Brazilian peppertree: a poster child for invasive plants in Florida

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Invasive plants in Florida

The growth in global trade has resulted in unprecedented movement of plants and animals outside of their native ranges (di Castri 1989; Pimental 2011). The majority of introductions of alien species have little impact on native ecosystems, but a few species become established in natural areas and threaten native biodiversity, alter ecological processes, and often have severe economic consequences (Mack et al. 2000). Invasive plants are estimated to cost the U. S. economy $123 billion per year (U.S. Department of Interior 2009).

In the continental USA, Florida stands out as the recipient of the most exotic plant invaders (U.S. Congress 1993; Simberloff 1997), with 1421 non-native species growing outside of cultivation (Wunderlin and Hansen 2008), and infesting an estimated 1.0 million acres (Lee et al. 2009). Florida's elevated susceptibility to invasion likely stems from several factors, including a highly disturbed environment, which is known to promote the invasion of alien species (Hobbs and Huenneke 1992). Secondly, Florida's depauperate native flora (Ewel 1986) may exert low 'biotic resistance' - the ability of native communities to resist invasion (Lodge 1993; Maron and Vilà 2001). Finally, huge numbers of exotic plants are continually being brought into Florida, the vast majority of which are intentionally introduced through the ornamental plant trade (Reichard and White 2001). Thus, opportunities for invasion into Florida may simply be elevated due to constant, high propagule pressure (Simberloff 1997).

Brazilian peppertree

Schinus terebinthifolia Raddi (Anacardiaceae), commonly referred to as Brazilian peppertree, is a plant of South America origin characterized by having shiny alternate compound leaves and multi-stemmed branches that often form an impenetrable tangle (Cuda et al. 2006). This species is native to Brazil, Argentina and Paraguay (Barkley 1944; 1957). In the U.S., Brazilian peppertree occurs in Florida, Texas, Alabama, California and Hawaii (EDDMapS 2012). Records indicate that Brazilian peppertree was imported into Miami in 1898 and 1899 (Morton 1978), and later into Punta Gorda by Dr. George Stone around 1926 (Nehrling 1944). Recent molecular studies support the historical record. Two genetic types of Brazilian peppertree have been identified in Florida (referred to as A and B), and since their arrival, they have extensively hybridized (Williams et al. 2005; 2007). The western A haplotype was introduced into Punta Gorda from southeastern Brazil, and the eastern B haplotype was introduced into Miami from northern Brazil near Salvador, Bahia (Williams et al. 2005; Mukherjee et al. 2012). These two source populations of Florida's hybrid trees are separated by approximately 800 km in Brazil, and thus, have not had the opportunity to hybridize in the native range. Florida's hybrid trees are therefore genetically distinct from trees that occur in the native range. According to Geiger et al. (2011), Florida hybrids have higher survival, growth rates, and produce more biomass than the parental plants when grown together in a common garden.

There was a long lag period, perhaps 50-60 years, between the time that Brazilian peppertree was first introduced into Florida, and the time it was recognized as invading natural ecosystems (Morton 1978). Lag times may be caused by slow population growth during initial stages of introduction followed by an exponential growth phase, or be a reflection of the time required for the selection of genotypes adapted to novel environments encountered in an introduced range (Mack et al. 2000; Sakai et al. 2001; Crooks 2005). Mukherjee et al. (2012) speculated that the lag period was due in part to genetic adaptations and evolution that followed hybridization of the two genetic types that invaded Florida. Ecological niche modeling suggests that one trait which may have evolved since the introduction of Brazilian peppertree, is cold tolerance. This trait may be responsible for recent northward spread of Brazilian peppertree in Florida and into southern Alabama (EDDmapS 2012; Mukherjee et al. 2012).

Impacts in Florida

Brazilian peppertree is considered to be one of the most serious invasive plants in Florida (Schmitz et al. 1997) and is classified as a Category I invasive plant species by the Florida Exotic Plant Pest Council (FLEPPC 2011). Rodgers et al. (2012) estimate that ~283,000 hectares of south and central Florida are invaded by Brazilian peppertree, including disturbed sites (e.g., canal banks, fallow farmlands), and natural communities (e.g., pinelands, hardwood hammocks and mangrove forests)

(Cuda et al. 2006). Several attributes may contribute to its invasiveness, including a large number of fruits produced per female plant, an effective mechanism of dispersal by birds (Panetta and McKee 1997), tolerance to shade (Ewel 1978), fire (Doren et al. 1991), and drought (Nilson and Muller 1980a), allelopathic effects on neighboring plants (Gogue et al. 1974; Nilson and Muller 1980b; Morgan and Overholt 2005; Overholt et al. 2012), and tolerance to saline conditions (Ewe 2001; Ewe and Sternberg 2002). The invasion and displacement of native species by Brazilian peppertree poses a serious threat to biodiversity in many ecosystems in Florida (Morton 1978; Cuda et al. 2006). Several studies have shown that Brazilian peppertree contributes to other invasive species problems, a phenomenon referred to as 'invasional meltdown' (Simberloff and Van Holle 1999). For instance, Clouse (1999) showed that leaf-litter under Brazilian peppertree plants growing in the previously farmed land known as Hole-in-the-Donut area of the Florida Everglades serves as a safe refuge for some exotic ants that would otherwise not have gained such a strong foothold in this native habitat. Brazilian peppertree has also been reported as an alternate host and reservoir for the exotic root weevil (*Diaprepes abbreviatus*), a serious pest of citrus in Florida and California (McCoy et al. 2003). Furthermore, Brazilian peppertree is contributing to and benefiting from the establishment of the black spiny-tailed iguana (*Ctenosaura similis* (Gray)) in southwest Florida (Jackson and Jackson 2007).

In addition to the ecological impacts, Brazilian peppertree presents a health risk to humans. Like most other members of the Anacardiaceae family, Brazilian peppertree contains active alkenyl phenols (e.g. urushiol, cardol), which can cause contact dermatitis and inflammation to sensitive individuals (Tomlinson 1980). Moreover, individuals may experience respiratory problems such as chest pains, acute headaches, eye irritation, and flu-like symptoms when in close proximity to the plants. Direct contact with the plant sap may result in a rash followed by intense itching. Ingesting the bark, leaves, and fruits can be toxic to humans, mammals, and birds (Morton 1978). Thus, the continuous increase of Brazilian peppertree infestations coupled with its allergenic properties could negatively affect the multi-billion dollar tourist industry in Florida (Smith and Brown 1994).

Management

Mechanical methods, such as cutting, burning and flooding, and herbicide application are commonly used in combination for controlling Brazilian peppertree in Florida (Gioeli and Langeland 1997; Langeland 2001). For example, cut-stump treatments or basal bark applications of triclopyr can effectively control Brazilian peppertree (Langeland and Stocker 2001). However, these methods are unsuitable for some natural areas (e.g., mangrove forests) because of their potential for negative effects to non-target species (Doren and Jones 1997). Both chemical and mechanical control measures have been used with some success, but maintenance programs are required to prevent regrowth (Koepp 1978). In addition, these methods are labor intensive and costly, particularly for large infestations. A pilot restoration project to remove 24.4 ha of Brazilian peppertree from Hole-in-the-Doughnut in the Everglades National Park was completed at a cost of $640,000 (Doren et al. 1990). However, it was calculated that it would cost $20 million and take 20 years to restore the entire 2000 ha parcel of the Hole-in-the-Doughnut (Doren et al. 1990).

Biological control

Classical biological control involves the introduction of host-specific natural enemies from a weed's native range to reduce populations in the introduced range, under the premise that the invader became aggressive due to escape from its natural enemies (enemy release hypothesis) (Williams 1954; Harris 1998; van Driesche and Bellows 1996; Keane and Crawley 2002). Brazilian peppertree provides an illustration of this concept. Surveys in Florida in the 1980s identified several generalist insect herbivores, but damage to Brazilian peppertree was minimal (Cassani 1986; Cassani et al. 1989). In contrast, surveys conducted in South America have revealed a high diversity of specialized natural enemies (Bennett et al. 1990; Bennett and Habeck 1991; Habeck et al. 1994; Cuda et al. 2006; McKay et al. 2009), several of which may have potential for biological control. However, none have yet been released. Research on a defoliating sawfly that was shown to be highly host specific to Brazilian peppertree (Medal et al. 1999; Cuda et al. 2005), was halted after the larvae were found to contain compounds toxic to mammals (Dittrich et al. 2004), and possibly birds. Other candidate agents performed poorly on Florida Brazilian peppertree (Manrique et al. 2008; Cuda et al. 2012) or were shown to feed on related non-target plants during quarantine studies (Davis et al. 2011; Oleiro et al. 2011; Wheeler et al. 2011; McKay et al. 2012).

Despite the lack of success in biological control of Brazilian peppertree, the future appears promising. Research on two candidate agents, a defoliating tortricid moth, *Episimus unguiculus* Clarke (Martin et al. 2004) and a stem boring weevil *Apocnemidophorus piptzi* (Faust), has been completed and petitions for their field release are pending approval of the United States Department of Agriculture. Additionally, recent exploration in Brazil has identified promising new natural enemies, including a thrips, *Pseudophilothrips ichini* Hood, and a group of gall forming psyllids in the genus *Calophya* (Burckhardt et al. 2011; Christ et al. 2012). The thrips feed gregariously on growing shoot tips and flowers, preventing new growth and causing flower abortion (Cuda et al. 2006; Mound et al. 2010). Psyllids in the genus *Calophya* are highly host-specific (Burckhardt and Basset 2000), and form pit-galls in plant foliage causing growth abnormalities and eventual leaf drop (Downer et al. 1988). If released, these natural enemies may decrease the competitive ability and reproduction of Florida's Brazilian peppertrees, resulting in reduced weed populations in the field.

Lessons learned and future directions

Brazilian peppertree illustrates many of the general concepts of invasive plant ecology. Similar to the majority of invasive plants, Brazilian peppertree was introduced and popularized as an ornamental. The low level of insect herbivory of Brazilian peppertree in Florida supports the 'enemy release hypothesis' (Williams 1954; Keane and Crawley 2002), and provides a theoretical basis for the search for biological control agents in the native range. Hybridization has been implicated in the aggressiveness of Brazilian peppertree in Florida (Mukherjee et al. 2012), and appears to be a common thread in many plant invasions (Ellstrand and Schierenbeck 2000). The lag period between the introduction of Brazilian peppertree, and its recognition as invasive, is also a common feature of invasion ecology (Kowarik 1995; Crooks 2005), and likely is a result of hybridization followed by natural selection of genetic types well-adapted to Florida's environment (Mukherjee et al. 2012). Finally, growing evidence of positive interactions between Brazilian peppertree and other exotic species (Clouse 1999; McCoy et al. 2003; Jackson and Jackson 2007) provides support for the invasional meltdown hypothesis proposed by Simberoff and Van Holle (1999).

A practical question is: What lessons can be gained from the experiences with Brazilian peppertree that could be applied to the management of other invasive species? One is certainly the difficulty of managing an exotic plant once it becomes firmly established over a large geographic area. Thus, a primary objective of invasive plant management should be the avoidance of future problems through regulatory methods that limit the arrival of new, potentially invasive plants. Historically, with the exception of a few plants included on the Federal Noxious Plant List (the majority of which are already in the U.S.A), all that was required to introduce plants or seeds was evidence that they were not infested with plant pathogens or pest insects (USDA/APHIS 2012). This has changed slightly with recently enacted NAPPRA **(**Not Authorized Pending Pest Risk Analysis) regulations, which in 2011 established a new category of plants which cannot be imported prior to the completion of a risk analysis. Properly administered weed risk assessment would go a long way in decreasing future problems with invasive plants (Gordon et al. 2008).

In addition to these regulatory measures, more effort should be directed towards educating the public about the threats of invasive plants, and invasive species in general. The demand for novel plants may decline if people were more aware of the environmental and economic costs associated with invasive species. It is encouraging that a survey of consumers at the Philadelphia Flower Show in 2004 revealed that a majority (>80%) of respondents were aware that exotic plants were used in landscapes, and that some exotic plants cause problems in natural areas. In Minnesota, Yue et al. (2011) found that consumers would be willing to pay a premium for plants labeled as non-invasive or native, suggesting that new labeling regulations could curb the demand for invasive and potentially invasive plants.

Finally, biological control provides the only sustainable and economically feasible solution to the Brazilian peppertree problem in Florida. Biological control has a long history of success in the regulation of invasive species worldwide (Hartley 1990; Julien and Griffith 1998; Grevstad 2006; Tipping et al. 2009), and in some ecosystems, such as natural areas and aquatic habitats, biological control may be the only viable management option. Even though no biological control agents have been released against Brazilian peppertree, much has been learned about its genetics, ecology, distribution and natural enemies, and the future is promising.

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