ABSTRACT

WEST, AMANDA MARIE. Biology and Management of Bushkiller (*Cayratia japonica)*. (Under the direction of Robert J. Richardson).

Bushkiller [*Cayratia japonica* (Thunb.) Gagnep] is a nonnative invasive perennial vine in the Vitaceae family that was identified in North Carolina in 2005. Concern of potential economic and environmental consequences of this introduction prompted research to be conducted at North Carolina State University evaluating bushkiller biology and management. A risk assessment was prepared following the USDA-APHIS template entitled "Weed-Initiated Pest Risk Assessment Guidelines for Qualitative Assessments", v. 5.3. Phenotypic plasticity, rapid growth rate, persistence of underground rhizomes, lack of natural control agents, stress tolerance, increasing costs of control, impacts on ecosystem function and structure, and societal impacts are some of the characteristics that yielded a medium-high risk potential for bushkiller, emphasizing it should be listed at the Federal level, the state level (NC), or both. Selected herbicides were evaluated to develop bushkiller control recommendations. In greenhouse study 1 at 4 WAT, triclopyr (2.24 or 4.5 kg ae/ha), triclopyr plus 2,4-D (1.12 and 1.12 kg ae/ha), triclopyr plus 2,4-D plus aminopyralid (1.12, 1.12, and 0.12 kg ae/ha), and triclopyr plus glyphosate (1.12 and 1.12 kg ae/ha) controlled bushkiller 100%. In greenhouse study 2 at 4 WAT, 2,4-D (1.12 kg ae/ha), DPX-KJM44 (0.35 kg ae/ha), DPX-KJM44 plus 2,4-D (0.35 and 1.12 kg ae/ha), sulfometuron plus DPX-KJM44 (0.33 and 0.35 kg ae/ha), and sulfometuron plus imazapyr (0.33 and 1.68 kg ae/ha) controlled bushkiller at least 98%. In field study 1, glyphosate (4.4% v/v), triclopyr (2.2% v/v), triclopyr plus 2,4-D (2.2 and 1.75% v/v), and triclopyr plus aminopyralid (2.2 and 0.18% v/v) controlled bushkiller 88 to 93% at 1 MAT. However by 10 MAT, no control from these treatments was observed. In field study 2, bushkiller was controlled 88 to 99% at 10 MAT by DPX-KJM44 (0.5% v/v), imazapyr (2.5% v/v), sulfometuron (1.5 g/L), and sulfometuron plus metsulfuron (1.5 and 0.3 g/L). Results from the herbicide studies indicated triclopyr controlled bushkiller in the greenhouse, but not in the field, where DPX-KJM44, imazapyr, and sulfometuron plus metsulfuron showed the greatest control. Research trials were conducted to evaluate bushkiller under inter- and intraspecific competition. In the interspecific competition study, bushkiller [*Cayratia japonica* (Thunb. ex Murray)], trumpetcreeper [C*ampsis radicans* (L.) Seem.], and wild grape (*Vitis spp*.) were grown alone, two species per pot, or three species per pot. Bushkiller had the greatest final height and biomass of the three species when each was grown alone. When all three species were grown together, bushkiller grew over twice the height of trumpetcreeper, over 3 times the height of wild grape, and over 4 times the biomass of either species. When height was plotted over time, competition did not affect bushkiller or wild grape growth rate, but trumpetcreeper growth was reduced when grown with bushkiller. This indicates bushkiller will grow faster than trumpetcreeper and wild grape and may alter ecosystem structure and function with time. In the intraspecific competition study, bushkiller was grown in cultures of 1, 2, and 3 plants per pot. Final height of bushkiller was not affected by intraspecific competition; however bushkiller dry weight decreased with increasing competition. Bushkiller is likely to thrive in monoculture, however biomass per plant may be lowered as number of plants per population increases.

Biology and Management of Bushkiller (*Cayratia japonica*)

by
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DEDICATION

"Die when I may, I want it said of me that I plucked a weed and planted a flower where ever I thought a flower would grow" (*Abraham Lincoln*). This thesis is dedicated to all the "weed pluckers" of the world.

BIOGRAPHY

Amanda M. West was born near Clyde, North Carolina and grew up in a small mountain community called Fines Creek. She received her B.S. degree in Environmental Science with a Minor in Economics at the University of North Carolina Asheville. During an internship with the Student Conservation Association in Big South Fork National River and Recreation Area, Tennessee, Amanda became aware of the threats posed by exotic invasive plant species on natural ecosystems. She decided to pursue a M.S. in Weed Science and a Minor in Ecology. During her graduate career, Amanda has been active in the Aquatic Plant Management Society, the South Carolina Aquatic Plant Management Society, the Weed Science Society of North Carolina, and the Northeast Weed Science Society. She enjoys spending her free time doing volunteer work, mountain biking, camping, hiking, and reading. Amanda envisions herself working in a career that involves environmental stewardship.

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Background

Bushkiller [*Cayratia japonica* (Thunb.) Gagnep] is a perennial herbaceous liana (tree-climbing plant) in the Vitaceae family with an aggressive, twining growth habit that overtops surrounding vegetation. Bushkiller is native to temperate, subtropical, and tropical forests in Southeast Asia, Japan, India, Malaysia, Australia, and Taiwan (Figure 1) (Hsu and Kuoh 1999). Bushkiller is not native to the United States and was first reported in Texas in 1964 (Brown 1992). Since that time, bushkiller has also been documented in Louisiana, Mississippi, Alabama and North Carolina (Figure 2) (Hansen and Goertzen 2006; Koop and Dubon 2007; Krings and Richardson 2006; Shinners 1964; USDA-NRCS 2006). In August 2005 this plant was reported in a residential area in Winston Salem (Forsyth County, North Carolina) (Figure 3) and identified at North Carolina State University (Krings and Richardson 2006). Subsequently bushkiller has been confirmed to infest other areas of North Carolina including Reynolda Gardens (Forsyth County, North Carolina), Charlotte (Mecklenburg County, North Carolina), Lexington (Davidson County, North Carolina), and Youngsville (Franklin County, North Carolina), and appears invasive at each site (Craig Mauney, personal communication 2008; Krings and Richardson 2006; Soule et al. 2008). The detrimental economic and environmental consequences of a new exotic invasive perennial in North Carolina and the lack of published literature concerning bushkiller prompted research to be conducted at North Carolina State Univerisity. Therefore, the goal of the thesis research herein was to expand available information regarding biology and management of bushkiller.

Preferred habitat and climatic tolerance

Bushkiller is commonly associated with grasslands, rural fields, and bushes within its native habitat (Kakutani et al. 1989; Ohwi et al. 1984). Portions of Northeast India where bushkiller is native (Assam, Meghalaya, Sikkim, Nagaland, Manipur, Mizoram, and Tripura) are some of the wettest regions of the world, due largely to seasonal rainfall from monsoons (Anonymous 2008a; USDA-ARS 2008). Northeast India has average yearly temperatures ranging from 10 to 42 C and average yearly rainfall of 200 cm, with a maximum of 1100 cm rainfall per year (Anonymous 2008a; Kaman 2008). In Queensland, Australia, bushkiller has been recorded growing in areas where the average annual rainfall is between 60 and 80 cm (AVH 2008). In Japan, the northernmost extent of bushkiller habitat range is Hokkaido, where winter temperatures are as low as -7 degrees C (USDA-ARS 2008). The locations of these reports represent an extreme diversity of ecosystems, suggesting bushkiller is a generalist species that may have an adaptive phenotypic plasticity in response to variable climate.

Taxonomy and Biology

Bushkiller is in the order Rhamnales, family Vitaceae, genus Cayratia (Juss.), and the species name is most commonly cited as [*Cayratia japonica* (Thunb.) Gagnep.] (Figure 4)

(USDA-ARS 2008; USDA-NRCS 2006). Synonyms to *Cayratia japonica* include [*Cissus japonica* (Willd.)], [*Cissus obovata* (Lawson)], [*Columella japonica* (Thunb.) Merr.] and [*Vitis japonica* (Thunb.)]. Commonly called bushkiller in the United States, in the native range some common names of this species include sorrel vine, java, javan grape, yabugarashi, and yabu- karashi. (USDA-ARS 2008; USDA-NRCS 2006).

Bushkiller stems are much elongate, branched, and striate (Ohwi et al. 1984). Young parts of the stem are furfuraceous, short-puberulent and flat with a purplish tint (Ohwi et al. 1984). Tendrils are bifurcating, not disc-tipped, and develop opposite the leaves (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Tendril growth indicates a tendency for the plant to reach out to climb nearby vertical structures, with a unique feature typical of Vitaceae in that tendril formation is discontinuous (Mullins et al. 1992).

Bushkiller leaves are petiolate, pedate quinquefoliate with leaflets ovate, marginally serrate, mucronate at the tip, acute at the base, 1.5 to 4 cm broad and 3 to 8 cm long, with pubescent midribs on both sides and 1 to 3 cm long petioles. The terminal leaflet is ovate to broadly-lanceolate and longer than the 4 lateral leaflets (Hsu and Kuoh 1998). Trifoliate leaves and leaves with 7 leaflets have also been observed on stems with 5-foliate leaflets, with the terminal leaflet remaining broader and longer than the other leaflets (Figure 5) (A. West, personal observation).

The inflorescence of bushkiller is axillary, corymbose or umbellate with short granular hairs (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Flowers are bisexual, short-pedicellate, 5 mm, with 4 green deflexed, deltoid-ovate petals and 4 stamens opposite the petals, disc is red, salmon-colored, yellow to white depending on stage, anthers are ellipsoid, style is conical and short, and stigma is minute (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). For bushkiller in Japan, the flowering season is 5 months, from the middle of June to the middle of October (Kakutani et al. 1989). In North Carolina, bushkiller has been observed flowering from May through September (A. West, personal observation). Kakutani et al. (1989) found an average of 117 buds per inflorescence, with plants flowering continuously for 1 to 2 months (2 to 5 blooms daily). Changes in flower morphology over time have been described by Kakutani et al. (1989) and Soule et al. (2008). Kakutani et al. (1989) observed flowers with 4 green petals (2 to 3 mm), a red flower disc (2 to 3 mm), four stamen (2 to 3 mm) producing pollen grains, and a yellow small style (1 mm) at 2 hours after opening (HAO). At 2 HAO, the petals and stamens fell and the disc gradually became pink (salmon-colored) to orange (Kakutani et al. 1989). At 6 to 8 HAO, the style extended to 2 mm and at 12 HAO, the style became white (Kakutani et al. 1989). After 12 HAO, there were no further morphological changes and the flowers remained 3 to 5 days (Kakutani et al. 1989).

Bushkiller fruit is globose and deep purple to black at ripening (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Each fruit contains 2 to 4 seeds with broad, transverse raised ridges on each side and a narrow impressed longitudinal band (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984).

Roots of bushkiller are creeping at the juvenile stage (A. West, personal observation) and develop much-elongate rhizomes over time with extended root hairs (Ohwi et al. 1984). Due to the clonal growth habit of bushkiller, it is difficult to determine the spatial distribution and numbers of individual plants (Kakutani et al. 1989).

Ecology

The growth habit of bushkiller resembles that of kudzu [*Pueraria lobata* (Willd)]. At locations in North Carolina where bushkiller has been observed, it has been observed to overtop trees and grow in monoculture as ground cover (A.West, personal observation). Bushkiller is a perennial plant that reproduces from both root fragments and seed in its native range (Kakutani et al. 1989; Ohwi et al. 1984; Okada et al. 2003). Thus far in the United States, bushkiller has only been reported to reproduce via asexual reproduction, through suckers from adventitious roots (Alford 2003; Brown 1992; Shinners 1964; Soule et al. 2008). It is assumed that bushkiller populations are triploids in the United States, as plants have not yet been observed to produce mature fruit (Alford 2003; Brown 1992). However, if diploid individuals are found the potential for bushkiller spread becomes much greater. In Japan, diploid and triploid individuals have been found within the same population (Okada 2003). Both ploidy levels produced fruit, however, only diploid individuals produced viable seed. Research findings suggest that bushkiller may exist in a self-pollinating state and low pollen fertility may explain why some diploid individuals produce fruits and others do not (Kakutani et al. 1989; Okada et al. 2003).

Inflorescences have been observed at all locations in North Carolina with pollinators such as wasps, bees, ants, and butterflies visiting the mature flowers (A. West, personal observation). These observations are consistant with some of the insects that pollinate bushkiller in its native range (Figure 6; Kakutani et al. 1989).

Typically the flowers abort post-dehiscence, therefore, no fruits are produced (Alford 2003; Brown 1992; GBIPG 2007). However, in 2007, fruit was observed on about 2% of the population at the Charlotte site (Figure 7); these remained green but abscissed before ripening to maturity (Soule et al*.* 2008). Fruits were collected during this time and the seeds were extracted from 3 fruits. Eight seeds were planted in pots with growing medium (Metro Mix® 200; Sun Gro Horticulture, Bellevue, WA) and placed in a greenhouse at North Carolina State University. The remaining 10 fruits were placed in a Petri dish (7.6 cm) on a moist paper towel (Figure 8). No germination was observed from either treatment under normal growing conditions for four months after planting (data not presented).

Other Uses

Cayratia japonica is used as a medicinal plant in traditional medicine in Southeast Asia. The stem bark is used as an antidote, boiled leaves are applied to the head for violent headaches, dried and powdered flowers are used for fever, and aerial parts are applied for fever and malaria (IMPGC 2008). Studies that screen extracts and isolate constituents of traditional medicinal plants in Malaysia and Thailand against human cancer cell lines have included *Cayratia japonica* (Lee and Houghton 2005). Another study examined the monoamine oxidase inhibitory components from *Cayratia japonica*, one of the classes of drugs prescribed for the treatment of depression (Han et al. 2007). A newsletter article entitled "Herbs used in Chinese Fish Farms" published by the AAHRI (Aquatic Animal Health Research Institute 1994) suggests adding 7 kg crushed bushkiller to a 600 m^3 pond to prevent and treat bacterial and fungal diseases.

Justification

Invasive species are estimated to cost the United States economy $120 billion per year (Pimentel et al. 2005). Kudzu alone costs an estimated $100 to 500 million per year just in forest productivity losses (Forseth and Innis 2004). Of the 25,000 non-indigenous plant species in the United States, an estimated 5,000 have escaped into natural ecosystems (Pimentel et al. 2005). About 42% of the species listed as threatened or endangered under the Endangered Species Act in the United States have seen their populations dwindle primarily due to the invasion of non-indigenous species (Pimentel et al. 2005).

Perhaps most sensitive to an invasive Vitaceae would be native members of this family and other organisms that rely on native Vitaceae for food or habitat. Peppervine [*Ampelopsis spp.* (L.)], Virginia creeper [*Parthenocissus quinquefolia* (L.) Planch], and grapes [*Vitis spp.* (L.)] are all Vitaceae native to North America. Peppervine species are a source of food for white-tailed deer [*Odocoilues virginianus* (Zimmermann)] and other wildlife species such as raccoons [*Procyon lotor* (Linnaeus)] (Stine 2006). Many birds including Northern cardinals [*Cardinalis cardinalis* (Linnaeus)], Eastern bluebirds [*Sialia sialis* (Linnaeus)], and wild turkeys [*Meleagris gallopavo* (Linnaeus)] as well as mammals such as Eastern chipmunks [*Tamias striatus* (Linnaeus)], Eastern gray squirrels [*Sciurus carolinensis* (Linnaeus)] and white-tailed deer feed on the berries and foliage of Virginia creeper, and humans and animals alike consume grapes (Stine 2006). Thus, loss of native Vitaceae due to direct competition or the spread of an alternate host for damaging pests would have serious ecological consequences. For these reasons, serious economic and environmental damage could occur if bushkiller is not eradicated from the United States.

By displacing other native species such as wild grape, bushkiller could potentially alter ecosystem processes and reduce biodiversity. Community structure may change dramatically as this plant creates a new canopy; this has been noted at the Charlotte, NC site where bushkiller is forming a monoculture similar to kudzu (A. West, personal observation). The Charlotte, Winston Salem, and Lexington sites in NC are within or bordering residential areas, causing concern for homeowners whose trees, shrubbery, gardens and other landscaping attributes are being affected by bushkiller (personal communications with homeowners). In Winston Salem, there is approximately 1.6 ha of bushkiller at Reynolda Gardens, and the head horticulturist there has recorded the plant overtopping and killing hemlocks [*Tsuga spp.* (L.)] and bald cypress [*Taxodium distichum* (L.) Rich.] planted for bank stabilization, as well as establishing itself in a monoculture 1.2 m tall along the streambank (Craig Mauney, personal communication). He also noted that the severe drought experienced across North Carolina in 2007 did not deter the growth of bushkiller and that at 1 month after treatment (MAT) with glyphosate, bushkiller had approximately 1 m shoot regeneration (Craig Mauney, personal communication).

Due to an extensive root system and clonal growth habit, bushkiller would be extremely difficult to control in no-till agricultural production and as a contaminant in the nursery trade. Redvine [*Brunnichia ovata* (Walter) Shinners] and trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau], two other perennial vines are among the 10 most troublesome weeds in cotton (*Gossypium hirsutum* L.), soybean (*Glycine* Willd.), and corn (*Zea mays* L.) in the southern United States (Reddy 2005). These vines reduce crop yield and quality as well as harvest efficiency. In a study by Reddy (2005) one trumpetcreeper plant per 0.5 m^2 caused 18% yield loss in soybeans. Bushkiller may similarly impact crops should it move into these systems. Additionally, bushkiller may also serve as a host to chilli thrips [*Scirtothrips dorsalis* (Hood)], a polyphagous exotic pest that has been identified as a threat to over 20 crops in Florida (Hodges et al. 2005).

It is unknown how bushkiller was introduced into the United States, however it appears that the plant was introduced to Winston Salem as an ornamental (Ken Foster, personal communication 2006). In the 5 states where bushkiller has been found (TX, LA, MS, AL and NC), it only occurs in a limited set of counties, and even then, these point occurrence could be easily eradicated (Figure 6) (Koop and Dubon 2007). There is strong interest in official control, particularly in North Carolina where the status of bushkiller is being reviewed by the North Carolina Department of Agriculture and Consumer Services, Plant Industry

Division in an attempt to have the plant added as a class B noxious weed to the North Carolina state noxious weeds list (Rick Iverson, personal communication). In Charlotte, North Carolina, the city is planning and willing to fund a complete eradication of bushkiller (Jim Matthews, personal communication). Private home and land owners in all counties of North Carolina with bushkiller infestations have expressed desire to eradicate this plant from their properties (multiple personal communications).

Published information on bushkiller is limited to geographic distribution (Alford 2003; Brown 1992; Shinners 1964), with almost no information available on biology or management. Therefore, research is needed to further understand the biology and ecology of bushkiller and to develop management, preventative, and eradication strategies. Due to the lack of information concerning bushkiller biology, a review of Vitaceae family biology follows. After an extensive literature review, the final sections of this chapter give a brief overview of the biology and management of other perennial vine species.

Vitaceae (grape family) background and taxonomy

Vitaceae are dicots, mostly woody or herbaceous lianas or shrubs characterized by the appearance of tendrils and inflorescences opposite to the leaves and stamens opposite the petals (Gerrath and Posluszny 2007; Mullins et al. 1992; Wilson et al. 2005). Important characteristics of the Vitaceae family include vigor, floriferousness, regenerative capacity, stress tolerance and longevity (Mullins et al. 1992). Many Vitaceae spp. are of major economic importance, therefore most of the research concerning this family has a horticulture perspective (Wilson et al. 2005). However, the family is also of vast ecological importance.

The Vitaceae family comprises 10 genera: [*Vitis* (Tournef) L.], [*Ampelocissus* (Planch.)], [*Pterisanthes* (BLUME.)], [*Clematicissus* (Planch.)], [*Tetrastigma* (Miq.) Planch.], [*Landukia* (Planch.)], [*Parthenocissus* (Planch.)], [*Ampelopsis* (MICH.)], [*Rhoicissus* (Planch.)], and [*Cissus* (L.)] (Mullins et al. 1992). The genera *Vitis* and *Cissus* are further divided into sections. For *Vitis,* section 1 is [*Euvitis* (Planch)], and section 2 is [*Muscadinia* (Planch)]. For *Cissus*, section 1 is [*Eucissus* (Planch.)], section 2 is [*Cayratia* (JUSS.)], and section 3 is [*Cissus* (Planch.)] (Mullins et al. 1992). Bushkiller is a species in the *Cayratia* section of the *Cissus* genus. *Cissus* contains 350+ species and is a heterogenous genus with both herbaceous and woody plants bearing tetramerous (parts in fours) flowers (Mullins et al. 1992). The genus *Cayratia* includes 63 species distributed thoughout Africa, Asia, Australia, and the Pacific Islands (USDA-ARS 2008). *Cayratia* are found mostly in Asia and are very heterogeneous in morphology and karyotype (Mullins et al. 1992).

North American grape species are divided into two taxa: *Vitis* and *Muscadinia* (Anonymous 2008b). All species within *Vitis* are interfertile, they freely hybridize where sympatric, and their bloom dates overlap, resulting in the occurrence of natural hybrids and hybrid zones (Anonymous 2008b). This makes the *Vitis* genus difficult to distinguish taxonomically, therefore most wild grapes are referred to as *Vitis* (L.) *spp.* Wild grapes are distributed throughout the United States (USDA-NRCS 2006) (Figure 9).

Vitaceae that are common in the Southeastern United States include peppervine (*Ampelopsis arborea* L.), marine ivy (*Cissus trifoliata* L.), Virginia creeper (*Parthenocissus quinquefolia* L. Planch), muscadine (*Vitis rotundifolia* Michaux), downy or sweet winter grape (*Vitis cinerea* Englem. Ex Millardet), fox grape (*Vitis labrusca* L.), pigeon or summer grape (*Vitis aestivalis* Michaux), frost or chicken grape (*Vitis vulpine* L.), riverside grape (*Vitis riparia* Michaux), and sand or sugar grape (*Vitis rupestris* Scheele) (Foote and Jones 1989).

Shoot development in *Vitis* (L.) *spp.*

The first-formed leaves are axillary buds which contain 2 basal scales (prophylls) and a series of primordial leaves with no tendrils present (Mullins et al. 1992). The juvenile stage is short and the switch into adult morphology is abrupt, happening once 6 to 10 leaves have been produced from the apical meristem (Mullins et al. 1992). The apical meristem compromises an outer tunica of 2 cell layers covering an inconspicuous corpus (Mullins et al. 1992). The tip of the shoot is typically triangular and is composed of the apical meristem, leaf and tendril primordial, and young, unexpanded leaves and tendrils (Mullins et al. 1992). There are no terminal buds, regrowth occurs from the uppermost lateral bud on the most lignified (ripened) portion of the stem (Gerrath 1993; Mullins et al. 1992). Tendrils developing opposite the leaves indicate a tendency for the lianas to reach out to climb nearby vertical structures, but not necessarily a stage of sexual maturity (Mullins et al. 1992). A unique feature of any *Vitis* lianas is that tendril formation is discontinuous (Mullins et al. 1992; Wilson et al. 2005). Often, every third node on the stem will be missing a tendril, and in successive cycles the ‘missing’ tendril will occur on opposite sides of the stem (Gerrath 1993; Gerrath and Posluszny 2007; Mullins et al. 1992; Wilson et al. 2005).

The shoot apical meristem in members of Vitaceae is unique in that it produces committed leaf primordial and uncommitted primordial, developing via fixed (elongation of the internodes and leaves formed in dormant buds) and free growth (elongation through continuous production of leaf primordia at the apical meristem) (Gerrath 1993; Mullins et al. 1992). There is a distinct 3-node modular construction of *Vitis* shoots, and this is apparent in species in which tendrils form at 2 of every 3 nodes, but less apparent in species that have tendrils at every node (Gerrath and Posluszny 2007). Internodes are elliptical with a photosynthetic epidermis bearing stomata and epicuticular wax (Mullins et al. 1992). Small globular excrescences known as ‘sap balls’ or ‘pearls’ appear on the stem, petioles, leaves, and tendrils under conditions of high temperature and humidity, though their function is not understood (Mullins et al. 1992). The presence of a hard, lignified pith (diaphragm) at each node results in a discontinuous pith that is distinguishable among Vitaceae (Mullins et al. 1992). Shoots grow rapidly, most Vitaceae species increase in length 3 to 4 cm/day and produce a new leaf or tendril primordium every 2 to 3 days (Mullins et al. 1992).

Leaf structure of *Vitis* (L.) *spp.*

Vitis leaves consist of a lamina, petiole, and a pair of stipules (Mullins et al. 1992). The predominant leaf form is palmately veined, and the art and science of *ampelography* uses measurements of vein length and angles between the 5 main veins and the connecting veins to distinguish cultivars (Galet 1979; Mullins et al. 1992). Leaf margins are toothed and each tooth has a hydathode at the tip, which is a water-excreting gland (Mullins et al. 1992). The upper epidermis of the leaf is basically devoid of stomata but has ‘soft’ epicuticular wax and palisade tissue that compromises up to 50% of the leaf’s thickness (Mullins et al. 1992; Radler and Horn 1965). The lower epidermis lacks a cuticle but is pubescent (Mullins et al. 1992). There are two abscission zones on a *Vitis* leaf, one where the petiole and lamina meet and another where the petiole attaches to the stem and senescence is activated through signals from the lamina (Mullins et al. 1992).

Inflorescences, flowers, and fruits of *Vitis* (L.) *spp.*

Vitaceae lianas have inflorescences homologous to tendrils, forming in the position of tendrils when present (Gerrath and Posluszny 2007; Mullins et al. 1992; Srinivasan and Mullins 1979). Flowering in a mature *Vitis* is typically in three phases: (1) anlagen (uncommitted primordial) is formed by the apices of latent buds on shoots of the current growing season; (2) this primordium matures into either an inflorescence, a tendril, or an intermediate structure; and (3) when an inflorescence is formed, flowering occurs at the time of bud burst in the next season (Gerrath and Posluszny 2007; Mullins et al. 1992; Srinivasan and Mullins 1979). *Vitis* growing in temperate regions may produce inflorescences and flowers in the same season (Mullins et al. 1992). Flowers are bisexual, formed in panicles, staminate, 5-merous, calyx-lobes obscure, petals connate at apex, disc with 5 nectary glands, ovary 2-locular with 2 ovules in each locule, style pyramidal, deciduous as a whole at antithesis (Ohwi 1984). Shortly after antithesis the ovaries expand and fruit formation begins (Gerrath 1993). Fruits are berries with 2 to 4 seeds, pyriform, rostrate at base, and 2-grooved on the ventral side (Ohwi 1984).

The Root System of *Vitis* (L.) *spp.*

Tolerance to anoxia (absence of oxygen), capacity to penetrate the soil profile 3 m or more, ability to regenerate new roots, organic nutrient storage, and presence of mycorrhizal associations make the roots of *Vitis* resilient to varying environmental conditions (Mullins et al. 1992; Nassar and Kliewer 1966; Possingham and Groot-Obbinck 1971). Propagation by root cuttings results in a more highly divided root system than plants grown from seed (Richards 1983). The main framework of roots (6 to 100 mm diameter) are usually found 30 to 35 cm deep in the soil profile and their numbers have been observed to remain constant after the 3rd year from planting (Mullins et al. 1992). Smaller roots (2 to 6 mm diameter) grow out from this framework horizontally as ‘spreaders’ or downward as ‘sinkers’, constantly branching to produce fibrous (absorbing) ephemeral roots (Mullins et al. 1992). Ephemeral roots make up the largest portion of the total root mass and are continually being replaced by lateral roots (Mullins et al. 1992).

Virginia creeper [*Parthenocissus quinquefolia* (L.) Planch] biology

A perennial vine in the Vitaceae family, Virgina creeper is a native to the Eastern United States (USDA-NRCS 2006) (Figure 9). Unlike other Vitaceae spp., the branched tendrils of Virginia creeper are usually terminated by large adhesive discs (Lutz 1943). Thus, Virginia creeper does not cause water and nutrient restrictions to host plants that are typical of many lianas (Lutz 1943). As the common name suggests, Virginia creeper is often observed as ground cover with a creeping growth habit.

Virginia creeper is the plant most likely confused with bushkiller in the Eastern United States because it also has petiolate leaves divided into 5 coarsely toothed leaflets, occasionally bearing 3 or 7 leaflets. Virginia creeper may easily be distinguished from bushkiller, however, as its leaves are palmately quinquefoliate, but never pedate quinquefoliate. The leaflets are typically all the same size rather than the terminal leaflet being larger, and the tendrils are disc-tipped rather than bifurcating. For Virginia creeper, all leaflets are the same shape and size. Bushkiller, however, has a terminal leaflet broader and longer than the other leaflets (Ohwi 1984). Additionally, Virginia creeper leaves turn scarlet in autumn whereas bushkiller leaves do not. Inflorescences of Virginia creeper are panicles, flowers are composed of 5 cucullate petals alternate to 5 sepals and opposite to the stamens, a basal disc, ovary, short style, short stigma stamens and the gynoecium is bright yellow with nectar at the reduced basal disc (Wilson and Posluszny 2003). Flowers are a greenish color with a mixture of red over their petals and calyx cup (Wilson and

Posluszny 2003). By the end of the growing season, flowers may form a blue–black berry that contains 1 to 4 seeds.

Virginia creeper helps to protect forest soils and watersheds, alleviates erosion, and is an excellent food source and ground cover for native fauna in the Southeast (Francis 2008). Birds including cardinals, bluebirds, and turkeys as well as mammals such as chipmunks, squirrels and white-tailed deer feed on the berries and foliage of Virginia creeper (Stine 2006).

Porcelainberry [*Ampelopsis brevipedunculata* (Maxium.) Trauvt] biology and managment

Like bushkiller, porcelainberry is a deciduous perennial vine in the Vitaceae family whose tendrils allow it to twine around other plants, climbing up to 20 ft in height. The literature concerning porcelain-berry is even sparser than that concerning bushkiller, however, it is frequently cited as a vigorous invader of open to forested habitats in twelve states across the Northeastern United States where it has escaped cultivation (Foote and Jones 1989; USDA-NRCS 2006; Young 2006) (Figure 9). It grows very well in moist soils at elevations of 152 to 609 m. It may be identified by alternate, palmate, broadly ovate leaves with a heart-shaped base and 3 to 5 coarsely-toothed lobes (Young 2006). The bark of porcelainberry does not peel like most common *Vitis* (Young 2006).

Young (2006) recommends pulling porcelainberry vines in the fall or spring prior to flowering to prevent seed formation and for vines too large to pull, a cut-stem treatment with a systemic herbicide. The most effective control cited is a triclopyr amine applied as a foliar or cut-stem treatment (both at 2.5% solution) or triclopyr ester applied as a basal bark application (20 to 30% solution in oil) (Young 2006).

Kudzu [*Pueraria Montana* (Lour.) Merr. variety *lobata* (Willd.)] background

Native to Asia, kudzu is now listed as a noxious weed in ten states across the southeast (USDA-NRCS 2006) (Figure 9). Kudzu is a leguminous vine with stems that can reach lengths of 10 to 30 m and semi-woody tuberous roots that can reach depths of 5 m (Miller 2003). It is often seen along roadsides smothering trees and obstructing road signs, posing a danger to travelers. The environmental and economic implications of kudzu are far from diminutive and include displacement of native vegetation leading to diminished food resources for native wildlife, increased control costs on rights-of-way and natural areas, and diminished aesthetic value of land infested. Approximately 810,000 ha of mesic forest communities are dominated by kudzu in the United States (Harrington et al. 2003).

In 1876, kudzu was displayed at the Centennial Exposition in Philadelphia, PA and quickly became employed by the Soil Erosion Service and Civilian Conservation Corp to mitigate soil erosion (Forseth and Innis 2004). More than 85 million kudzu seedlings were planted in the Southeast during the first half of the 20th century for erosion control (Forseth and Innis 2004). By 1953 the threat to native trees and shrubs was becoming realized and kudzu was removed from the list of approved plants for erosion control (Forseth and Innis 2004). In 1997 it was finally placed on the Federal Noxious Weed List (Forseth and Innis 2004).

Current estimates state that kudzu covers 3 million hectares in the Eastern United States and is increasing by 50,000 ha per year (Forseth and Innis 2004).

Kudzu Biology and Management

Kudzu is a perennial leguminous vine in the Fabaceae family with trifoliate leaves whose roots may compromise over 50% of the plant's biomass (Forseth and Innis 2004). The leaves have membranous margins with golden-colored hairs and are pointed at the tip (Miller 2003). Kudzu has showy purple flowers with yellow centers from June through September that arise from raised nodes on the stalk (Miller 2003). The fruits are flattened pods 3 to 8 cm long and 8 to 12 mm wide, green when first-formed and ripening to a tan color with stiff hairs (Miller 2003). Kudzu thrives in both high-light and shaded environments but will usually grow best at the forest edges. High allocation to extension growth, frequent rooting of stems at the nodes, high photosynthetic rate, high leaf area indices (m^2 leaf area per m^2 ground area), large hydraulic capacitance in roots and rhizomes, and ability to fix atmospheric N_2 make kudzu an aggressive competitor and a difficult weed to manage or eradicate (Bergmann and Swearingen 2005; Forseth and Innis 2004; Harrington et al. 2003). A structural parasite, kudzu will climb other plants at a rate of 3 cm to 19 cm per day and develop multiple canopy layers whose leaf area indices are comparable to entire deciduous forest canopies (Forseth and Innis 2004).

The extensive root system of kudzu is the greatest limiting factor to control. Leaving a single root crown may result in new infestations within a single growing season (Bergmann and Swearingen 2005). Thus, mowing is time-consuming and may not achieve eradication. Control of well established kudzu stands may take up to 10 years of repeated mowing and herbicide application (Mitich 2000). Concerns of non-target vegetation injury and herbicide persistence are raised as difficulties to successful control. Kudzu has historically required more than one treatment during the growing season (Bergmann and Swearingen 2005; Berisford et al. 2006; Forseth and Innis 2004). Harrington et al. (2003) found burning of kudzu typically stimulated resprouting, but burning employed after an initial herbicide treatment plus two years successive retreatment with clopyralid, triclopyr, metsulfuron, picloram, or tebuthiuron provided good control. Despite good control, at the termination of the study 4 years after treatment (YAT) there was 15% kudzu cover in plots treated with clopyralid and 1 to 2% cover in triclopyr, metsulfuron, picloram, and tebuthiuron plots, suggesting eventual recovery of kudzu in these plots (Harrington et al. 2003). Kay and Yelverton (1998) suggested herbicide applications made to kudzu during the dormant-season to alleviate concerns of non-target vegetation and brown-out associated with in-season treatments. In March 1997, prior to leafout or new stem growth, treatments of dicamba, 2,4-D plus triclopyr ester, triclopyr ester, clopyralid, dicamba, and tank mixes of clopyralid with either dicamba or triclopyr ester applied at 18.7 L/ha (except clopyralid applied at 1.6 L/ha) were sprayed over kudzu stems at a field site in Wake and Franklin Counties, NC (Kay and Yelverton 1998). Ratings made 28 weeks after treatment (WAT) showed all treatments provided over 90% control (Kay and Yelverton 1998). Hipkins (1998) tested two-year successional treatments of the diglycolamine salt of dicamba applied at 1.68 and 2.24 kg/ha, triclopyr ester at 1.68 and 2.24 kg/ha, metsulfuron methyl at 0.168 and 0.252 kg/ha and tank mixes of the dicamba and metsulfuron methyl at 1.68 and 0.084 kg/ha and 1.12 and 0.168 kg/ha, respectively in April 1996 and again in March 1997 to a kudzu field site in Washington County, VA. An evaluation 14 WAT in 1997 showed dicamba at 2.24 kg/ha as the superior treatment with 90% control (Hipkins 1998). Further research is needed on dormant season treatment methods.

Kudzu biocontrol has recently gained interest, but may be difficult. Kudzu is a member of Fabaceae, and closely related to soybean (Forseth and Innis 2004). Preliminary studies showed kudzu produces volatiles in response to herbivory that increase the rate of predation by generalist predators, primarily *Polistes* spp. (Hymenoptera: Vespidae) (Kidd 2002). Britton et al. (2003) surveyed 25 species of insects feeding on kudzu, 7 of which also fed on other leguminous crops making them inappropriate choices as biocontrols, but several leaf-feeding beetles and sawflies with no other known hosts were identified. Kidd (2002) found *Pseudoplusia includens* (Walker), the soybean looper, could be used as a model herbivore for future studies in kudzu biocontrol, and Forseth and Innis (2004) referred to the fungal pathogen *Myrothecium verrucaria* as holding promise for future kudzu control (Forseth and Innis 2004).

Economic losses from lost forest productivity due to kudzu have been estimated to be

$100 to 500 million per year (Forseth and Innis 2004). Britton et al. (2003) cited Dr. Coleman Dangerfield, a forest economist at the University of Georgia, as stating it costs $500 per ha per year for 5 years to successfully control kudzu on productive forest land, a value that exceeds the profit that may be made from the average 25-year-old stand of pine at that acreage. Power companies in the United States are estimated to spend $1.5 million dollars per year for kudzu control (Britton et al. 2003). While there is significant literature concerning the economics of kudzu control, documentation of the effects of this invasive on native plant communities are few and far between. Clearly, further research is necessary to determine how kudzu affects both the structure and function of ecosystems, particularly in the Eastern United States where it is not uncommon to see acres of kudzu monoculture along forest edges and highway systems.

Japanese honeysuckle [*Lonicara japonica* (Thunberg)] biology and management

Japanese honeysuckle is a vine in the Caprifoliaceae family, and it is now considered an invasive species on every continent except Antarctica. The distribution of Japanese honeysuckle is limited only by drought, heavy frost, and temperatures unsuitable for seed stratification (Schierenbeck 2004). It thrives in most of the United States, outside the Northwest region (USDA-NRCS 2006) (Figure 9). Native to Japan and Korea, this perennial climbing vine may exist in a semi-evergreen to evergreen state, depending on the climate (Bravo 2006).

The twisting growth habit of Japanese honeysuckle as it grows vertically on trees and shrubs may induce girdling and directly kill them (Bravo 2006). This plant may also grow horizontally, and this trait combined with the phenotypic plasticity of leaves from full sun to shaded environments allows Japanese honeysuckle to maintain a higher specific leaf area than surrounding plants (Schierenbeck 2004). It may be identified by pubescent, ovate to oblong leaves occurring opposite or three per stem node (Schierenbeck 2004). Flowers are fragrant with a two-lipped corolla that is white, pink or yellow (Schierenbeck 2004). Fruits are sessile, oval-shaped, 6 to 7 mm in diameter and purple to black at maturity with 1 to 15 brown-black seeds (2 to 3 mm in length) (Schierenbeck 2004). Although it may outcompete native plants for water, impede orchard or other farming operations, and provide rodent habitat, Japanese honeysuckle provides benefits to numerous desirable wildlife species such as white-tailed deer, wild turkeys, migratory birds and others (Schierenbeck 2004). Predation of Japanese honeysuckle fruits by these species provide a mode of dispersal, ensuring the plant will spread across forested areas. If control is desired, it must be noted that hand-pulling, mowing, and fire may only induce further sprouting (Schierenbeck 2004). A combination of 10 g metsulfuron-methyl, 200 ml glyphosate, and 100 mL surfactant per 100 L H_20 has been shown to provide control of Japanese honeysuckle (Williams et al. 2001).

Trumpetcreeper [*Campsis radicans* (L.) Seem.] biology and management

Trumpetcreeper is a perennial climbing or trailing vine in the Bignoniaceae family that ascends via aerial rootlets instead of tendrils and may reach 12 m in length (Bradley et al. 2004; Foote and Jones 1989). It is common in forests across the United States (USDA-NRCS 2006) (Figure 9). Leaves are opposite and pinnately compound with 7 or more leaflets (Foote and Jones 1989). This native deciduous vine is often planted in landscaping around fences due in part to showy trumpet-shaped orange or red flowers whose nectar is an important food source for ruby throated hummingbirds [*Archilochus colubris* (Linnaeus)], honeybees [*Apis mellifera* (Linnaeus)], and bumblebees [*Bombus spp.* (Latreille)] from June to September (Bertin 1982; Elias and Gelband 1975). Fruits are capsules 10 to 20 cm long that often hang on the vine through the winter (Bertin 1982; Elias and Gelband 1975).

Unfortunately, trumpetcreeper is among the 10 most troublesome weeds in cotton, soybean, and corn in the midsouthern United States (Reddy 2005). Trumpetcreeper reduces crop yield and quality as well as harvest efficiency. Even at low densities trumpetcreeper can interfere with soybean; one trumpetcreeper plant per 0.5 m^2 can cause 18% loss in yield (Reddy 2005). Bradley et al. (2004) found that when compared to an untreated control in a conventional herbicide system in soybean (paraquat PRE followed by lactofen POST, or acifluorfen, fomesafen, imazamox, or cloransulam POST) trumpetcreeper stem densities were not reduced 1 YAT. One of the major reasons for limited control is a deep root system. Edwards and Oliver (2004) found burying trumpetcreeper root stock at depths up to 23 cm did not have a significant effect on biomass production. In the same study, root stock cut as small as 2 cm in length produced shoots 8 weeks after planting (WAP) (Edwards and Oliver 2004).

Literature Cited

Alford, M.H. 2003. Noteworthy collections: Mississippi. Castanea 68: 93.

Anonymous. 2008a. North East India: India Tourism Network. http://www.north-east-india.com/. Accessed August 29, 2008.

Anonymous. 2008b. Grape Crop Germplasm Committee Genetic Vulnerability Statement 2004. USDA-GRIN. http://www.ars-grin.gov/npgs/cgc_reports/grape2004vulnerability.html. Accessed September 8, 2008.

Aquatic Animal Health Research Institute (AAHRI) 1994. Herbs used in Chinese fish farms. (Newsletter article) Kasetsart University Dept. of Fisheries, Bangkok, Thailand. Vol. 3, No. 2, Dec. 1994)

Bartlett, T. 2005. BugGuide: Identification, Images, & Information for Insects, Spiders & their Kin for the United States & Canada. Iowa State University Entomology. http://bugguide.net/node/view/15740. Accessed September 8, 2008.

Bergmann, C. and Swearingen, J. M. 2003. Kudzu (*Pueraria Montana var lobata*). Plant Conservation Alliance Alien Plant Working Group. http://www.nps.gov/plants/alien/fact/pulo1.htm. Accessed July 23, 2008.

Berisford, Y. C., P. B. Bush, and J. W. Taylor, Jr. 2006. Leaching and persistence of herbicides for kudzu (*Pueraria montana*) control on pine regeneration sites. Weed Sci. 54: 391-400.

Bertin, R. I. 1982. Floral biology, hummingbird pollination and fruit production of trumpet Creeper (Campsis radicans, Bignoniaceae). Am. J. of Bot. 69: 122-124.

Bradley,K. W., E. S. Hagood, Jr., and P. H. Davis. 2004. Trumpetcreeper (*Campsis radicans*) control in double-crop glyphosate-resistant soybean with glyphosate and conventional herbicide systems. Weed Tech. 18: 298-303.

Bravo, M. A. 2006. Japanese honeysuckle (*Lonicera japonica*). Plant Conservation Alliance Alien Plant Working Group. http://www.nps.gov/plants/alien/fact/loja1.htm. Accessed July 23, 2008.

Britton, K. O., D. Orr, and J. Sun. 2003. Invasive plants of the Eastern United States. Kudzu. Available at http://www.invasive.org/eastern/biocontrol/25Kudzu.html. Accessed July 23, 2008.

Brown, L.E. 1992. *Cayratia japonica* (Vitaceae) and *Paederia foetida* (Rubiaceae) adventive in Texas. Phytologia 72: 45-47.

AVH. 2008. Australia's Virtual Herbarium (AVH) public access map: *Cayratia japonica.* Royal Botanic Gardens Melbourne. http://www.rbg.vic.gov.au/. Accessed September 3, 2008.

Edwards, J. T. and L. R. Oliver. 2004. Emergence and growth of trumpetcreeper (Campsis radicans) as affected by rootstock size and planting depth. Weed Tech. 18: 816-819.

Elias, T. S. and H. Gelband. 1975. Nectar: its production and functions in trumpetcreeper. Science 189: no. 4199, pp. 289-291.

Foote, L. E. and Jones, S. B. Jr. 1989. Native Shrubs and Woody Vines of the Southeast; Landscaping Uses and Identification. Timber Press, Inc. Portland, OR.

Forseth, I. N. and A. F. Innis. 2004. Kudzu (*Pueraria montana*): history, physiology, and ecology combine to make a major ecosystem threat. Critical Reviews in Plant Sci. 23: 401-413.

Francis, J. K. 2008. *Parthenocissus quinquefolia* (L.) Planch. Virginia creeper. USDA-Forest Service. http://www.fs.fed.us/global/iitf/pdf/shrubs/Parthenocissus%20quinquefolia.pdf. Accessed September 9, 2008.

Galet, P. 1979. A practical ampelography; grapevine identification. Comstock Pub. Cornell Univ. Press, Ithaca.

GBIPG. 2007. The quiet invasion: a guide to the invasive plants of the Galveston bay area. Houston Advanced Research Center and Galveston Bay Estuary Program. http://www.galvbayinvasives.org/. Accessed March 5, 2008.

Gerrath, J. M. 1993. Developmental morphology and anatomy of grape flowers. Hortic. Rev. Vol. 13: 315- 333.

Gerrath, J. M. and Posluszny. 2007. Shoot architecture in the Vitaceae. Can. J. Bot. 85: 691-700.

Han, H. A., S. S. Hong, J. S. Hwang, M. K. Lee, B. Y. Hwang, and J. S. Ro. 2007. Monoamine oxidase inhibitory components from *Cayratia japonica*. Arch Pharm Res. 2007 Jan30 (1):13-7 17328236 (P,S,E,B)

Hansen, C. J. and L. R. Goertzen**.** 2006. *Cayratia japonica* (Vitaceae) naturalized in Alabama. Castanea 71: 248–251.

Harrington, T. B., L. T. Rader, and J. W. Taylor, Jr. 2003. Kudzu (*Pueraria montana*) community responses to herbicides, burning, and high-density loblolly pine. Weed Sci. 51: 965-974.

Hipkins, P. L. 1998. Control of kudzu during the dormant season. Proc. South. Weed Sci. Soc. 51: 191.

Hodges, G., G. B. Edwards, and W. Dixon. 2005. Pest Alert: Chilli thrips *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae): A new pest thrips for Florida. Florida Dept. of Ag. & Consumer Services, Division of Plant Industry. http://www.doacs.state.fl.us/pi/enpp/ento/chillithrips.html. Accessed September 9, 2008.

Hsu, Tsai-Wen and C. Kuoh. 1999. *Cayratia maritima* B.R. Jackes (Vitaceae), a new addition to the flora of Taiwan. Bot. Bull. Acd. Sin. 40: 329-332.

Indian Medicinal Plant Growers' Consortium (IMPGC) 2008. http://www.impgc.com/plantinfo_A.php?id=1941. Accessed February 20, 2008.

Kakutani, T., T. Inoue, and M. Kato. 1989. Nectar secretion pattern of the dish-shaped flower, *Cayratia japonica* (Vitaceae) and nectar utilization patterns by insect visitors. Res. Popul. Ecol. 31: 381-400.

Kaman, B. 2008. Water Management in Northeast India. Assam Times. http://www.assamtimes.org/blog/1276.html. Accessed September 3, 2008.

Kay, S. H. and F. H. Yelverton. 1998. Dormant season herbicide treatments for kudzu control. Proc. South. Weed Sci. Soc. 51: 190-191.

Kidd, K. A. 2002. Interaction of Kudzu, *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) and Arthropods in North Carolina. Ph.D. Diss., Dept. of Entomology, Raleigh, NC: NC State Univ. 111 pp.

Krings, A. and R.J. Richardson. 2006. *Cayratia japonica* (Vitaceae) new to North Carolina and an updated key to the genera of Vitaceae in the Carolinas. SIDA 22: 813-815.

Lee, C. C. and P. Houghton. 2005. Cytotoxicity of plants from Malaysia and Thailand used traditionally to treat cancer. Journal of Ethnopharmacology 100: 237-243.

Lutz, H. J. 1943. Injuries to trees caused by *Celastrus* and *Vitis*. Bulletin of the Torrey Botanical Club. 70: 436-439.

Mitich, L. W. 2000. Intriguing world of weeds: kudzu (*Pueraria lobata* [Wild.] Ohwi.). Weed Tech. 14: 231-235.

Miller, J. H. 2003. *Nonnative Invasive Plants of Southern Forests: A Field Guide for Identification and Control.* NC. #SRS-62, USDA-Forest Service, Southern Research Station, Asheville.

Mullins, M. G., A. Bouquet, and L. E. Williams. 1992. *Biology of the Grapevine*. Cambridge University Press, New York, NY.

Koop, A. and S. Dubon 2007. Animal and Plant Health Inspection Service (APHIS): New Pest Advisory Group (NPAG) report for *Cayratia japonica* (Thunb. Ex Murray) Gagnep: Bushkiller. Doc. 20071019

Nassar, A. R. and H. M. Kliewer. 1966. Free amino acids in various parts of *Vitis vinifera* at different stages of development. Proc. Amer. Soc. Hort. Sci. 89: 281-294.

Ohwi, J., F. Meyer, and E. Walker. 1984. Flora of Japan. Smithsonian Institution. Washington, D.C. pp. 618-620.

Okada, H., H. Tsujaya, and M. Okamoto. 2003. Intra-specific polyploidy and possible occurance of some genetic types for pollen development in *Cayratia japonica*, Vitaceae. Acta Phytotax. Geobot. 54: 69-75.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Eco. Econ. 52: 273-288.

Possingham, J. V. and J. Groot-Obbink. 1971. Endotropic mycorrhiza and the nutrition of grapevines. *Vitis* 10: 120-130.

Radler, F. and D. H. S. Horn. 1965. The composition of the grape cuticle wax. Aust. J. Chem. 18: 1059-1069.

Reddy, K.N. 2005. Deep tillage and glyphosate-reduced redvine (*Brunnichia ovata*) and trumpetcreeper (*Campsis radicans*) populations in glyphosate-resistant soybean. Weed Tech. 19: 713-718.

Richards, D. 1983. The grape root system. Hort Reviews 5: 127-168.

Schierenbeck, K. A. 2004. Japanese honeysuckle (*Lonicara japonica*) as an invasive species; history, ecology, and context. Critical Reviews in Plant Sci. 23: 391-400.

Shinners, L.H. 1964. *Cayratia japonica* (Vitaceae) in southeastern Louisiana: new to the United States. Sida 1: 384.

Soule, J. T.,J. Matthews, K. C. Blackmon, and T. L. Mellichamp. 2008. Noteworthy collections: North Carolina observations on the invasive Cayratia japonica (Vitaceae) in North Carolina, including six new records for the state. Castanea 73: 42-45.

Srinivasan, C. and M. G. Mullins. 1979. Flowering in *Vitis*: Conversion of tendrils into inflorescences and bunches of grapes. Planta 145: 187- 192.

Stine, M. 2006. Louisiana ecosystems and plant identification. LSU. http://rnrstreamer.lsu.edu/ecosystems/webtour/enter.htm. Accessed September 10, 2008.

USDA-ARS, National Genetic Resources Program. 2008. *Germplasm Resources Information Network - (GRIN)* [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?410986. Accessed April 10, 2008.

USDA-NRCS. 2006. The PLANTS Database (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 United States. Accessed August 30, 2008.

Williams, P.A., Timmins, S. M., Smith, J. M. B., and Downey, P. O. 2001. The biology of Australian Weeds, Japanese honeysuckle (*Lonicera japonica* Thunb.) Plant Prot. Quarterly 16: 90-100.

Wilson, T. C., J. M. Gerrath, and U. Posluszny. 2005. Morphological and anatomical development in the Vitaceae. VIII. Comparative development of three Cyphostemma (Vitaceae) species reveals important vegetative and reproductive differences among the species. Can. J. Bot. 84: 702-716.

Wilson, T. and U. Posluszny. 2003. Novel variation in the floral development of two species *Parthenocissus*. Can. J. Bot. 81: 738-748.

Young, J. 2006. Porcelainberry (*Ampelopsis brevipedunculata*). Plant Conservation Alliance Alien Plant Working Group. http://www.nps.gov/plants/alien/fact/ambr1.htm. Accessed July 23, 2008.

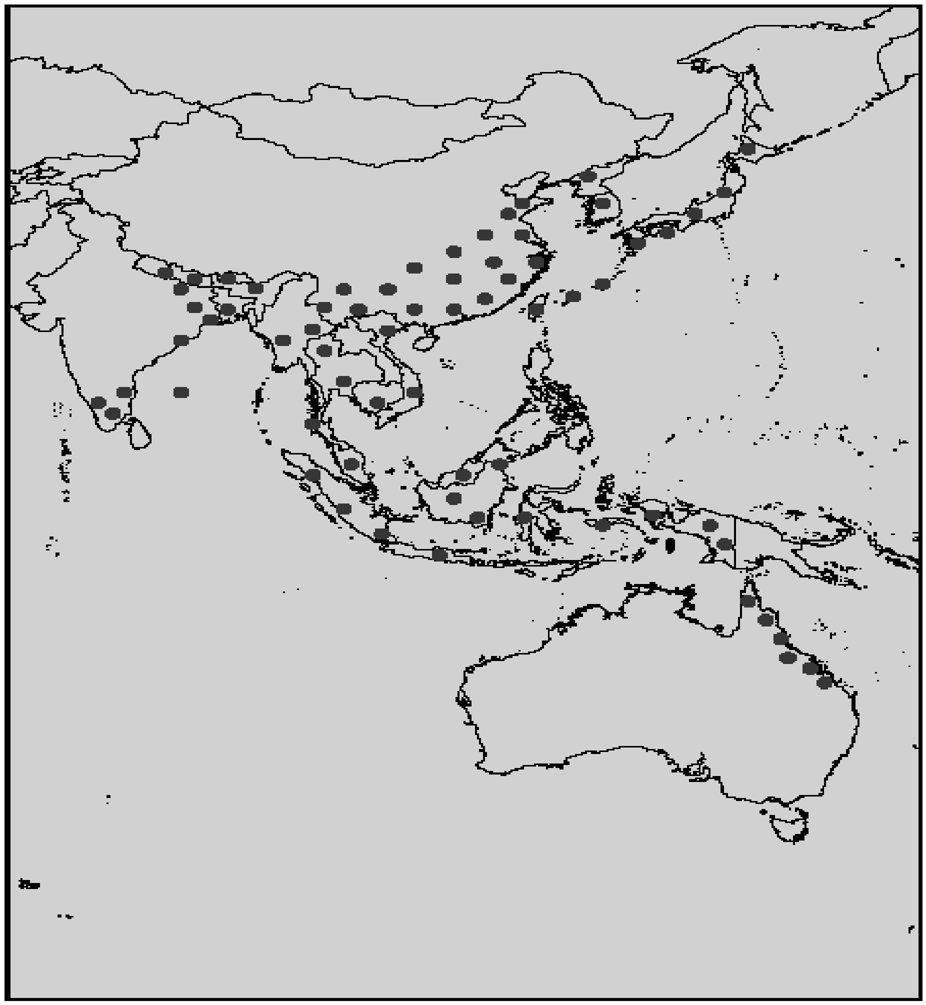


Figure 1. Native range of bushkiller (A. West 2008).

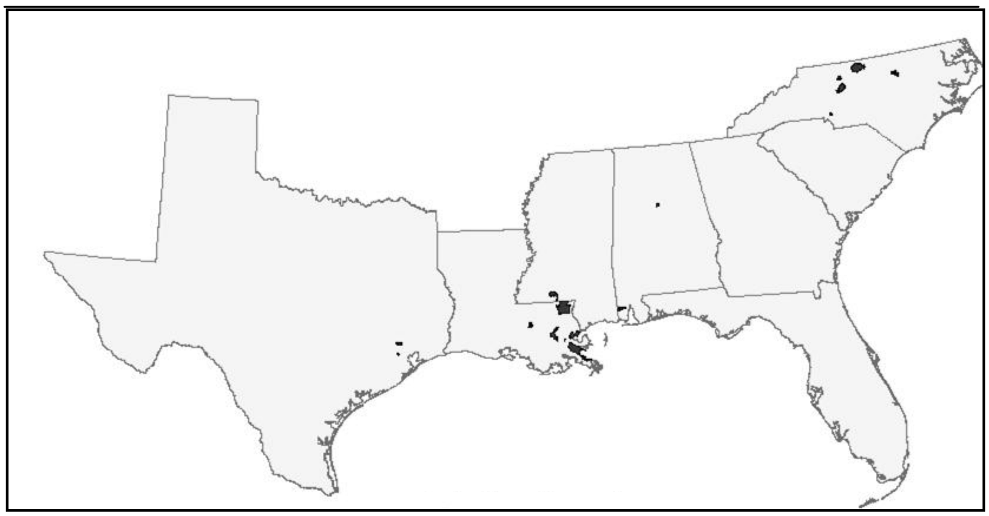


Figure 2. Reports of bushkiller in the United States by zip code. Created by D. Borchert and S. Kubilis (Koop and Dubon 2007).

Figure 3. Bushkiller overtopping trees and climbing a power line in Winston Salem, North Carolina (M. Burton).

<u>Taxon: *Cayratia japonica* (Thunb.) Gagnep.</u>

Kingdom: ***Plantae*** - plants

Subkingdom: ***Tracheobionta*** – vascular plants

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

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

Class: ***Magnoliopsida*** - dicotyledons

Subclass: ***Rosidae***

Order: ***Rhamnales***

Family: **Vitaceae** – grape family

Genus: ***Cayratia*** Juss. - cayratia

Species: ***Cayratia japonica*** (Thunb.) Gagnep. - bushkiller

Synonyms to *Cayratia japonica*: *Cissus japonica* (Willd.), *Cissus obovata* (Lawson), *Columella japonica* (Thunb.) Merr. and *Vitis japonica* (Thunb.).

Common name in the United States: bushkiller.

Other common names: sorrel vine, java, javan grape, yabugarashi, yabu-karashi.

Figure 4. Taxonomic classification of bushkiller (USDA-ARS 2008; USDA-NRCS 2006).

Figure 5. Bushkiller shoot with pedate quinquifoliate and trifoliate leaves (A. West)

1. Lepidoptera
(butterflies and moths):
a. *Papilio xuthus* LINNAEUS [this species not found in the US, but other *Papilio spp.,* such as *Papilio rutulus* (Western tiger swallowtail), are native]
b. *Graphium sarpedon* LINNAEUS [genus name changed to *Eurytides; Eurytides marcellus* (zebra swallowtail) found in US]

2. *Coleptera*
(beetles):
a. *Popiuia japonica* NEWMAN (Japanese beetle, introduced in US)

3. *Hymenoptera*
(ants):
a*. Iridomyrmex glaber* MAYR (no species of *Iridomyrmex* native to US)
b. *Formica japonica* MOTSCHULSKY (this species not found in US, but other *Formica spp.* are)
c. *Lasius niger* LINNE (black garden ant, native to US)

(wasps):
a. *Scolia oculata* MATSUMU (*Scolia spp*. found in US)
b. *Cerceris japonica* ASHMEAD (*Cerceris spp.* found in US)
c. *Vespa xanthoptera* CAMERON (Japanese hornet, introduced to US)
d. *Vespa analis* FABRICIUS (*Vespa spp.* found in US)
e. *Polistes mandarinus* SAUSSURE (*Polistes spp.* found in US)
f. *Polistes jadwigae* DALLA TORR~ (*Polistes spp.* found in US)
g. *Polistes jokohamae* EADOSZKOWSKI (*Polistes spp.* found in US)
h. *Polistes snelli* SAUSSURE (*Polistes spp.* found in US)
i. *Polistes chinensis* FABRIClUS (*Polistes spp.* found in US)
j. *Bembix niponica* F. SMITH (*Bembix spp*. found in US)
k. *Braconidae* sp. (*Braconidae* spp. found in US)

(bees):
a. *Lasioglossum (Lasioglossum) occidens* SMITH (*Lasioglossum spp.* found in US)
b. *Lasioglossum (Lasioglossum) scitulim* SMITH (*Lasioglossum spp.* found in US)
c*. Lasioglossum (Evylaeus) japonica* DALLA TORRE (*Lasioglossum spp.* found in US)
d. *Apis cerana* FABRICIUS (*Apis spp*. found in US)

Figure 6. List of flower visiting insects sampled on bushkiller in Japan (Kakutani et al. 1989) and their occurrence in the United States (Bartlett 2005).

Figure 7. Bushkiller fruit development at the Charlotte, NC population (A. West).

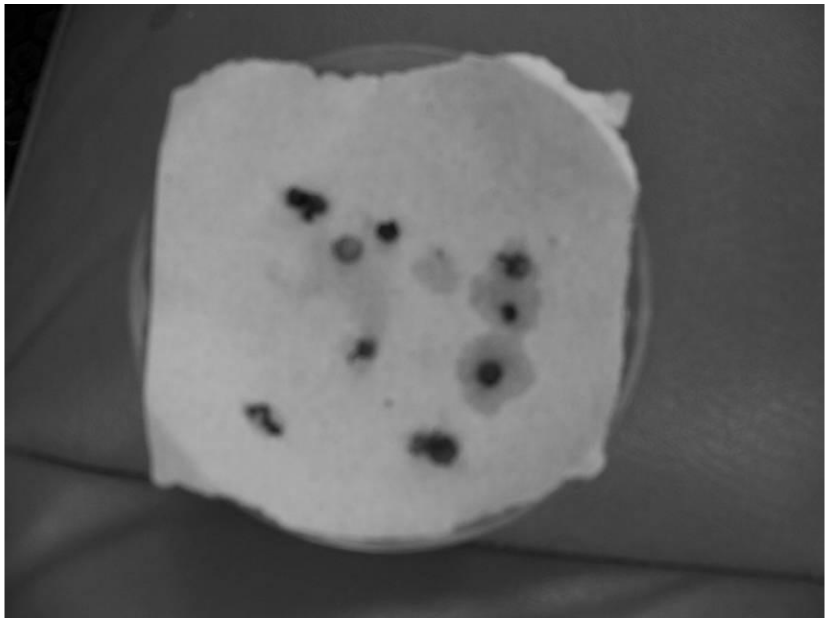


Figure 8. Bushkiller fruit collected at the Charlotte, North Carolina site placed in a Petri dish to determine seed viability (A. West).

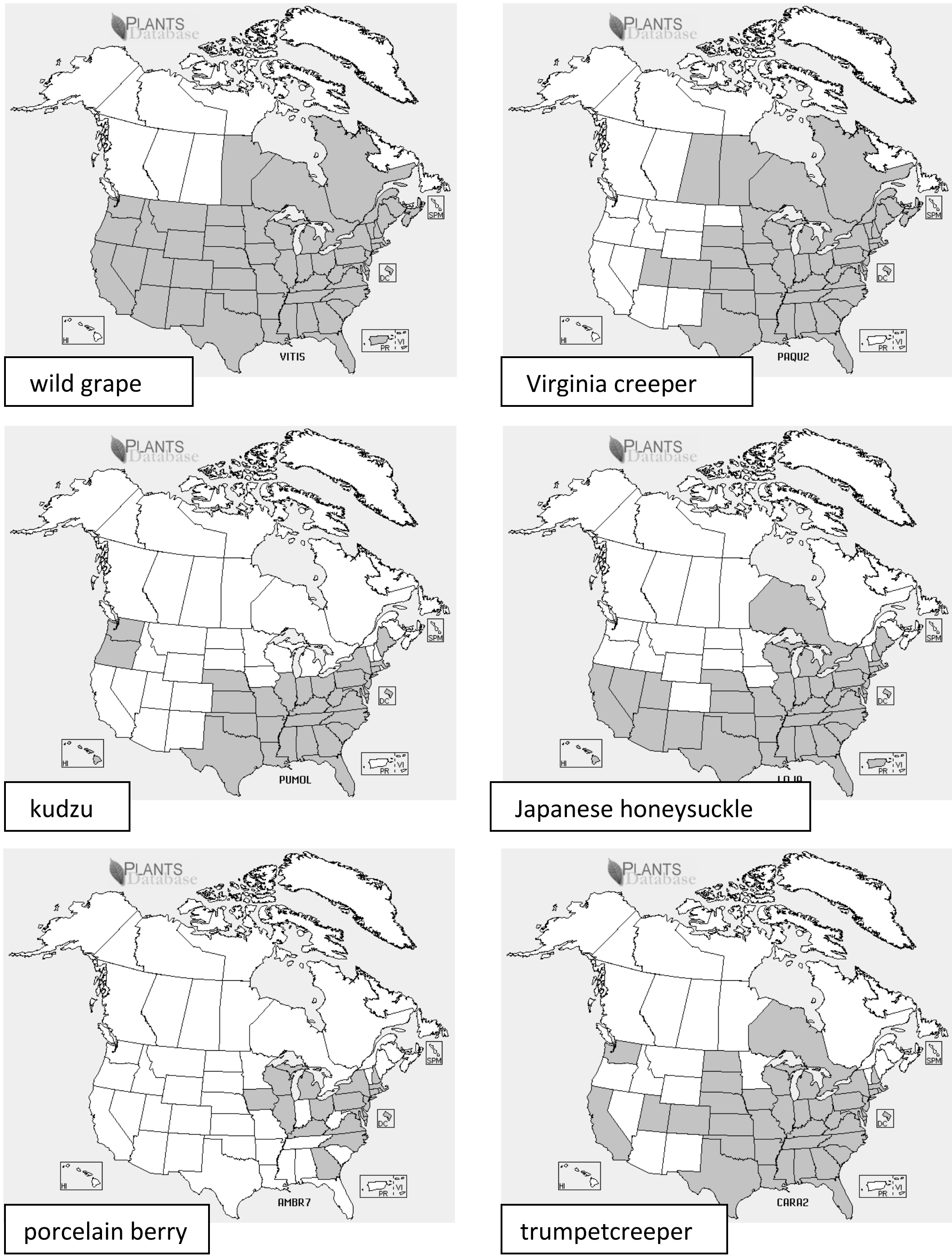


Figure 9. Distribution of wild grape, Virginia creeper, kudzu, Japanese honeysuckle, porcelainberry, and trumpetcreeper in the United States (USDA-NRCS).

Chapter 2

Bushkiller Response to Selected Herbicides

Abstract

Greenhouse and field studies were conducted to determine bushkiller response to selected herbicides. Greenhouse study 1 evaluated efficacy of 2,4-D, aminopyralid, glyphosate, triclopyr, and mixtures of these herbicides applied postemergence (POST) to bushkiller, trumpetcreeper, and Virginia creeper. At 1 month after treatment (MAT), bushkiller control with all treatments containing triclopyr was 91 to 100%. Virginia creeper response was similar to that of bushkiller, but trumpetcreeper control was below 79% with all treatments. Greenhouse study 2 evaluated efficacy of 2,4-D, DPX-KJM44, imazapyr, metsulfuron, sulfometuron, and mixtures of these herbicides applied POST to bushkiller. At 1 MAT, 2,4-D, imazapyr plus sulfometuron, sulfometuron plus metsulfuron, and treatments containing DPX-KJM44 controlled bushkiller at least 90%. Field study 1 evaluated efficacy of glyphosate, triclopyr, glyphosate plus triclopyr, triclopyr plus 2,4-D, and triclopyr plus aminopyralid applied POST to bushkiller. No control was evident from any treatment at 10 MAT. Field study 2 was conducted to evaluate efficacy of DPX-KJM44, imazapyr, metsulfuron, sulfometuron, and sulfometuron plus metsulfuron applied POST to bushkiller. At 10 MAT, plots treated with DPX-KJM44, imazapyr, sulfometuron, and sulfometuron plus metsulfuron controlled bushkiller 99, 93, 88, and 91%, respectively.

Introduction

Bushkiller [*Cayratia japonica* (Thunb.) Gagnep] is a perennial herbaceous vine in the

Vitaceae family with an aggressive, twining growth habit that overtops surrounding vegetation. Bushkiller may be distinguished by pedate quinquefoliate leaves with the terminal leaflet longer than the 4 lateral leaflets, discontinuous tendril formation, and axillary, corymbose, or umbellate inflorescences with flowers red, salmon-colored, yellow, or white (Hsu and Kuoh 1999; Krings and Richardson 2006; Ohwi et al. 1984). Bushkiller has extensive rhizomes (Ohwi et al. 1984).

Bushkiller is native to temperate, subtropical, and tropical forests in Southeast Asia, Japan, India, Malaysia, Australia and Taiwan (Hsu and Kuoh 1999). It was first reported in Texas in 1964 (Brown 1992). Since that time, bushkiller has also been documented in Louisiana, Mississippi, Alabama and North Carolina (Hansen and Goertzen 2006; Krings and Richardson 2006; Shinners 1964; USDA- NRCS 2006). The growth habit of bushkiller resembles that of kudzu [*Pueraria lobata* (Willd)], which is estimated to cost $100 to 500 million per year just in forest productivity losses (Forseth and Innis 2004). Bushkiller has been observed to overtop trees and grow as a monoculture in NC (A.West, personal observation).

Perennial vines may become invasive in annual and perennial cropping systems, tree plantations, agroforestry, forest restoration/regeneration, parks, and natural areas. When management of perennial vines becomes a necessity, management strategies must focus on long term control (Averill et al. 2008). Often, manual control methods such as mowing or hand-removal is impractical as suckering from buds and roots is typical of perennial vines

(Averill et al. 2008; Lawlor and Raynal 2002; Main et al. 2006; Mueller et al. 2003). The use of herbicides may often provide a more selective and efficient tool in managing perennial vines (Averill et al. 2008; Berisford et al. 2006; Chachalis et al. 2001; Harrington et al. 2003; Lawlor and Raynal 2002; Main et al. 2006; Mueller et al. 2003).

One of the most important decisions when employing herbicides into an integrated pest management strategy for perennial vines is herbicide selection. Often, species such as kudzu, trumpetcreeper [*Campsis radicans* (L.) Seem.], Virginia creeper [*Parthenocissus quinquefolia* (L.) Planch], Chinese yam (*Dioscorea opposite* Thunb.), and pale swallow-wort (*Vincetoxicum rossicum* Kleo) require treatment over multiple-seasons with herbicides that translocate to their extensive root systems (Averill et al. 2008; Berisford et al. 2006; Bradley et al. 2003; Chachalis et al. 2001; Harrington et al. 2003; Lawlor and Raynal 2002; Main et al. 2006; Mueller et al. 2003; Richardson et al. *in press*). Herbicides frequently used for perennial vine control include 2,4-D, glyphosate, and triclopyr (Averill et al. 2008; Berisford et al. 2006; Bradley et al. 2003; Chachalis et al. 2001; Harrington et al. 2003; Lawlor and Raynal 2002; Main et al. 2006; Mueller et al. 2003; Richardson et al. *in press*). Other herbicides registered for non-cropland use to control perennial species include aminopyralid, imazapyr, metsulfuron, and sulfometuron (Anonymous 2006a; Anonymous 2006b; Anonymous 2007; Anonymous 2008). DPX-KJM44 (proposed common name: aminocyclopyrachlor) is a new active ingredient herbicide from DuPont Land Management under development for non-cropland use (Claus et al 2008).

An extensive literature review indicated that control recommendations for bushkiller were not available. In order to create successful management programs, herbicide efficacy must be determined. Therefore, the objective of this research was to evaluate herbicides in greenhouse and field settings for bushkiller control. We selected herbicides registered or in development for non-cropland control of perennial weed species. Trumpetcreeper and Virginia creeper were also included in one greenhouse study to evaluate herbicide selectivity.

Materials and Methods

In greenhouse study 1, bushkiller was propagated from root stock collected in Winston Salem, NC while trumpetcreeper and Virginia creeper were propagated from root stock collected in Raleigh, NC. Root fragments were planted in 9-cm square pots containing a commercial potting mix (Metro Mix® 200; Sun Gro Horticulture, Bellevue, WA). Plants were allowed to grow and then treated at approximately 30 cm tall.

Pots were watered daily and fertilized weekly with Miracle-Gro® Water Soluble Lawn Food (36-6-6; The Scotts Company, Marysville, OH). Treatments in study 1 included 2,4-D (Weedar® 64; Nufarm, Burr Ridge, IL) at 1.12 kg ae/ha, aminopyralid (Milestone®; Dow AgroSciences, Indianapolis, IN) at 0.12 kg ae/ha, glyphosate (Touchdown Pro® Syngenta, Greensboro, NC) at 1.12 kg ae/ha, triclopyr (Garlon® 3A; Dow AgroSciences, Indianapolis, IN) at 1.12, 2.24, and 4.5 kg ae/ha, glyphosate at 1.12 kg ae/ha plus triclopyr at 1.12 kg ae/ha, triclopyr at 1.12 kg ae/ha plus 2,4-D at 1.12 kg ae/ha, triclopyr at 1.12 kg ae/ha plus aminopyralid at 0.12 kg ae/ha, and triclopyr at 1.12 kg ae/ha plus 2,4-D at 1.12 kg ae/ha plus aminopyralid at 0.12 kg ae/ha.

Greenhouse study 2 was conducted only with bushkiller, which was propagated and grown as described for study 1. Treatments included 2,4-D at 1.12 kg ae/ha, DPX-KJM44 at 0.35 kg ae/ha, DPX-KJM44 plus 2,4-D, imazapyr (Arsenal®; BASF, Research Triangle Park, NC) at 1.68 kg ae/ha, metsulfuron (Escort XP®; DuPont, Wilmington, DE) at 0.088 kg ae/ha, sulfometuron (Oust® XP; DuPont, Wilmington, DE) at 0.33 kg ae/ha, sulfometuron plus DPX-KJM44, sulfometuron plus imazapyr, and sulfometuron plus metsulfuron.

Treatments in greenhouse studies 1 and 2 were applied using an air-pressurized indoor spray chamber equipped with an 8002E flat-fan nozzle calibrated to deliver a spray volume of 190 L/ha at 140 kPa. Each herbicide treatment was mixed immediately prior to application. After spraying, plants were returned immediately to the greenhouse. Each treatment in study 1 included a nonionic surfactant (Induce®; Helena Chemical Co., Collierville, TN) at 0.25% v/v, while a methylated seed oil (SunEnergy®, Brewer International Co., Vero Beach, FL) at 1% v/v was used in study 2. These surfactants were added to increase absorption of herbicides. Each greenhouse study included four treatment replications; each replication was one pot containing one bushkiller plant. Treatments were arranged in a completely randomized design and repeated twice. Visual estimates of weed control were determined at 1 MAT (month after treatment) in comparison to a non-treated control. Weed control was rated on a 0 to 100% scale where 0% equals no plant response and 100% equals plant death. Phytotoxicity symptoms for each treatment such as stunting, chlorosis, and necrosis were cumulatively assessed in comparison to the non-treated for weed control ratings. For example, a rating of 40 would indicate that 40% of the plant exhibited phytotoxicity symptoms. At 1 MAT, plant shoots were harvested and oven dried at 50 C to constant moisture for dry weight determination.

Field studies were conducted in Lexington and Charlotte, NC where bushkiller had been reported problematic. The Lexington site was adjacent to a small farm (35^{o} 49'08.37"N, 80^{o} 17'17.06"W) and the Charlotte site was in a riparian area along Douglas Branch (35 ^{o} 12'34.2"N, 80 ^{o} 47'1.60"W). Plots were 90 m^2 and contained 100% coverage of bushkiller, with shoot lengths ranging from 5 to 15 m. Herbicide applications at both sites were made August 8, 2007. Treatments in field study 1 (Lexington) included glyphosate at 4.4% v/v, triclopyr at 2.2% v/v, glyphosate at 4.4% v/v plus triclopyr at 2.2% v/v, triclopyr at 2.2% v/v plus 2, 4-D at 1.75% v/v, and triclopyr at 2.2% v/v plus aminopyralid at 0.18% v/v. Treatments in field study 2 (Charlotte) included DPX-KJM44 at 0.5% v/v, imazapyr at 2.5% v/v, metsulfuron at 0.3 g ai/L, sulfometuron at 1.5 g ai/L, and sulfometuron at 1.5 g ai/L plus metsulfuron at 0.3 g ai/L. Treatments in both field studies were applied with a CO_2-pressurized backpack sprayer equipped with a handgun (Spraying Systems, Co., #5 nozzle) at the rate of 280 L/ha. Herbicide solutions were mixed immediately prior to application. Each treatment included a methylated seed oil at 1% v/v, as well as a marker dye to ensure adequate coverage. Due to the limited distribution of bushkiller in NC and initiation of eradication programs, the field studies could only be conducted once with three treatment replications. Visual estimates of weed control were determined at 1 and 10 MAT in comparison to a non-treated control plot. Weed control was rated as described for the greenhouse studies.

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). The non-treated control was not included in statistical analysis of visual ratings. Mean separation was based on arcsine square root transformation of percentage data, but non-transformed means are presented for clarity.

Results and Discussion

In greenhouse study 1 at 1 MAT, triclopyr at 2.24 and 4.5 kg ae/ha, triclopyr plus 2,4-D, triclopyr plus 2,4-D plus aminopyralid, and triclopyr plus glyphosate controlled bushkiller 100% (Table 1). Control with 2,4-D, triclopyr at 1.12 kg ae/ha, and triclopyr plus aminopyralid was lower and 93, 95, and 91%, respectively. Aminopyralid and glyphosate alone did not control bushkiller more than 22%, and dry weights were 1.35 to 1.45 g. In comparison, non-treated bushkiller dry weight was 1.96 g, and dry weights of all other treatments did not exceed 0.33 g.

Triclopyr at 2.24 and 4.5 kg/ha controlled trumpetcreeper 67 to 78% at 1 MAT, with dry weights of 0.51 and 0.69 g (Table 1). All other treatments controlled trumpetcreeper 34 to

49% with dry weights between 0.78 and 1.06 g. Non-treated trumpetcreeper dry weight was 1.24 g. Bradley et al. (2003) found 2,4-D applied POST at 280 g/ha reduced trumpetcreeper populations 45 to 69% 3 MAT (months after treatment) in corn (*Zea mays* L.). In a study evaluating trumpetcreeper control in double-crop glyphosate resistant soybean, Bradley et al. (2004) reported glyphosate applied POST at 0.84 kg ai/ha and 1.1 kg ai/ha reduced trumpetcreeper populations 30 to 66% at 12 MAT.

Triclopyr alone and all triclopyr mixtures except triclopyr plus aminopyralid controlled Virginia creeper 96 to 100% (Table 1). Surprisingly, control with triclopyr plus aminopyralid at 53% was much lower than triclopyr alone at 96%. Dry weight of triclopyr plus aminopyralid was 3.77 g and significantly greater than all other triclopyr treatments which did not exceed 2.16 g. Virginia creeper control with other treatments was generally similar to that of bushkiller. This finding is consistent with previous work examining control of perennial weeds in Fraser fir (A*bies fraseri* Pursh Poir.) plantations. Triclopyr and triclopyr mixtures provided 93 to 98% control of Virginia creeper and 98 to 100% control of wild grape 11 MAT, and similar control was observed with 2,4-D. (Richardson et al. *in press*).

In greenhouse study 2 at 1 MAT, 2,4-D, DPX-KJM44, DPX-KJM44 plus 2,4-D, sulfometuron plus DPX-KJM44, and sulfometuron plus imazapyr controlled bushkiller at least 98% (Table 2). Control was 90% with sulfometuron plus metsulfuron, while imazapyr, metsulfuron, and sulfometuron controlled bushkiller 73 to 76%. Dry weights of 2,4-D, DPX-KJM44, DPX-KJM44 plus 2,4-D, sulfometuron plus DPX-KJM44, and sulfometuron plus imazapyr treatments were 1.38 to 1.86 g compared to the non-treated control at 3.43 g. Imazapyr, metsulfuron, sulfometuron, and sulfometuron plus metsulfuron had final dry weights of 1.94, 2.23, 2.28, and 2.11 g, respectively.

In field study 1, glyphosate, triclopyr, triclopyr plus 2,4-D, and triclopyr plus aminopyralid controlled bushkiller 88 to 93% at 1 MAT, however, by 10 MAT no control was observed (Table 3). In Winston Salem, NC, 3 seasons of triclopyr treatments at 2 treatments per season applied as cut-stem (100% solution) or foliar (5% v/v) applications decreased bushkiller cover at least 80%, but control after one season was only about 30% (A. West, personal observation). Suzuki (1988) found glyphosate to be unsuccessful in controlling bushkiller, and although triclopyr was more effective than glyphosate, the length and thickness of the subterranean stems of bushkiller limited control with triclopyr as compared to other perennial weeds.

Greater control was observed in field study 2. At 1 MAT, DPX-KJM44 controlled bushkiller 97%, while other treatments did not exceed 33% (Table 4). Bushkiller was controlled 88 to 99% at 10 MAT by DPX-KJM44, imazapyr, sulfometuron, and sulfometuron plus metsulfuron, but no control was observed from metsulfuron.

These results indicate that triclopyr and triclopyr mixtures were effective on small plants in the greenhouse, but less effective in the field. DPX-KJM44, imazapyr, and sulfometuron plus metsulfuron did control bushkiller at 10 MAT in the field. Further research is needed to determine long-term control with multiple applications of these herbicides. Due to the limited distribution of bushkiller thus far, control efforts must focus on eradication to ensure the plant does not spread, causing further damage economically or ecologically.

Literature Cited

Anonymous 2006 a. Arsenal® herbicide label. BASF Corporation. Available online: http://www.cdms.net/LDat/ld746002.pdf. Accessed Novemeber 21, 2008.

Anonymous 2006 b. Oust XP® herbicide label. Dupont Land Management. Available online: http://www.dupont.com/ag/us/prodinfo/prodsearch/information/H65144.pdf. Accessed November 21, 2008.

Anonymous 2007. Escort ® herbicide label. DuPont Land Management. Available online: http://www.dupont.com/ag/us/prodinfo/prodsearch/information/H65521.pdf. Accessed Novemeber 21, 2008.

Anonymous 2008. Milestone® herbicide label. Dow AgroSciences. Available online: http://www.cdms.net/ldat/ld77N006.pdf. Accessed Novemeber 21, 2008.

Averill, K. M., A. DiTommaso, and S. H. Morris. 2008. Response of pale swallow-wort (Vincetoxicum rossicum) to triclopyr application and clipping. Invasive Plant Sci. And Mgmt. 1: 196-206.

Berisford, Y. C., P. B. Bush, and J. W. Taylor, Jr. 2006. Leaching and persistance of herbicides for kudzu (Pueraria montana) control on pine regeneration sites. Weed Sci. 54: 391-400.

Bradley, K. W., E. S. Hagood, Jr., and P. H. Davis. 2003. Evaluation of Postemergence Herbicide Combinations for Long-Term Trumpetcreeper (*Campsis radicans*) Control in

Corn (*Zea mays*). Weed Tech. 17: 718-723.

Bradley, K. W., E. S. Hagood, and P. H. Davis. 2004. Trumpetcreeper (Campsis radicans) control in double-crop glyphosate-resistant soybean with glyphosate and conventional herbicide systems. Weed Tech. 18: 298–303.

Brown, L.E. 1992. *Cayratia japonica* (Vitaceae) and *Paederia foetida* (Rubiaceae) adventive in Texas. Phytologia 72: 45-47.

Chachalis, D., K. N. Reddy, and C. D. Elmore. 2001. Characterization of leaf surface, wax composition, and control of redvine and trumpetcreeper with glyphosate. Weed Sci. 49: 156-163.

Claus, J., R. Turner, G. Armel, and M. Holliday. 2008. DuPont aminocyclopyrachlor (proposed common name) (DPX-MAT28/KJM44) herbicide for use in turf, IWC, bare-ground and brush markets. Proc. 5th International Meeting International Weed Sci. Congress. pp. 277.

Forseth, I. N. and A. F. Innis. 2004. Kudzu (*Pueraria montana*): history, physiology, and ecology combine to make a major ecosystem threat. Critical Reviews in Plant Sci. 23: 401-413.

Hansen, C. J. and L. R. Goertzen**.** 2006. *Cayratia japonica* (Vitaceae) naturalized in Alabama. Castanea 71: 248–251.

Harrington, T. B., L. T. Rader-Dixon, and J. W. Taylor. 2003. Kudzu (*Pueraria montana*) community responses to herbicides, burning, and high-density loblolly pine. Weed Sci. 51: 965-974.

Hsu, Tsai-Wen and C. Kuoh. 1999. *Cayratia maritima* B.R. Jackes (Vitaceae), a new addition to the flora of Taiwan. Bot. Bull. Acd. Sin. 40: 329-332.

Krings, A. and R.J. Richardson. 2006. *Cayratia japonica* (Vitaceae) New to North Carolina and an updated key to the genera of Vitaceae in the Carolinas. SIDA 22: 813-815.

Lawlor, F. M. and D. J. Raynal. 2002. Response of swallow-wort to herbicides. Weed Sci. 50: 179-185.

Main, C. L., J. E. Beeler, D. K. Robinson, and T. C. Mueller. 2006. Growth, reproduction and management of Chinese yam (*Dioscorea oppositifolia*). Weed Tech. 20: 773-777.

Mueller, T. C. , D. K. Robinson, J. E. Beeler, C. L. Main, D. Soehn, and K. Johnson. 2003. *Dioscorea oppositifolia* L. phenotypic evaluations and comparison of control strategies. Weed Tech. 17: 705-710.

Ohwi, J., F. Meyer, and E. Walker. 1984. Flora of Japan. Smithsonian Institution. Washington, D.C. pp. 618-620.

Richardson, R. J., M. W. Marshall, R. E. Uhlig, and B. H. Zandstra. *In press*. Virginia-creeper (P*arthenocissus quinquefolia*) and Wild Grape (V*itis* spp.) Control in Fraser Fir (A*bies fraseri*).

Shinners, L.H. 1964. *Cayratia japonica* (Vitaceae) in southeastern Louisiana: new to the United States. Sida 1:384.

Suzuki, K. 1988. Studies on weed control in a citrus orchard III : control of broad leaf perennial weeds. Bulletin of the Fruit Tree Research Station, B. Okitsu, Japan 15 : 21-34.

USDA- NRCS. 2006. The PLANTS Database (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA. Accessed August 30, 2008/

Table 1. Control and dry weight of bushkiller, trumpet creeper, and Virginia creeper 1 MAT with selected postemergence herbicides in greenhouse study 1.[a,b]

Herbicide[c]	Rate	Bushkiller		Trumpetcreeper		Virginia creeper	
		Control	Dry wt.	Control	Dry wt.	Control	Dry wt.
	kg ae/ha	%	g	%	g	%	g
2, 4-D	1.12	93 b	0.33 c	41 c	0.89 bc	83 b	1.98 d
Aminopyralid	0.12	22 c	1.35 b	34 c	1.06 ab	21 d	6.22 b
Glyphosate	1.12	21 c	1.45 b	36 c	0.98 abc	11 d	7.45 b
Triclopyr	1.12	95 b	0.21 c	43 c	0.94 abc	96 ab	1.93 d
Triclopyr	2.24	100 a	0.06 c	78 a	0.69 cd	100 a	2.16 d
Triclopyr	4.5	100 a	0.13 c	67 ab	0.51 d	99 a	1.94 d
Triclopyr + 2, 4-D	1.12 + 1.12	100 a	0.06 c	34 c	0.91 abc	100 a	1.67 d

Table 1. Cont.

Triclopyr +	1.12 +	100 a	0.19 c	46 bc	0.92 abc	99 a	2.09 d
2, 4-D +	1.12 +						
Aminopyralid	0.12						
Triclopyr +	1.12 +	91 b	0.29 c	35 c	0.94 abc	53 c	3.77 c
Aminopyralid	0.12						
Triclopyr +	1.12 +	100 a	0.13 c	49 bc	0.78 bcd	98 ab	1.68 d
Glyphosate	1.12						
Non-treated	--	0	1.96 a	0	1.24 a	0	9.16 a

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

[b] Abbreviations: MAT, month after treatment.

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

[d] 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. Control and dry weight 1 MAT with selected postemergence herbicides in greenhouse study 2.[a,b]

Herbicide[c]	Rate	Control	Dry wt.
	kg ae/ha	%	g
2,4-D	1.12	100 a	1.61 de
DPX-KJM44	0.35	100 a	1.68 cde
DPX-KJM44 + 2,4-D	0.35 + 1.12	100 a	1.38 e
Imazapyr	1.68	76 bc	1.94 bcd
Metsulfuron	0.088	76 bc	2.23 b
Sulfometuron	0.33	73 c	2.28 b
Sulfometuron + DPX-KJM44	0.33 + 0.35	100 a	1.51 de
Sulfometuron + Imazapyr	0.33 + 1.68	98 a	1.86 bcd
Sulfometuron + Metsulfuron	0.33 + 0.088	90 ab	2.11 b
Non-treated	--	0	3.43 a

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

Table 2. Continued.

[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.

Table 3. Bushkiller control with selected postemergence herbicides in field study 1.[a,b]

Herbicide[c]	Rate	1 MAT[d]	10 MAT
	% v/v	------------------%------------------	
Glyphosate	4.4	93 a	0 c
Triclopyr	2.2	88 ab	0 c
Glyphosate + Triclopyr	4.4 + 2.2	80 b	0 c
Triclopyr + 2, 4-D	2.2 + 1.75	90 ab	0 c
Triclopyr + Aminopyralid	2.2 + 0.18	90 ab	0 c

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

[d] 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 4. Bushkiller control with selected postemergence herbicides in field study 2. [a,b]

Herbicide [c]	Rate	1 MAT [d]	10 MAT
		------------------%	------------------
DPX-KJM44	0.5 % v/v	97 a	99 a
Imazapyr	2.5% v/v	33 c	93 a
Metsulfuron	0.3 g/L	28 c	0 c
Sulfometuron	1.5 g/L	10 d	88 b
Sulfometuron + Metsulfuron	1.5 + 0.3 g/L	28 c	91 ab

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

[d] 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.

Chapter 3

Bushkiller Growth in Interspecific and Intraspecific Competition

Abstract

Bushkiller was evaluated under inter- and intraspecific competition. In experiment 1, bushkiller [*Cayratia japonica* (Thunb.) Gagnep], trumpetcreeper [C*ampsis radicans* (L.) Seem.], and wild grape (*Vitis* spp.) were grown alone and in two or three species mixtures in pots in a greenhouse. Of the three species, bushkiller grew the tallest and had the greatest final biomass when grown alone. When all three species were grown together, bushkiller grew over twice the height of trumpetcreeper, over 3 times the height of wild grape, and over 4 times the biomass of either competing species. Plots of height over time showed that competition did not affect bushkiller or wild grape growth rate, but trumpetcreeper growth was reduced when grown with bushkiller. In experiment 2, bushkiller was grown in cultures of 1, 2, and 3 plants per pot to determine intraspecific competition effects on growth. Final height of bushkiller was not affected by intraspecific competition; however, bushkiller biomass decreased with increasing competition.

Introduction

Bushkiller is a perennial vine in the Vitaceae family with an aggressive growth habit that climbs and shades surrounding vegetation. Bushkiller is native to temperate, subtropical, and tropical forests in Southeast Asia, Japan, India, Malaysia, Australia, and Taiwan (Hsu and Kuoh 1999). Bushkiller is invasive in the United States where it was first reported in Texas in 1964 (Brown 1992). Since that time, bushkiller has also been documented in Louisiana, Mississippi, Alabama and North Carolina (Hansen and Goertzen 2006; Krings and Richardson

2006; Shinners 1964; USDA-NRCS 2006).

Bushkiller has been observed overtopping trees in North Carolina in a manner similar to kudzu [*Pueraria lobata* (Willd)]. Native to Asia, kudzu is listed as a noxious weed in ten states across the Southeastern United States (USDA-NRCS 2006). It is estimated that 3 million ha of the Southeastern US is covered in kudzu and increasing at 50,000 ha per year. (Forseth and Innis 2004). Kudzu is often observed outcompeting native trees and shrubs along highways and forest edges. Edges between forest and non-forest habitats favor plants that are shade and often competition intolerant. About 44% of trees in the continental United States are estimated to be less than 90 m from an edge (McDonald and Urban 2006, Riitters et al*.* 2002). In the Piedmont forests of North Carolina, two drought-tolerant oak species [*Quercus stellata* (Wangenh) and *Quercus falcata* (Michx.)] and trumpetcreeper are common edge species (McDonald and Urban 2006). Exotic species such as kudzu and bushkiller may overtop edge tree species, forming monocultures and decreasing biodiversity.

Competition is one of the main factors that structure plant communities, therefore relative competitive ability of a plant may be used to predict its abundance in a plant community (Fraser and Keddy 2005). Grime (1973) described the four consistent features of “competitive” species: tall stature, a growth form (usually a large densely-branched rhizome or expanded tussock structure) which allows extensive and intensive exploitation of the environment above and below ground, a high maximum potential relative growth rate, and a tendency to deposit a dense layer of litter on the ground surface. Bushkiller has a tall stature (shoots have been observed 10 to 15 m tall in Charlotte, NC) and densely-branched roots/rhizomes (A. West, personal observations). Phenotypic plasticity is another key characteristic of an invasive plant species and its ability to outcompete other plants (Burns and Winn 2006). Bushkiller inhabits a wide range of environmental conditions in its native range, from some of the wettest regions in the world to arid grasslands, and regions where winter temperatures drop to -7 degrees Celsius (USDA-ARS 2008).

Interspecific competition involves two or more plant species, and the magnitude of competition at the individual level can be quantified as the per unit effect of individuals of neighboring species on the response of some target species, where response is a given measure of plant fitness (Firbank and Watkinson 2008; Goldberg 1996; Harper 1977). Intraspecific competition involves one species, and can be quantified as the per unit effect of individuals of that species on the response of other individuals of the same species (Firbank and Watkinson 2008; Goldberg 1996; Harper 1977).

The simple additive approach is one method of demonstrating competition in plants (Connolly et al 2001; Cousens 1991; Firbank and Watkinson 1985; Freckleton and Watkinson 2000; Gibson et al 1999). This design compares plants grown 'with' and 'without' competition. Mixtures in the additive approach typically consist of a fixed, 1:1 ratio of two species, however, some studies are difficult to classify as simple, diallel or additive in design (Freckleton and Watkinson 2000). Some of the problems associated with the additive design such as the confounding effects of species proportion and density are resolved using the target-neighbor design (Cousens 1991; Firbank and Watkinson 1985; Freckleton and Watkinson 2000; Gibson et al 1999). This involves growing an individual of a 'target species' with varying abundances of 'neighbors' (either associate species or itself) (Cousens 1991; Firbank and Watkinson 1985; Freckleton and Watkinson 2000; Gibson et al 1999).

We designed an experiment combining the simple additive approach with the target-neighbor design to determine interspecific competition between the exotic invasive bushkiller vine ('target' species) and two native vine species, trumpet creeper and wild grape ('neighbors'). Trumpetcreeper and wild grape are important vines in Southeastern United States forest communities. The nectar from trumpetcreeper flowers is one of the primary food sources for ruby-throated hummingbirds (*Archilochus colubris* Linnaeus) (Robinson et al. 1996) and wild grapes provide food for a variety of birds and mammals.

Often, the per unit biomass effect of neighbors on individuals of a target species is measured as the slope of a regression of target plant performance against the biomass of neighbors. To account for the dynamics of species interactions as they vary between the initiation and the completion of a competition experiment, numerous sequential measurements of each species per treatment are recorded (Connolly 2001). Due to the climbing growth habit of the three perennial vine species in our experiment, it was determined that the destructive sampling method associated with weekly biomass measurements would not effectively demonstrate the effect of height on competition. Vine height can be a key determinate of relative competitive ability in fertile environments with dense canopy cover (Aerts 1998). Prolific vines are associated with structural disturbance in a plant community as they compete for light and overtop existing vegetation to create a new canopy layer (Aerts 1998; Forseth and Innis 2004). A comparison of the slopes of regression curves created from regularly collected height measurements yields a quantitative measure of the effect of neighboring species on height growth over time (Gibson et al 1999; Goldberg and Landa 1991). Slopes of treatments with each species grown alone compared to each species grown in combination with one or both other species can be used to demonstrate the difference in height growth as influenced by interspecific competition.

In order to address the effects of intraspecific competition on bushkiller growth, we conducted a second experiment in which bushkiller plants were grown at three densities. Final biomass of a plant species depends on initial size and relative growth rate during the course of an experiment (Gibson et al 1999; Freckleton and Watkinson 2000). We measured final biomass for both the interspecific and intraspecific competition experiments.

Materials and Methods

To determine interspecific competition (experiment 1), root stock was obtained in June 2006. Bushkiller root stock was collected in Winston Salem, Forsyth County, North Carolina, United States and wild grape root stock was collected from Reedy Creek Field Lab, Raleigh, Wake County, North Carolina, United States. Trumpetcreeper root stock was purchased from Blue Ridge Nursery, North Carolina, United States. Each species was propagated from this root stock in a greenhouse and allowed to reach 30 cm in height. Plants were then transplanted into pots 30 cm diameter with 25 cm depth. Wild grape root stock was planted 2 weeks earlier than bushkiller and trumpetcreeper to increase size uniformity among species at the start of the experiment. This was done to reduce size bias, where one species may be judged as more competitive simply because it was the larger plant at the onset of the experiment.

Treatments included each species planted alone, all combinations of two different species, and all three species planted together. The density of bushkiller, trumpet creeper, and wild grape in each treatment was held at one to preclude significant intraspecific interactions. Treatments with 1 species had 1 plant per pot, treatments with 2 species had 2 plants per pot, and treatments with 3 species had 3 plants per pot. Treatments were replicated 3 times and placed in randomized locations in the glass greenhouse with a total of 21 experimental pots. The first experiment was initiated June 26, 2007 and a repeat was initiated on October 12, 2007.

To determine intraspecific competition (experiment 2), bushkiller root stock was collected and propagated as described for experiment 1. Treatments included one, two, or three bushkiller plants per pot. Treatments were replicated four times and placed in randomized locations in the greenhouse. The first experiment was initiated March 14, 2008 and a repeat was initiated on June 12, 2008.

Pots in both experiments contained a commercial potting mix (Metro Mix® 200; Sun Gro Horticulture, Bellevue, WA), and one support structure was secured in the middle of each pot to serve as a climbing medium for the three vine species. Average daily temperature for the duration of both experiments was 32 C. Pots were watered twice daily and fertilized once weekly with Miracle-Gro® Water Soluble Lawn Food (36-6-6; The Scotts Company, Marysville, OH).

In experiment 1, height measurements of the tallest shoot per species per pot were taken once a week for 6 weeks. We subtracted 30 cm from each measurement recorded because all plants started at 30 cm height. At 6 weeks after initiation (6 WAI), the number of inflorescences were counted for each species and all above-ground biomass was harvested and separated by species. The experiment was ended 6 WAI because some of the bushkiller vines had reached the greenhouse ceiling at this time. Plant biomass was oven dried at 50 C to a constant weight for biomass determination. In experiment 2, height of tallest shoot per pot and number of leaves per plant were measured at 6 WAI. All plant above-ground biomass was harvested, separated by treatment, and oven dried to a constant weight at 50 C for biomass determination.

Data from both experiments were subjected to analysis of variance and means were separated using Fisher's Protected LSD ($P \leq 0.05$). Competition treatments in experiment 1 resulted in the following 12 experimental treatments for data analysis: bushkiller planted alone, trumpet creeper planted alone, wild grape planted alone, bushkiller in bushkiller and trumpet creeper planted together (BKTC), trumpet creeper in BKTC, bushkiller in bushkiller plus wild grape (BKWG), wild grape in BKWG, trumpet creeper in trumpet creeper plus wild grape (TCWG), wild grape in TCWG, bushkiller in bushkiller plus trumpet creeper plus wild grape (BKTCWG), trumpet creeper in BKTCWG, and wild grape in BKTCWG. To analyze growth over time in experiment 1, a repeated measures linear mixed model with time as an independent variable and treatment as a class variable was fitted (SAS Institute Inc. 2008). Both time and treatment were considered fixed effects. The model included a separate intercept and slope for each experimental treatment. Treatment effects represented differences in the intercepts for the regression lines of growth on time, while treatment by time interaction represented the separate slopes fitted. Type III tests of fixed effects were used for testing treatment (intercept) and time (slope) effects after all other effects were included in the model, i.e., significance of treatment slopes on time were tested conditional on the observed intercepts and similarly when testing treatment effects (West et al., 2005). Pairwise comparisons of slopes between treatments were made using the ESTIMATE statement in SAS PROC MIXED. In experiment 1, linear regression curves of height growth on time ($y = y_0 + a_x\text{Time}$) were modeled in SAS. In experiment 2, linear regression curves of final biomass and number of leaves per plant ($y = y_0 + a_x$) were modeled in SAS. No treatment by repetition interactions were observed, therefore data were pooled by experiment.

Results and Discussion

Height growth rates, represented by the magnitude of the slope of the regression curves (Figure 1) separated by species regardless of competition. When grown alone, the slope of bushkiller was 49.5 and greater than trumpetcreeper and wild grape at 38.1 and 8.7, respectively (Table 1). Rapid elongation rate is a trait common of invasive vines that make them structural parasites in a forest community (Forseth and Innis 2004). Slope estimates for bushkiller and wild grape height when in competition did not differ from the slopes for the two species when grown alone. However, the slope for trumpetcreeper was negatively affected when grown in competition with bushkiller or bushkiller and wild grape. No significant differences (p=0.84) were found between intercepts for the separate regression lines.

Grown alone, final heights of bushkiller, trumpetcreeper, and wild grape were 276, 217, and 54 cm, respectively (Table 2). Bushkiller and wild grape heights did not differ when grown in competition as compared to heights when grown alone. Trumpetcreeper was 102 cm shorter when grown with both bushkiller and wild grape than when grown alone. When bushkiller, trumpetcreeper, and wild grape were grown together, their final heights were 266, 114, and 37 cm, respectively. Bushkiller was the only species to produce inflorescences, and when in competition with trumpetcreeper the number produced was lower than when grown alone or with wild grape.

The average above-ground biomass of bushkiller grown alone was 221 g (Table 2). This value was 102 g greater than trumpetcreeper grown alone and 168 g greater than wild grape grown alone. Bushkiller biomass was reduced when grown with trumpetcreeper, but did not differ when grown with wild grape or both species. Trumpetcreeper biomass was 119 g grown alone, and this value dropped to 15 and 20 g when grown in competition with bushkiller or bushkiller and wild grape. Wild grape biomass was 20 to 53 g when grown alone or in competition, with no significant difference in these values.

In experiment 2 the mean final height of bushkiller was not significantly different when grown in treatments of one, two, or three plants and ranged from 306 to 314 g (data not presented). The final biomass however, was 244 g for one plant, 220 g for two plants, and 216 g for three plants with a significant linear decrease (Figure 2). Likewise, the number of leaves per plant decreased in a linear fashion from 37 to 26.

In final height and biomass, bushkiller exceeded trumpetcreeper and wild grape whether grown alone or in competition. These differences may indicate bushkiller as the superior resource competitor. The significant increase in final height of bushkiller when grown with wild grape versus bushkiller grown alone may indicate neighboring vine species stimulate bushkiller elongation or serve as a ladder for bushkiller shoot support. Final shoot height and final biomass of trumpetcreeper grown alone was negatively impacted when grown in competition with bushkiller or bushkiller and wild grape, but not when grown with wild grape. The effects of an exotic species on a native species, and the effects of the native species competing with other native species are important comparisons when quantifying interspecific competition. If the exotic species is competitively superior to natives, it is expected to affect growth of native species more than coexisting natives (Vila and Weiner 2004). Wild grape was not affected by its coexisting native, trumpetcreeper, nor vice-versa, however, bushkiller negatively affected trumpetcreeper growth. This indicates that aggressive competition is absent between the two native species but bushkiller is the competitively superior species (Firbank and Watkinson 2008; Goldberg 1996; Harper 1977).

In experiment 2, intraspecific competition had no effect on bushkiller height, however, there was a difference in biomass and leaf number as affected by plant density. We conclude that this plant may thrive in monoculture, although per plant biomass and leaf number may decrease as density increases.

The interspecific competition experiment was conducted during the initial stages of plant development, with all plants starting at an average of 30 cm in height. The dynamics of the interactions between these species may change significantly over an extended period beyond the length of this experiment (Connolly 2001). In natural systems, the transition from primary to secondary succession in a forest brings changes such as light and soil properties, soil-vegetation feedbacks, biomass accumulation, productivity, accumulation, and species composition (Guariguata and Ostertag 2001). The interspecific and intraspecific competition examined in this experiment indicate that the structural and functional properties of an ecosystem will be significantly altered to the detriment of native vine (and other) species when the exotic bushkiller vine is introduced.

Literature Cited

Aerts, R. 1999. Interspecific competition in natural plant communities: mechanisms, trade-offs, and plant-soil feedbacks. Exp. Bot. 50: 29-37.

Brown, L.E. 1992. *Cayratia japonica* (Vitaceae) and *Paederia foetida* (Rubiaceae) adventive in Texas. Phytologia 72(1): 45-47.

Burns, J. H. and A. A. Winn 2006. A comparison of plastic responses to competition by invasive and non-invasive congeners in the Commelinaceae. Bio. Inv. 8: 797-807.

Connolly, J., P. Wayne, and F. A. Bazzaz. 2001. Interspecific competition in plants: how well do current methods answer fundamental questions? Am. Nat. 157: 107-125.

Cousens, R. 1991. Aspects of the design and interpretation of competition (interference) experiments. Weed Tech. 5: 664-673.

Firbank, L. G. and A. R. Watkinson. 1985. On the analysis of competition within two-species mixtures of plants. Appli Ecol. 22: 503-517.

Forseth, I. N. and A. F. Innis. 2004. Kudzu (*Pueraria montana*): history, physiology, and ecology combine to make a major ecosystem threat. Criti. Revi. in Plant Sci. 23: 401-413.

Fraser, L.H. and P.A. Keddy. 2005. Can competitive ability predict structure in experimental plant communities? Veg. Sci. 16: 571-578.

Freckleton, R. P. and A. R. Watkinson. 2000. Designs for greenhouse studies of interactions between plants: an analytical perspective. Journal of Ecology. 88: 386-391.

Gibson, D. J., J. Connolly, D. C. Hartnett, and J. D. Weidenhamer. 1999. Designs for greenhouse studies of interactions between plants. Ecology. 87: 1-16.

Goldberg, D. E. 1996. Competitive ability: definitions, contingency, and correlated traits. Philo. trans. bio. sci. 351: 1377-1385.

Goldberg, D. E. & Landa, K. 1991 Competitive effect and response: hierarchies and correlated traits in the early stages of competition. J. Ecol. 79, 1013-1030.

Grime, J.P. 1973. Competitive exclusion in herbaceous vegetation. Nature 242: 344-347.

Guariguata, M.R. and R. Ostertag. 2001. Neotropical secondary forest succession: changes in structural and functional characteristics. Forest Ecology and Mgmt. 148: 185-206.

Hansen, C. J. and L. R. Goertzen**.** 2006. *Cayratia japonica* (Vitaceae) naturalized in Alabama. Castanea 71: 248–251.

Harper, J. L. 1977. Population Biology of Plants. Academic Press, London.

Hsu, Tsai-Wen and C. Kuoh. 1999. *Cayratia maritima* B.R. Jackes (Vitaceae), a new addition to the flora of Taiwan. Bot. Bull. Acd. Sin. 40: 329-332.

Krings, A. and R.J. Richardson. 2006. *Cayratia japonica* (Vitaceae) New to North Carolina and an updated key to the genera of Vitaceae in the Carolinas. SIDA 22: 813-815.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1991. SAS® System for Mixed Models. Cary, NC: SAS Institute Inc.

McDonald, R.I. and D.L. Urban. 2006. Edge effects on species composition and exotic species abundance in the North Carolina Piedmont. Biological Invasions 8: 1049-1060.

Riitters, K.H., J.D. Wickham, R.V. O'Neill, K.B. Jones, E.R. Smith, J.W. Coulston, T.G. Wade, and J.H. Smith. 2002. Fragmentation of continental United States forests. Ecosystems 5: 815-822.

Robinson, T. R., R. R. Sargent, and M. B. Sargent. 1996. Ruby-throated hummingbird (*Archilochus colubris*). The Birds of North America, No. 204 (A. Poole and F. Gill eds.). The Birds of North America, Inc., Philadelphia, PA. 16 pp.

SAS Institute Inc. 2008. *SAS OnlineDoc® 9.1.3*. Cary, NC: SAS Institute Inc.

Shinners, L.H. 1964. *Cayratia japonica* (Vitaceae) in southeastern Louisiana: new to the United States. Sida 1:384.

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?410986 Accessed April 10, 2008.

USDA-NRCS. 2006. The PLANTS Database (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 United States. Accessed August 30, 2008.

Vila, M. and J. Weiner 2004. Are invasive plant species better competitors than native plant species? – evidence from pair-wise experiments. Okios 105: 229-238.

West, B., K. B. Welch, B. Gillespie, and A. T. Galecki. 2005. Linear Mixed Models: A Practical Guide Using Statistical Software. CRC Press. 353 pp.

Table 1. Slope estimates and slope comparisons in experiment 1[a] .

Species/Pairwise Comparison	Slope Estimate	Slope Comparsion	P-value
Bushkiller alone	49.54 ± 5.24	-------	-------
Bushkiller with trumpetcreeper	53.06 ± 5.24	-3.52	NS
Bushkiller with wild grape	58.57 ± 5.24	-9.03	NS
Bushkiller with both	50.57 ± 5.24	-1.03	NS
Trumpetcreeper alone	38.14 ± 4.14	-------	-------
Trumpetcreeper with bushkiller	25.23 ± 5.85	12.91	0.029
Trumpetcreeper with wild grape	39.67 ± 5.85	-1.53	NS
Trumpetcreeper with both	19.66 ± 5.85	18.48	0.002
Wild grape alone	8.73 ± 1.50	-------	-------
Wild grape with bushkiller	4.66 ± 1.50	4.07	NS
Wild grape with trumpetcreeper	10.43 ± 2.12	-1.70	NS
Wild grape with both	6.31 ± 2.12	2.42	NS

[a] Growth rate comparisons using the slope of height increase over time. Slopes were compared via pairwise comparisons of the slope of each species in monoculture versus its

Table 1. Continued.

slope in competition with one or both other species. A significant p-value indicates that the growth rate of a species in monoculture differs from its growth rate in mixture.

Table 2. Average height, dry biomass, and inflorescence number in experiment 1 (6 WAI)[a].

Treatment/Species	Height[b]	Dry biomass	Inflorescence
	cm	g	#
BK alone	267 ab	220.9 a	14 a
BK in grown with TC	280 ab	170.6 b	9 b
BK grown with WG	313 a	205.5 ab	15 a
BK grown with TC and WG	266 ab	209.6 ab	9 b
TC alone	216 bc	118.5 c	0 c
TC grown with BK	145 cd	15.3 d	0 c
TC grown with WG	212 bc	93.3 c	0 c
TC grown with BK and WG	114 de	20.0 d	0 c
WG alone	54 e	53.1 d	0 c
WG grown with BK	39 e	19.9 d	0 c
WG grown with TC	62 de	36.0 d	0 c
WG grown with BK and TC	83 de	42.6 d	0 c

Table 2. Continued.

[a] Abbreviations: WAI, weeks after initiation; BK, bushkiller; TC, trumpetcreeper; WG, wild grape.

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

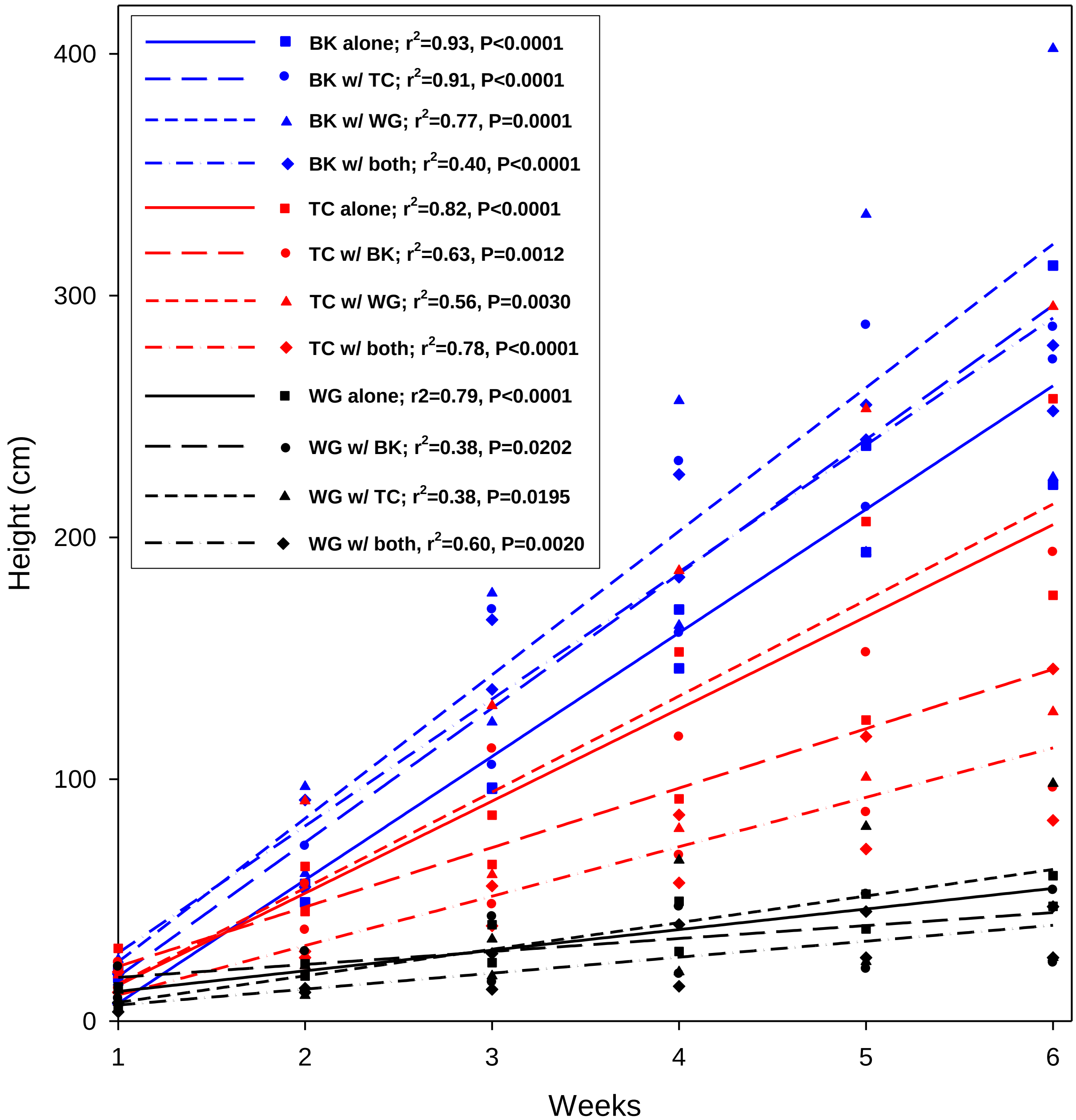


Figure 1. Rate of growth ($y = y_0 + a_x Time$) for bushkiller (BK), trumpetcreeper (TC) and wild grape (WG) grown alone and in interspecific competition.

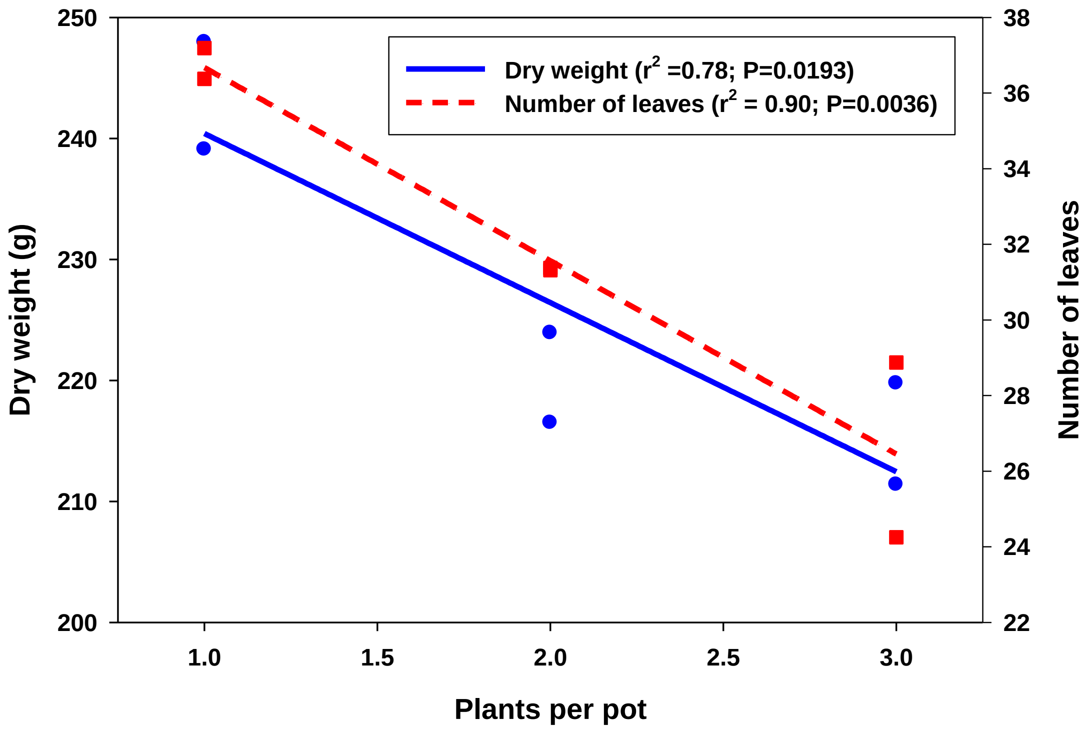


Figure 2. Dry weight at densities of 1, 2, and 3 bushkiller plants per pot and number of leaves per plant in experiment 2 (intraspecific competition).

Chapter 4

A Risk Assessment for a Potential Federal Noxious Weed: Bushkiller

Abstract

The USDA-APHIS template entitled "Weed-Initiated Pest Risk Assessment Guidelines for Qualitative Assessments" was used to develop a risk assessment for the potentially noxious weed, bushkiller [*Cayratia japonica* (Thunb.) Gagnep]. Components of the model include plant biology, climatic tolerance, pest status, consequences of introduction, spread and dispersal potential, economic impact, environmental impact, and other criteria. Ratings of negligible, low, medium, and high risk along with associated point values are assigned to various subcategories and then used to calculate the final assessment. Within the native range, bushkiller tolerates winter temperatures as low as -7° C, summer temperatures greater than 42 C, and average annual precipitation from 60 to 1,100 cm. Native range data was used to project potential range in the United States using the CLIMEX model. Model output suggested that bushkiller could survive minimum temperatures across most of the continental United States. A limitation to the spread of buskiller in the United States is lack of viable seed production. However, bushkiller does spread by vegetative means and has done so in North Carolina. Bushkiller would be expected to reduce crop yield and quality on infested sites and would lower commodity value, but is not expected to cause a loss of foreign markets due to the presence of a quarantine pest. Bushkiller has reduced community structure and plant diversity on affected sites, thus resulting in high environmental impact. As a final result, bushkiller was ranked as medium-high risk potential to the United States, and we recommend that it be listed at the Federal level, the state level (North Carolina), or both.

Introduction

Plants introduced into the United States may pose threats to natural and agricultural systems and should be closely monitored. Ballast water, boats, aquaculture, aquarium releases, live food, vehicles, ornamental trade, and government programs are just a few examples of potential introduction methods for exotic plants into the United States. Invasive species are estimated to cost the United States economy $120 billion per year (Pimentel et al. 2005). Of the 25,000 non-indigenous plant species in the United States, an estimated 5,000 have escaped into natural ecosystems (Cronk and Fuller 1995; Pimentel et al. 2005). About 42% of the species listed as threatened or endangered under the Endangered Species Act in the United States have seen their populations dwindle primarily due to the invasion of non-indigenous species (Pimentel et al. 2005).

Under the Plant Protection Act, Title 7 United States Code § 7701-7786. 2000 the United States Department of Agriculture - Animal and Plant Health Inspection Service (APHIS) lists in the noxious weed regulations (7 CFR § 360) those plant species officially designated as noxious weeds (APHIS 2000). The Act defines “noxious weed” as “any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment” (APHIS 2000). Under international agreements, a signatory country can prohibit importation only of quarantine pests (APHIS 2000). A quarantine pest is defined as “a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled”(ISPM #5, IPPC 2007). APHIS lists in the noxious weed regulations only weeds that meet the definition of a quarantine pest (APHIS 2000).

Bushkiller is an invasive plant in the grape family (Vitaceae) that was first documented in the United States in 1964 in Texas (Brown 1992). Since then, it is known to have spread to Alabama, Louisiana, Mississippi, and North Carolina (Hansen and Goertzen 2006; Koop and Dubon 2007; Krings and Richardson 2006; Shinners 1964; USDA-NRCS 2006). Our objective was to use the APHIS template entitled “Weed-Initiated Pest Risk Assessment Guidelines for Qualitative Assessments” to evaluate the level of risk associated with the establishment and spread of bushkiller in the United States, and thereby if this plant should be listed as a noxious weed at the Federal or state (North Carolina) level.

Methods and Results

Methods were divided into stages following the “Weed-Initiated Pest Risk Assessment Guidelines for Qualitative Assessments” template (modified from APHIS 2000).

Stage 1: Initiating Pest Risk Analysis Process. *Step 1.* Document the initiating event for the pest risk assessment. This event occurred when a plant specimen was sent to North Carolina State University (NCSU) from Winston Salem (Forsyth County) for identification. Alexander Krings, curator of the NCSU herbarium, identified the specimen as bushkiller

[*Cayratia japonica* (Thunb.) Gagnep] (Krings and Richardson 2006). The specimen was collected in August 2005 in a residential area where homeowners expressed concern about the aggressive growth of the plant. This vine has a growth habit resembling kudzu [*Pueraria lobata* (Willd)], suggesting that it may cause similar economic and environmental damages. Concerns associated with bushkiller are typical of invasive perennial vines and include the displacement of native vegetation and wildlife, increased control costs in right-of-way and natural areas, and diminished aesthetic value of land (Van Driesche et al*.* 2002).

After an initial application of triclopyr did not control bushkiller at the Winston Salem site (A. West personal observation) concern mounted about effective control measures for this weed. A Bushkiller Task Force was formed in North Carolina consisting of Forsyth County master gardeners, concerned homeowners, students and faculty at NCSU, and North Carolina Department of Agriculture and Consumer Services (NCDA & CS) personnel that joined in an attempt to contain the infestation. In 2007, six additional infestations were found in Charlotte, North Carolina and Lexington, North Carolina (Soule et al. 2008). The city of Charlotte, North Carolina initiated funding of bushkiller eradication measures, promoting the importance of the weed risk assessment.

Step 2. Identify any prior risk assessments made for the weed*.* After an extensive literature review, no prior risk assessments were found for bushkiller in the United States.

Step 3. Establish the identity of the weed. Using available literature and personal observation from field populations and greenhouse-propagated bushkiller, the following information was documented about the species.

The botanical name for bushkiller is *Cayratia japonica* (Thunb.) Gagnep, and it is a member of the Vitaceae family. Synonyms include *Cissus japonica* (Willd.), *Cissus obovata* (Lawson), *Columella japonica* (Thunb.) Merr. and *Vitis japonica* (Thunb.) (USDA-ARS 2008; USDA-NRCS 2006). The accepted common name is bushkiller in the United States, while in the native range it is often called sorrel vine, java, javan grape, or yabugarashi (Chinese) (USDA-ARS 2008; USDA-NRCS 2006) Bushkiller is a perennial, herbaceous vine with stems much elongate, branched, and striate (Ohwi et al. 1984). Young parts of the stem are furfuraceous, short-puberulent and flat with a purplish tint (Ohwi et al. 1984). Tendrils are bifurcating, not disc-tipped, and develop opposite the leaves (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Leaves are petiolate, pedate quinquifoliate with leaflets ovate, marginally serrate, 1.5 to 4 cm broad and 3 to 8 cm long with a central leaflet longer and broader than the other 4 leaflets (Ohwi 1984). Some leaves may have 3 leaflets or 7 leaflets with the majority of the leaves being pedate quinquifoliate (A. West personal observation). The inflorescence of bushkiller is axillary, corymbose or umbellate with short granular hairs (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Flowers are bisexual, short-pedicellate, 5 mm, with 4 green deflexed, deltoid-ovate petals and 4 stamens opposite the petals, disc is red, salmon-colored, yellow to white depending on stage, anthers are ellipsoid, style is conical and short, and stigma is minute (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Fruit is fleshy, black, and rounded with 2 to 4 ridged seeds (Hsu and Kuoh 1998; Krings and Richardson 2006; Ohwi et al. 1984). Roots of bushkiller are creeping at the juvenile stage (A. West, personal observation) Aggressive rhizomes develop with maturity and readily produce new shoots (Ohwi 1984).

Thus far in the United States, bushkiller has only been reported to reproduce asexually, mostly through adventitious shoots from roots (Alford 2003; Brown 1992; Shinners 1964). Pollinators including but not limited to honeybees, wasps, and ants have been observed visiting flowers on all bushkiller populations in North Carolina for 3 growing seasons (A. West personal observation). Typically across its range in the United States (Texas, Louisiana, Mississippi, Alabama, and North Carolina), flowers abort and fruit do not develop to maturity (Alford 2003; Brown 1992; GBIPG 2007). However, in 2007, fruit was observed on some individuals of the Charlotte, North Carolina population; these remained green and abscised before ripening to maturity (A. West personal observation). Roots/rhizomes have been dug from a meter underground at North Carolina infestations (A. West personal observation), with prolific shoot production at all depths. While shoots have died back in the winter at these sites, roots/rhizomes overwintered and were producing new shoots by April of the following growing season.

The genus *Cayratia* includes 63 species distributed throughout Africa, Asia, Australia, and the Pacific Islands (USDA-ARS 2008). Bushkiller is distributed primarily in Southeast Asia, Japan, India, Malaysia, Australia, and has also been documented in Taiwan (USDA-ARS 2008; USDA-NRCS 2008). Beyond the native distribution, bushkiller has been documented in Texas, Louisiana, Mississippi, Alabama, and North Carolina, United States (Figure 1) (Koop and Dubon 2007). Bushkiller is commonly found in a range of ecosystems, including grasslands, rural fields, and sub-tropical to tropical forests (Kakutani 1989; Ohwi 1984). Portions of Northeast India (Assam, Meghalaya, Sikkim, Nagaland, Manipur, Mizoram, and Tripura) where bushkiller is native are some of the wettest regions of the world, due largely to seasonal rainfall from monsoons (Anonymous 2008a; USDA-ARS 2008). Northeast India has average annual temperatures ranging from 10 to 42 C and an average yearly rainfall of 200 cm, with a maximum annual precipitation of 1100 cm of rainfall per year (Anonymous 2008a; Kaman 2008). In Queensland, Australia, bushkiller has been recorded growing in areas where average annual rainfall is 60 to 80 cm (AVH 2008). In Japan, the northernmost extent of bushkiller habitat range is Hokkaido, where winter temperatures drop to -7 degrees C (USDA-ARS 2008). This climatically diverse native range may indicate great phenotypic plasticity of bushkiller.

Stage 2: Assessing pest risk. *Step 4.* Verify quarantine pest status using geographic and regulatory criteria. The International Plant Protection Convention defines a quarantine pest as one having “potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled” (IPPC 2007). It is unknown how bushkiller was introduced into the United States, however a homeowner in Winston Salem (Ken Foster, personal communication 2006) stated that the plant may have been introduced as an ornamental. This has not been confirmed.

In the 5 states where bushkiller has been found (Texas, Louisiana, Mississippi, Alabama, and North Carolina), it only occurs in a limited set of counties (Koop and Dubon 2007), and eradication may be possible. Supporting quarantine pest status (sensu IPPC), there is strong interest in eradication and management. In North Carolina the status of bushkiller is being reviewed as a class B noxious weed (North Carolina Administrative Rules Commission) (Rick Iverson, personal communication). In Charlotte, North Carolina, the city initiated an eradication program in 2008 (Jim Matthews, personal communication). Property owners in all North Carolina counties where bushkiller is found have expressed a desire to eradicate this plant from their properties.

Step 5. Assess the economic and environmental importance of the weed. There were 5 parts to step 5, labeled A, B, C, D, and E. Scores for parts A, B, C, and D of step five were rated on a scale of negligible, low, medium or high with associated score values 0, 1, 2, or 3, respectively. These values were totaled in part E for an overall economic and environmental risk summary (Table 4).

Part A. Identify the establishment potential and habitat suitability for the weed. The CLIMEX program (DYMEX simulator 2.0) was used to model the potential range of bushkiller in the United States. Match climates is a function of the CLIMEX program that takes one location and matches it to another location based on environmental variables such as maximum temperature, minimum temperature, total rainfall, relative humidity, rainfall pattern, and soil moisture, respectively. The environmental variable selected to model the potential range of bushkiller in the United States was minimum temperature. Two geographic locations were selected for input to the program: the southernmost (Queensland, Australia) and the northernmost (Hokkaido, Japan) extent of bushkiller in the native range. The minimum temperatures in these locations were matched to minimum temperatures in the United States. Two maps were produced by CLIMEX, one showing regions in the United States matching climates in Queensland and one showing regions in the United States matching climates in Hokkaido (Figure 2).

Bushkiller was given a rating of high with an associated score of 3 for habitat suitability based on the CLIMEX model output (Table 4). These models and the wide range of habitats in the native range of bushkiller suggest it could thrive in most of the United States.

Part B. Evaluate the biological attributes of the weed that allow it to spread and identify dispersal mechanisms (Table 1). Bushkiller readily produces new shoots from newly developed root tissue (A. West, personal observation). New shoots will emerge from root fragments as small as 1 cm in length buried to a depth of 20 cm or 5 cm root length buried to a depth of 40 cm (A. West, unpublished data). To date, dispersal in the United States may be limited to root fragments because plants have not yet been observed to produce mature fruit (A. West personal observation; Alford 2003; Brown 1992). However, if diploid individuals are found, the potential for natural spread becomes much greater. In Japan, diploid and triploid individuals have been found within the same population (Okada et al. 2003). Both ploidy levels produced fruit, however only some of the diploid individuals produced viable seed. Research suggests that bushkiller may exist in a self-pollinating state and low pollen fertility may explain why some diploid individuals produce fruits and others do not (Kakutani et al. 1989; Okada et al. 2003).). Because the fruit are fleshy (Vitaceae family), seeds will likely be dispersed when birds consume the fruit.

Based on these factors, bushkiller was rated as medium risk with an associated score of 2 for spread and dispersal mechanisms based on a high reproductive potential (Table 4). This rating would be promoted to high if individuals were found producing viable seed in the United States, because bushkiller would then have both a high reproductive potential and highly mobile propagules.

Part C. Evaluate the economic impact associated with the introduction of the weed (Table

2). Bushkiller outcompeted trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau] in an inter-specific competition trial (A. West unpublished data). Redvine [*Brunnichia ovata* (Walter) Shinners] and trumpetcreeper are among the 10 most troublesome weeds in cotton (*Gossypium hirsutum* L.), soybean (*Glycine* Willd.), and corn (*Zea mays* L.) in the midsouthern United States (Reddy 2005). These vines reduce crop yield and quality as well as harvest efficiency and it has been observed that even low densities of trumpetcreeper can interfere with soybean and that one trumpetcreeper plant per 0.5 m^2 can cause 18% yield loss (Reddy 2005).

In no-till agronomic systems, bushkiller may be even more problematic as the extensive root tissue storage will not be hindered and glyphosate may not control the plant (A. West, unpublished data). In Lexington, North Carolina, this plant has become problematic for a fruit and mushroom producer (Brad Owen, personal communication). Bushkiller was listed as an economically important foreign weed by APHIS in 1977 (Reed 1977) and has been illustrated in Farmland Weed in China (Zhirong 1990) as damaging to dry-land crops and fruit trees.

The costs of control for this plant are expected to be significant, as repeated seasons of triclopyr application to bushkiller have proven unsuccessful thus far at the Winston Salem site (A. West, personal observation). Herbicides used in an attempt to control bushkiller at Mercer Botanic Garden in Texas resulted in only 30% control over a period of three years

(Tu 2001). Furthermore, bushkiller roots become dormant when covered with heavy mulch, allowing regeneration thereafter (GBIPG, 2007). No further work has documented control of this plant. Hand-weeding is not considered a viable bushkiller control option due to the extensive root system and the ability of this plant to regenerate a new shoot from very small root fragments (A. West personal observation). As a perennial vine with such regeneration capacity, bushkiller has the potential to create problems in orchards, agroforestry, no-till agronomic systems, and the nursery trade. Initial results in greenhouse experiments found bushkiller producing 5 to 10 times the biomass of native trumpetcreeper and wild grape plants (A. West unpublished data). Additionally, bushkiller may also serve as a host to chilli thrips (*Scirtothrips dorsalis* Hood), a polyphagous exotic pest that has been identified as a threat to over 20 crops in Florida (Hodges et al. 2005).

Two of the three primary types of economic damage apply to bushkiller, reduced crop yield and lowering commodity value. This yields a high risk rating with an associated score of 3 for economic impact of bushkiller (Table 4).

Part D. Assess the environmental impact of the weed (Table 3). Community structure may change dramatically as bushkiller creates a new canopy; this has been noted at the Charlotte, North Carolina site where it is forming a monoculture (A. West, personal observation). In creating a new canopy, bushkiller will displace native flora and fauna. In the same manner, bushkiller may also pose a threat to endangered or threatened species populations in communities where it becomes established. There is no direct evidence of bushkiller altering fire regimes in an ecosystem; however as a climbing vine species it has the potential to serve as a fuel ladder in forest fires. The Charlotte, Winston Salem, and Lexington sites in North Carolina are within or bordering residential areas, causing concern for homeowners whose trees, shrubbery, and other landscaping attributes are being negatively affected by bushkiller (personal communications with homeowners, 2006 and 2007).

Bushkiller meets at least three of the environmental criteria, yielding a rating of high with an associated score of 3 for environmental impact (Table 4). Bushkiller has the potential to cause major damage to the environment with significant losses to plant ecosystems and subsequent physical environmental degradation.

Part E. Sum parts A through D, indicating the consequences of introduction risk rating (Table 4). Risk ratings are negligible (sum= 0 to 2), low (sum= 3 to 6), medium (sum= 7 to 10) and high (sum= 11 to 12). The total numeric score for bushkiller was 11, indicating a high risk rating for consequences of introduction. This summary of economic and environmental criteria indicates bushkiller establishment and spread, and potential economic and environmental impacts.

Step 6. Assess the likelihood of introduction into the United States. Bushkiller is already established in the United States, so there was no need to assess the likelihood of introduction. We considered instead the likelihood of continued introduction. It appears that all known populations in the United States are triploid based upon lack of sexual reproduction and preliminary chromosome testing (A. West, unpublished data; Alford 2003; Brown 1992; Shinners 1964), therefore emphasis should be placed on preventing introduction of diploid individuals that may initiate sexual reproduction.

Bushkiller has medicinal value in Southeast Asia, where its stem bark is used as an antidote, boiled leaves are applied to the head for violent headaches, dried and powdered flowers are employed for fever, and aerial parts are applied for fever and malaria (IMPGC 2008). This may result in interest in cultivation in the United States. Bushkiller produces unusual flowers for 5 months of the growing season and has potential to be considered a great ground cover in landscaping, increasing the interest in cultivation and trade of this plant in the nursery industry. After an extensive search in nursery catalogs and online, bushkiller was not found for sale in the United States, as of December 2008.

The overall likelihood of introduction risk rating was medium with an associated score of 2 for bushkiller (Table 5). This risk rating may be moved to high if diploid individuals and/or viable seed are found in the United States. Seed production would create a vector for long range and continuous dispersal via birds or mammals.

Step 7. Determine the overall pest risk potential of the weed. An estimate of pest risk potential was produced by considering the consequences of introduction and the likelihood of introduction scores (Table 5). The overall pest risk potential is calculated from the sum of scores for likelihood of introduction and consequences of introduction. The overall pest risk potential for bushkiller was medium-high.

Discussion

Bushkiller has an overall pest risk potential of medium-high based on information to date. This conclusion is based on the following: vast potential geographic distribution, rapid growth and competitiveness, ability of roots to overwinter and produce new shoots from very small fragments buried to depths up to 40 cm, potential for successful seed germination, limited effective control techniques, and numerous other economic and environmental concerns. Bushkiller meets the definition of a potential noxious weed under the Plant Protection Act, therefore we recommend that importation of this plant or plant products be prohibited in the United States. This plant is present but not widely distributed in the United States at this time. Bushkiller has been found in point locations in TX, LA, MS, AL, and NC. Though not known to be sold commercially, potential medicinal and landscape uses may create interest leading to a new market encouraging the spread of this weed. This risk assessment suggests further measures should be taken to list this plant as a noxious weed at the Federal level, the State level, or both.

Literature Cited

Alford, M.H. 2003. Noteworthy collections: Mississippi. Castanea 68:93

Anonymous. 2008a. North East India: India Tourism Network. http://www.north-east india.com/. Accessed August 29, 2008.

APHIS 2000. United States Department of Agriculture- Animal and Plant Health Inspection Service. Pest risk assessment tempelate version 5.3. http://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/weedriskassmnt99.shtml/. Accessed May 10, 2008.

AVH. 2008. Australia's Virtual Herbarium (AVH) public access map: *Cayratia japonica.* Royal Botanic Gardens Melbourne. http://www.rbg.vic.gov.au/. Accessed September 3, 2008.

Brown, L.E. 1992. *Cayratia japonica* (Vitaceae) and *Paederia foetida* (Rubiaceae) adventive in Texas. Phytologia 72: 45-47.

Cronk, Q. and J. Fuller. 1995. Plant Invaders: The Threat to Natural Ecosystems. Chapman and Hall, London, U.K.

Galveston Bay Estuary Program (GBIPG). 2007. The quiet invasion: a guide to the invasive plants of the Galveston bay area. Houston Advanced Research Center and Galveston

Bay Estuary Program. http://www.galvbayinvasives.org/. Accessed March 5, 2008.

Hansen, C. J. and L. R. Goertzen**.** 2006. *Cayratia japonica* (Vitaceae) naturalized in Alabama. Castanea 71: 248–251.

Hodges, G., G. B. Edwards, and W. Dixon. 2005. *Pest Alert: Chilli thrips* Scirtothripsdorsalis *Hood (Thysanoptera: Thripidae): A new pest thrips for Florida.* Florida Dept. of Ag. & Consumer Services, Division of Plant Industry. http://www.doacs.state.fl.us/pi/enpp/ento/chillithrips.html/ Accessed September 9, 2008.

Hsu, Tsai-Wen and C. Kuoh. 1999. *Cayratia maritima* B.R. Jackes (Vitaceae), a new addition to the flora of Taiwan. Bot. Bull. Acd. Sin. 40: 329-332.

Indian Medicinal Plant Growers' Consortium (IMPGC). 2008. http://www.impgc.com/plantinfo_A.php?id=1941. Accessed 02/20/2008

International standards for phytosanitary measures (IPPC). 2007. 1 - 27. International Plant Protection Convention and the Food and Agriculture Organization of the United Nations, Rome.

Kakutani, T., T. Inoue, and M. Kato. 1989. Nectar secretion pattern of the dish-shaped flower, *Cayratia japonica* (Vitaceae) and nectar utilization patterns by insect visitors.

Res. Popul. Ecol. 31: 381-400.

Kaman, B. 2008. Water Management in Northeast India. Assam Times. http://www.assamtimes.org/blog/1276.html. Accessed September 3, 2008.

Krings, A. and R.J. Richardson. 2006. *Cayratia japonica* (Vitaceae) new to North Carolina and an updated key to the genera of Vitaceae in the Carolinas. SIDA 22: 813-815.

Koop, A. and S. Dubon 2007. Animal and Plant Health Inspection Service (APHIS): New Pest Advisory Group (NPAG) report for *Cayratia japonica* (Thunb. Ex Murray) Gagnep: Bush killer. Doc. 20071019

Ohwi, J., F. Meyer, and E. Walker. 1984. Flora of Japan. Smithsonian Institution. Washington, D.C. pp. 618-620.

Okada, H., H. Tsujaya, and M. Okamoto. 2003. Intra-specific polyploidy and possible occurance of some genetic types for pollen development in *Cayratia japonica*, Vitaceae. Acta Phytotax. Geobot. 54: 69-75.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Eco. Econ. 52: 273-288.

Reddy, K.N. 2005. Deep tillage and glyphosate-reduced redvine (*Brunnichia ovata*) and trumpetcreeper (*Campsis radicans*) populations in glyphosate-resistant soybean. Weed Tech. 19: 713-718.

Reed, C. F. 1977. Economically Important Foreign Weeds: Potential Problems in the United States. Agriculture handbook No. 498, USDA-APHIS. pp. 411.

Shinners, L.H. 1964. *Cayratia japonica* (Vitaceae) in southeastern Louisiana: new to the United States. Sida 1: 384.

Soule, J. T. J. Matthews, K. C. Blackmon, and T. L. Mellichamp. 2008. Noteworthy collections: North Carolina observations on the invasive *Cayratia japonica* (Vitaceae) in North Carolina, including six new records for the state. Castanea 73: 42-45.

Suzuki, K., K. Hirose, and K. Kawase. 1988. Studies on weed control in a citrus orchard. III. Control of broad leaf perennial weeds. Bulletin of the Fruit Tree Research Station, B Okitsu, Japan. 15: 21-34.

Tu, M. 2001. Weed Alert! *Cayratia japonica* (Thunb. ex Murray) Gagnep. (bushkiller, sorrel vine). http://tncweeds.ucdavis.edu/alert/alrtcayr.html Accessed October 21, 2008.

USDA-NRCS. 2006. The PLANTS Database (http://plants.usda.gov) National Plant Data Center, Baton Rouge, LA 70874-4490 United States. Accessed February 20, 2008.

USDA-ARS, National Genetic Resources Program. 2008. *Germplasm Resources Information Network - (GRIN)* [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?410986/. Accessed April 10, 2008.

Van Driesche, R., *et al.*, 2002, Biological Control of Invasive Plants in the Eastern United States, USDA Forest Service Publication FHTET-2002-04, p. 413

Zhirong, W. 1990. Farmland Weeds in China: A Collection of Coloured Illustrative Plates. Agriculture Publishing House, Beijing, China. pp. 167.

Table 1. Biological attributes of bushkiller that allow spread and dispersal mechanisms[1] (applicable indicated by YES; not applicable indicated by NO) (Modified from APHIS 2000).

Biological attribute	Applicable?
Consistant and prolific seed production	NO
Rapid growth to reproductive maturity	YES
High germination rate under a wide range of conditions	NO
Ability to suppress growth of other plants by releasing a chemical inhibitor	NO
Ability to persist as dormant underground propagules	YES
Seed dormancy	NO
Stress tolerance, including the ability to resist herbicides	YES
Ability to colonize a wide variety of habitats	YES
Lack of natural control agents	YES
Well developed storage tissue	YES
Dispersal by wind, water, machinery, animals, and/or humans	YES

Table 1. Continued.

[1] Sources: A. West, personal observation; Brown 1992; GBIPG 2007; Hsu 1999; Kakutani 1989; Krings and Richardson 2006; Okada et al. 2003; USDA-ARS 2008; USDA-NRCS 2006.

Table 2. Economic impacts associated with bushkiller[1] (applicable indicated by YES; not applicable indicated by NO) (Modified from APHIS 2000).

Economic impact	Applicable?
Reduced crop yield (*e.g.* parasitism, competition, or harboring pests)	YES
Lowering of commodity value (*e.g.* increasing cost of production or control costs)	YES
Loss of markets (foreign or domestic) due to the presence of a new quarantine pest	NO

[1] Sources: A. West, unpublished data; Brad Owen, personal communication; GBIPG 2007; Hodges et al. 2005; Reed 1977; Suzuki 1988; Tu 2001; Zhirong 1990.

Table 3. Environmental impacts associated with bushkiller[1] (applicable indicated by YES; not applicable indicated by NO) (Modified from APHIS 2000).

Environmental impact	Applicable?
Impact ecosystem processes (*e.g.* alter hydrology, sedimentation rates, fire regimes, nutrient regimes, changes in productivity, growth, yield, vigor, etc.)	NO[2]
Impact natural community composition (*e.g.* reduce biodiversity, affect native populations, affect endangered or threatened species, impact native fauna, etc.)	YES
Impact community structure (*e.g.* change density of a layer, cover the canopy, eliminate or create a layer, impact wildlife habitats, etc.)	YES
Impact human health such as allergies or changes in air or water quality	NO
Have sociological impacts on recreation patterns and aesthetic or property values	YES
Stimulate control programs including pesticides or introduction of a nonindigenous biological control agent	YES

[1] Sources: A. West, personal observation and unpublished data; GBIPG 2007; personal communication with property owners in North Carolina.

[2] No direct evidence, although bushkiller may serve as a fuel ladder in forest fires (GBIPG 2007).

Table 4. Risk ratings for step 5 of the pest risk assessment for bushkiller (modified from APHIS 2000).

	Rating	Numerical Score	Explanation
Part A	High	3	Habitat Suitability
Part B	Medium	2	Reproductive potential
Part C	High	3	Economic Risk
Part D	High	3	Environmental Risk
Part E[1]	High	11	Consequences of introduction

[1] Part E is the sum of parts A through D, indicating consequences of introduction risk rating.

Table 5. Overall risk potential of bushkiller (modified from APHIS 2000).

Likelihood of Introduction (Rating : Score)	Consequences of Introduction (Rating : Score)	Overall Pest Risk Potential
Negligible (0)	Negligible (0)	Negligible
Negligible (0)	Low (1)	Negligible
Negligible (0)	Medium (2)	Negligible
Negligible (0)	High (3)	Negligible
Low (1)	Negligible (0)	Negligible
Low (1)	Low (1)	Low
Low (1)	Medium (2)	Low
Low (1)	High (3)	Low
Medium (2)	Negligible (0)	Negligible
Medium (2)	Low (1)	Low
Medium (2)	Medium (2)	Medium
Medium (2)[1]	**High (3)**[2]	**Medium-High**[3]
High (3)	Negligible (0)	Negligible
High (3)	Low (1)	Low
High (3)	Medium (2)	Medium-High
High (3)	High (3)	High

[1] Likelihood of introduction

[2] Consequences of introduction

[3] Overall pest risk potential

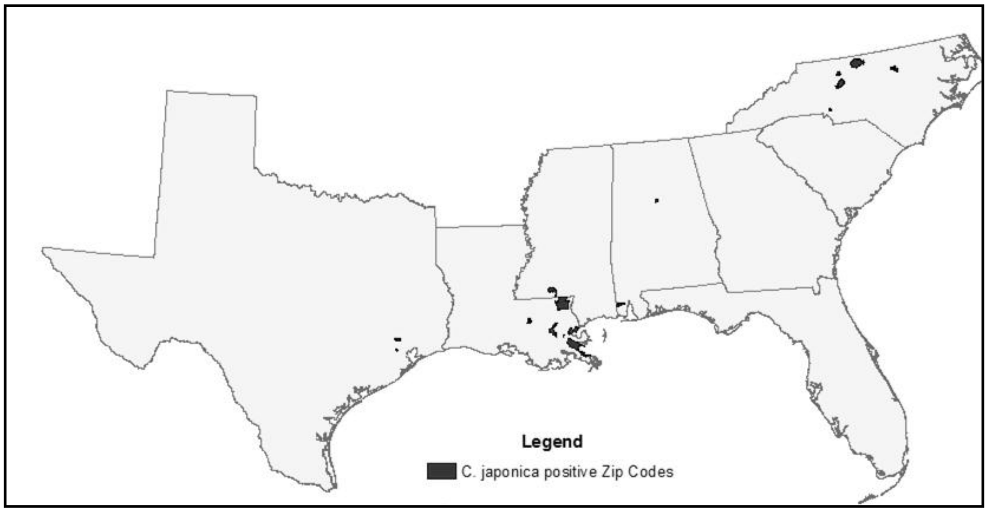
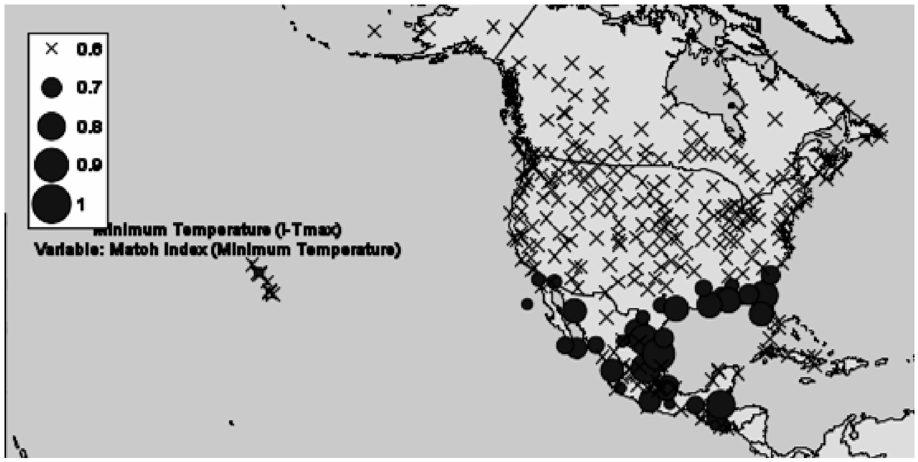


Figure 1. Reports of bushkiller in the United States by zip code. Created by D. Borchert and S. Kubilis (Koop and Dubon 2007).

Results of Climate Match: Brisbane (Queensland, Australia) Minimum Temperatures:



Results of Climate Match: Sapporo (Hokkaido, Japan) Minimum Temperatures:

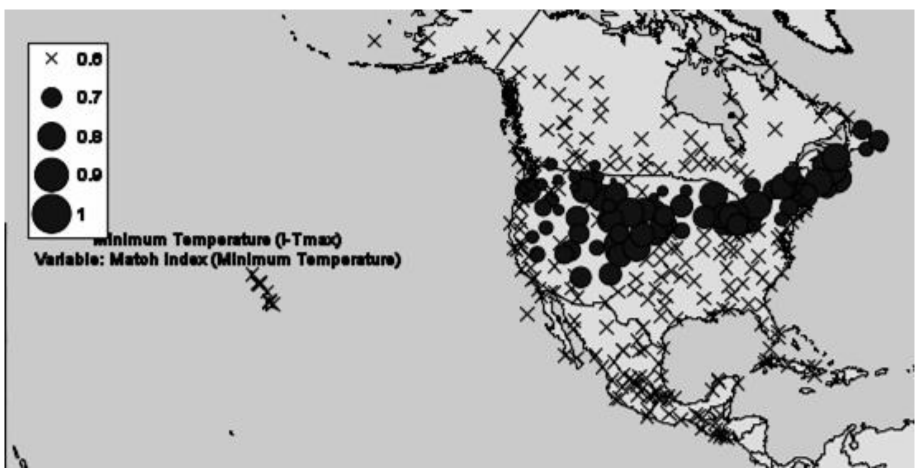


Figure 2. CLIMEX models for bushkiller (large circles indicate a value of 1, or 100% climate match. Smaller circles represent 90, 80, and 70% climate matches, respectively, and locations marked with an x represent a 60% climate match) (DYMEX simulator 2.0, 2008). Created by A. West.