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Controlling invasion of the exotic shrub (*Mimosa pigra*) in tropical Australian wetlands

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Introduction to exotics in Australia

Exotics have been introduced to Australia since the time of European settlement, beginning in the 1800s. Whether deliberately or accidentally introduced, some species such as feral cats (*Felis catus*), the cane toad (*Bufo marinus*), athel trees (*Tamarix aphyllabitou*) and the bitou bush (*Chrysanthemoides monilifera*), have wrought devastation. The majority of exotics have little impact on the natural ecosystem, but those that do (between 2-40 %) are aggressive invaders that can successfully compete for niches previously occupied by native species. Many exotics not currently problematic have the potential to cause serious damage in the future (Hobbs and Humphries 1995). These exotics negatively modify the richness and abundance of other species and therefore alter the function of the natural ecosystems (Storrs and Lonsdale 1995). In Australia, about 15% of the overall vascular flora are naturalized alien species, which is estimated to be 15,000-20,000 species (Environment Australia 1998). The Northern Territory, with around 4-5 % weeds, has the lowest percentage of any state or territory in Australia. However, in the Northern Territory, *Sida sp.*, salvinia (*Salvinia molesta*), *Hyptis suaveolens*, water hyacinth (*Eichhornia crassipes*), and giant sensitive plant (*Mimosa pigra*) are considered major threats (CSIRO 1997). *Mimosa pigra*, in particular, is considered one of Australia's worst weeds of conservation. In this paper, I will discuss methods to control *Mimosa pigra* and some areas of future research.

Invasiveness of *Mimosa pigra*

Mimosa pigra L. (Mimosaceae) poses a tremendous threat to agriculture, the conservation of wetlands and land use practices of the Aboriginal people of Australia (Braithwaite et al. 1989). *Mimosa pigra* (hereafter mimosa) is a woody perennial shrub with a deep tap root and can grow to 6 m tall. It is an aggressive prickly shrub and can form dense monospecific stands on the floodplains of northern Australia. Mimosa can survive both a seven month dry season and flooding in the wet season. One plant, within an average stand, can produce more than 9000 seeds annually, which fall mostly between the mid-wet season and the mid-dry season. In a typical thicket, this would average to about 220,000 seeds per year (Lonsdale 1992). The seeds are borne in clusters of bristly pods that break up into segments containing a seed. The seeds can remain dormant in the ground for a number of years before germinating.

***Mimosa pigra* (shrub) (ANCA 1996)**

Mimosa favors a wet-dry tropical climate and would probably not be a major problem in regions with an annual rainfall of less than 750 mm or greater than 2250 mm, except in cases of clear cutting. Mimosa does not appear to grow preferentially in any soil type, but is found most commonly in floodplains and riverbanks within soils ranging from black cracking clays to sandy clays to coarse siliceous river sand. Seed production and plant life expectancy are greater on black cracking clays than on the lighter clays and silty loams (Lonsdale 1992).

Mimosa is a native plant of Central America and probably entered the Northern Territory of Australia prior to the 1890s through the Darwin Botanic Gardens (Lonsdale et al. 1995 and references therein). It remained a minor localized weed for over 100 years as it was confined to the Darwin area. However, mimosa seeds eventually spread and were found upstream along the Adelaide River, whereupon reaching the wet-dry tropics north of Darwin, it increased dramatically with the help the feral water buffalo (Lonsdale et al. 1995, Miller and Wilson 1995, Lonsdale 1993a). Mimosa also spread in ensuing years, especially during the 1970s, covering more than 800 km^2 of wetlands in subcoastal Northern Territory by 1989. Infestations can nearly double in just over one year and on average every 6 years (Lonsdale and Farrell 1998, Lonsdale et al. 1995, Lonsdale 1993b). By 1981, much of the Adelaide River floodplains were covered by nearly monospecific stands (Lonsdale et al. 1995, Lonsdale 1993b).

At present, mimosa is confined to the coastal floodplains of the Northern Territory in an arc extending from Western Australia into Queensland. Within this area is Kakadu National Park. Here, mimosa is regarded as their most important biological threat, being capable of transforming species-rich tropical wetlands, sedgelands and grasslands into monospecific stands that exclude native birds, lizards and vegetation (ANCA 1996a, Braithwaite et al. 1989). Since the initial discovery of mimosa in Kakadu in the early 1980s, the Australian National Conservation Agency (ANCA) has managed to keep the park virtually free of mimosa, unlike the major infestations which occur on the borders of Kakadu in wetland systems to the east and west (Lindner 1995). However, invasion from these neighboring infestations as well as long-lived seed banks pose a serious and continuing problem (ANCA 1996b, Lonsdale et al. 1995). A four-member team from local agencies (Australian National Parks and Wildlife Service--ANPWS and Aboriginal landowners) has made considerable efforts to eradicate the species wherever it appears in the Park. Monitoring and surveillance continue to take place in order to locate new infestations and prevent further importation of seeds from outside the park (Lonsdale et al. 1995, Lonsdale and Lane 1994).

Northern Australia (ANCA 1996): Locations of Mimosa pigra as compiled from the Herbarium of the Northern Territory, Darwin. The map was generated from Environment Australia's species mapper (http://www.environment. gov.au/search/mapper.html) - 13 September 1996, Accessed 17 May 1999. Note that actual distribution extends much beyond these locations.

Control efforts

Mimosa-infested land is currently managed by the Department of Conservation and Land Management (WA CALM--in Western Australia), and by the Conservation Commission of the Northern Territory (CCNT) (Osterzee 1996). Kakadu National Park is jointly administered by a Board consisting of the traditional Aboriginal landowners and the national ANCA. The Conservation Strategy of the Northern Territory (CSNT), set in 1994, developed goals of land and heritage conservation, sustainable use, maintenance of a clean environment and objectives to increase knowledge of the natural resources in order to conserve, better manage and discover the potential for their sustainable use (Osterzee 1996). The immediate priorities identified were the ephemeral and intermittent wetlands. The Territory Parks and Wildlife Conservation Act of 1993 offered protection to wildlife habitats for the maintenance of biodiversity through a formal reservation system.

Efforts to prevent the spread of mimosa are generally focused on the control of major infestations. It has been suggested that greater effort should be directed at controlling the outbreak of satellite populations away from the main stands (Moody and Mack 1988). Several small satellites will grow and occupy space more quickly than one large focus. Efforts to control nascent foci were attempted in Kakadu National Park. Cook et al. (1996) looked at two sites, one east and one west of Kakadu National Park. Modeling efforts indicated that seed and plant predation could slow the rate of spread considerably through the destruction of the isolated foci. However, no folivores have established sufficiently to produce the degree of control required to slow the rate of spread. Until biocontrol agents become more widely established and proven effective in the field, chemical and mechanical control will remain a more effective means for preventing or slowing the spread of *M. pigra* (Cook et al. 1996).

The location of past mimosa invasions must be closely monitored after all plants have been destroyed, because the seed remains viable for many years (Lonsdale 1993b). Cook et al. (1996) found that outbreaks required sustained control for seven years or more because of the establishment of plants from the seedbank. Regular searches for any new outbreaks are conducted with the goal of eradication as a priority. Vehicles or machinery considered possible vectors of mimosa seeds are required to be washed down in order to remove any seed before entering the Park. The ANPWS will encourage and, where possible, assist in controlling mimosa infestations outside the Park, which otherwise could act as permanent sources of seed for Park infestations.

Where appropriate, invasion sites of mimosa are fenced to eliminate the risk of seed spread by buffalo, pigs and other feral animals (ANCA 1996b). Successful weed control not only involves a released biological control insect, but also the competitive interactions between the weed and other species. The rate of spread of mimosa has slowed down markedly since the removal of feral water buffalo, possibly as a result of enhanced interspecific competition against seedlings for the recovering floodplain flora (Lonsdale and Farrell 1998). The significant effect of inter-specific competition further corroborates the suggestion that the removal of buffalo enhanced inter-specific competition against the seedlings and so reduced the spread rate of mimosa (Lonsdale 1993b).

Chemical

Chemical methods are currently the primary means of controlling mimosa populations. Over twenty-one herbicides (applications from aerial spraying, bark and stem injections and soil treatments) have been tested for their effectiveness (Lonsdale et al. 1995). Currently, 2,4,5-T, tebuthiuron (Graslan 20P®), fluroxypyr (Starane®), metsulfuron methyl (Brush-Off®), dicamba (Banvel 200®) and hexazinone (Velpar®) are the principal chemicals used to control mimosa (Lonsdale et al. 1995, Miller and Siriworakul 1992).

The timing of application is critical in chemical treatment. Graslan is typically applied first and must be applied before the floodplain becomes wet but after the risk of fires is reduced. Stardane is then used to kill remaining scattered plants after Graslan application has defoliated the plants (Schultz and Barrow 1995). Fluroxypyr and metsulfuron methyl are recommended as aerially applied foliar spays. Mimosa needs to be actively growing in order to translocate tebuthiuron (a root absorbed residual herbicide) in certain soil conditions, but application should be carried out before the plants set seed (Lane et al. 1997, Lonsdale et al. 1995). However, considering the observed 43% survival rate of seedlings treated with tebuthiuron and the vast seedbank, tebuthiuron has not been an effective herbicide against seedlings (Lane et al. 1997). The application of herbicides to such a large dense stand also requires the use of aircraft (Schultz and Barrow 1995). Because mimosa is so aggressive and any remaining plants may recur, the area is often burned after chemical application (Schultz and Barrow 1995).

Mechanical

Mechanical removal of mimosa may involve bulldozing, chaining, or burning (Creager 1992, Noble 1992). A gelled gasoline is typically applied from aircraft and the stands completely burned in addition to the chemical treatments (Lonsdale and Miller 1993). However, mimosa is fire resistant and requires additional efforts, such as chaining, to enhance burning. Fire alone may actually increase mimosa densities by plant regrowth and enhanced seed germination (Miller and Lonsdale 1992). Use of a helitorch also helps achieve a more complete burn.

Burning removes the mimosa litter and allows ground team access for physical removal. Fire also increases the germination of the mimosa seed bank so that seedlings can be controlled the following season with the same herbicide and fire treatments (Schultz and Barrow 1995). Additionally, mimosa seedlings are susceptible to competition from native grasses, so seeding an area after herbicide and fire applications can be effective. Physical and mechanical methods of control are only temporary control options, however. Regrowth will occur unless a suitable herbicide is immediately applied (Siriworakul and Schultz 1992).

Biological Control

In Australia, of the 114 phytophagous insect species that are found on *Mimosa pigra*, only 13 are endophagous and the mimosa flowers, fruit, and seed were largely uneaten by these species (Wilson et al. 1990). A survey of native phytophagous insects in Central and South America discovered 441 species on *Mimosa pigra*, seven of which are specialists (Harley et al. 1995). In addition, seed predation by ants and mice did not reduce the likelihood of seed spread (Wilson 1989).

Eleven species have thus far been released against *Mimosa pigra* in Australia, nine insects and two pathogenic fungi (CSIRO 1998a). All have established in the field except for the most recently released seed-feeding insects, *Sibinia fastigiata* and *Chalcodermus serripes,* for which it is too early to confirm establishment (CSIRO 1998a). The four species of seed feeders were selected because they attack seed at different stages of maturity: young green seed, old green seed and hard seed. Although the species released collectively damage vegetative and reproductive parts of the plant, mature leaves and roots are still largely undamaged, but are heavily attacked by insects in the native range.

The flower-feeding weevils, *Coelocephalapion aculeatum* and *C. pigrae*, are capable of inflicting heavy damage to flower bud and were released in 1992 and 1994, respectively (Lonsdale et al. 1995, Forno et al. 1994). The seed-feeding beetles, *Acanthoscelides quadrildentatus* and *A. puniceus* were the first insects introduced from Mexico in 1983. Adults oviposit on the seed pods and the larvae tunnel through the wall of the pod and into the seed. Unfortunately, these species have not attained high population densities in Australia (Lonsdale et al. 1995). Two stem-boring moths, *Neurostrota gunniella* and *Carmenta mimosa* were released in 1989, although only *Neurostrota gunniella,* is widely established and was nearly ubiquitous through the Australian range of mimosa by 1991 (Lonsdale et al. 1995). *Neurostrota guinniella* is located even in remote isolated plants, and appears to slow the plant's growth rate significantly. *Neurostrota* has had a measurable effect on the canopy growth of mimosa, but it is unclear whether there has been a concomitant effect on seed output. However, plant size and fecundity are closely coupled. *Neurostrota* also enhances the infection rates of the pathogen, *Botryodiplodia theobromae* (Wilson and Pitkethley 1992). Thus, *Neurostrota* is having a significant negative impact on mimosa (Farrell et al. 1992).

The fungal pathogens, *Phloeospora mimosae-pigrae* and *Diabole cubensis*, have severely attacked mimosa in Mexico and look promising in Australia (Lonsdale et al. 1995). Aerial application of the fungus, *Phloeospora mimosae-pigrae*, by the Department of Primary Industry and Fisheries, resulted in more than 2000 liters being applied to mimosa in the Finniss and Adelaide River systems. The fungus appears to have established.

Selection of further agents is currently focusing on agents that attack mature leaves and roots. Many species of leaf feeding Lepidoptera are also being assessed, as are leaf beetles whose larvae feed on the roots of mimosa. New methods of rapidly screening leaf beetles are being developed in an effort to discover effective species quickly. More broadly, the current focus of research is to incorporate new generic principles of host range testing with the theory of insect behavior and new test designs (CSIRO 1998a). A computer model based on the known ecology of the weed is also being developed, to allow the consequences of different management options to be tested. The model is currently undergoing sensitivity analysis. Through the Australian Centre for International Agricultural Research (ACIAR) supported projects, the biological control research has been extended to Thailand, Malaysia, Indonesia, and Vietnam, which also have increasing problems with *M. pigra* (CSIRO 1998a).

Revegetation

Old stands of mimosa can out-compete most flood plain species, but the use of herbicides followed by burning and reseeding native vegetation typically results in a greater diversity of native herbs than in untreated areas. However, there has been some difficulty re-establishing native plants to areas once dominated by mimosa, even in treated areas (Schultz and Barrow 1995, Miller and Lonsdale 1992). The destruction of mimosa is therefore only the first stage in returning to the pre-mimosa community. Re-establishment of native species is also required, and may be difficult. Assisted revegetation and cost-effective removal of dead or debilitated mimosa can help restore pre-mimosa conditions to many areas (Cook and Setterfield 1995).

Prevention

One of the most powerful weapons against weed incursions is initial prevention. On a local level, education and enforcement are key methods of management, including formation of land-care groups and meetings with landholders. The spread of mimosa can be prevented by: appropriate management for commercial grazing of cattle and buffalo, the purchase of clean stock feed and clean crop and pasture seed, enhanced control of feral pig damage, washing down livestock from infested areas with a quarantine of 48 hours, not using or moving sand and soil from infested areas, controlling mimosa located upstream of clean areas, controlling mature and juvenile mimosa before seeding, keeping mimosa away from roads, railways, and access points, using fire to prevent woody weed encroachment, and maintaining dense ground-cover for competition

(Benyasut and Pitt 1992). Since the removal of feral water buffalo, new mimosa outbreaks are becoming rarer (Lonsdale 1993b).

Conclusion

Mimosa pigra now infests areas in Africa, Southeast Asia, Thailand, Peninsular Malaysia and the United States as well as Australia. The impalatability of leaves to mammalian herbivores (Lonsdale et al. 1995) and high reproductive output will continue to make mimosa a noxious species in areas it invades. Continued development of techniques for monitoring and control along with aggressive management strategies can help prevent the further spread of mimosa. The use of GIS for monitoring mimosa's spread is possibly helpful and currently being used in Kakadu National Park.

Current efforts at the CSIRO Entomology Division include the undertaking of a large field experiment to investigate the integration of mimosa control methods of herbicide application, chaining, burning and biological control. One treatment within the integrated experiment will involve application of seeds of native grasses. Mimosa is a poor competitor with other vegetation, and it is hoped that revegetation may hinder its chances of re-establishing (P. Edwards, personal communication). These integrated experiments are particularly important for areas where aerial application of herbicides is not possible.

There are many steps to prevent further spread of mimosa, such as quarantine procedures, reduction of feral animal abundance, and elimination of satellite populations. However, further studies need to look at the ability of native species to prevent the re-establishment of mimosa in treated areas and the possibility of augmenting biological control agents in dense stands. Studies investigating particular aspects of weed ecology, distribution and control methods should be encouraged by all affected countries as well as the collaboration of scientists, their resources and results. The integrated use of mechanical, chemical, and biological control along with prevention and revegetation are essential to preventing the further spread of mimosa. While these methods are effective in locally removing mimosa populations, a watershed and ecosystem approach must be adopted to reduce the infestations and restore vital habitat. The effective control of mimosa in Kakadu National Park is encouraging in the battle to reduce the number of mimosa infestations (ANCA 1996b). Carefully planned timing of control efforts along with competition between native and exotic species will further help to reduce the spread of mimosa (Cook and Setterfield 1995).

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