Beach Vitex (*Vitex rotundifolia*): Medicinal Properties, Biology, Invasive Characteristics and Management Options[1]

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Abstract

Beach Vitex (BV) (*Vitex rotundifolia*-L. f.) has become a major invasive plant in the fragile beach ecosystems of the Carolinas. This prostrate, salt tolerant shrub from the Pacific Rim was introduced to the southeastern United States as a landscape plant. It has since established large-scale clonal monocultures through rapid vegetative reproduction. Concerns surrounding exclusion of native species and inhibition of sea turtle nesting have served as the impetus for control efforts of BV in coastal areas of southeastern US. In areas where it occurs naturally, native peoples have included BV in their pharmacopias for treatment of many ailments. The purpose of this review is to raise awareness of its invasive potential while serving as a compilation of information about the biology, ecology and medicinal properties of BV. Its potential beneficial uses indicate a need for further exploration and development of this plant but only in areas away from the coast. This plant is a major invasive problem in coastal areas for many reasons and must be dealt with quickly so that it will not become a larger problem. Imazapyr effectively controlled beach vitex in reported greenhouse and field studies applied either as a cut stem treatment or as a foliar spray.

Index words: Carolina beaches, Coastal landscape plants, Herbicides, Invasive plants.

Significance to the Horticulture Industry

Beach Vitex (BV) is a low-growing, salt tolerant, shoreline shrub that belongs to the Lamiaceae family. It was introduced as a landscape plant in North and South Carolina to reduce beach erosion after major hurricanes in the mid 1980s. It has become an invasive plant on primary dunes, reducing native plant populations and possibly interfering with sea turtle nesting activities. Medicinal studies have indicated the potential of BV for cancer therapy. Casticin, a flavonoid found in extracts of BV fruits, has demonstrated an ability to inhibit growth of human cancer cells. BV may also be used in the treatment of allergies, antibiotic-resistant bacteria, and pain. Rotundial (found in BV leaves) is an insect repellant more powerful than deet. BV produces a thick, waxy cuticle containing large amounts of diverse n-alkanes. These compounds are transferred to the surface of sand particles where they cause intense hydrophobicity in the substrate. This could be responsible for the establishment and maintenance of clonal monocultures by preventing BV seedling establishment. Effective control methods explored to date incorporate imazapyr herbicide as a foliar or cut stem treatment. All control studies of BV have indicated that multiple seasons of retreatment maybe required for successful eradication.

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Introduction

Beach Vitex (BV) is a low-growing shoreline shrub member of the family Lamiaceae and subfamily Viticoideae (Harley et al. 2004; IPNI 2008; USDA 2009). The Lamiaceae have recently experienced major taxonomic revision. As a result, *Vitex* and all other former members of the Verbenaceae save those in the subfamily Verbenoideae are now members of Lamiaceae (Harley et al. 2004). BV was moved to Lamiaceae based on cladistic analyses that supported the reclassification to establish two monophyletic families from the paraphyletic Verbenaceae and polyphyletic Lamiaceae (Cantino 1992). This new classification scheme was initially proposed by Cantino et al. (1992) though it has since been supported by cpDNA analysis (Wagstaff et al. 1998), rbcL sequence analysis (Wagstaff and Olmstead 1997), chemotaxonomic studies (vonPoser et al. 1997; Alvarenga et al. 2001) and other analyses (Ryding, 2007). The current classification of BV may be found in Table 1 and is carefully detailed in Harley et al. (2004). This recent revision has resulted in some confusion regarding the classification of BV in the literature with many researchers incorrectly placing BV in Verbenaceae. The readers should be aware that the most recent *Vitex* genus level revisions have placed *V. rotundifolia* in synonymy with *V. trifolia* subsp. *littoralis* Steenis (deKok 2007; deKok 2008). This is not the first time that BV has been placed within *V. trifolia*. Moldenke (1958a, 1958b) placed *V. rotundifolia* in synonymy with *V. trifolia* var *simplicifolia*. This placement was in disagreement with Corner (1939), and the earlier placement was supported by Fosberg (1962) and Wagner et al. (1999).

There are 236 genera and 7173 species classified as Lamiaceae (Harley et al. 2004). Members of this large plant family are found throughout tropical and temperate regions of the world though they are absent in higher latitudes (Harley et al. 2004). The subfamily Viticoideae consists of 10 genera and from 375-550 species (due to

Table 1. Taxonomic nomenclature of Beach Vitex

Taxon: ***Vitex rotundifolia*** **L. f.**

Kingdom: ***Plantae*** - Plants
Subkingdom: ***Tracheobionta*** – Vascular plants
Superdivision: ***Spermatophyta*** – Seed plants
Division: ***Magnoliophyta*** – Angiosperms
Class: ***Magnoliopsida*** – Dicots
Subclass: ***Asteridae***
Order: ***Lamiales***
Family: **Lamiaceae**
Subfamily: **Viticoideae**
Genus: ***Vitex*** L. – chastetree
Species: ***Vitex rotundifolia*** L. f. – beach vitex

large conflicts regarding the number of species present in the genus *Premna*) (Harley et al. 2004). Approximately 250-300 species are members of the genus *Vitex* (Harley et al. 2004; Wagner et al. 1999; FOCEC 1994; deKok 2007).

Among the members of Lamiaceae, there are many species that have been of significant economic importance for thousands of years. The most recognized and economically important plants are the aromatic herbs – sage (*Salvia*), peppermint (*Mentha*), spearmint (*Mentha*), thyme (*Thymus*), oregano (*Origanum*), marjoram (*Origanum*), savory (*Satureja*), rosemary (*Rosmarinus*), and lemon balm (*Melissa*) (Harley et al. 2004). The plants of Lamiaceae are also used as ornamentals, nectar sources, flavorings for food, perfumes, and medicines (Harley et al. 2004). In the genus *Vitex*, there are several species that are of commercial value for timber in the Far East (Harley et al. 2004).

Only a few *Vitex* species can be found in the US including *V. agnus-castus*, *V. divaricata*, *V. glabrata*, *V. negundo*, *V. parviflora*, *V. trifolia*, and *V. rotundifolia* though none are native to the contiguous 48 states (USDA 2009). *Vitex agnus-castus* and *Vitex trifolia* are present in the US landscape trade (Olsen and Bell 2005).

The generic epithet of BV, *Vitex*, is derived from the Latin *viere*, meaning "to bind or twist" in reference to the rope-like stems produced by some species in the genus (Wagner et al. 1999). The specific epithet is derived from the Latin, *rotundus*, which means "round, spherical", and *folium*, meaning "leaf." A multitude of common and scientific names have been applied to this plant species. The taxonomic confusion surrounding BV has resulted from its presence in so many different countries throughout the Pacific. According to Munir (1987), the following botanical names are synonyms of *Vitex rotundifolia* L. f., *Vitex ovata* Thunb., *Vitex repens* Blanco , *Vitex trifolia* L. var. *simplicifolia* Cham., *Vitex trifolia* L. var. *unifoliolata* Schauer, *Vitex trifolia* L. var. *obovata* Benth., *Vitex trifolia* L. var. *unifoliata* Miq., *Vitex agnus-castus* L. h *ovata* Kuntze , *Vitex trifolia* L. var. *ovata* (Thunb.), *Vitex trifolia* L. var. *repens* Ridley, *Vitex trifolia* L. subsp. *littoralis* Steenis and *Vitex trifolia* L. sensu.

Common names for BV are numerous. For instance, there are many English names including round-leaved chaste tree, single-leaf chaste tree (Porcher et al. 2004), chasteberry, and monk's pepper (USDA 2009). BV is known as Dan ye man jing (FOCEC 1994), Hamagou (Shinichi et al. 2000) and Man Hyung Ja (Shin et al. 2000) in China, Japan, and Korea, respectively. BV also has a host of Hawaiian common names including the following: kolokolo kahakai, hinahina kolo, manawanawa, mawanawana, pohinahina, and polinalina (HNPPD 2001).

Literature Review

Current and Potential Uses

Modern scientific efforts have resulted in the discovery of many chemical compounds present in BV leaves and fruits including flavones, monoterpenes, diterpenes, alkaloids, sesquiterpenoids, glucosides, and aryl naphthalenes norlignans (Asaka et al. 1973; Sakurai et al. 1999; Tada and Yasuda 1984; Kouno et al. 1988; Kondo 1986; Kawazoe et al. 1999; Kimura et al. 1996). The activities of some of these compounds have been characterized.

Many studies have shown the potential of BV as a cancer therapy. Casticin, a flavonoid found in extracts of BV fruits, has demonstrated an ability to inhibit growth of human cancer cells while having no effect on normal cells (Ono et al. 2002; Kobayakawa et al. 2004; Haïdara et al. 2006). Three polymethoxyflavonoids (Ko et al. 2000), one flavanoid (Ko et al. 2002), and one diterpene (Ko et al. 2001) were found to limit proliferation of human myeloid leukemia cells through induction of apoptosis. Ferruginol, a diterpene, was found to have antioxidant capabilities stronger than those of BHA (butylated hydroxyanisole) (Ono et al. 1999). Vitexicarpin, another flavonoid from BV, was found to inhibit t-lymphocyte proliferation and the growth of two cancer cell lines (You et al. 1998). The researchers suggested that the compound might moderate the effects of inflammatory and immune-regulatory disorders such as rheumatoid arthritis and lymphoma. Miyazawa et al. (1995) found that (+)-polyalthic acid, a compound found in methanolic extracts of BV fruits, exhibits antimutagenic activity.

BV also maintains the possibility as a useful agent for treatment of female health issues. Hu et al. (2007c; 2007d) found that both the essential oil and specific compounds from BV have estrogen-like biological activity and that BV has the potential as a treatment for hormone-related diseases. Many of the compounds present in BV have similarities to those of *V. agnus-castus*. As a result, BV may have potential uses in the treatment of pre-menstrual syndrome (Berger et al. 2000). These compounds were used to combat high levels of prolactin in the blood (Hu et al. 2007a).

Studies have also demonstrated potential for BV usage in treatment of allergies, antibiotic resistant bacteria, and pain. Shin et al. found that BV fruit extracts inhibit immediate type allergic reactions in vitro and in vivo (2000). Casticin was shown to block effects of histamine release from sensitized mast cells (Gemini et al. 2002). Both of these studies illustrate potential for BV for anti-allergy usage. Some phenylnaphthalene-type lignin compounds from roots were found to have antibacterial activity against methicillin resistant *Staphylococcus aureus* (Kawazoe et al. 2001). Several iridoid glucosides from BV were found to have variable but strong analgesic effects on mice (Okuyama et al. 1998). Other studies have found significant pain relief activities of BV extracts and extract fractions but acknowledge that clinical testing is necessary to confirm these activities in humans (Hu et al. 2007a).

Rotundial, an insect repellant found in the leaves of BV, was found to be more powerful than deet (N,N-diethyl-m-toluamide) in studies comparing the two chemicals against yellow fever mosquito (Aedes aegypti L.) (Watanabe et al. 1995). This compound may see future evaluation as an insect repellant to prevent diseases and dangers associated with mosquitoes.

BV is produced for traditional medicine related uses in Korea and China, and as a result, it is of great economic importance locally. Propagation by seed is known to be time consuming, inefficient and often unsuccessful (Park et al. 2004). An in vitro protocol was developed for mass production of this plant (Park et al. 2004). The authors found that propagation by cuttings is highly efficient and successful when two node cuttings are stuck in regular pine bark/sand media on placed under mist.

BV was found to enhance soil organic matter and soil microbe biomass over other types of plant dune cover (Yoshitake 2008). Microbes are largely responsible for degradation of toxins and pollutants (Loser et al. 1998). If BV can be found to encourage microbial community development, it might serve to assist in bioremediation efforts on polluted dunes.

Finally, BV is used in many inland South Carolina landscapes. The authors know of several plantings in Clemson, SC. BV presents no real invasive danger away from the coast because its low growing habit and lack of shade tolerance make it a poor competitor against taller shrubs. It is an attractive deciduous flowering shrub addition to the landscape that may potentially provide proximity related insect protection similar to that observed near Citronella plants (*Pelargonium citrosum*) (Figure 1).

Botanical Description

BV is a deciduous, sprawling shrub that typically grows to 10-40 cm tall (potentially as tall as 90 cm). Its characteristic nodal rooting allows the plant to form dense mats that extend from mother plants at distances of more than 10 m (Munir 1987). Young stems are square and green or purple, fleshy at the tips, and as the stems mature develop into round, brown, and woody. Bark will crack and fissure with age. Branches from running stems are erect. Leaves possess a strongly aromatic scent that intensifies when leaves are crushed (Wagner et al. 1999). Leaves are typically simple, though they can occasionally be palmately trifoliate or 2-lobed (Munir 1987). No trifoliate specimens have been observed by the authors in the Carolinas. Leaf blades measure 2 to 6.5 cm in length and 1 to 4.5 cm in width (Wagner et al. 1999). Margins are entire, and the leaf shape varies slightly from ovate to obovate. Bases are acute while apexes are generally obtuse but can be acute and occasionally emarginate as well. Surfaces are tomentose both top and bottom with the upper surface being dark green and bottoms ranging from light green to silver or white (FOTEC 1978). The base of the petiole is often somewhat purple, measuring up to 1 cm in length. Blades are cupped down slightly. Veins are lighter green than surrounding tissue.

Panicles can be terminal or axillary and are indeterminate. Inflouresences measure 3 to 7 cm in length. The calyx is cup shaped and 4 to 4.5 cm long. Corollas are zygomorphic, purple to blue-purple, and short pedunculate. They are two lipped and funnel form (8 mm in length). Stamens (4) are didynamous and extend beyond the corolla tube (9 to 10 mm), while styles extend beyond the stamens (12 mm) (Wagner et al. 1999). Pollen is tricolpate. Ovaries consist of two carpels with each containing two single seeded locules. Fruits are green during expansion and then turn yellow and red before maturing to bluish black. Globose drupes (FOCEC 1994) (frequently characterized in the literature as "seeds") are subtended by persistent, toothed, pubescent calices. Drupes are spherical and black (diameter approximately 5 mm) with thick waxy coatings; fruits are hard and non-fleshy and contain four seeds (or fewer by abortion) in separate compartments (deKok 2007). Endosperm is absent (Corner 1939; Moldenke 1958a; Moldenke 1958b). Ploidy level is $2n = 32$ (Wagner et al. 1999).

Distribution and Habit

The natural range of BV includes much of the Pacific Rim and many of the Pacific islands. This wide distribution that includes many different countries resulted in the generation of the many synonyms that have been applied to this species. Munir (1987) observed specimens that had been collected from Northern and Western Australia, New Guinea, Indonesia, New Caledonia, Polynesia, Hawaii, Malaya, Philippines, and Hong Kong. Moldenke (1971, 1980) reported BV in Brazil, Mauritius, Reunion, Bangladesh, Sri Lanka, Andaman Islands, China, Taiwan, Japan, Ryukyu Islands, Korea, Indochina, Thailand, Borneo, and Sarawak while Sivarajan and Manilal (1982) found BV in southern India. Cultivation of BV has been reported in England, Florida, Germany, the Hawaiian Islands, Hong Kong, Java, Johnston Island, Maryland, and New York (Moldenke 1980). At present in the US, BV has become naturalized only in coastal regions of southeastern states along the east and gulf coasts.

BV grows naturally along both sandy and rocky coasts up to 15 m above sea level (Wagner et al. 1999). In some cases, BV plants grow all the way to the ocean waves themselves. The plant appears to be highly tolerant of the harsh beach dune environment characterized by intense heat, high wind, and elevated salinity (Dirr 1998). The method of plant salt tolerance is presently unknown, however, it is likely that the hairs on leaves help limit leaf water loss while the deep root systems (at least 60 cm) of BV enhance its ability to deal with the hot, dry sand dune environment (Cousins et al. 2009).

Yeeh et al. (1996) found that the genetic diversity within populations was much lower than the average for most woody plants. Additionally, the divergence between populations was found to be higher. There were large genetic differences between populations, indicating that

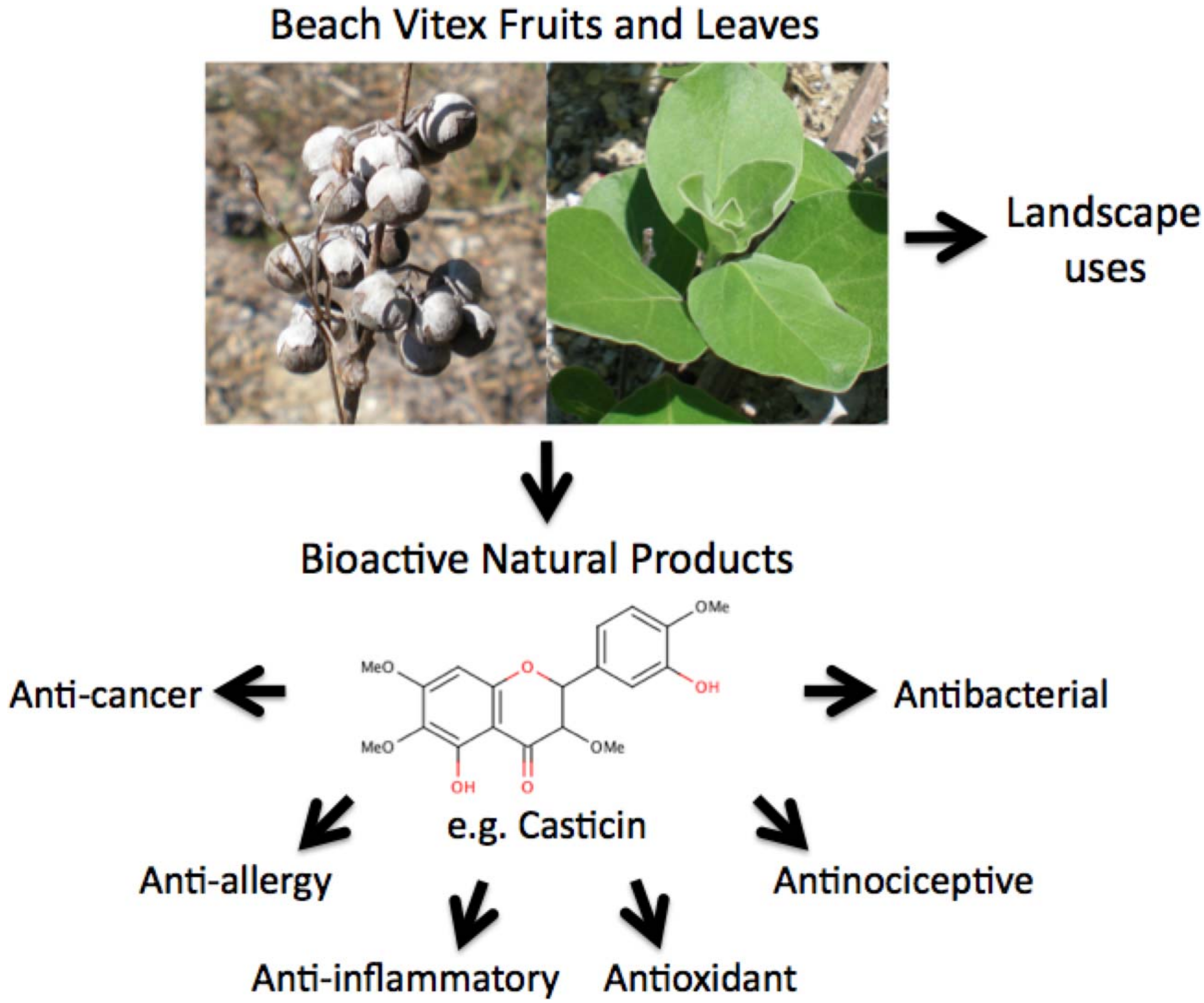

Fig. 1. Uses and potential uses of Beach Vitex and the bioactive compounds that it produces.

there is limited gene flow between populations. This is understandable due to the limited niche that BV inhabits. The fact that the populations are largely clonal may enhance genetic drift. Similarly, Hu et al. (2007b) noted significant variation in the geneotype and chemotype of various collected samples of BV from across China. Genotypic and chemotypic variations were closely associated. Hu et al. (2008) found that there was large variation between populations while there was lower variation within populations. They also found that plants within 20 m of each other were closely related. It was believed that differentiation of separated populations might be the cause of variations between populations.

History

BV naturally colonized the Pacific Rim and Pacific islands. The center of Vitex diversity appears to be in the Old World though a few species are present in Central America and the Caribbean (Harley et al. 2004). Indigenous peoples found many uses for BV that have been chronicled in texts associated with many far eastern pharmacopias. BV has been used by humans for hundreds of years in the countries of Korea, China and Japan (Kimura et al. 1996).

Traditionally, Asian pharmacopias employed BV in the treatment of many maladies. A traditional BV fruit preparation, Fructus Viticis (the fruit of *Vitex rotundifolia*), was frequently employed by traditional medicine and is detailed in the Pharmacopeia of the People's Republic of China (Zheng and Li 2003 in Hu et al. 2008). This preparation has been used to treat the common cold, headaches, migraines, sore eyes, night blindness, muscle pain (muscular pain), neuralgia (radiating pain along a nerve course), traumatic injury, and rheumatalgia (joint pain) (Kimura et al. 1996). Additionally, the plant has been used as a febrifuge, tonic, and for suppression of nasal tumors (Duke 2008). In southern Japan, BV has been used traditionally as a mosquito repellant (Nishimura 2001).

BV was first introduced to the United States in 1955 (from Japan) by the US National Arboretum (USNA), and there were at least five additional subsequent introductions by two different institutions (Olsen and Bell 2005). A USNA expedition to Korea in 1985 and subsequent promotion of BV as a landscape plant by the University of North Carolina Arboretum is credited with serving as the driving force for large scale planting of this species (Olsen and Bell 2005). Before 1985, the plant was rarely seen in gardens and generally unavailable in the landscape trade (Olsen and Bell 2005). During the late 1980s, BV was widely planted in coastal locations. It was believed that BV would serve to maintain dune integrity while showcasing its attractive foliage and floral characteristics as a landscape plant (Raulston 1993).

Monocultures of BV became established in areas where planted along the Carolina coast. It may also spread to areas where not planted, and ocean dispersed fruits have led to colonization of at least one undeveloped island along the coast. The danger that the plant presents was made known to conservation-minded individuals, and the Beach Vitex Task Force (BVTF) was created to combat this threat. Since the genesis of this program, control and eradication efforts have begun in South and North Carolina.

BV was added to the North Carolina Noxious Weed List in 2009; this classification makes possession, sale and transport of BV illegal in NC (McGrath 2009). In South Carolina, ordinances banning planting and requiring BV removal have also been ratified. These ordinances were passed in areas including Edisto Beach, Georgetown County, Isle of Palms, Kiawah Island, Pawleys Island, and Folly Beach (BVTF 2009). North Carolina ordinances banning BV have been passed in Bald Head Island, Caswell Beach, North Topsail Beach, Ocean Isle, Pine Knoll Shores, and Topsail Island (BVTF 2009). Several populations of BV were discovered at sites near Norfolk, Virginia, and control efforts are being investigated (Harper 2008).

Biology and Ecology

BV grows throughout the summer months in temperate and tropical areas of the Pacific. In temperate areas, BV is deciduous and loses its leaves during the cool nights of fall. In the southeast, leaves emerge in April while flowering occurs from June to August with fruiting following shortly. Fruits may remain attached to the plant into the early spring. BV successfully overwinters on the dunes in South and North Carolina and in gulf coastal areas.

Research has shown that flowering does not occur in the first season following germination; however, in the laboratory setting, flowering has been observed in the second season. It is believed that first flowering typically occurs in the second or third season in the natural setting (Cousins et al. 2010b).

Insect visitation is the likely method of pollen transfer due to the spacial separation of the anthers and stigmas, which would make self-pollination unlikely. Abe reported that BV flowers on Nishino-shima Island were visited by flies, butterflies, and ants though most of the visitors were ants (2006a). Abe (2006b) additionally observed many different pollinators visiting flowers of BV including honeybees, beetles, flies, and ants. Diverse groups of pollinators visit the flowers in search of the 0.5 μl/flower nectar reward (Abe 2006b). Research conducted on North and South Carolina beach infestations found pollinator activity was variable from year to year but consistent with increased fruit and seed set (Murren et al 2014). Due to this wide range of visitors, it is unlikely that the plant would require a specialist insect to mediate successful pollination.

BV can produce more than 6,000 seeds per m^2 (Gresham and Neal 2004). Interestingly, the number of seeds present in each fruit is variable from 0 to 4. As many as 20% of the fruits were found to be parthenocarpic, and less than 4% of fruits contain a full complement of seeds (Cousins et al. 2010a). Significant positive correlations were discovered between the number of seeds in the fruit and the fruit's mass and diameter (Cousins et al. 2010a). Cousins et al. (2010a) also characterized significant soil seed banks for BV along the coast of South Carolina. Time course findings indicated that seeds remain viable for 4 years following vegetation removal (Cousins et al. 2010a).

ChongMin and EulSoo (2001) studied germination rates of BV and found rates of 71% in the laboratory and 30% in sea sand with no germination rate difference between dry and moist stratification. This is in partial agreement with Cousins et al. (2010a) who found that germination percentages exceeding 80% could be achieved with stratification at 10 degrees C for 8 to 12 weeks. Additionally, moist stratification and presoaking prior to moist stratification were necessary for consistent, replicable results. ChongMin and EulSoo (2001) mention red and yellow seeds as having been analyzed. The authors believe that they are referring to the fruits as a whole and not the seeds alone. Since drupes mature green before turning yellow then red and finally dark brown, ChongMin and EulSoo may have been studying fruits that had not yet reached maturation drying. This could explain the discrepancies between the two experiments.

There has been some confusion in the literature regarding the seed dispersal. Some authors claim bird dispersal, however, BV drupes lack fleshy sugar or calorie rich tissue that is typically indicative of avian dispersal. These fruits would provide little to no nutritional value to their agents of dispersal. Also, despite the authors' numerous observations of fruit-covered dune plants, birds eating BV fruits have never been observed. Many findings support the conclusion that fruits are not typically transported by birds.

There is, however, much evidence to support a water-based dispersal mechanism. BV plants are present throughout the Pacific including coastal areas of two continents and many islands. Bird and water dispersal are the only two mechanisms that could allow a plant to spread such long distances. As previously noted, bird dispersal is highly unlikely. Fruits are covered with thick coatings of hydrophobic cuticular waxes that allow them to resist water penetration (Cousins et al. 2009). Fruits readily float for extended periods of time (author observations). Other researchers have observed BV fruits floating on rivers and oceans (Munir 1987).

In addition to their water repellent structure, the drupes of BV have diverse chemistry that may contribute to their resilient nature. Many studies relating to secondary metabolites of seeds and their medicinal qualities have been carried out. Various diterpenes have been isolated and

Table 2. Invasive potential for BV according to rating systems developed by researchers in different parts of the world.

Ranking (number[z])	Rating Definition	# categories	Area	Source
Serious Threat, Hard to Control (4)	Impact vs. Control Feasibility	4	Florida	Hiebert and Stubbendieck 1993
High (4)	Threat Significance	5	California	Randal et al. 2001
Very High (4)	Removal Funding Priority	4	New Zealand	Timmins and Owen 2001
High (4,2)	Eco. Impact, Mgt. Difficulty	5, 2	Florida	Fox et al. 2008
Reject Introduction (3)	Plant Introduction Evaluation	3	Australia	Pheloung et al. 1999

[z]Number designation was created by assigning numbers to each severity ranking category. The lowest category was assigned a 1 and the subsequent categories were assigned successive number

characterized in methanolic extracts from fruits of Beach Vitex (Ono et al. 1998; Ono et. al. 2001). Intensely hydrophobic cuticular compounds also likely contribute to maintenance of drupe integrity (Cousins et al. 2009).

After germination, small seedlings grow long roots and small shoots in the first season. Seedlings frequently do not survive the first year of their existence in the harsh dune environment (Cousins et al. 2010a). Clonal and/or sexual reproduction begins in the second or third seasons after germination. The main method of propagation locally is through long runner branches that root very easily. Plants can grow at a rate of more than 3 m per year (BVTF 2009). Some runners may grow to a length of more than 20 m (BVTF 2009).

BV displays the hallmarks of having a C_3 photosynthetic pathway such as the absence of Kranz anatomy, high $\delta^{13}C$ discrimination, and a relatively high CO_2 compensation point for photosynthesis (Bielenberg, DG personal communication.) Authors' observations in greenhouse and field settings indicate that BV can be induced to water stress in short periods of time in small pot environments. The deep root systems of BV (at least 60 cm) are capable of providing large amounts of water and are most likely responsible for preventing desiccation on the dune despite the use of a C_3 photosynthetic scheme.

Ecological concerns surrounding BV invasions are many. Sea turtle enthusiasts believe that BV inhibits egg-laying by serving as a physical barrier that bars sea turtles from crawling to acceptable locations. They also believe that the plants can trap or confuse baby turtles after they hatch, preventing them from reaching the ocean (BVTF 2009). In light of the fact that South and North Carolina is home to the Loggerhead turtle (*Caretta caretta*) – endangered, the Green Turtle (*Chelonia mydas)* – endangered, and the Kemp's Ridley (*Lepidochelys kempii*) – critically endangered, this issue is highly contentious and significant. Additionally, BV rapidly out-competes native species such as sea oats (*Uniola paniculata* L.) (Gresham and Neal 2004) while damaging ecosystems for endangered coastal plant species such as sea beach amaranth (*Amaranthus pumilus* Rafinesque). Preliminary research indicates that BV does not trap as much sand as Southern sea-oats (Gresham and Neal 2004). BV could thus encourage beach erosion by excluding sea oats while not efficiently stabilizing dunes on its own.

An insect repelling metabolite in the leaves of BV might also help eliminate insect problems for the plant making BV a better competitor (Watanabe et al. 1995). Additionally, many members of *Vitex* (though not *V. rotundifolia* specifically) have been found to produce ecdysteroids (Sena Filho et al 2008). Ecdysteriods are compounds that have been found to control insect development and reproduction (Adler and Grebenok 1999). Plants often produce these compounds (Dinan 2001), and ecdysteroids have demonstrated abilities to disrupt insect endocrine function (Adler and Grebenok 1999).

Yokouchi et al. 2007 found that BV emitted large amounts of methyl chloride from its leaves. BV was one of the 6 highest emitting species of 33 possessing this characteristic. Methyl chloride is produced naturally, but it may be responsible for 16% of the negative impacts on the stratospheric ozone layer (WMO 2003).

Yoshioka et al. (2004) found phenolic and flavonoid compounds from BV fruits and leaves that functioned as growth regulators by altering root growth rates in a lettuce seedling bioassay. Many similar phenolic acid and flavonoid compounds have been shown to possess allelopathic qualities (Correa et al. 2000; Wu et al. 2001; Wu et al. 2002).

Invasive Potential

In the areas where BV is present in the coastal regions of North and South Carolina, it is dominating the dune ecosystems, excluding native species, and maybe negatively impacting sea turtle lifecycles (Gresham and Neal 2004). BV creates oppressive monocultures by shading out native species (Socha and Roecher 2004). According to several invasiveness rating systems developed by many authors from around the world, BV is classified as having high to very high invasive potential and would not be recommended for introduction (Table 2). Its main invasive characteristics are its rapid growth, vegetative reproduction, massive fruit production, and water dispersal mechanism. To date, fruit production and dispersal are a concern though only a few instances of successful colonization have been noted (authors observation).

BV appears to share most of its characteristics with K selected type weeds though it does possess some of the most critical characteristics of r type weeds (Pianka 1970). The perennial nature of the plant coupled with significant root systems and large running stems and vegetative reproduction support K classification. However, the large seed set is a tenant of r classification. On close examination, BV has some of the characteristics from each weedy classification making it particularly predisposed to invasiveness. This allows it to spread to new areas rapidly while being particularly difficult to control in areas already infested.

BV has a thick, waxy cuticle containing a large amount of diverse n-alkanes (waxes). These compounds are transferred to the surface of sand particles where they cause intense hydrophobicity in the substrate (Cousins et al. 2009). This activity could be responsible for assisting in the maintenance of monocultures by preventing seedling establishment of other species.

The tenacity of this plant was also shown indirectly in its native environment as Kim (2005) found when severe damage occurred to native ecosystems this ususally resulted in decreased species density from 10 to 3 species per m^2 since 1983; however, BV remained a commonly observed species. Also, in one location near Litchfield Beach, South Carolina, USA, nine plants covered 158 m^2 of primary dune in seven years.

Management Options. *Mechanical Control.* The physical removal of plant parts from the dune surface has been practiced despite the labor intensive nature of such methods of control. Mechanical control alone is ineffective due to significant quantity of rooted underground stems that are capable of rapid BV shoot regeneration. Removal of all underground BV stems would require extensive substrate tillage leading to destruction of the few non-BV dune stabilizing plants and increased beach erosion.

Biological Control. No biological control systems are known. Chemicals produced by these plants help it resist attack from insects. The authors have never observed disease on populations in the field or in the greenhouse environment though it is occasionally attacked by aphids in the greenhouse.

Chemical Control. Many studies have been conducted in attempts to develop a successful control method for BV. These studies have evaluated a host of herbicides using multiple indivual plant treatments (IPT) methods (Cousins et al. 2006). Glyphosate (Aquamaster) has proven largely ineffective with foliar and cut stem applications and high concentrations are employed (authors unpublished results). This is likely due to lack of sufficient mobility of glyphosate in BV (True 2009). Triclopyr (Renovate) was also not effective at controlling large, established BV plants (authors unpublished results). Other herbicides that have been tested and found ineffective (less than 55% control) or inconsistently effective are penoxsulam (Grasp), aminopyralid (Milestone), metsulfuron (Manor), imazamox (Raptor), carfentrazone (Quicksilver), fluvoxypyr (Spotlight), and dicamba (Vanquish) (True 2009; authors unpublished results).

Imazapyr (Habitat) (1.2 g ai·cm^{-1}) applied to recently cut stems effectively controlled BV in both greenhouse and field studies (Whitwell et al. 2016). Foliar applications in greenhouse and field studies confirmed that imazapyr effectively controlled BV at rates of 1.0, 1.4 and 2.0 kg ai·ha^{-1}. Imazapyr effectively controlled BV in these studies whether applied either as a cut stem treatment or as a foliar spray. Glyphosate and triclopyr treatments were ineffective and resulted in BV regrowth (Whitwell et al. 2016).

The most effective control method explored to date incorporates imazapyr treatments. BV above ground stems are cut with blades to expose cambial layers. A 6% solution of imazapyr (applied as 20% Habitat) is then painted on the cut surface. Cutting the stem and painting is done on both the proximal and distal sides of any locations where significant runner rooting has occurred. After six months, all visible above ground plant parts are removed from the sites so non invasive beach plants can be planted. Any regrowth is treated in the same fashion as before. The process is repeated until the site has zero regrowth. All control studies of BV have indicated that multiple seasons of retreatment maybe required for successful eradication. Regrowth has been observed by members of the Beach Vitex Task Force. Additionally, care must be taken to avoid secondary infestations from other invasive plants such as *Similax* sp following BV removal.

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