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Review and analysis of the surveys for natural enemies of *Mimosa pigra*: What does it tell us about surveys for broadly distributed hosts?

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Abstract

Mimosa pigra L. (Mimosaceae), a serious weed in Australia and Asia, has been the target of a biological control project for 25 years. This woody legume occurs naturally in all tropical American countries from Mexico to Argentina and on many Caribbean islands. In this paper, we analysed the results of surveys for natural enemies of *M. pigra* conducted in seven countries by several different collectors and which revealed ~420 species of insects and five of fungi. We assessed the survey effort relative to the natural distribution of the host-plant to show that large areas of the natural distribution were not covered. We examined the known distribution of the natural enemies to show that most natural enemies occur over the majority of the range of the host, although the Isthmus of Panama is a barrier to many species. This indicates that few potential agents were missed. We show species accumulation curves for three sites to estimate the number of visits required to find most species at a site. Although the species accumulation curves continued to rise, even after 28 collections and 101 insects found at one site, the species utilised for biological control were found relatively early. We expect that these general conclusions (that those insects with potential for biological control are widely distributed and relatively quickly discovered) are applicable to biological control surveys of any target that occurs continuously over a wide geographic range, but possibly not to targets that occupy disjunct distributions.

Keywords: Biological control of weeds; Agent selection; Woody weeds; Species accumulation curves; Species richness

1. Introduction

Mimosa pigra is the most common and widely dispersed of all shrubby *Mimosa* species extending naturally from tropical lowland Mexico to north-eastern Argentina on stream banks, and seasonally flooded shores, along ditches and in seasonally wet savanna, and sometimes as a pest of irrigated land (Barneby, 1991). *Mimosa* is one of the largest genera of mimosoid legumes with approximately 500 species (Barneby, 1991). The centre of origin of the genus is probably the moist region in central South America (Polhill and Raven, 1981). The major centre of diversification is Central Brazil which today has very high diversity and endemism (Simon and Proenca, 2000). The genus was established possibly as early as the late Cretaceous, with the greatest diversification occurring during the Eocene and Oligocene from 14 to 36 mya (Caccavari, 1996). The land bridge between the two American continents formed about 6 mya and allowed colonisation of the north from the south (Polhill and Raven, 1981). Whether *M. pigra* migrated along this route or originated in North America and migrated south is

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unknown. It is of interest that its closest relative, *Mimosa asperata* L., only occurs in North America and therefore probably evolved there.

In Australia and south-east Asia, *M. pigra* is a highly invasive and damaging weed of wetlands, affecting both agriculture and conservation (Lonsdale, 1992). A biological control project against *M. pigra* has been continuously active since 1979. Surveys of natural enemies were conducted from field stations in Brazil then Mexico (Segura and Heard, 2004). These collections revealed approximately 420 insect natural enemies (Harley et al., 1995) and five fungi (Evans et al., 1995). About 45 of these organisms were formally assessed for their biological control potential, and 14 were released in Australia (Heard and Segura, 2004).

No economic evaluation of the *M. pigra* biological control project has been done, but we estimate the full cost to have been US$20M over 24 years. Financial records for all years were not found, but we interpolated to cover the missing years and bought all figures to 2004 dollars. The cost of exploration was approximately 10% of the total or US$2M. The cost of agent evaluation, which consisted mainly of studies on agent biology and host specificity testing, was about 30% or US$6M. This work led to the release of 14 species at a cost of about US$570,000 per agent, which is similar to (after adjusting for inflation) the estimate of US$400,000 for the pre-release studies of biological control agents released in Canada (Harris, 1991). The remainder of the project budget was spent on mass rearing and release (20%), and studies on plant ecology, monitoring of establishment and evaluation of impact (30%), and integrated management (10%). Could this large investment have been more efficiently allocated to achieve a better result? Should a greater proportion of the budget have been spent on selecting the agents?

In this paper, we review the manner in which surveys for biological control agents of *M. pigra* were conducted. We map the distribution of collecting effort over the distribution of the plant and discuss whether significant areas were neglected. We examine the distribution of agents to determine the level of endemism which we use to predict whether exploration in new areas is likely to reveal new agents. We also use species accumulation curves to examine whether repeated collecting at particular sites was done too few or too many times. This paper is most relevant to the first stage of agent selection: the exploration needed to generate a list of potential agents and their distribution. Many other weeds have a similar, broadly distributed distribution in the native range, e.g., *Acacia nilotica* L. in Africa and Asia, *Melaleuca quinquenervia* (Cav.) Blake in Australia, and the conclusions of this study may also be relevant to such species. Also surveys for potential biological control agents are an important source of data on insect distribution patterns and the conclusions may have implications for general issues of diversity and species richness.

2. Materials and methods

2.1. Distribution of collecting effort

From 1980 to 1982, surveys of natural enemies were conducted from a field station in Curitiba, Brazil. Subsequently, a station was established in Acapulco, Mexico in 1984 and moved to Veracruz, Mexico in 1987 where it has continued until the present. In addition to Mexico and Brazil, exploratory trips in search of biological control agents were made to Costa Rica, Honduras, Venezuela, Belize, and Cuba. A minimum of 1 h was spent collecting at each site. Specimens of mature and immature arthropods were collected by hand-picking, aspirating or beating. Collections were biased towards groups with good prospects for biological control and so ants, carabid and scarab beetles, and grasshoppers were not included (Harley et al., 1995).

A data sheet, listing information on the site, current conditions, and results, was completed each time a field collection was made. These data were entered into a relational database, which was queried for lists of all sites and the number of times collections were made. A map generated from these data was overlaid on a map of the distribution of *M. pigra* (Barneby, 1991) to identify areas where collections had not been made. Only the collections made between 1980 and the end of 1993 were included, as, by then, most natural enemies had been identified. As part of the survey work, collections were also made on the closely related *M. asperata* in Mexico and USA. These collections are not included in our study, as this plant did not reveal any agents not already found on the target weed.

2.2. Distribution of herbivores

Here, we address the question of whether further exploration should be conducted in areas within the distribution of *M. pigra* which have not been surveyed. We approached this question by examining the distribution of selected agents and determining what proportion has a limited distribution. We selected a subset of 20 insects and four fungi for which the distribution and taxonomy were known with reasonable certainty as a result of their assessment for agent potential (Table 2).

To investigate the relationship between abundance and distribution, we classified the 20 insects from Table 2 into either common or uncommon and wide ranging or restricted and applied a χ^2 and Fisher's exact test to the resulting contingency table. The scores in Harley et al. (1995) were used for abundance. For distribution, we scored species as restricted if they occurred in only one