. 59. p. 65-73.

Howes, B.L., J.M. Teal, and S. Peterson. 2005. Experimental Phragmites control through enhanced sediment sulfur cycling. Ecological Engineering. Vol. 25. p. 292-303.

Kamrin, Michael A. *Pesticide Profiles: Toxicity, Environmental Impact, and Fate.* Boca Raton, FL: CRC Press. 1997.

Kay, S.H. 1995. Efficacy of wipe-on applications of glyphosate and imazapyr on common reed in aquatic sites. Journal of Aquatic Plant Management. Vol. 33. p. 25-26.

Ko, W.G., T.H. Kang, S.J. Lee, Y.C. Kim, and B.H. Lee. 2001. Rotundifuran, a labdane type diterpene from *Vitex rotundifolia*, induces apoptosis in human myeloid leukaemia cells. Phytotherapy Research. Vol. 15. p. 535-537.

Lee, Y. et al. 2008. Analysis on the components of the *Vitex rotundifolia* fruit and stem. Journal of the Korean Society of Food Science Nutrition. Vol. 37. p. 184-189.

Maddox, V., R. Westbrooks, J.D. Byrd Jr., and B. Brabson. 2008. Invasive Plant Atlas of the MidSouth: Beach vitex. Mississippi State GeoResources Institute. Available Online: http://www.gri.msstate.edu/ipams/Species.php?SName=& CName=Beach+vitex (Accessed June 2008).

Mal, T. K., and L. Narine. 2004. The biology of Canadian weeds. 129. *Phragmites* *australis* (Cav.) Trin. ex Steud. Canadian Journal of Plant Science. Vol. 84. p. 365-396.

Monteiro, A., I. Moreira, and E. Sousa. 1999. Effect of prior common reed *(Phragmites australis)* cutting on herbicide efficacy. Hydrobiologia. Vol. 415. p. 305-308.

Mozdzer, T.J., C.J. Hutto, P.A. Clark, and D.P. Field. 2008. Efficacy of imazapyr and glyphosate in the control of non-native *Phragmites australis*. Restoration Ecology. Vol. 16. p. 221-224.

Olsen, R.T. and A.C. Bell. 2005. History of Beach Vitex Cultivation: A Potential Invasive Ornamental. SNA Research Conference. Vol. 50. p. 531-533.

Ono, M., T. Yanaka, M. Yamamoto, Y. Ito, and T. Nohara. 2002. New diterpenes and norditerpenes from the fruits of *vitex rotundifolia*. Journal of Natural Products. Vol. 65. p. 537-541.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and Economic costs associated with non-indigenous species in the United States. BioScience. Vol. 50. p. 53-64.

Raulston, J.C. 1993. The Chronicles of the NCSU Arboretum. The NCSU Arboretum. Available online:http://www.ncsu.edu/jcraulstonarboretum/ publications/chronicles/chronicles.html. (Accessed June 2008).

Reichard, S.H. and P. White. 2001. Horticulture as a pathway of invasive plant introductions into the United States. BioScience. Vol. 51. p. 103-113.

Rudrappa, T., J. Bonsall, J.L. Gallagher, D.M. Seliskar, and H.P. Bais. 2007. Root-secreted allelochemical in the noxious weed *Phragmites australis* deploys a reactive oxygen species response and microtubule assembly disruption to execute rhizotoxicity. Journal of Chemical Ecology. Vol. 33. p. 1898-1918.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. PNAS. 99:4:2445-2449.

Senseman, S., ed. *Herbicide Handbook.* Ninth Edition. Lawrence, KS: Weed Science Society of America, 2007. p. 353.

Shay, J.M. and C.T. Shay. 1986. Prairie marshes in western Canada, with specific reference to the ecology of five emergent macrophytes. Canadian Journal of Botany. Vol. 64. p. 443-454.

Shin, T., S. Kim, J. Lim, E. Suh, H. Jeong, B. Kim, E. Park, W. Hwang, D. Rye, S. Baek, N. An, and H. Kim. 2000. Effect of *Vitex rotundifolia* on immediate-type allergic reaction. Journal of Ethno-Pharmacology. Vol. 72. p. 443-450.

Smith, S.M. 2005. Manual control of *Phragmites australis* in freshwater ponds of Cape Cod National Seashore, Massachusetts, USA. Journal of Aquatic Plant Management. Vol. 43. p. 50-53.

South Carolina Native Plant Society (SCNPS). 2004. Hawaiian plant threatens South Carolina Dunes. URL: www.scnps.org/PDFs/vitex.pdf (Accessed June 2008).

Tewksbury, L., R. Casagrande, B. Blossey, P. Häfliger, and M. Schwarzlände. 2002. Potential for biological control of *Phragmites australis* in North America. Biological Control. Vol. 23. p. 191-212.

The Biodiversity Partnership. Invasive Species in North Carolina. Available online: http://www.biodiversitypartners.org/invasive/factsheets/NC.pdf (Accessed June 2008).

USDA-ARS, National Genetic Resources Program. 2008. *Germplasm Resources Information Network - (GRIN)* [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. URL: http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?41839 (Accessed June 2008).

USDA Plants Database. 2008. Available Online: http://plants.usda.gov/java/profile?symbol=PHAU7&mapType=Large&format=Print&photoID=phau7_001_avp.tif (Accessed June 2008).

Uva, R.H., J.C. Neal, and J.M. DiTomaso. *Weeds of the Northeast*. Ithaca, NY: Cornell University, 1997. p. 76.

Weakley, Alan. 2008. Flora of the Carolinas, Virginia, Georgia, northern Florida, and surrounding areas. UNC Herbarium, North Carolina Botanical Garden, University of North Carolina at Chapel Hill. p. 829.

Westbrooks, R.G. and J. Madsen. 2006. Federal regulatory weed risk assessment beach vitex (*Vitex rotundifolia* L. f.). Available online:

http://www.northinlet.sc.edu/resource/vitex_files/march06/Beach%20Vitex%20Weed%20Risk%20Assessment%20Summary3-06%20-%20RWestbrooks….pdf. (Accessed May 2008).

Westbrooks, R.G. 2007. *Vitex rotundifolia* (shrub). National Biological Information Infrastructure (NBII) & IUCN/SSC Invasive Species Specialist Group (ISSG). Available Online:http://www.issg.org/database/species/ecology.asp?si=1110&fr=1&sts=&%20ang=FR&ver=print&prtflag=false. (Accessed June 2008).

Wilcove, D.S., Rothstein, J. Dubrow, A. Phillips, and E. Losos. 1998. Quantifying threats to

imperiled species in the United States. BioScience 48:607-615.

World Health Organization (WHO). Medicinal Plants in the Republic of Korea. WHO Regional Publications: Western Pacific Series No. 21. 1998. p. 293.

Wu, Z. Y. & P. H. Raven, eds. *Flora of China. Vol. 17 (Verbenaceae through Solanaceae)*. Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis. 1994. p. 30.

<u>Taxon: *Vitex rotundifolia* L.</u>

Kingdom: ***Plantae*** - plants

Subkingdo: ***Tracheobionta*** – vascular plants

Superdivision: ***Spermatophyta*** – seed plants

Division: ***Magnoliophyta*** – angiosperms, flowering plants

Class: ***Magnoliopsida*** - dicotyledons

Subclass: ***Asteridae***

Order: ***Lamiales***

Family: **Verbenaceae** – verbena family

Genus: ***Vitex*** L. – chastetree

Species: ***Vitex rotundifolia*** L.f. – roundleaf chastree

Synonyms to *Vitex rotundifolia*: *Vitex ovata* Thunb., *Vitex trifolia* L. var. *simplicifolia* Cham.

Other common names: beach vitex

Figure 1.1 Botanical classification of beach vitex (USDA 2008).

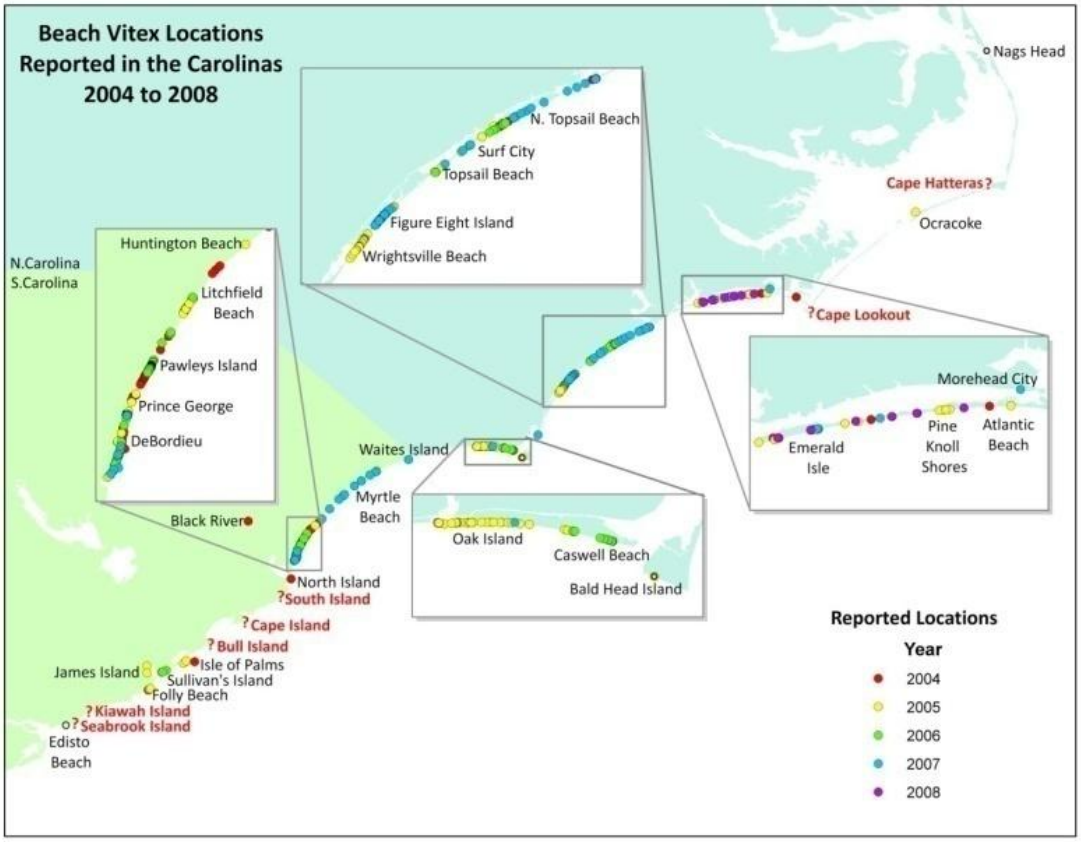

Figure 1.2 Beach vitex sites found by year in North Carolina. (Anonymous 2008b).

Table 1.1 Herbicides, application methods, and rates recommended for control of beach vitex or similar woody species.[1]

Herbicide	Application method	Rate[2]	Reference
2,4-D + dichlorprop (2,4-DP)	High volume foliar	1 to 1.5% v/v	Maddox 2008
	Frill, basal, cut stump	3 to 4% v/v in oil	Maddox 2008
Fosamine	Low volume foliar	6.7 to 16.2 kg ai/ha	Maddox 2008
Glyphosate	Cut stump	25% + 1% adjuvant + 1% dye v/v	Anonymous 2008a; Gresham, personal communication
Imazapyr	Low volume foliar or soil	.56 to 1.7 kg ae/ha	Maddox 2008
	Hack and squirt	10% + 1% MSO v/v	Anonymous 2008a
Metsulfuron	Low volume foliar	43 to 126 g ai/ha	Maddox 2008
	High volume foliar	21 to 84 g ai/ha	Maddox 2008
Triclopyr	Basal bark	20% + 80% oil v/v	Anonymous 2008a

[1] Abbreviations: MSO, methylated seed oil.

[2] Herbicides mixed in water unless oil is specified.

CHAPTER 2

EFFICACY OF AQUATIC USE HERBICIDES FOR PHRAGMITES CONTROL

ABSTRACT

Field studies were conducted in 2006 and 2007 to evaluate efficacy of glyphosate, imazamox, imazapyr, penoxsulam, triclopyr, and a mixture of imazapyr plus glyphosate applied postemergence on common reed [*Phragmites australis* (Cav.) Trin. ex Steud.]. At 12 to 16 WAT (weeks after treatment), Phragmites was controlled at least 93% with imazapyr at either 1.25 or 2.5% v/v, and at least 73% with glyphosate at the same rates. At 47 to 66 WAT, control by glyphosate and imazapyr was equivalent and at least 88%. Phragmites was controlled with triclopyr at initial ratings (at least 79%), but control was less than 13% at 47 to 66 WAT due to extensive regrowth. Control with 1.25% v/v imazamox did not exceed 51% and control with 0.45% v/v penoxsulam did not exceed 23% at any rating.

INTRODUCTION

Common reed [*Phragmites australis* (Cav.) Trin. ex Steud.] is an invasive perennial grass found in almost the entire continental United States (Kay 1995) and having a near-worldwide spread (Weakley 2008). Commonly called Phragmites, it forms dense aggregations in fresh, salt, and brackish wet areas including marshes, stream and lake banks, drainage ditches, and roadsides (Mal and Narine 2004). Phragmites has drastically increased in numbers and distribution over the past 150 years (Saltonstall 2002). Phragmites withstands salt and alkaline waters and can grow in still or flowing water (Uva et al. 1997), aggressively taking over these water areas and displacing native species (Weakley 2008).

Phragmites is classified as a "cryptic" invader because it cannot be easily identified as native or introduced (Saltonstall 2002). A native form of *Phragmites australis* [(Cav.) Trin. ex Steud. *Ssp. americanus*] is rare and grows in freshwater marshes (Weakley 2008). This haplotype has been displaced from New England and has greatly decreased in numbers in other parts of the country, as the introduced aggressive haplotype dominates (Saltonstall 2002). The invasive haplotype is considered one of the most profuse plant species in coastal wetlands of the U.S. (Blossey 2002).

A primary concern with Phragmites is the invasion of coastal wetlands. The presence of Phragmites is often considered as a sign of wetland disturbance (Blossey 2002). Phragmites invasion reduces floral and faunal biodiversity and changes the structure of the ecosystem (Mozdzer et al. 2008). Phragmites grows in waters of varying salinities and has the tendency to outcompete native brackish-water plant species, thus degrading habitats for native insects and animals. Vasquez et al. (2005) found that the invasive biotype of Phragmites tolerated much higher levels of salinity than did two native biotypes. On much of the eastern US coast, Phragmites is replacing the dominant native plant *Spartina alterniflora* (Loisel.) (Able and Hagan 2000). The shift from *Spartina alterniflora* to Phragmites is shown to have a negative effect on larval and small juvenile fish (Able and Hagan 2000).

Previous research has evaluated Phragmites management with herbicides, cutting, burning, and de-watering (Mal and Narine 2004). Selective grass herbicides commonly used in ornamentals and turf management (clethodim, fenoxaprop, fluazifop, dithiopyr, MSMA, and sethoxydim) did not control Phragmites in greenhouse studies (Derr 2008a). Monteiro et al. (1999) found that cutting or mowing in the fall prior to a spring herbicide application improved Phragmites control. In this study, both isopropylamine (2.9 kg ai/ha) and trimesium (2.6 kg ai/ha) salts of glyphosate provided equivalent control, but treatment rates of 2.5% v/v rather than 2% v/v showed greater control (400 and 320 L/ha application volume, respectively) (Monteiro et al. 1999). Ailstock et al. (2001) found Phragmites treatment with glyphosate or glyphosate plus burning, greatly reduced Phragmites abundance and increased plant biodiversity. However, this study found frequent reestablishment due to the prolific nature of Phragmites rhizomes (Ailstock et al. 2001).

The Virginia Cooperative Extension Service has recommended foliar applications of glyphosate at labeled rates for Phragmites control (Barnes 2003). However, Mozdzer et al. (2008) found that an imazapyr foliar application (2 to 5% v/v) was more effective than glyphosate (2% v/v). Kay (1995) found that wipe on applications of imazapyr or glyphosate did not provide sufficient control of Phragmites. Derr (2008b) evaluated postemergence herbicides for Phragmites control, with treatments in summer and fall. In field and greenhouse studies, glyphosate (2% v/v) and imazapyr (1% v/v) reduced Phragmites growth at least 80%. Fosamine treatments controlled only 68% of Phragmites 7 months after treatment (MAT), and 43% 10 MAT (Derr 2008b). Imazapyr and glyphosate can be applied to foliage in summer or fall, with equivalent results the following year Derr (2008b). In summer, Phragmites plants are smaller and easier to spray, compared to fall when Phragmites is much taller (Derr 2008b).

Derr (2008a) also evaluated Phragmites responses to mowing and herbicide applications. Plots treated with 2.24 kg ai/ha glyphosate had a higher control rating than those treated with 1.12 kg ai/ha glufosinate (96 vs. 71% control, respectively). Mowing every two weeks resulted in control of 93% of Phragmites 4 MAT, while mowing every four or eight weeks provided less control of 81 and 69% 4 MAT respectively. At 12 MAT, plots that were mowed every two, four, and eight weeks all had similar control levels. Mowing could be a control option for Phragmites where non-chemical options are preferred. Regardless of control method, Phragmites needs to be monitored and managed for subsequent years to combat regrowth (Ailstock et al. 2001, Barnes 2003, Derr 2008a, Derr 2008b, Monteiro et al. 1999).

While numerous herbicides have been evaluated for Phragmites control, the focus has often been on products labeled for terrestrial sites rather than aquatic sites. Triclopyr is registered for use on aquatic sites and the product label also lists Phragmites as a species controlled. However, little information is available with regard to actual triclopyr efficacy on this weed. In addition, two herbicides recently registered for aquatic use, imazamox and penoxsulam, have not been fully evaluated for Phragmites control. The objective of this research was to evaluate herbicides with aquatic site registrations for long-term Phragmites control.

MATERIALS AND METHODS

Field study 1. A field herbicide trial was initiated on June 6, 2006 in a brackish marsh near Aurora, NC to evaluate control with four different herbicides registered for application to aquatic sites. Plots were 7 m long by 3 m wide, and were located in a well-established 2 to 3 m tall stand of Phragmites. Treatments included glyphosate (Touchdown Pro, Syngenta Crop Protection, Inc.; Greensboro, NC) at 1.25 and 2.5% v/v, imazapyr (Habitat, BASF Corporation; Research Triangle Park, NC) at 1.25 and 2.5% v/v, imazapyr (1.25% v/v) plus glyphosate (1.25% v/v), penoxsulam (Galleon SC, SePRO Corporation; Carmel, IN) at 0.45% v/v, and triclopyr (Renovate, SePRO Corporation; Carmel, IN) at 5% v/v. Equivalent broadcast rates for each treatment are listed in Table 2.1. Herbicides were applied using a CO_2-pressurized backpack sprayer with a handgun and application volume of 280 L/ha. Applications were applied to foliage and sprayed to wet, but not runoff. All treatments included a non-ionic surfactant (Induce, Helena Chemical Co.; Collierville, TN) at 0.25% v/v.

Experimental design was a randomized complete block with three treatment replications. At treatment, weather conditions were sunny with 10% cloud cover, 31 C, and 70% relative humidity. Phragmites control was estimated visually at 16 and 66 weeks after treatment (WAT) on a 0 to 100% scale. Ratings compared treated plots to nontreated plots and considered chlorosis, necrosis, and stunting, with 0% corresponding to no control and 100% corresponding to complete plant death.

Field study 2. In 2007, a separate Phragmites trial was initiated at Carolina Beach and Wilmington, NC. Experimental plots were 6 m long and 3 m wide, and located in a well-established 1 to 3 m tall stand of Phragmites. Five currently registered aquatic herbicides were selected including glyphosate, imazamox, imazapyr, penoxsulam, and triclopyr. Treatments included glyphosate at 1.25 and 2.5% v/v, imazamox at 0.625 and 1.25% v/v, imazapyr at 1.25 and 2.5% v/v, triclopyr at 5% v/v, and penoxsulam at 0.45% v/v. Equivalent broadcast rates for each treatment are listed in Table 2.2. All treatments included 0.25% v/v nonionic surfactant. A nontreated control was also included.

Study design was a randomized complete block with four treatment replications. Experimental treatments were applied to foliage with 280 L/ha spray volume. Applications were sprayed to wet, but not runoff. At treatment, weather conditions were sunny with 5% cloud cover, 30 C, and 45% relative humidity. Plots were rated at 12 and 47 WAT on a 0 to 100% scale as described in field study 1.

Statistical analysis. Data were subjected to analysis of variance and means were separated using Fisher's Protected LSD ($P \leq 0.05$) in SAS v. 9.1 (SAS Institute Inc., Cary, NC). Non-treated controls were not included in statistical analysis of visual ratings. Phragmites percent control was arcsine square root transformed prior to analysis in order to maintain homogeneity of variance; however, the untransformed means are presented for clarity. Data were combined across study repetitions in field study 2 as no treatment by year interaction occurred.

RESULTS AND DISCUSSION

Field trial 1. At 16 WAT, control with all imazapyr, glyphosate, and triclopyr treatments was at least 91% (Table 2.1). Phragmites was not controlled with penoxsulam, however. At 66 WAT, control with all rates of imazapyr and glyphosate was at least 96%. Control with triclopyr and penoxsulam did not exceed 3%, which indicates significant Phragmites regrowth from initial control after triclopyr application.

Field trial 2. At 12 WAT, Phragmites control was 93% or greater with imazapyr (Table 2.2). Control with glyphosate and triclopyr treatments was 73 to 79%, while imazamox and penoxsulam did not control Phragmites greater than 47%. At 47 WAT, control with all imazapyr and glyphosate treatments was still significantly highest and at least 88%. Control with imazamox was 48 to 49% and was 12% or less with triclopyr and penoxsulam, again indicating significant Phragmites regrowth from initial control after triclopyr application.

In both trials, imazapyr controlled Phragmites at least 95% the year following treatment. Greater than 90% control of Phragmites with imazapyr has been reported previously (Derr 2008b; Mozder et al. 2008; J. Whetstone personal communication). The high level of long-term glyphosate control (88 to 98%) was slightly greater than expected, and equivalent to imazapyr. Other researchers have reported Phragmites control to be equivalent with imazapyr and glyphosate (Derr 2008b) or for imazapyr to provide slightly better control (Mozder et al. 2008; J. Whetstone, personal communication).

While triclopyr is labeled for Phragmites control (Anonymous 2008b), the initial control observed with triclopyr on this grass species was still surprising. Mervosh and Roach (2007) reported similar results with triclopyr field treatments and Derr (2008b) reported a 92% fresh weight reduction in container-grown Phragmites regrowth. Mervosh and Roach (2007) established that timing, spray volume, and coverage are factors that likely influence triclopyr efficacy on Phragmites. Lewis et al. (2009) reported efforts to control bermudagrass [*Cynodon dactylon* (L.) Pers.] in desirable zoysiagrass [*Zoysia japonica* (Steud.)] with triclopyr plus aryoxyphenoxypropionate herbicide mixtures. The activity of triclopyr on certain grass species should be evaluated further as it could increase utility of this herbicide for selective grass removal from desirable grass species.

The two newly registered aquatic herbicides, imazamox and penoxsulam, did not control Phragmites at the rates evaluated. The maximum registered penoxsulam rate for aquatic sites is 0.1 kg ae/ha and less than the rate evaluated in these trials (Anonymous 2007), thus penoxsulam should not be expected to control Phragmites. Burns (2008) did report imazamox activity on Phragmites although application rate and level of control was not specified. Imazamox is registered for use on aquatic sites at rates as high as 5% v/v for spot applications (Anonymous 2008a). This rate may be more effective than the 1.25% v/v rate evaluated in this study. Additional research should evaluate maximum imazamox rates, as the selectivity provided by this herbicide would generally be more preferable than the relatively non-selective options of glyphosate and imazapyr.

LITERATURE CITED

Ailstock, M.S., C.M. Norman, and P.J. Bushman. 2001. Common reed *Phragmites australis*: Control and effects upon biodiversity in freshwater nontidal wetlands. Restoration Ecology. Vol. 9. p. 49-59.

Anonymous. 1997. Common Wetland Plants of North Carolina. Raleigh, NC: NC Department of Environment, Health, and Natural Resources, Division of Water Quality. Available Online: http://h2o.enr.state.nc.us/esb/Wetplant/grassframe.htm. (Accessed July 2008).

Anonymous. 2003. Touchdown Pro herbicide label. Syngenta Crop Protection, Inc. Available online: http://www.syngentacropprotection-us.com. (Accessed January 2009).

Anonymous. 2004. Habitat herbicide label. BASF Corporation. Available online: http://www.vmanswers.com. (Accessed January 2009).

Anonymous. 2007. Galleon SC herbicide label. SePRO Corportation. Available online: http://www.sepro.com/documents/Galleon_Label.pdf (Accessed January 2009).

Anonymous. 2008a. Clearcast herbicide label. BASF Corporation. Available online: http://www.cdms.net/LDat/ld7J8005.pdf (Accessed January 2009).

Anonymous. 2008b. Renovate 3® herbicide label. SePRO Corporation. Available online: http://www.sepro.com/documents/Renovate_Label.pdf (Accessed

January 2009).

Aulbach-Smith, C.A. and S.J. de Kozlowski. *Aquatic and Wetland Plants of South Carolina.* Columbia, SC: South Carolina Department of Natural Resources, 1996. p. 87.

Barnes, V.P. 2003. Identification and control of common reed (*Phragmites australis*) in Virginia. Virginia Extension publication. Available Online: http://www.ext.vt.edu/pubs/weeds/427-101/427-101.pdf. (Accessed August 2008).

Blossey, B. 2002. Native to North America or introduced or both? Ag Web, Cornell University, Ithaca, NY. Available online: http://www.invasiveplants.net/Phragmites/phrag/natint.htm (Accessed January 2009).

Burns, B. 2008. Reviewing Clearcast (imazamox) EUP in aquatic plant management. Proc. Weed Sci. Soc. Am. Vol. 48. p. 128.

Chambers, R.M., L.A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquatic Botany. Vol. 64. p. 261-273.

Derr, J.F. 2008a. Common reed (*Phragmites australis*) response to mowing and herbicide application. Invasive Plant Science and Management. Vol. 1. p. 12-16.

Derr, J.F. 2008b. Common reed (*Phragmites australis*) response to postemergence herbicides. Invasive Plant Science and Management. Vol. 1. p. 153-157.

Fell, P. S. Warren, and A.E. Curtis. 2006. Short-term effects on macroinvertebrates and fishes of herbiciding and mowing *Phragmites australis*-dominated tidal marsh. Northeastern Naturalist. Vol. 13. p. 191-212.

Kay, S.H. 1995. Efficacy of wipe-on applications of glyphosate and imazapyr on common reed in aquatic sites. Journal of Aquatic Plant Management. Vol. 33. p. 25-26.

Lewis, D.F., J.S. McElroy, J.C. Sorochan, J.T. Brosnan, and G.K. Breeden. 2009. Efficacy of aryloxyphenoxypropionate herbicides for bermudagrass control in zoysiagrass fairways. Proc. Northeast. Weed Sci. Soc. Vol. 63. p. 44.

Mal, T. K., and L. Narine. 2004. The biology of Canadian weeds. 129. *Phragmites australis* (Cav.) Trin. ex Steud. Canadian Journal of Plant Science. Vol. 84. p. 365-396.

Mervosh, T.L., and D.P. Roach. 2007. Efficacy of glyphosate, imazapyr, and triclopyr for Phragmites management in a Connecticut marsh. Proc. Northeast. Weed Science Soc. Vol. 61. p. 73.

Monteiro, A., I. Moreira, and E. Sousa. 1999. Effect of prior common reed *(Phragmites australis)* cutting on herbicide efficacy. Hydrobiologia. Vol. 415. p. 305-308.

Mozdzer, T.J., C.J. Hutto, P.A. Clark, and D.P. Field. 2008. Efficacy of imazapyr and glyphosate in the control of non-native *Phragmites australis*. Restoration Ecology. Vol. 16. p. 221-224.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. PNAS. 99:4:2445-2449.

Uva, R.H., J.C. Neal, and J.M. DiTomaso. *Weeds of the Northeast*. Ithaca, NY: Cornell University, 1997. p. 76.

Weakley, Alan. 2008. Flora of the Carolinas, Virginia, Georgia, northern Florida, and surrounding areas. UNC Herbarium, North Carolina Botanical Garden, University of North Carolina at Chapel Hill. p. 829.

Table 2.1 Phragmites control with selected post-emergent herbicides in field study 1.[a]

Herbicide [c]	Rate		Control[b]	
	Application	Broadcast [d]	16 WAT [e]	66 WAT
	% v/v	kg ae/ha	%	
Glyphosate	1.25	0.61	96 ab	98 a
Glyphosate	2.5	1.2	97 ab	98 a
Imazapyr	1.25	0.81	96 ab	100 a
Imazapyr	2.5	1.62	97 ab	100 a
Imazapyr + glyphosate	1.25 + 1.25	0.82 + 0.61	100 a	96 a
Penoxsulam	0.45	0.3	17 d	3 c
Triclopyr	5	4.9	91 bc	0 c

[a] Abbreviations: WAT, weeks after treatment.

[b] Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.

[c] NIS at 0.25% v/v included with all treatments.

[d] Equivalent broadcast rate listed for reference.

[e] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (P≤0.05). Non-treated control not included in statistical analysis of visual ratings.

Table 2.2 Phragmites control with selected post-emergent herbicides in field study 2.[a,b]

Herbicide[d]	Rate		Control[c]	
	Application	Broadcast[e]	12 WAT[f]	47 WAT
	% v/v	kg ae/ha	%	
Glyphosate	1.25	0.61	73 b	88 a
Glyphosate	2.5	1.2	78 b	90 a
Imazamox	0.625	0.42	47 c	49 b
Imazamox	1.25	0.84	51 c	48 b
Imazapyr	1.25	0.81	94 a	95 a
Imazapyr	2.5	1.62	93 a	95 a
Penoxsulam	0.45	0.3	23 d	0 e
Triclopyr	5	4.9	79 b	12 d

[a] Results pooled across Carolina Beach and Wilmington, NC locations due to no treatment by location interaction.

[b] Abbreviations: WAT, weeks after treatment.

[c] Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.

[d] NIS at 0.25% v/v included with all treatments.

[e] Equivalent broadcast rate listed for reference.

[f] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Non-treated control not included in statistical analysis of visual ratings.

CHAPTER 3

EFFICACY OF SELECTED HERBICIDES ON BEACH VITEX

ABSTRACT

Beach vitex [*Vitex rotundifolia* L.f.] is a problematic invasive plant on the North and South Carolinas coasts. Field and greenhouse studies were conducted from 2006 through 2008 to evaluate the efficacy of aminopyralid, glyphosate, imazamox, imazapyr, metsulfuron, penoxsulam, triclopyr, and mixtures of imazapyr plus glyphosate, glyphosate plus triclopyr, and triclopyr plus 2,4-D applied postemergence on beach vitex. In one experiment, beach vitex control at 1 month after treatment (MAT) was greatest with glyphosate and glyphosate plus imazapyr (73% to 84%). At 12 MAT, control with glyphosate alone and glyphosate plus imazapyr was 90 and 94%, respectively. Control with triclopyr mixtures was less than 36% at 1 MAT and less than 11% at 12 MAT. In a second experiment, at 1 MAT glyphosate, imazapyr, and metsulfuron controlled beach vitex 66 to 82%. Control with aminopyralid, imazamox, and penoxsulam was less than 50%. At 8 MAT greatest control was observed with glyphosate and imazapyr (83 and 90%, respectively). Control levels with other treatments were significantly lower at 19 to 52%. In the greenhouse study at 3 WAT, control was 37 to 68% with glyphosate and 41 to 76% with imazapyr. At 5 WAT, control was 34 to 87% with glyphosate and 48 to 95% with imazapyr. Dry

weight was 4.47 to 5.00 g in glyphosate treatments and 3.50 to 6.18 in imazapyr treatments as compared to the nontreated dry weight of 6.93 g.

INTRODUCTION

Vitex rotundifolia L.f. is a perennial woody shrub that thrives on coastal sand dunes. This plant is native to Hawaii and countries of the Pacific Rim including China, Japan, Taiwan, Thailand, Indonesia, Malaysia, Papua New Guinea, Philippines, Australia, Fiji, and New Caledonia (USDA-ARS 2008). *Vitex rotundifolia* has many common names, but is mainly called beach vitex or roundleaf chastetree in the continental United States. It has been placed in both the *Lamiaceae* and *Verbenaceae* families, but is now accepted in *Verbenaceae* (USDA-ARS 2008). There are approximately 250 *Vitex* species worldwide (Wu et al. 1994), with two commonly found in nurseries, chastetree (*V. agnus-castus* L.) and Indian three leaf vitex (*V. trifolia* L.) (Olsen and Bell 2005).

In 1985, the US National Arboretum sponsored a plant collecting expedition to the Republic of Korea (Olsen and Bell 2005). After this expedition, beach vitex was recommended and sold for southeastern US coastal landscapes, before any known research was done to determine its potential invasiveness in these areas (Olsen and Bell 2005). Its attractiveness and proposed dune stabilization characteristics seemed a perfect fit for North and South Carolina coasts, although it has since emerged as an invasive species.

In 2006, Randy Westbrooks and John Madsen estimated in the Beach Vitex Federal Regulatory Weed Risk Assessment, that approximately 5.7 ha of North and South Carolina's coastline was infested with beach vitex. Approximately 125 sites have been found in South Carolina, averaging 280 square meters each (Westbrooks and Madsen 2006). Beach vitex is also present in Alabama, Georgia and Florida (Maddox et al. 2008; D. Suiter, US Fish and Wildlife, personal communication).

In areas of beach vitex establishment few other species are present, and those species found under the mass of vitex do not outcompete it (Gresham and Neal 2004). Plants like marsh pennywort [*Hydrocotyle umbellate* (L.)], cord grass [*Spartina patens* (Aiton) Muhl.], sea oats [*Uniola paniculata* (L.)], and beach grass [*Ammophila breviligulata* (Fernald)] cannot compete in beach vitex stands due to lesser height, stature, or reproductive vigor (Gresham and Neal 2004). Beach vitex has also been shown to release allelopathic compounds into the surrounding soil as well as compounds that cause the soil to be hydrophobic (Gresham and Neal 2004). Cousins et al. (2009) found that the sand under areas of beach vitex was significantly hydrophobic. This hydrophobicity is caused by cuticular alkanes from beach vitex leaves and fruits, and persists in the sand for at least three years after removal of beach vitex (Cousins et al. 2009).

High potential for beach vitex spread is due to prolific seed production as well as long runners that root at multiple nodes and potential stem fragmentation (Gresham and Neal 2004). These reproductive methods allow dissemination by humans, animals, and even floating (Gresham and Neal 2004). Beach vitex was found on an undeveloped beach 2.6 km from the closest planted population (Gresham and Neal 2004). Based on native habitat and hardiness, beach vitex can grow in eastern coastal zones as far north as Rhode Island, south to Florida and west to Texas, as well as on the entire west coast from California to Washington (Olsen and Bell 2005).

Unmanaged, beach vitex would negatively affect the Carolinas coast. It overcomes and outcompetes native dune species, including the federally threatened seabeach amaranth (*Amaranthus pumilis* Raf.) (Westbrooks and Madsen 2006). Dense mats interfere with native waterfowl and sea turtle nesting (Brabson 2006; Westbrooks and Madsen 2006). Large multimillion-dollar beach renourishment projects can also be hindered by beach vitex growth (Westbrooks and Madsen 2006). In addition, beach vitex is not as efficient at trapping wind-blown sand to build dunes as some native dune plant species (Anonymous 2008b). The extensive fibrous root system of sea oats is better suited for dune stabilization (SCNPS 2004). The beach vitex soil seed bank is persistent and will repopulate cleared areas (Cousins et al. 2006). Because of these impacts beach vitex was ranked “high” in habitat suitability, “high” in spread potential after establishment, “medium” in economic importance, and “high” in environmental importance, which gives it on overall risk potential score of “high” on the APHIS risk assessment model (Westbrooks and Madsen 2006).

The South Carolina Beach Vitex Task Force was formed in 2003, and comprised federal, state, and local agencies. In 2005, North Carolina joined the task force, making it the Carolinas Beach Vitex Task Force. This group operates under the mission of early detection, prevention, rapid assessment, rapid response, and restoration of the Carolinas Coast (Anonymous 2008b). The Task Force is currently working with localities to implement eradication programs. However, there is little beach vitex control information available to aid development of these programs. Therefore, field and greenhouse research was conducted to evaluate selected herbicides for beach vitex control.

MATERIALS AND METHODS

Field trial 1. In June 2006, a field herbicide trial was initiated on Bald Head Island, NC. Experimental plots were 3 m wide by 4 m long, and were located in a well-established, 1.5 m tall stand of beach vitex on beachfront sand dunes. A randomized complete block design was used to compare efficacy of postemergent herbicides and herbicide combinations on beach vitex. Treatments included glyphosate (Touchdown Pro, Syngenta Crop Protection, Inc.; Greensboro, NC) at 10% v/v, glyphosate (5% v/v) plus imazapyr (Habitat, BASF Corporation; Research Triangle Park, NC) at 0.5% v/v, glyphosate (5% v/v) plus triclopyr (Renovate, SePRO Corporation; Carmel, IN) at 0.75% v/v, and triclopyr (0.75% v/v) plus 2,4-D (Weedar 64, Nufarm Co.; St. Joseph, MO) at 0.6% v/v. Equivalent broadcast rates are listed in Table 3.1. Non-ionic surfactant at 0.25% v/v was included with each treatment. A nontreated control was also included.

Experimental treatments were applied to foliage at 280 L/ha with a CO_2 pressurized backpack sprayer. Applications were applied to wet, but not runoff. At treatment, weather conditions were sunny with 40% cloud cover, 32 C, and 65% relative humidity. Treatments were replicated three times. The trial was repeated on September 12, 2007, on a similar site on Figure Eight Island, NC, with equivalent treatments and rates. Plots for repeat were 3 m wide by 5 m long and located in a 1 to 2 m tall stand of beach vitex. At treatment of application, weather conditions were sunny with 60% cloud cover, 31 C, and 50% relative humidity. Two replications of the repeated trial were mowed by a landscaper and lost. Thus, only one repetition from the trial repeat could be included in analysis. Beach vitex control in both trials was estimated visually at 1 and 12 months after treatment (MAT) on a 0 to 100% scale. Ratings compared treated plots to nontreated and considered chlorosis, necrosis, and stunting, with 0% corresponding to no control and 100% corresponding to complete plant death.

Field trial 2. On September 12, 2007, two repetitions of a field herbicide trial were initiated on the south end of Figure Eight Island, NC. Experimental plots were 3 m wide by 6 m long, and were located in a well-established, 1.5 m tall stand of beach vitex on beachfront sand dunes. A randomized complete block design was used to compare efficacy of six postemergent herbicides on beach vitex. Treatments included glyphosate at 1, 2, 5, and 10% v/v, aminopyralid (Milestone VM, Dow AgroSciences; Indianapolis, IN), imazamox (Clearcast, BASF Corporation; Research Triangle Park, NC), imazapyr, and penoxsulam (Galleon SC, SePRO Corporation; Carmel, IN) at 1.5% v/v, and mesulfuron (Ally XP, DuPont; Wilmington, DE) at 10 g/L. Equivalent broadcast rates are listed in Table 3.2. Each non-glyphosate treatment included methylated seed oil (Sunenergy, Brewer International; Vero Beach, FL) at 1% v/v. A nontreated control was also included. Experimental treatments were applied to foliage at 280 L/ha with a CO_2-pressurized backpack sprayer. Applications were applied to wet, but not runoff. At treatment, weather conditions were sunny with

30% cloud cover, 31 C, and 75% relative humidity. Treatments were replicated three times. Beach vitex control was estimated visually at 1 and 8 months after treatment (MAT) as described for field trial 1.

Greenhouse trial. A repeated greenhouse study was also conducted to evaluate the effect of glyphosate and imazapyr rate on beach vitex control. beach vitex terminal stem clippings were planted into 10 cm square pots in concrete sand. Slow release fertilizer (Osmocote Classic 19-6-12, The Scotts Company; Marysville, OH) was added to each pot. Plants were allowed to mature in a greenhouse for two months, with irrigation twice daily for 5 minutes, and temperatures of 29 C during the day and 24 C at night. Day length was 14 hours, and night length was 10 hours. Plant size at time of application was 55 to 65 cm in the first repetition and 25 to 35 cm in the second repetition.

The study design was a randomized complete block and treatments were replicated three times. Glyphosate application rates were 1.11, 2.25, 5.61, and 11.19 kg ai/ha. Imazapyr rates were 0.35, 0.68, 1.01, and 3.36 kg ai/ha and all treatments included methylated seed oil at 1% v/v. A nontreated control was also included. Experimental treatments were applied to foliage using an air-pressurized indoor spray chamber equipped with a single 8002E flat-fan nozzle calibrated to deliver a spray volume of 280 L/ha. After herbicide application, plants were immediately returned to the greenhouse. Plants were rated for herbicide control on a 0 to 100% as described in field trial 1. Plants were rated at 3 and 5 WAT. At 5 WAT, plants were clipped at the soil surface and shoots were oven dried at 82 C for 48 hours for dry weight determination. Dry weight data is expressed as percent dry biomass reduction as compared to dry biomass of untreated plants.

Statistical analysis. All data were subjected to analysis of variance and means were separated using Fisher's Protected LSD ($P \leq 0.05$) in SAS v. 9.1 (SAS Institute Inc., Cary, NC). Non-treated control treatments were not included in statistical analysis of visual ratings. Percent control of beach vitex was arcsine square root transformed prior to analysis in order to maintain homogeneity of variance; however, the untransformed means are presented for clarity. Data were combined across study repetitions where no treatment by year interaction occurred. Structured rates in field trial 1 and the greenhouse trial were also subjected to linear regression using the equation $y=y_o+ax$. Linear regression for imazapyr rate in the greenhouse trial was not significant ($P=0.05$) and therefore, is not presented.

RESULTS AND DISCUSSION

Field trial 1. At 1 MAT, glyphosate (10% v/v) controlled beach vitex 84%, and glyphosate (5%) plus imazapyr (0.5% v/v) controlled beach vitex 73% (Table 3.1).

Glyphosate plus triclopyr and triclopyr plus 2,4-D did not control beach vitex greater than 36%. At 12 MAT, control with glyphosate alone and glyphosate plus imazapyr was 90 and 94%, respectively. Control with triclopyr mixtures was 9 to 11%.

Field trial 2. At 1 MAT, glyphosate, imazapyr, and metsulfuron controlled beach vitex 66 to 82% (Table 3.2). Control with aminopyralid, imazamox, and penoxsulam was 46, 51, and 29%, respectively. At 8 MAT greatest control was observed with glyphosate and imazapyr (83 and 90%, respectively). Other treatments were significantly lower at 19 to 52%. Glyphosate control increased linearly with increasing rate (Figure 3.1). Line slope was greater at 8 MAT, indicating a greater benefit long-term to increased glyphosate rate than at 1 MAT.

Greenhouse trial. At 3 WAT, control was 37 to 68% with glyphosate and 41 to 76% with imazapyr (Table 3.3). At 5 WAT, control was 34 to 87% with glyphosate and 48 to 95% with imazapyr. Increasing glyphosate rate did increase control in a linear fashion, but linear regression for imazapyr was not significant at P=0.05 (Figure 3.2). beach vitex dry weight did decrease in a linear response to increasing rate of both glyphosate and imazapyr. Dry weight was 4.47 to 5.00 g in glyphosate treatments and 3.50 to 6.18 in imazapyr treatments as compared to the nontreated dry weight of 6.93 g (Table 3.3).

Based upon linear regression models, 9.4 and 10.2 kg ae/ha glyphosate is required to provide 80% control (EC_{80}) of beach vitex in the greenhouse and field at 5 WAT, respectively (data not presented). These are extraordinarily high rates required for control with glyphosate and typical glyphosate use rates do not exceed 4.2 kg ae/ha (Senseman 2007). In contrast, greenhouse EC_{80} for imazapyr was 1.52 kg ae/ha (data not presented). Typical imazapyr use rates for broadcast application range 0.56 to 1.7 kg ae/ha (Senseman 2007).

While only one mixture of glyphosate (5% v/v; equivalent to 5.6 kg ae/ha) plus imazapyr (0.5% v/v; equivalent to 0.33 kg ae/ha) was evaluated, this treatment was as effective as the equivalent glyphosate rate of 11.2 kg ae/ha. This lower use rate mixture would improve the cost efficiency of the eradication programs as well as apply less active ingredient to the environment. Additional research should be conducted with glyphosate plus imazapyr mixtures.

The only other documented research on beach vitex control was provided by Cousins et al. (2006), evaluating glyphosate, imazapyr, imazamox, triclopyr, and carfentrazone on container-grown beach vitex. At 8 MAT, 90% or greater control was observed with 5% v/v glyphosate (AquaMaster), 2.5 and 5% v/v imazapyr, 2.5 and 5% v/v imazamox, 5% v/v triclopyr, and 2.5 and 5% v/v carfentrazone. Due to different glyphosate formulations and application volumes, the 5% v/v glyphosate rate evaluated by Cousins is similar to the 10% v/v rate evaluated in the current research, thus the glyphosate results are generally in agreement. Rates of imazapyr, imazamox, and triclopyr evaluated by Cousins et al. (2006) were generally greater than the rates in our research and would explain the greater control observed with imazamox and triclopyr. Jack Whetstone with Clemson University observed greater vitex control on field sites with 5% v/v imazapyr than 10% v/v glyphosate (personal communication).

In conclusion, glyphosate, imazapyr, or mixtures of these two herbicides may control beach vitex when applied to foliage. Foliar applications would greatly increase eradication efficiency over the cut stem treatments currently recommended by the Beach Vitex Task Force. However, applications should only be made under advantageous environmental conditions.

LITERATURE CITED

Anonymous. 2003. Touchdown Pro herbicide label. Syngenta Crop Protection, Inc. Available online: http://www.syngentacropprotection-us.com. (Accessed January 2009).

Anonymous 2004. Habitat herbicide label. BASF Corporation. Available online: http://www.vmanswers.com. (Accessed January 2009).

Anonymous 2006. Ally XP herbicide label, DuPont. Available online: http://www.dupont.com/ag/us/prodinfo/prodsearch/information/H65072.pdf. (Accessed January 2009).

Anonymous 2007. Galleon SC herbicide label. SePRO Corportation. Available online: http://www.sepro.com/documents/Galleon_Label.pdf (Accessed January 2009).

Anonymous. 2008a. Carolinas Beach Vitex Task Force Website, hosted by North Inlet-Winyah Bay National Estuarine research Reserve. Available online: www.beachvitex.org (Accessed January 2009).

Anonymous. 2008b. Clearcast herbicide label. BASF Corporation. Available online: http://www.cdms.net/LDat/ld7J8005.pdf (Accessed January 2009).

Anonymous. 2008c. Milestone VM herbicide label. Dow AgroSciences. Available online: http://www.cdms.net/LDat/ld7I2004.pdf (Accessed January 2009).

Anonymous. 2008d. Renovate 3 herbicide label. SePRO Corporation. Available online: http://www.sepro.com/documents/Renovate_Label.pdf (Accessed January 2009).

Anonymous. 2008e. Weedar 64 herbicide label. NuFarm Inc. Available online: http://www.cdms.net/LDat/ld08K018.pdf (Accessed January 2009).

Brabson, B. 2006. Beach vitex task force: How one person can make a difference. 8th Annual Southeast Exotic Plant Council Symposium. Available Online: http://www.se-eppc.org/SEPPCSymposiumProgram2006fin.pdf (Accessed June 2008).

Cousins, M., T. Whitwell, and J. Briggs. 2006. Viability of beach vitex (*Vitex rotundifolia*) seed: and invasive coastal plant. SNA Research Conference. Vol. 51. p. 417-419.

Gresham, C. 2006. Identifying and managing beach vitex. Clemson University Extension Home and Garden Information Center. Available Online: http://hgic.clemson.edu/pdf/hgic2315.pdf (Accessed May 2008).

Gresham, C. and A. Neal. 2004. An evaluation of the invasive potential of beach vitex (*Vitex rotundifolia*). Bell W. Baruch Institute of Coastal Ecology and Forest Science. Clemson University. Georgetown, SC. In publication.

Maddox, V., R. Westbrooks, J.D. Byrd Jr., and B. Brabson. 2008. Invasive Plant Atlas of the MidSouth: Beach vitex. Mississippi State GeoResources Institute. Available Online: http://www.gri.msstate.edu/ipams/Species.php?SName=&

CName=Beach+vitex (Accessed June 2008).

Olsen, R.T. and A.C. Bell. 2005. History of Beach Vitex Cultivation: A Potential Invasive Ornamental. SNA Research Conference. Vol. 50. p. 531-533.

Senseman, S., ed. *Herbicide Handbook.* Ninth Edition. Lawrence, KS: Weed Science Society of America, 2007.

South Carolina Native Plant Society (SCNPS). 2004. Hawaiian plant threatens South Carolina Dunes. URL: www.scnps.org/PDFs/vitex.pdf (Accessed June 2008).

USDA-ARS, National Genetic Resources Program. 2008. *Germplasm Resources Information Network - (GRIN)* [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. URL: http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?41839 (Accessed June 2008).

Westbrooks, R.G. and J. Madsen. 2006. Federal regulatory weed risk assessment beach vitex (*Vitex rotundifolia* L. f.). Available online: http://www.northinlet.sc.edu/resource/vitex_files/march06/Beach%20Vitex%20Weed%20Risk%20Assessment%20Summary3-06%20-%20RWestbrooks….pdf. (Accessed May 2008).

World Health Organization (WHO). Medicinal Plants in the Republic of Korea. WHO Regional Publications: Western Pacific Series No. 21. 1998. p. 293.

Wu, Z. Y. & P. H. Raven, eds. *Flora of China. Vol. 17 (Verbenaceae through Solanaceae)*. Science Press, Beijing, and Missouri Botanical Garden Press, St.

Louis. 1994. p. 30.

Table 3.1 Beach vitex control with postemergent herbicides in field study 1.[a]

Herbicide[c]	Rate		Control[b]	
	Application	Broadcast[d]	1 MAT[e]	12 MAT
	% v/v	kg ae/ha	%	
Glyphosate	10	11.2	84 a	90 a
Glyphosate + imazapyr	5 + 0.5	5.6 + 0.33	73 a	94 a
Glyphosate + triclopyr	5 + 0.75	5.6 + 0.54	35 b	9 b
Triclopyr + 2,4-D	0.75 + 0.6	0.74 + 0.54	36 b	11 b

[a] Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.

[b] Abbreviations: MAT, months after treatment.

[c] NIS at 0.25% v/v included with all glyphosate combination treatments.

[d] Equivalent broadcast rate listed for reference.

[e] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Non-treated control not included in statistical analysis of visual ratings.

Table 3.2 Beach vitex control with postemergent herbicides in field study 2.[a]

Herbicide[c]	Rate		Control[b]	
	Application	Broadcast[d]	1 MAT[e]	8 MAT
	% v/v	kg ae/ha	%	
Aminopyralid	1.5	1	46 bc	24 d
Glyphosate	10	11.2	77 a	83 a
Imazamox	1.5	0.5	51 b	37 c
Imazapyr	1.5	1.0	82 a	90 a
Metsulfuron	10 g/L	1.68	66 ab	52 b
Penoxsulam	1.5	1	29 c	19 d

[a] Abbreviations: MAT, months after treatment.

[b] Weed control rated on 0 to 100% scale; 0% = no plant response and 100% = complete death.

[c] MSO at 1% v/v included with all imazapyr treatments.

[d] Equivalent broadcast rate listed for reference.

[e] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Non-treated control not included in statistical analysis of visual ratings.

Table 3.3 Beach vitex control in the greenhouse with postemergent herbicides.[a,b]

Herbicide[c]	Rate	Control 3 WAT[d]	Control 5 WAT	Dry weight
	kg ae/ha	%	%	g
Glyphosate	1.12	47 abc	34 d	4.98 ab
Glyphosate	2.24	37 c	56 bcd	5.00 ab
Glyphosate	5.6	53 abc	76 abc	4.47 ab
Glyphosate	11.2	68 abc	87 a	4.48 ab
Imazapyr	0.34	41 bc	48 cd	6.18 ab
Imazapyr	0.67	66 abc	77 ab	5.08 ab
Imazapyr	1.01	76 a	88 a	3.50 b
Imazapyr	3.36	72 ab	95 a	3.90 b
Nontreated	--	--	--	6.93 a

[a] Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.

[b] Abbreviations: WAT, weeks after treatment.

[c] MSO at 1% v/v included with all imazapyr treatments.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Non-treated control not included in statistical analysis of visual ratings.

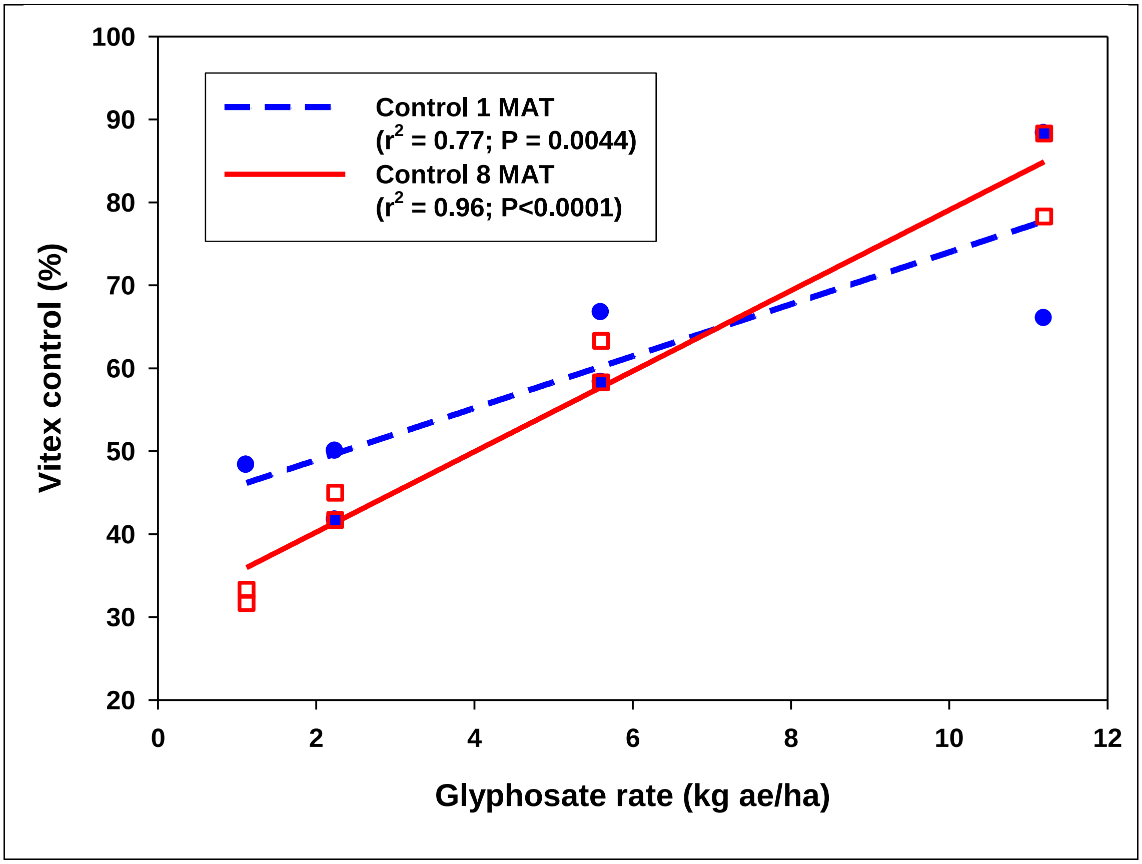

Figure 3.1 Beach vitex response to increasing glyphosate rate in the field study ($y = y_0 + ax$; 1 MAT: $r^2 = 0.77$; $P = 0.0044$; 8 MAT: $r^2 = 0.96$; $P < 0.0001$).

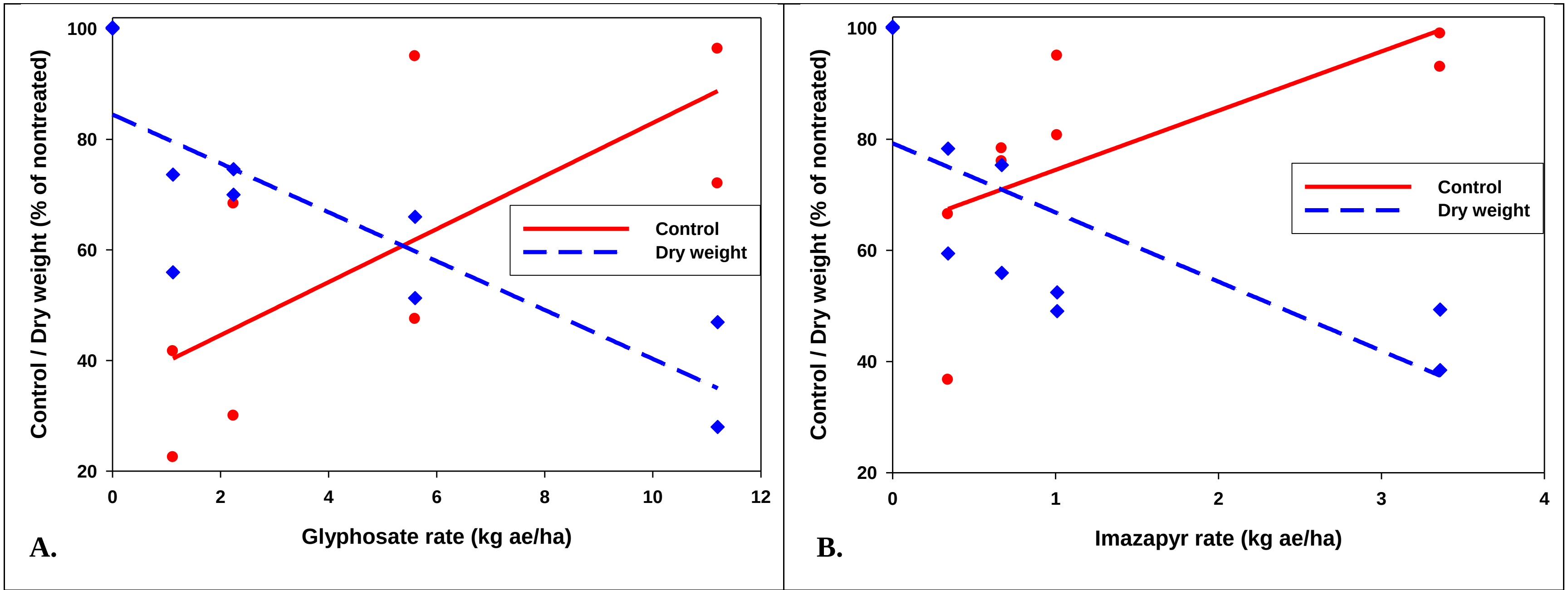

Figure 3.2 Beach vitex control at 5 weeks after treatment and dry weight response to increasing glyphosate and imazapyr rates in the greenhouse.

A.) Glyphosate ($y = y_0 + ax$; control: $r^2 = 0.51$; $P = 0.0466$; dry weight: $r^2 = 0.69$; $P = 0.0027$).

B.) Imazapyr ($y = y_0 + ax$; control: $r^2 = 0.46$; $P = 0.0659$; dry weight: $r^2 = 0.52$; $P = 0.0186$).

CHAPTER 4

ABSORPTION AND TRANSLOCATION OF ^{14}C-GLYPHOSATE IN BEACH VITEX

ABSTRACT

The absorption and translocation of glyphosate in beach vitex was evaluated with cut stem and foliar applications. Plants were treated with a prepared ^{14}C-glyphosate solution and harvested at 6, 24, 48, 92, and 196 hours after treatment. Samples were oxidized and radioactivity was quantified using liquid scintillation spectrometry. In beach vitex cut stems, time of harvest was not significant indicating that all absorption and translocation occurred within the first six hours after treatment. The greatest amount of herbicide recovered remained in the stump (348,408 DPM). A moderate amount translocated to the first root section (14,572 DPM) and a minimal amount translocated to root segments greater distances from the stump (1,657 and 617 DPM for second 10 cm of roots and end roots, respectively). In foliar treatments, the greatest recovered herbicide remained in the treated leaf at 17,828 DPM. Recovered ^{14}C-glyphosate in other plant parts did not differ and ranged 1,222 to 4,300 DPM. At 6 and 24 HAT, 2,081 to 2,825 DPM were recovered. Greater amounts of 6,432 to 9,661 were recovered at 48 to 196 HAT. Translocation of the applied herbicide was generally low with both application methods.

INTRODUCTION

Vitex rotundifolia L.f. is a perennial woody shrub that thrives on coastal sand dunes. It is native to Hawaii and countries of the Pacific Rim including China, Japan, Taiwan, Thailand, Indonesia, Malaysia, Papua New Guinea, Philippines, Australia, Fiji, and New Caledonia (USDA-ARS 2008). *V. rotundifolia* has many common names, but is mainly called beach vitex (beach vitex) or roundleaf chastetree in the continental United States. It has been placed in both the *Lamiaceae* and *Verbenaceae* families, but is now accepted in *Verbenaceae* (USDA-ARS 2008). There are approximately 250 *Vitex* species worldwide (Wu et al. 1994), with two commonly found in nurseries, chastetree (*V. agnus-castus* L.) and Indian three leaf vitex (*V. trifolia* L.) (Olsen and Bell 2005).

In 1985, the US National Arboretum sponsored a plant collecting expedition to the Republic of Korea (Olsen and Bell 2005). After this expedition, beach vitex was recommended and sold for southeastern US coastal landscapes, before any known research was done to determine its potential invasiveness in these areas (Olsen and Bell 2005). Its attractiveness and proposed dune stabilization characteristics seemed a perfect fit for North and South Carolina coasts, although it has since emerged as an invasive species.

In 2006, Randy Westbrooks and John Madsen estimated in the Beach Vitex Federal Regulatory Weed Risk Assessment, that approximately 5.7 ha of North and South Carolina's coastline was infested with beach vitex. Approximately 125 sites have been found in South Carolina, averaging 280 square meters each (Westbrooks and Madsen 2006). Beach vitex is also present in Alabama, Georgia and Florida (Maddox 2008; D. Suiter personal communication).

In areas of beach vitex establishment few other species are present, and those species found under the mass of vitex do not outcompete it (Gresham and Neal 2004). Plants like marsh pennywort, cord grass, sea oats, and beach grass cannot compete in beach vitex stands due to lesser height, stature, or reproductive vigor (Gresham and Neal 2004). beach vitex has also been shown to release allelopathic compounds into the surrounding soil as well as compounds that cause the soil to be hydrophobic (Gresham and Neal 2004). Cousins et al. (2009) found that the sand under areas of beach vitex was significantly hydrophobic. This hydrophobicity is caused by cuticular alkanes from beach vitex leaves and fruits, and persists in the sand for at least three years after removal of beach vitex (Cousins et al. 2009).

High potential for beach vitex spread is due to prolific seed production as well as long runners that root at multiple nodes and potential stem fragmentation (Gresham and

Neal 2004). These reproductive methods allow dissemination by humans, animals, and even floating (Gresham and Neal 2004). beach vitex was found on an undeveloped beach 2.6 km from the closest planted population (Gresham and Neal 2004). Based on native habitat and hardiness, beach vitex can grow in eastern coastal zones as far north as Rhode Island, south to Florida and west to Texas, as well as on the entire west coast from California to Washington (Olsen and Bell 2005).

Unmanaged, beach vitex would negatively affect the Carolinas coast. It overcomes and outcompetes native dune species, including the federally threatened seabeach amaranth (*Amaranthus pumilis* Raf.). Dense mats interfere with native waterfowl and sea turtle nesting (Brabson 2006; Westbrooks and Madsen 2006). Large multimillion-dollar beach renourishment projects can also be hindered by beach vitex growth (Westbrooks and Madsen 2006). In addition, beach vitex is not as efficient at trapping wind-blown sand to build dunes as some native dune plant species (Anonymous 2008). The extensive fibrous root system of sea oats is better suited for dune stabilization (SCNPS 2004). The beach vitex soil seed bank is persistent and will repopulate cleared areas (Cousins et al. 2006). Because of these impacts beach vitex was ranked “high” in habitat suitability, “high” in spread potential after establishment, “medium” in economic importance, and “high” in environmental importance, which gives it on overall risk potential score of “high” on the APHIS risk assessment model (Westbrooks and Madsen 2006).

The South Carolina Beach Vitex Task Force was formed in 2003, and comprised federal, state, and local agencies. In 2005, North Carolina joined the task force, making it the Carolinas Beach Vitex Task Force. This group operates under the mission of early detection, prevention, rapid assessment, rapid response, and restoration of the Carolinas Coast (Anonymous 2008). The Task Force is currently working with localities to implement eradication programs. However, there is little beach vitex control information available to aid development of these programs.

In the early 1970s the Monsanto Company developed the agricultural herbicide glyphosate (Woodburn 2000). The primary mode of action of glyphosate is the inhibition of 3-P-shikimate-1-carboxyvinyltransferase (5-enolpyruvylshikimate-3-phosphate synthase or EPSP synthase,) an important enzyme in the shikimate pathway (Steinrucken and Amrhein 1995). It is a phloem mobile systemic herbicide that is known for its effectiveness on rhizome rich perennials (Peterson et al. 2001).

The vast root and rhizome systems of beach vitex call for a systemic chemical control method. Glyphosate has a very low mammalian toxicity and almost no soil activity due to high adsorption to soil colloids (Peterson et al. 2001). As a result, it a low-risk herbicide option for use on sensitive beach vitex locations. Because beach vitex is commonly found on delicate coastal sand dunes, herbicide application methods other than foliar spray may be necessary in order to eliminate the potential for off-target movement due to common high winds. Controlling invasives while encouraging native species growth is a goal in any eradication project. Reducing nontarget plant death in these areas is important due to the need for erosion control. In typical beach vitex removal programs, native dune plants will be planted in the area for reestablishment. After applications of glyphosate, no time is needed to wait before planting desired plants due to the tight binding of glyphosate to soil colloids (Senseman 1997).

One popular recommendation for beach vitex control includes cutting stems just above the soil level and immediately applying a 10% v/v glyphosate solution (Gresham 2006). The objective of this study was to evaluate glyphosate absorption and translocation by beach vitex using two application methods, cut stem and foliar spray. Cut stem treatments can be very effective on woody weed species, but are significantly more labor-intensive than foliar spraying.

MATERIALS AND METHODS

Beach vitex terminal stem clippings were planted into 10 cm square pots in concrete sand. Slow release fertilizer (Osmocote Classic 19-6-12, The Scotts Company; Marysville, OH) was added to each pot. Plants were allowed to grow to 15 to 20 cm in a greenhouse for two months, with irrigation twice daily for 5 minutes, and temperatures of 29 C during the day and 24 C at night. Day length was 14 hours, and night length was 10 hours. All plants had single stems with similar diameters between six and ten mm.

The ^{14}C-glyphosate treatment solution was prepared by diluting ^{14}C-glyphosate (^{14}C-methyl labeled, specific activity 2.04 GBq/mmol, 99% purity in an aqueous stock solution of 7.4 MBq/ml as *N*-[phosphonomethyl]glycine) in a commercial formulation of glyphosate (Round Up Weather Max, Monsanto Company; St. Louis, MO). Plants were subjected to a cut stem herbicide application of a 50:50 ^{14}C-glyphosate solution and methylated seed oil (MSO). Stems were cut off 2 cm above the soil surface. Immediately after cutting, 20 µL of the prepared treatment were applied in 20 droplets to the cut surface of the stem using a metal syringe. Approximately 400,000 DPM or 0.18 µCi of radioactivity was applied to each cut stem.

Additional plants were subjected to a foliar application of glyphosate. One of the uppermost fully extended leaves was marked with a permanent marker on each plant.

The plants were then treated in a cabinet sprayer with 1.12 kg ae/ha glyphosate plus 1% (v/v) MSO. After drying, 10 µL of the ^{14}C-glyphosate solution at 1% v/v were applied to the marked leaf of each plant in 1 µL droplets with a metal syringe. Approximately 300,000 DPM or 0.14 µCi of radioactivity was applied to each treated leaf. Plants were sub-irrigated with water as needed.

Treated plants were harvested at 6, 24, 48, 96, and 192 hours after treatment (HAT). At harvest, cut stem treated plants were separated into: 2 cm stump, first 10 cm of roots, second 10 cm of roots, and the remaining roots. Foliar treated plants were separated into the treated leaf, the leaf opposite the treated leaf, plant tissue above the treated leaf, all shoot below the treated leaf, and the roots. The treated leaves were washed immediately after harvest by gently shaking for 1 minute in 20 ml of a 50:50 solution of methanol and MSO to remove unabsorbed radioactivity. A 1 ml aliquot of the leaf rinse was added to 15 ml of scintillation cocktail, and radioactivity was quantified using liquid scintillation spectrometry. All root samples were rinsed to remove soil at time of harvest. Harvested samples were then dried in an oven at 90 C for 72 hours.

After drying, each sample was weighed and then ground into a fine dust using a simple coffee grinder or mortar and pestle. A portion of each ground sample (0.05

g), or the entire sample if it weighed less than 0.05 g, was then placed into an individual piece of filter paper, folded into an envelope, and labeled. These were then combusted in an OX-500 Biological Material Oxidizer. Radioactivity from oxidations was quantified using liquid scintillation spectrometry in a TRI-CARB 2100TR Liquid Scintillation Analyzer.

Total radioactivity present in all plant sections was considered as absorbed ^{14}C-glyphosate. Radioactivity present in all parts except the treated stump or leaf was considered as translocated and expressed as ^{14}C-glyphosate recovered per plant section. Data is presented in DPM as well as percent of applied radioactivity that was recovered. The experiment was repeated in time. All data were subjected to two-way analysis of variance with factors of time and plant part, and means were separated using Fisher's Protected LSD ($P \leq 0.05$) in SAS v. 9.1 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

In beach vitex cut stems, no harvest time by plant part interaction was present and the main effect of harvest time was not significant (data not presented). Lack of harvest time significance indicates that no appreciable absorption and translocation occurred after the first six hours from treatment. Absorption into cut stems may not occur after the stems dry, which may explain lack of continued absorption over time. The main effect of plant part was significant and the greatest amount of herbicide recovered remained in the stump (348,408 DPM, 87.1% of applied) (Table 4.1). A moderate amount translocated to the first root section (14,572 DPM, 4.86% of applied) and a minimal amount translocated to root segments greater distances from the stump (1,657 and 617 DPM for second 10 cm of roots and end roots, respectively). Glyphosate typically translocates in a source to sink direction, therefore removing the shoot may stop this process and in turn reduce or limit the amount of glyphosate that translocates within the remaining plant segments.

In foliar treatments, a harvest time by plant part interaction was present and both main effects were significant (data not presented). An average of 200,128 DPM, 67% of applied, was collected from the leaf wash over all harvest times, and leaf wash by harvest time was not significant. The greatest absorbed and recovered herbicide remained in the treated leaf at 17,828 DPM, or 6% of applied (Table 4.2). Other absorption and translocation studies found similar results (Bowmer et al. 1993; Green et al.1992; Ferreira and Reddy 2000; Reddy 2007). Recovered ^{14}C-glyphosate in other plant parts did not differ and ranged 1,222 to 4,300 DPM (0.4 to 1.4% of applied)). At 6 and 24 HAT, 2,081 to 2,825 DPM (0.7 to 0.94%) were recovered. Significantly greater amounts, 6,432 to 9,661 DPM or 2.1 to3.2% of applied, were recovered at 48 to 196 HAT.

Green et al. (1992) found that woody species tolerant to glyphosate absorbed significantly less glyphosate than did glyphosate susceptible woody species. The tendency for beach vitex to be somewhat glyphosate tolerant at low rates (S. True, unpublished data) may be related to absorption. Green et al. (1992) also reported that translocation patterns contribute significantly to glyphosate tolerance in some woody species. The amount of ^{14}C-glyphosate that moved into the roots was found to be higher in susceptible and lower in tolerant plants (Green 1992). In other woody perennials, absorption and translocation increased over time in redvine [*Brunnichia ovata* (Walter) Shinners] and *Erythroxylum* spp. (Ferreira and Reddy 2000; Reddy 2000). Reddy (2000) found that redvine is controlled 98% with 4.48 kg/ha, which is much lower than the rate required in the greenhouse for beach vitex control (S. True, unpublished data). Ferreira and Reddy (2000) found that differences in absorption and translocation of glyphosate in *Erythroxylum* spp. may partially explain the reported differences in susceptibility to glyphosate.

Chachalis and Reddy (2004) also found increased translocation and absorption of ^{14}C-glyphosate on trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau], another woody species, with increased HAT. Trumpetcreeper translocation was different from beach vitex however in that a relatively similar amount of ^{14}C-glyphosate moved to the roots as stayed in the treated leaf (9.7 vs. 9% of absorbed ^{14}C-

glyphosate, respectively) (Chachalis and Reddy 2004). Trumpetcreeper was controlled greater than 98% with glyphosate rates of 1.68 and 3.36 kg ae/ha and regrowth from rootstocks of treated plants was completely inhibited (Chachalis and Reddy 2004). The difference in glyphosate susceptibility between beach vitex and trumpetcreeper is possibly due to translocation patterns, and amount of herbicide which reaches the root systems of treated plants.

In conclusion, absorption patterns were different for cut stem and foliar applied glyphosate, but translocation to roots occurred in both treatments. Relatively low amounts of translocation from foliar applications may explain beach vitex relative tolerance to glyphosate.

LITERATURE CITED

Anonymous. 2007. Roundup WeatherMAX herbicide label. Monsanto Corportation. Available online: http://www.cdms.net/LDat/ld5UJ047.pdf (Accessed January 2009).

Anonymous. 2008. Carolinas Beach Vitex Task Force Website, hosted by North Inlet-Winyah Bay National Estuarine research Reserve. Available online: www.beachvitex.org (Accessed January 2009).

Bowmer, K.H., P.L. Eberbach, and G. McCorkelle. Uptake and translocation of 14-C glyphosate in *Alternanthera philoxeroides* (Mart.) Griseb. (alligator weed) I. Rhizome concentrations required for inhibition. Weed Research. Vol. 33. p. 53-57.

Brabson, B. 2006. Beach vitex task force: How one person can make a difference. 8th Annual Southeast Exotic Plant Council Symposium. Available Online: http://www.se-eppc.org/SEPPCSymposiumProgram2006fin.pdf (Accessed June 2008).

Chachalis, D. and K. Reddy. 2004. Pelargonic Acid and Rainfall Effects on Glyphosate Activity in Trumpetcreeper (*Campsis radicans*). Weed Technology. Vol. 18. p. 66-72.

Cousins, M., T. Whitwell, and J. Briggs. 2006. Viability of beach vitex (*Vitex rotundifolia*) seed: and invasive coastal plant. SNA Research Conference. Vol.

51. p. 417-419.

Ferreira, J.F.S. and K.N. Reddy. 2000. Absorption and translocation of glyphosate in *Erythroxylum coca* and *E. novogranatense*. Weed Science. Vol.48. p. 193-199.

Green, T.H., P.J. Minogue, C.H. Brewer, G.R. Glover, and D.H. Gjerstad. 1992. Absorption and translocation of C-14 glyphosate in 4 woody plant species. Canadian Journal of Forest Research. Vol. 22. p. 785-789.

Gresham, C. 2006. Identifying and managing beach vitex. Clemson University Extension Home and Garden Information Center. Available Online: http://hgic.clemson.edu/pdf/hgic2315.pdf (Accessed May 2008).

Gresham, C. and A. Neal. 2004. An evaluation of the invasive potential of beach vitex (*Vitex rotundifolia*). Bell W. Baruch Institute of Coastal Ecology and Forest Science. Clemson University. Georgetown, SC. In publication.

Maddox, V., R. Westbrooks, J.D. Byrd Jr., and B. Brabson. 2008. Invasive Plant Atlas of the MidSouth: Beach vitex. Mississippi State GeoResources Institute. Available Online: http://www.gri.msstate.edu/ipams/Species.php?SName=&CName=Beach+vitex (Accessed June 2008).

Olsen, R.T. and A.C. Bell. 2005. History of Beach Vitex Cultivation: A Potential Invasive Ornamental. SNA Research Conference. Vol. 50. p. 531-533.

Peterson, D.E., D.L. Regehr, C.R. Thompson, and K. Al-Khatib. 2001. Herbicide Mode of Action. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Available Online: http://www.oznet.ksu.edu/ library/crpsl2/c715.pdf. (Accessed September 2008).

Reddy, K.N. 2000. Factors affecting toxicity, absorption, and translocation of glyphosate in redvine (*Brunnichia ovata*). Weed Technology. Vol. 14. p. 457-462.

South Carolina Native Plant Society (SCNPS). 2004. Hawaiian plant threatens South Carolina Dunes. URL: www.scnps.org/PDFs/vitex.pdf (Accessed June 2008).

Steinrucken, H.C and N. Amrhein.1980. The herbicide glyphosate is a potent inhibitor of 5-enolpyruvylshikimate-3-phosphate synthase. Biochemical and Biophysical Research Communication. Vol. 94. P. 1207-1212.

USDA-ARS, National Genetic Resources Program. 2008. *Germplasm Resources Information Network - (GRIN)* [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. URL: http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?41839 (Accessed June 2008).

Westbrooks, R.G. and J. Madsen. 2006. Federal regulatory weed risk assessment beach vitex (*Vitex rotundifolia* L. f.). Available online: http://www.northinlet.sc.edu/resource/vitex_files/march06/Beach%20Vitex%20Weed%20Risk%20Assessment%20Summary3-06%20-%20RWestbrooks….pdf.

(Accessed May 2008).

Woodburn, A. 2000. Glyphosate production, pricing, and use worldwide. Pest Management Science. Vol. 56 p. 309-312.

World Health Organization (WHO). Medicinal Plants in the Republic of Korea. WHO Regional Publications: Western Pacific Series No. 21. 1998. p. 293.

Wu, Z. Y. & P. H. Raven, eds. *Flora of China. Vol. 17 (Verbenaceae through Solanaceae)*. Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis. 1994. p. 30.

Table 4.1 ^{14}C-glyphosate absorption and translocation by plant part applied to beach vitex cut-stems.[a]

Plant Part	DPM	Percent of Applied
Stump	348,408 a	87.1%
First Roots	14,572 b	4.86%
Second Roots	1,657 c	0.41%
End Roots	617 c	0.15%

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (P≤0.05).

Table 4.2 ^{14}C-glyphosate absorption and translocation by plant part and harvest time when applied to beach vitex foliage .[a,b]

Plant Part	DPM	Percent of Applied	Harvest Time (HAT)	DPM
Treated Leaf	17,828 a	5.94%	6	2,081 b
Above	4,300 b	1.43%	24	2,825 b
Below	3,557 b	1.19%	48	7,333 a
Opposite Leaf	1,300 b	0.43%	96	9,661 a
Roots	1,222 b	0.41%	192	6,432 a

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Abbreviations: HAT, hours after treatment.