Integrated management of *Mimosa pigra*

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Summary The introduced tropical American shrub, *Mimosa pigra* L. (Mimosaceae) forms impenetrable thickets over more than 800 km^2 of the Northern Territory, greatly reducing biodiversity, competing with pastures and hindering access to water, posing a threat to the pastoral and tourism industries.

Biological control is a promising control strategy due to the cost of chemical and physical control, exacerbated by difficult access to stands that often flood for months. Ten insect and two fungal biological control agents have been released in Australia over the last 19 years and some are now having a measurable impact on mimosa. However, it is not yet clear if biological control will provide sufficient and widespread control and alternative control methods are currently needed. To study interactions between control strategies a large-scale integrated control experiment was established at Wagait, in the Finniss river catchment, NT, Australia. This paper documents progress towards sustainable control of mimosa on Australia.

Keywords Biological control, fire, herbicide, woody weed, wetlands.

INTRODUCTION

Mimosa infestations often flood for months, making access for ground control difficult. Large infestations have invaded paperbark (*Melaleuca* sp.) swamp-forest where aerial herbicide spraying and controlled burning cannot be performed. This and the cost of chemical and physical control together with the sheer scale of many mimosa infestations makes biological control the most promising long-term strategy (Forno 1992).

However, biological control does not yet provide the level of control required and a range of other techniques have been tried to manage mimosa, including aerial application of herbicide (Miller and Siriworakul 1992), mechanical control (Siriworakul and Schultz 1992) and fire (Miller and Lonsdale 1992). There are advantages and disadvantages associated with each technique. For example, mechanical control rarely kills plants; healthy mimosa is difficult to burn, plants often resprout and buried seeds survive and become germinable, so follow-up control is necessary (Miller and Lonsdale 1992). For these reasons, Miller *et al.* (1992) suggested an integrated management program, combining various techniques, may provide cost effective management.

Although in some regions mimosa is still highly invasive there is evidence the rapid expansion of mimosa has been greatly reduced (Lonsdale (1993) showed populations doubled in size every 14 months in the late 1970s and early 1980s). This is partially due to strategic control of satellite infestations (e.g. Cook *et al.* 1996) and large-scale programs that cleared approximately 10000 ha of mimosa across a range of sites including Oenpelli and Melaleuca Station and Wagait Aboriginal Reserve on the Adelaide and Finniss River floodplains, respectively. There is also evidence that culling feral water buffalo as part of the Brucellosis and Tuberculosis Eradication Campaign (BTEC) which reduced overgrazing of floodplain grasses (Braithwaite and Roberts 1995) further reduced mimosa's ability to invade (Lonsdale 1993). Ongoing population dynamics studies indicate biological control is also having an impact. Seed banks beneath mimosa stands on the Adelaide (Paynter, unpublished data) and Finniss (Barratt *et al.*, unpublished data) River floodplains have declined by 1–2 orders of magnitude, compared to those measured by Lonsdale *et al.* (1988), and are approaching levels recorded in the native range by Lonsdale and Segura (1987). Plant mortality, attributed to attack by *Neurostrota gunniella* Busck and *Carmenta mimosa* Eichlin and Passoa, has been recorded.

Five biological control agents are currently confirmed to have established and persisted in Australia: the twig and stem-mining moths *N. gunniella* and *C. mimosa*; the seed-feeder *Acanthoscelides puniceus* Johnson, the flower-feeder *Coelocephalapion pigrae* Kissinger and the leaf-feeding beetle *Chlamisus mimosae* Karren. Of these, the impact of *N. gunniella*, which reduced seed production by up to 60% (Lonsdale and Farrell 1998) and reduced seedling growth by 30% (Paynter and Hennecke 2001), has already been studied. For unknown reasons *Chlamisus mimosae* only established in the Finniss River catchment, where it is locally common, but has negligible impact on mimosa. Although both species of *Acanthoscelides* released (*A. puniceus* and A. *quadridentatus* Schaeffer) initially established, only *A. puniceus* has been recorded in recent collections. This agent has been considered a failure, destroying only 0.8% of mimosa seed (Wilson and Flanagan 1991). Therefore, recent priorities have been to determine the impact of *C. mimosa* and *C. pigrae.*

MATERIALS AND METHODS

Monitoring agent impact Measuring impact of *C. pigrae* has been difficult. It spread rapidly throughout the range of mimosa, following its initial release in July 1994. Therefore, there are no sites where it is absent that can used to compare plant performance to sites where it is common. Insecticide or cage exclusion experiments cannot be performed because they also kill or exclude pollinators (Lonsdale and Farrell 1998), laboratory manipulation studies are hampered by a *c.* 97% natural abortion rate of flower heads (Lonsdale 1988). The only option to estimate impact of this insect has been to compare the contemporary performance of mimosa plants with the performance of plants recorded prior to the release of biological control agents (Lonsdale 1988). To this end regular samples are collected from litter trays set up at a biological control agent release site at Beatrice Lagoon (12° 37' S, 131° 19' E; altitude 5 m), on the Adelaide River floodplain, repeating similar observations made there between 1984–1986 (Lonsdale 1988). The number of seeds per pod and the number of pods produced per inflorescence are used to calculate the proportion of 'successful' inflorescences, based on the number of seeds and aborted inflorescences in a litter tray sample. Monthly samples of flowers have also been made to determine the proportion of inflorescences attacked and degree of attack by *C. pigrae*.

Demonstrating the impact of *C. mimosa* has been similarly problematic: An insecticide exclusion trial set up at Beatrice Lagoon, using the systemic insecticide failed to exclude *C. mimosa*, indeed QDPI advice for control of the closely related moth *C. chrysophanes*, a pest of lychees and persimmons, is to remove and burn infested branches! Luckily, *C. mimosa* is a relatively slow disperser (Ostermeyer 2000) and a range of sites were available where it has yet to colonise, which could be compared to sites where it is already abundant. Eight sites on the Finniss River catchment (four with *C. mimosa*; four without) were chosen in 1999 and a further eight sites (four with *C. mimosa*; four without) were selected on the Adelaide River Catchment in 2000. Five litter trays were set up within the stands at each site to monitor the seed rain and 25 plants were tagged per site to allow us to monitor their survival over time.

The integrated control experiment We give only an overview of the experimental approaches here: detailed methods will be described elsewhere. The experiment was set up within mature mimosa stands at Wagait Aboriginal Reserve, in the Finniss River catchment, Northern Territory, Australia (12° 56' S, 130° 33' E alt. *c.* 20 m). The experiment covers *c.* 128 ha, recreating the scale that is required for practical control of mimosa.

The initial experimental design consisted of four replicates of the following treatments, conducted in 100 m × 200 m plots, either alone, or in conjunction with a crushing treatment (by bulldozer): a control; single herbicide applications (in the 1997, 1998 and 1999 wet seasons) and repeat herbicide applications as follows:

1. 1997 + 1998 wet seasons
2. 1997 + 1999 wet seasons
3. 1998 + 1999 wet seasons
4. 1997 + 1998 + 1999 wet seasons

To investigate the response of mimosa, subjected to the various herbicide and bulldozing regimes, to fire the entire field site was burnt in November 2000.

Sampling methods Before allocating treatments (November 1997), four 1 × 5 m quadrats were located in each 100 × 200 m plot and the number and diameters (at ground level) of mimosa stems recorded. Aboveground biomass was estimated using a correlation between stem diameter and dry weight (T. Schatz, unpublished data) so that subsequent censuses could measure the effect of treatment on survival (number of stems) and biomass.

Further samples were performed using a random quadrat (1 × 1 m) to estimate the number of mimosa seedlings that germinated and percentage cover of mimosa, competing plants, litter, and bare ground before treatments were applied and again: in November 1999, following the herbicide treatments; in November 2000, immediately following the fire, and in November 2001, to monitor regeneration following fire. The percentage cover of mimosa in the plots was also estimated from aerial photographs taken from a helicopter flown approximately 300 m above the plots in April 1998 (pre-herbicide and bulldozing treatments), July 2000 (post-herbicide and bulldozing treatments) and July 2001 (after the fire treatment). Biological control agents were sampled within the plots to determine the effect of control treatments on their abundance.

RESULTS AND CONCLUSIONS

The experiments outlined above have produced large and complex data sets, which we intend to analyse and publish in a range of papers over the next two years. Here we present an overview of the results to date.

Impact of biological control Preliminary results indicate fewer pods are produced per inflorescence now, compared to the mid 1980s, prior to biological control, and there are fewer successful inflorescences per plant such that the annual seed production at

Beatrice Lagoon was approximately 70% lower in 2001 than in 1984–1986 (Table 1.).

The results might indicate that the flower-feeder *C. pigrae*, is having a large impact, however, *C. mimosa* is also abundant at Beatrice Lagoon and while experiments to monitor both species are ongoing we cannot yet confirm whether the reduction in seed production can be explained by the abundance of *C. pigrae* or *C. mimosa*. Indeed, the preliminary results from the experiment to measure *C. mimosa* impact described above, indicate the latter is having the greatest impact in mimosa.

Recent work indicates the most damaging levels of attack by *N. gunniella* (Smith and Wilson 1995) and *C. mimosa* (Paynter unpublished data) are restricted to stand edges and plants in the centre of stands are relatively undamaged. Whether stands continue to expand or contract will, therefore, depend on whether seed input and seedling survival at stand edges is sufficient for populations to increase, or if biological control agents prevent mimosa regeneration so stands shrink from the edge. There is evidence to suggest the latter is the case at a number of early release sites, at least in combination with fire. For example, a fire, which cleared an area of mimosa attacked by *C. mimosa* (which contains more dry, flammable, deadwood compared to green, healthy mimosa) at a release site on the Finniss River, pushed the edge of the stand back by *c.* 25 m in 2000. Only a few isolated seedlings emerged following the fire and these are now heavily damaged by *C. mimosa*. Plants at the new stand edge are again showing signs of heavy *C. mimosa* attack. A combination of successive fires and attack by *C. mimosa* has pushed the stand edge back by *c.* 50 m in the last ten years.

Whilst tentative signs indicate biological control is beginning to work, the scale of the problem – stands may cover hundreds, even thousands of hectares – indicates that if attack remains concentrated at stand edges, it may take centuries to clear stands (Figure 1).

Using a bulldozer or herbicide to split a 100 ha block of mimosa into 10 × 10 ha blocks can potentially accelerate the impact of biological control ten-fold by increasing the area of stand edge for agents to colonise (Figure 2), indicating that investigating an integrated approach to mimosa management will not only lead to the development of optimal combinations for the use of herbicide, mechanical control and fire (Paynter *et al.* 2000), but should also result in more rapid regulation of mimosa by biological control agents.

The integrated control experiment It is too early to report the results of the integrated experiment, but these should provide replicated, quantitative data on the

Table 1. Comparison of the annual flower production, the mean number of pods per inflorescence, the mean number of seeds per pod and the annual seed production of mimosa at Beatrice Lagoon pre-biological control in the mid-1980s (Lonsdale 1988) and in 2001.

	1984–1986	2001
Inflorescences per m^2	1792	2523
Pods per inflorescence	7.1	4.4
Seeds per pod	21.0	18.5
% Successful inflorescences	3.3	1.4
Seeds per m^2	9103	2868

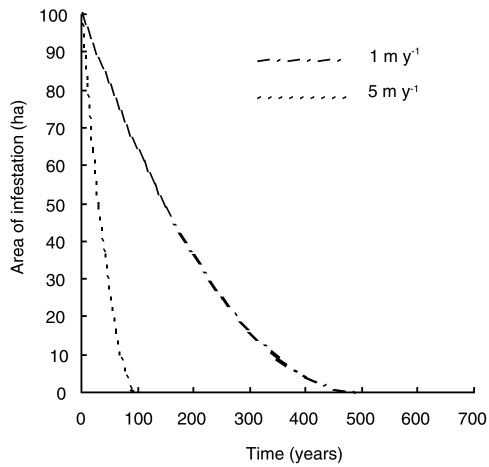

Figure 1. Area occupied by an initially 100 ha mimosa stand versus time (assuming a square 1000 × 1000 m stand contracting from the stand edge at a rate of 1.0 m and 5.0 m y^{-1}).

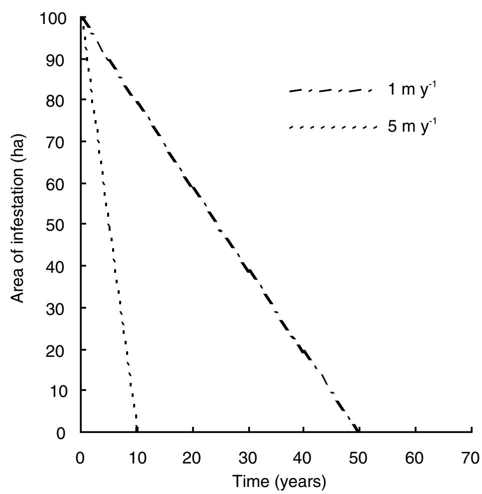

Figure 2. Area occupied by ten initially 10 ha mimosa stand versus time (assuming a square 1000 × 1000 m stand divided into ten 100 × 100 m stands contracting at a rate of 1.0 m and 5.0 m y^{-1}).

impact of fire, herbicide and bulldozing on mimosa and all five species of established biological control agents. Preliminary results indicate, on their own, a single herbicide application, mechanical control and fire are ineffective, but that combinations, such as herbicide, bulldozing and fire clear stands very effectively. As expected, biological control agent attack rates have increased as the mimosa stands were fragmented by herbicide and mechanical control and all agents had recolonised the few remaining plants within the plots within a year of the fire treatment.

FINAL CONCLUSIONS

Preference of biological control agents for stand edges indicates control measures, such as herbicide and fire, which break up stands into smaller patches or individual plants, should increase the proportion of plants available to biological control agents and therefore, enhance, rather than diminish, the impact of biological control.

A priority for the biological control program against mimosa is to find agents that are not confined to stand edges, so that plants within the centre of stands do not escape herbivory.

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