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Limitations by *Melaleuca quinquenervia* to Everglades Restoration

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Introduction

The Everglades of south Florida was once a river of grass. Over the past 150 years, human alteration of the area's hydrology and the introduction of exotic plant species have drastically changed this vast wetland and threatened its health. One of the most abundant and destructive invasive species is the paperbark tree *(Melaleuca quinquenervia)* from Australia. Originally planted as an ornamental, *M. quinquenervia* has spread throughout south Florida as a result of numerous introductions in various parts of the peninsula including the Everglades and the Big Cypress Swamp. The first establishment occurred when seedlings were planted along Biscayne Bay in 1906 (Turner et al. 1998). Independent introductions occurred in 1912 on the west coast of Florida near the Big Cypress Swamp, in 1936 when collected seeds were aerially broadcast over the eastern Everglades, and in 1941 when trees were planted on levees around Lake Okeechobee to provide soil stabilization (Turner et al. 1998; Florida Exotic Pest Plant Council 1999). The intent of this rather intensive series of introductions was to dry out south Florida's wetlands and to afforest the region thereby creating a timber resource (Laroche 1998). It was also thought that "draining the swamp" would facilitate development in the area (Bodle et al. 1994).

The area of the Florida peninsula south of Lake Okeechobee is about 3,000,000 ha. Today, it is estimated that *M. quinquenervia* covers 200,000 to 600,000 ha of this area (Bodle et al. 1994). Coverage varies from dense monotypic stands to single outlying trees, and the methods of control are dictated by degree of infestation (Bodle et al. 1994). The spread of this species is virtually unlimited in south Florida, and its proliferation further weakens the health of one of the largest wetlands in the world. *M. quinquenervia* readily invades both disturbed and undisturbed natural areas. In addition to invading native forested wetlands, this species converts herbaceous wetlands and effectively turns them into drier forested woodlands (Turner et al. 1998). These transformations from different types of wetland to monotypic tree stands result in a loss of native biodiversity from an area with a high incidence of endemism (Turner et al. 1998). Clearly this tree constitutes a serious threat to one of the world's most important freshwater ecosystems. This paper will examine the life history, geography, and control methods associated with this invasive pest species.

Everglades Ecosystem

The Everglades is a unique ecosystem. Many wetlands receive their water and nutrients from rivers overflowing their banks, but the Everglades is independent of rivers and streams. This ecosystem exists as a sheet flow and receives water and nutrients from rainfall (Lodge 1994). The slope from Lake Okeechobee in the north to tidal waters in the south averages around three cm/km. The Everglades is bordered by the higher elevation Big Cypress Swamp to the west and the Atlantic Coastal Ridge to the east, so in this landscape water is slowly guided southward.

The Everglades is a mosaic of different plant communities. The Everglades is most well known for freshwater marshes, particularly sawgrass marshes. Found within these open marshes are small forests of wetland tree islands. These provide habitat diversity in the form of protective cover and nesting sites for wildlife (Lodge 1994). Found on some of the more acidic soils, and therefore prone to *M. quinquenervia* invasion (see below), are cypress heads and domes. Occurring on higher ground in the region are tropical hardwood hammocks, which can be thought of as upland tree islands. Also occurring on somewhat higher elevations are pinelands. Slash pine (*Pinus elliottii*) is the common species in these areas. Mangrove swamps and islands dominated by several species of mangrove border the coast and are able to survive the brackish water due to the species' tolerance of salt water and tides. Finally, there are coastal saline flats, tidal creeks and shallow coastal marine waters found at the nexus of the wetland and the open salt water of Florida Bay and the Gulf of Mexico (Lodge 1994)..

Geography

Australia

Melaleuca (Myrtaceae) is one of the most diverse genera in Australia; including up to 250 species, mostly endemics (Turner et al. 1998). Many species occur in southwest Australia, but the *M. leucadendra* complex, to which *M. quinquenervia* belongs, occurs largely in northern Australia, which is more tropical than Florida (Turner et al. 1998). *M. quinquenervia* is the most southerly occurring of the *M. leucadendra* complex; the species' range is a thin band along Australia's east coast extending northward from Sydney to the tip of Cape York as well as New Guinea and New Caledonia (Turner et al. 1998). Common names in Australia include cajeput tree (for the oil found in its leaves), punk tree, and broadleaf paperbark tree (Holliday and Hill 1969; Bodle et al. 1994). Freshwater coastal wetlands and streambanks are typical habitats in Australia, but *M. quinquenervia* can also be found along the edges of brackish mangrove swamps (Holliday and Hill 1969; Turner et al. 1998). These habitats are preferred by humans for agriculture and urban development, and as such are considered threatened in Australia. Ironically, in various parts of that country, *M. quinquenervia* is listed as a vulnerable or even endangered species (Turner et al. 1998).

Florida

M. quinquenervia was introduced a number of times throughout south Florida, and its current range in that state remains south of Lake Okeechobee. Turner et al. (1998) point out that this species is rather "pre-adapted" to this part of Florida because of the many climatic similarities between its native range in Australia and its adopted range in south Florida. Both occupy similar latitudes in their native and introduced ranges, and typically experience wet summers and dry winters with frequent fires (Turner et al. 1998). The coastal wetlands of Louisiana and eastern Texas also have similar climatic conditions, and thus may also be susceptible to *M. quinquenervia* invasion (Turner et al. 1998).

In Florida, *M. quinquenervia* grows in a variety of areas, including roadsides, ditch banks, pastures, pine flatwoods, mesic prairies, sawgrass marshes, and in stands of cypress trees. Studies have shown that *M. quinquenervia* in Florida are quite different in appearance than *M. quinquenervia* in Australia. The Floridian trees are generally taller, straighter, and found in stands that are much more dense (Balciunas and Burrows 1993). Additionally, although this is not a salt-tolerant species, *M. quinquenervia* tends to encroach on the edges of mangrove swamps (Bodle et al. 1994). This diversity of suitable habitats has provided ample opportunity for *M. quinquenervia* establishment in south Florida and its rapid spread in recent decades is of great cause for concern.

Life history and biology of M. quinquenervia

M. quinquenervia is characterized by white, spongy bark. The inner layers of this bark hold in moisture, which helps insulate mature trees from fire and protect the cambium and dormant epicormic trunk buds (Turner et al. 1998). Additionally, the flaky outer layers of bark common to many species of the *Melaleuca* genus, help conduct a fire into the canopy of the tree, destroying leaves and branches, but leaving the roots and trunk largely unaffected (Myers 1983).

M. quinquenervia trees are prolific seed producers. Trees of the species can flower within three years of germination, and have been observed to flower up to five times per year (Bodle et al. 1994). One flower spike can produce 30 to 70 seed capsules, each containing 200 to 350 seeds. These capsules can remain attached to the tree for up to 7 years (Rayachhetry et al. 1998). A single, open-grown *M. quinquenervia* tree approximately 10 m in height stores over 20 million seeds in its capsules; some of the tallest *M. quinquenervia* trees recorded in Florida are around 27 m tall (Myers 1983). The windborne seeds are extremely tiny with as many as 34,000 seeds/g, but typically do not travel more than 170 m from the source tree (Turner et al. 1998). Hurricane events, however, could propel seeds as far away as 7 km from the source tree (Bodle et al. 1994).

A recent study by Rayachhetry et al. (1998) looked at canopy-held seed viability, and found that up to 85% of canopy-stored seeds may be empty and unable to produce seedlings. However, based on their estimates of seed production, a 21 m tree may be capable of producing well over 5 million viable seeds. Thus, in spite of the small proportion of germinable seeds, *M. quinquenervia* still produces an immense seed crop.

In addition to the light, but constant seed rain associated with the nonsynchronous opening of some capsules, a large amount of seeds are released from capsules following a disruption to their vascular connections. These disruptions occur with stresses such as fire, frost, mechanical damage, herbicide treatments or self-pruning (Rayachhetry et al. 1998). This reaction to the many stressors associated with natural disturbance events and control options render *M. quinquenervia* a difficult species to control.

M. quinquenervia has both epicormic buds and the capability of root-sprouting. When a tree is cut, dormant epicormic buds, protected by the spongy bark, sprout new shoots producing a multi-stemmed coppice growth (Turner et al. 1998). Also, sprouts form from the roots of cut trees, so a line of trees may develop along the roots of a cut tree (Turner et al. 1998). *M. quinquenervia* was thought to be cold intolerant, but several severe freezes in Florida have revealed that while the trees do sustain heavy defoliation and damage, many form epicormic sprouts and recover completely (Bodle et al. 1994; Turner et al. 1998).

In its native range, *M. quinquenervia* is known to be an indicator of acid soils. Similarly, in Florida, *M. quinquenervia* thrives on sandy-acid soils, and germinates poorly in alkaline-marl soils; those sites with acid soils are thought to be more susceptible to invasion (Myers 1983). Additionally, sites where the hydroperiod permits growth during the wet season and ensures survival during the dry season are particularly susceptible to *M. quinquenervia* invasion and establishment. These are typically sites that remain moist to saturated, but rarely submerged during the four to six month wet season (Myers 1983).

Control Methods

A variety of control methods for *M. quinquenervia* have been attempted in south Florida, some with greater success than others. The following sections will examine various individual strategies, although the most accepted method of control is an integrated approach. Due to the high seed production associated with this species, eliminating outlying individuals is thought to be an effective primary strategy in controlling *M. quinquenervia*'s spread (Turner et al. 1998). Eradicating the species from Florida, if possible, will require the combination or mechanical, physical, chemical, and biological controls.

Mechanical

Due to the sensitivity of many of the infested areas in south Florida, the large-scale removal of *M. quinquenervia* by mechanical means is not a viable option because of potential disturbance to soils and nontarget vegetation (Bodle et al. 1994; Laroche 1998). However, removal using heavy equipment is an acceptable option in areas such as canal and utility rights-of-way and other similar areas adjacent to infested wetlands (Bodle et al. 1994; Laroche 1998). The only methods of mechanical control currently being utilized are the felling of trees in place and the manual removal of seedlings that are less than two m in height. As this is a highly labor intensive endeavor, it is feasible only in small areas (Bodle et al. 1994; Laroche 1998; Turner et al. 1998).

Physical

The two methods of physical control are burning and flooding. Fire is not a satisfactory control option for a number of reasons. Adult trees are fire resistant in that the paper-like outer bark burns quickly and sends the fire into the canopy. Also, *M. quinquenervia* has a protective layer of moisture filled bark that provides significant protection to the vascular cambium. Additionally, stresses such as fire catalyze seed release from the capsules. The more open canopy and fertile ash bed that result from a fire provide ideal conditions for seed germination and seedling establishment, and fires can result in extremely dense stands of three to four meter tall trees with up to 250,000 trees/ha (Turner et al. 1998). Fire is a potential control agent on small saplings that do not yet have a thick layer of protective bark, but there are many concerns associated with prescribed burns including effects on nontarget vegetation, seed release by seed trees, and liability issues (Turner et al. 1998). If prescribed burns are implemented, they should be timed to limit successful establishment of the seeds released during the fire. Optimal timing would be at the end of the wet season so that the seeds are attempting to germinate and establish during the dry season when conditions are not optimal (Florida Exotic Pest Plant Council 1999). However, periodic rains throughout the dry season may be enough to ensure seedling survival to the following wet season (Florida Exotic Pest Plant Council 1999)

Flooding is not likely to function well as a physical control agent, but further study is required. *M. quinquenervia* seeds are unable to germinate under water, and unless seedlings are completely submerged for a considerable period of time, they tend to withstand prolonged hydroperiods (Myers 1983). Additionally, when *M. quinquenervia* seedlings or saplings are submerged, they either rot and die or develop aquatic features such as aquatic heterophylly whereby the leaves of individual seedlings or saplings are differently shaped (Lockhart et al. 1999). Lockhart et al (1999) advocate maintaining water levels for the well being of other, native species as opposed to maintaining them for *M. quinquenervia* control.

Chemical

Chemical control of *M. quinquenervia* in south Florida is a vital component of eradication efforts, but must be done carefully. There are several commonly used methods, the most common being the frill or girdle or hack-and-squirt method, which entails girdling the circumference of mature trees and applying herbicide directly to the tree's cambium (Laroche 1998; Turner et al. 1998). Another herbicide method is the cut-stump strategy, which is simply the application of herbicide to the stump of a cut tree to prevent coppicing (Laroche 1998). Employing either of these strategies minimizes effects on non-target vegetation as treatment occurs on only one tree at a time; however, these techniques are labor intensive, extremely costly, and slow going in terms of the area treated (Turner et al. 1998). Laroche (1998) notes that a stressful event such as girdling and herbicide application will cause the tree to release millions of seeds from their capsules, so he advocates a follow-up treatment within two years of the initial treatment. Doing the second application in that time frame will ensure that the resulting seedlings are eliminated before they can produce viable seeds. Also, the cut-stump method should really only be used on small trees (< 5 cm in diameter) due to the navigation hazards that stumps bring when a marsh is wet (Laroche 1998). The most effective herbicides for ground use are hexazinone and tebuthiuron. Additionally, imazapyr in a 50% solution with water has proven to be most consistently effective when using the frill and girdle or cut-stump methods of application (Florida Exotic Pest Plant Council 1999).

Another herbicide control strategy is aerial application. Due to potential impacts on nontarget vegetation, this method is best employed when treating pure stands of *M. quinquenervia* (Turner et al. 1998). For this type of application, foliar-active, as opposed to soil-active, herbicides are preferred as they are more selective and have shorter residence times (Florida Exotic Pest Plant Council 1999). If appropriate foliar-active herbicides can be identified, aerial application could be a viable control technique. The limitations of individual tree treatments have already been discussed, and aerial application has the advantage of controlling many trees with each application (Laroche 1998; Turner et al. 1998). To maximize efficiency Laroche (1998) advocates herbicide application during January and February, as *M. quinquenervia* exhibits a flush of growth at this time.

A number of herbicides have been tested for aerial application success and results have been mixed. Only hexazinone at 4.5 kg/ha ai and tebuthiuron at 11.2 ha/kg ai produced greater than 80% control. However, the hexazinone is less damaging to some native species. In 1994, 526 ha of *M. quinquenervia* were treated with hexazinone yielding greater than 90% of trees killed with minimal regrowth. Unfortunately, the manufacturer did not renew the Special Local Need label, which allowed use of this herbicide in wetlands, and thus hexazinone has been off the market for *M. quinquenervia* control since 1995 (Florida Exotic Pest Plant Council 1999). In light of the unavailability of hexazinone, as an aerial application technique, Laroche (1998) recommends a combination of imazapyr at 1.68 kg/ha ai and glyphosate at 3 kg/ha ai applied with a methylated seed-oil surfactant in a total volume of 144-188 L/ha.

Biological

In addition to *M. quinquenervia*'s resistance to fire and tolerance of many different site conditions, the species enjoys a lack of natural competition in the form of insect herbivores and disease, and thus tends to thrive in its adopted range (Laroche and Ferriter 1992). In Australia, the largest *M. quinquenervia* trees are 20 to 25 m in height and 74 cm in diameter at breast height, while in Florida, the largest specimens can grow up to 29 m tall and have a diameter at breast height of up to 163 cm (Balciunas and Burrows 1993). The use of biological control organisms in Florida will ideally bring this growth rate into check by bringing natural enemies of the species from its native range in Australia to its new range in Florida.

Balciunas and Burrows (1992) studied the effects of insect herbivory on *M. quinquenervia* trees in Australia. They sprayed some trees with insecticides to control herbivores and left other trees unsprayed. The results of this experiment revealed that insect herbivory affects both *M. quinquenervia* growth rate and biomass, thus supporting the idea that biological control could make a difference in controlling *M. quinquenervia* in Florida.

Subsequent surveys for potential biological control agents in Australia have uncovered over 400 species of insects that feed on *M. quinquenervia* (Balciunas et al. 1994). Further screening for those that require *M. quinquenervia* to complete their life cycle have revealed a number of potential biocontrol agents. Five have been either approved for or have been studied further: a foliage-feeding weevil, *Oxyops vitiosa*; a defoliating sawfly, *Lophyrotoma zonalis*; a psyllid, *Boreioglycaspis melaleucae*; a leaf-blotching bug, *Eucerocoris suspectus*; and a coreid bug, *Pomponatius typicus* (Burrows and Balciunas 1998). Most likely, no single insect will provide effective control by itself; rather a suite of species will be necessary to reduce the reproductive potential of *M. quinquenervia* (Bodle et al. 1994).

O. vitiosa was the first biocontrol agent released in Florida. Studies of *O. vitiosa* in Australia revealed that its fourth larval instar feeds on new foliage, and each larvae is capable of destroying most leaves on several shoots of *M. quinquenervia* (Purcell and Balciunas 1994). Thus as a biocontrol agent this weevil is unlikely to cause widespread mortality in *M. quinquenervia*, rather, this species will help control the growth of *M. quinquenervia* trees, especially saplings (Balciunas et al. 1994). *O. vitiosa* was sent to the United States for quarantine studies in 1992. Approval for release came early in 1997, and the first release was made in April of that year (Florida Exotic Pest Plant Council 1999). Nine populations were established initially in areas with short hydroperiods, intermediate stages of *M. quinquenervia* invasion, and dry winter conditions (Florida Exotic Pest Plant Council 1999). *O. vitiosa* larvae were found to be most abundant from October to May when the new foliage is out, and generally, only adults were present during the summer. If a site is mowed during the summer, coppice growth is induced which brings an unseasonal abundance of new foliage, thereby stimulating reproduction and maintaining an unusually high larvae population (Florida Exotic Pest Plant Council 1999). Larvae from mowed sites have been collected and relocated to 29 additional sites, so *O. vitiosa* is now established throughout the range of *M. quinquenervia* in southern Florida (Florida Exotic Pest Plant Council 1999). No data are yet available on the effects of *O. vitiosa* on *M. quinquenervia* in south Florida (T. Center, pers. comm.).

The other potential biocontrol agents are in various stages of study. *L. zonalis* has been studied in quarantine, and was due to be released in the summer of 1999 (Florida Exotic Pest Plant Council 1999). *B. melaleucae* also damages *M. quinquenervia* saplings, and although this is not thought to be as potent an agent as *O. vitiosa*, the species has been further studied in quarantine in the United States for possible introduction into south Florida (Purcell et al. 1997; Florida Exotic Pest Plant Council 1999). Extensive studies of potential host plants other than *M. quinquenervia* have indicated that *B. melaleucae* has a very narrow laboratory host range, and should not pose a threat to any nontarget vegetation (Florida Exotic Pest Plant Council 1999). According to the Florida Exotic Pest Plant Council, permission to release this species should have come late in 1999, and no later reports are available. *E. suspectus* is in quarantine studies in Florida (Purcell et al. 1997). The adults and nymphs of *P. typicus* feed on the sap of young, growing shoots causing wilting. Its range is restricted to *Melaleuca* species and *Callistemon* species, especially *Callistemon viminalis*; *C. viminalis* is another species that has escaped cultivation in Florida and is becoming a weed (Burrows and Balciunas 1998). *P. typicus* was approved for quarantine studies in the United States in 1996 (Burrows and Balciunas 1998).

Remaining Questions

In 1948, Congress authorized the Central and South Florida Project. This project was undertaken to provide flood control, provide water for municipal, industrial, and agricultural uses, prevent saltwater intrusion, provide the water supply for the Everglades National Park, and protect fish and wildlife resources (U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD) 2000). To date, the project has included 1000 miles of canals, 720 miles of levees, 150 water control structures, and 16 major pump stations; it controls water for 6 million people, more than 300,000 ha of agricultural land, and 725,000 ha of Everglades habitat, including Everglades National Park (USACE and SFWMD 2000). Recognizing that in addition to successfully providing water to the region and facilitating its development, the project has greatly altered the ecosystem and often created unfavorable conditions for native plants and animals, the Army Corps and South Florida Water Management District want to modify the plan to restore, preserve, and protect the south Florida ecosystem while still providing for water related needs (USACE and SFWMD 2000).

Laroche and Ferriter (1992) point out that often times a disturbance, especially in the form of an altered hydroperiod, help facilitate invasion by an exotic species. Once a wetland becomes infested with an exotic species, the pest population often moves into adjacent areas (Laroche and Ferriter 1992). However, it is not clear if this is the case with *M. quinquenervia*; the largest stands are concentrated in areas of original introduction, and expansion has occurred in areas that have been altered by human activities (Laroche and Ferriter 1992).

Several interesting, unresolved facts emerge from this information. First, intensive *M. quinquenervia* introduction did not begin until the 1930’s when it was aerially broadcast across the eastern Everglades. Second, serious disturbance in the south Florida ecosystem began in the late 1940’s. Third, the *M. quinquenervia* population explosion has occurred in the last 40 to 50 years (Balciunas and Burrows 1993). These facts taken together beg the questions of how the alteration of the water regime in south Florida affected the invasion of *M. quinquenervia* and how the restoration of the water regime will affect the present *M. quinquenervia* population. Lockhart et al. (1999) do not advocate altering water levels in Lake Okeechobee for the purpose of *M. quinquenervia* control, but they do not discuss this in terms of how the natural water levels of the lake would have affected the ability of *M. quinquenervia* to establish itself. In fact, none of the papers reviewed here discussed the problem of *M. quinquenervia* in relation to the vastly altered flooding regime in south Florida, aside from a passing reference to disturbed systems being prone to invasion. A number of studies either looked at, or made reference to the effect of hydroperiod on *M. quinquenervia*, but neither the effect of the altered water regime, nor the effects of the proposed changes to the water regime on *M. quinquenervia* were discussed. It will be interesting indeed to see how this exotic pest species reacts to a partially restored water regime, and if the partially restored ecosystem is at all able to defend itself against the presence of *M. quinquenervia*.

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