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Case study

A systematic approach to biological control agent exploration and prioritisation for prickly acacia (*Acacia nilotica* ssp. *indica*)

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Abstract Agent selection for prickly acacia has been largely dictated by logistics and host specificity. Given that detailed ecological information is available on this species in Australia, we propose that it is possible to select agents based on agent efficacy and desired impact on prickly acacia demography. We propose to use the 'plant genotype' and 'climatic' similarities as filters to identify areas for future agent exploration; and plant response to herbivory and field host range as 'predictive' filters for agent prioritisation. Adopting such a systematic method that incorporates knowledge from plant population ecology and plant–herbivore interactions makes agent selection decisions explicit and allow more rigorous evaluations of agent performance and better understanding of success and failure of agents in weed biological control.

Key words agent prioritisation, biological control, climate matching, exploration, native host range, plant genotype matching.

INTRODUCTION

Prickly acacia, *Acacia nilotica* ssp. *indica* (Bentham) Brenan (Mimosaceae), is a weed of national significance in Australia, and is currently widespread throughout the natural grasslands of western Queensland (Mackey 1997). In the Mitchell grass downs of western Queensland, an area previously of natural grassland, this species infests over six million hectares and 2000 km of bore drains (Spies & March 2004). Prickly acacia is also present in the coastal regions of Queensland, the Northern Territory and Western Australia (Spies & March 2004), and has the potential to infest vast areas of Australia's native grassland ecosystems (Kriticos *et al*. 2003b). Mechanical and herbicide treatments are available to manage this weed (Jeffrey 1995; Spies & March 2004), but their use is not always economical. Classical biological control, a low-cost and permanent alternative, is considered as a viable option for the long-term sustainable control of this weed.

Biological control of prickly acacia was initiated in the early 1980s, with surveys conducted in Pakistan (Mohyuddin 1981, 1986), Kenya (Marohasy 1992, 1995) and South Africa (Stals 1997). Thus far six species of insects have been released in Australia, but only two of these species have become established in the field. These include a seed-feeding bruchid *Bruchidius sahlbergi* Schilsky from Pakistan (Wilson 1985; Palmer 1996) and a leaf-feeding geometrid *Chiasmia assimilis* (Warren) from Kenya and South Africa (Lockett & Palmer 2005). Among them, the seed predator is the only agent that occurs in all areas where prickly acacia occurs, including western Queensland where the largest populations of the plant occur. However, its impact on prickly acacia populations remains very low (Radford *et al*. 2001a). The leaf-feeding moth, on the other hand, became established in a few of the coastal sites in northern Queensland, but not in the Mitchell grass downs. Due to non-establishment of several of these agents in the targeted Mitchell grass downs areas, a climate matching analysis was carried out. The study indicated that several of these agents are more suited to coastal regions and they are less likely to establish in the hotter and drier weather conditions that is the norm in the Mitchell grass downs of western Queensland (Lockett & Palmer 2003; Senaratne *et al*. 2006).

Selection of regions to survey for agents has been based on logistics (i.e. access, safety, reliable contacts, etc.), and host specificity has been the sole agent selection criterion. The use of climate matching and comparison of plant genotypes between the native and invaded ranges has only been a reactive response to failures in agent establishment. Seldom have plant responses to herbivory, or identifying the weak links in plant population dynamics been used to guide agent selection, despite detailed ecological studies (Radford *et al*. 2001b,c, 2002) and the presence of a detailed demographic model (Kriticos *et al*. 2003a,b) of this species in Australia.

The need for effective biological control agents continues to be a priority in the Mitchell grass downs, where the introduced agents either have not established, or are as yet ineffective.

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PROPOSED APPROACH

Acacia nilotica has a broad native geographical range including much of Africa, central Asia and the Indian Subcontinent (Dwivedi 1993). *Acacia nilotica* is a highly variable species complex exhibiting significant morphological and genetic diversity. There are nine recognised subspecies in the native range with each subspecies having a distinct geographical range (Brenan 1983). Due to such genetic variability in the plant populations in its native range and also the wide range of climatic conditions under which prickly acacia either occurs in nature or is grown commercially, we propose to use the 'plant genotype' and 'climatic' similarities as filters to identify areas for future agent exploration. Once the most suitable area is identified, plant-based approaches (plant response to herbivory and identifying weak links in prickly acacia demography) will be applied as a 'predictive' filter for agent prioritisation. An additional 'field host range' filter based on field host range of potential agents in the native range will also be used to rule out potential agents prior to more expensive host-specificity testing. We elaborate on these below.

Plant genotype

Genetic studies have revealed that the invasive prickly acacia population in Australia is the subspecies *A. nilotica indica*, which is native to India and Pakistan (Wardill *et al*. 2005). This is further supported by plant morphological (Brenan 1983) and biochemical (Hannan-Jones 1999) studies. Insect and plant pathogen performance are likely to differ across plant genotypes (i.e. Ellison *et al*. 2004; Goolsby *et al*. 2006). The psyllid, *Acizzia melanocephala* Burckhardt & Mifsud, has a very restricted host range, confined to just a few African subspecies of *A. nilotica* and the target subspecies *A. nilotica indica* in Australia was not a suitable host (WA Palmer and ABR Witt, unpub. data 2005). This finding supports the need to search for coevolved biological control agents in India and Pakistan (Anonymous 1995; Wardill *et al*. 2005).

Surveys in Pakistan covering different climatic zones, including subtropical hot arid regions during 1980–85 (Fig. 1), identified 71 phytophagous insects associated with *A. nilotica indica* (Mohyuddin 1981, 1986). Among them, a seed-feeding beetle *B. sahlbergi* (Bruchidae) and a shoot-boring moth *Cuphodes profluens* Meyr. (Gracillariidae) were introduced into Australia (Mohyuddin 1981, 1986), but only one of them (*B. sahlbergi*) has become widely established (Wilson 1985). The probability of finding additional agents from Pakistan is low given the extensive nature of previous surveys. We therefore propose to conduct surveys in India. While the distribution of *A. nilotica indica* in Pakistan may be contiguous with that in India, prickly acacia occurs in a greater diversity of habitats in India (Mani 1974; Dwivedi 1993), which may imply a broader suite of potential agents. There is, however, limited information available on the incidence of insects and plant pathogens associated with *A. nilotica* in India (Pillai & Gopi 1990; Dwivedi 1993; Marohasy 1995; Pillai *et al*. 1995; Kapoor *et al*. 2004).

In India, prickly acacia is considered as a multipurpose tree. It occurs naturally and is also grown widely throughout India (Dwivedi 1993). Four of the nine recognised subspecies (*A. nilotica indica* (Benth.) Brenan, *A. nilotica subalata* (Vatke) Brenan, *A. nilotica cupressiformis* (J. Stewart) Ali & Faruqi and *A. nilotica adstringens* (Schumach. & Thonn.) Roberty) occur in India (Dwivedi 1993). Among them, *A. nilotica indica* is the most prevalent subspecies occurring throughout the country. Two subspecies (*A. nilotica indica* and *A. nilotica cupressiformis*) co-occur in Rajasthan (Fig. 2a) and Karnataka States, while subspecies *A. nilotica indica* and *A. nilotica subalata* co-occur in Tamil Nadu State (Fig. 2b). In Chattishgarh State, in addition to *A. nilotica indica*, a subspecies similar to *A. nilotica* ssp. *tomentosa* (Benth.) Brenan was also recorded along roadside plantations. Co-occurrence of various subspecies makes India a suitable place for identifying agents that are likely to be specialists on the subspecies in Australia.

Climatic suitability

In classical weed biological control, success or failure of agents is often determined by climatic factors. Due to unsuitable climatic conditions, biological control agents from Africa did not establish to date in arid Mitchell grass downs (Lockett & Palmer 2003; Senaratne *et al*. 2006). Agents from areas with climatic conditions similar to Mitchell grass downs, and the same plant genotype (*A. nilotica* ssp. *indica*) are more likely to succeed as effective biological control agents for prickly acacia in Australia (McFadyen 1991; Marohasy 1995).

A range of climate modelling approaches have been applied to prickly acacia, and all suggest that regions within Pakistan and India are likely to yield potential agents that are climatically adapted to Mitchell grasslands in Australia (Fig. 1). Matching the climatic conditions of areas in western Queensland where prickly acacia is invasive (i.e. Winton, Barcaldine and Hughenden) with regions in India suggests that a majority of the areas in India are suitable (Ecoclimatic Index = 50%), with Rajasthan State climatically the most suitable region (Ecoclimatic Index = 70%) for exploration (Fig. 1). Climate modelling based on a hypothetical insect that would be suited to the Mitchell grass downs, but not coastal Queensland, gives a more conservative prediction that India's north-west region is climatically the most suitable for exploration (Senaratne *et al*. 2006).

Plant response to herbivory

Weaknesses of the target weed can be exploited to focus the search for effective agents, thereby enhancing the success rate of biological control efforts (Kriticos *et al*. 1999). As prickly acacia populations are not seed limited, flower and seed-feeding agents would not be expected to have a major impact as weed biological control agents (Marohasy 1995; Kriticos *et al*. 1999). Seedlings and juveniles appear to be the most susceptible life stages to target for control (Kriticos *et al*. 1999). Empirical studies on the response of prickly acacia seedlings to herbivory in the native and introduced ranges will be used to guide agent selection decisions.

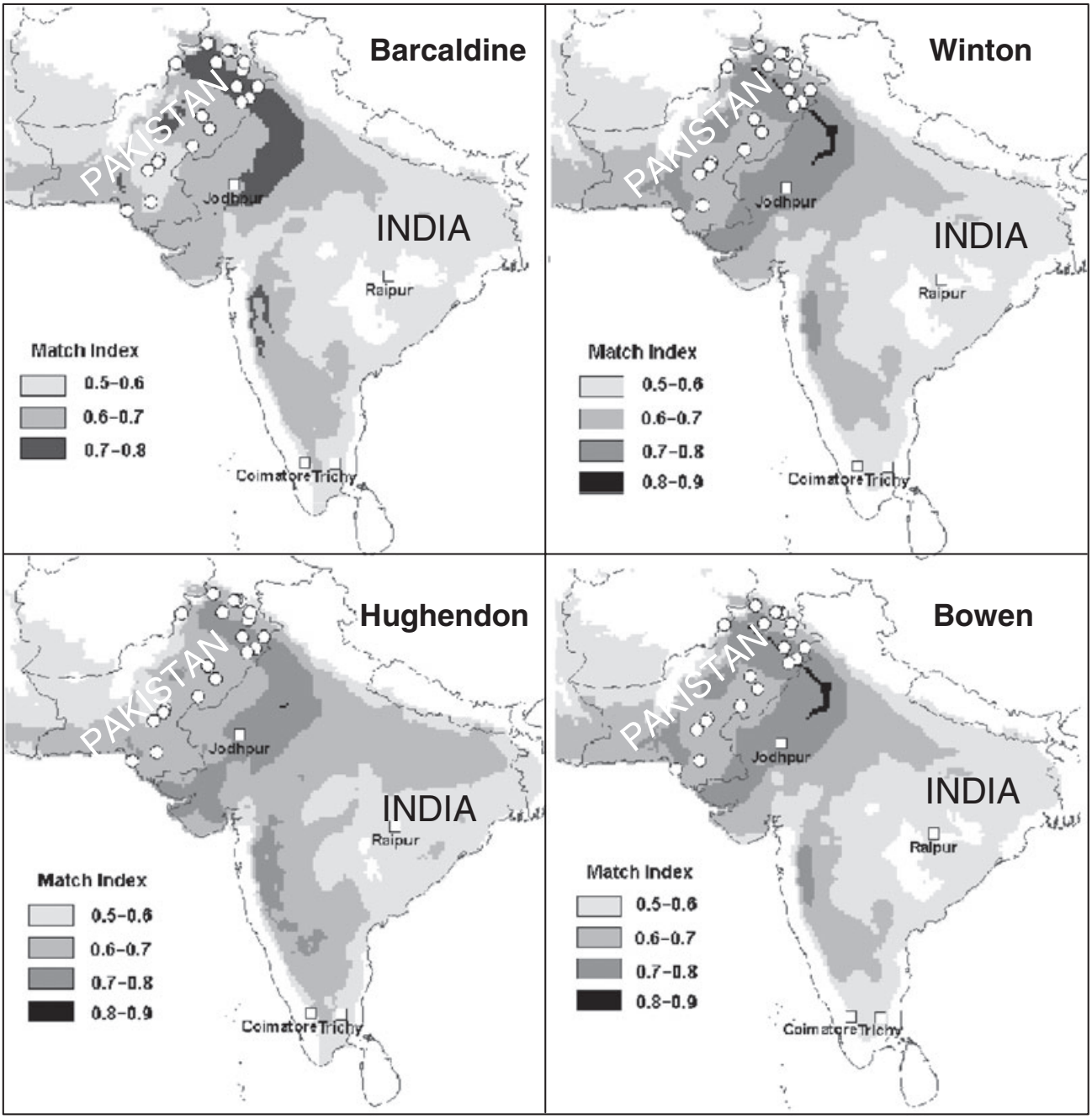

Fig. 1. Areas in Pakistan and India climatically (matching temperature and rainfall) similar to Mitchell grass downs in western Queensland (Barcaldine, Winton and Hughenden) and coastal north Queensland (Bowen). Empty circles (○) indicate sites where prickly acacia was surveyed during 1980–85 and the empty squares (□) are experimental stations from where surveys within India will be conducted.

A trial, to identify the type and intensity of herbivory required to reduce the survival and growth of prickly acacia seedlings, is in progress. Pre-release evaluation of the efficacy of potential biological control agents is often not used to prioritise agents in the native range. In the native range, insecticide-exclusion trials will be conducted in two sites (Rajasthan and Tamil Nadu), to quantify the impact of native herbivores on the survival and growth of prickly acacia seedlings and juveniles under field conditions. This information, along with the results from ongoing simulated herbivory trials and field-exclusion trials in Australia, will be used to assist in agent prioritisation.

Field host range

Host-specificity tests are usually conducted under quarantine conditions in the introduced range, and the host range of potential agents under natural conditions in the native range often is not fully known. Studies under open-field conditions in the native range will greatly enhance the knowledge on

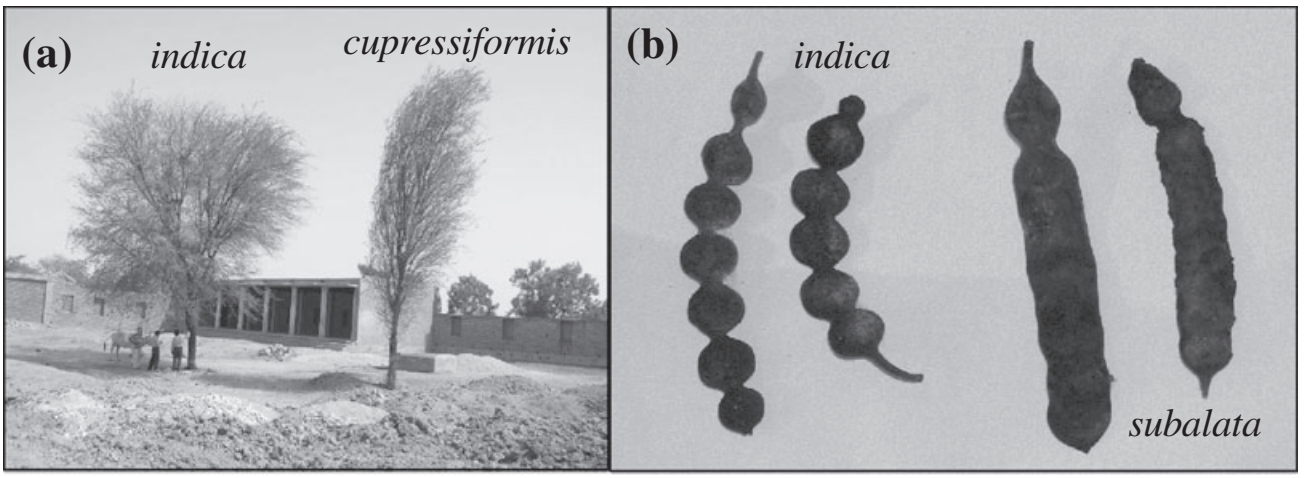

Fig. 2. Prickly acacia subspecies co-occurring in India. (a) *Acacia nilotica* ssp. *indica* and *A. nilotica* ssp. *cupressiformis* in Rajasthan. (b) Pods of *A. nilotica* ssp. *indica* and *A. nilotica* ssp. *subalata* co-occurring in Tamil Nadu.

ecological host range of candidate agents (e.g. Briese *et al*. 1995). This information will be used to prioritise agents for further host-specificity testing in the introduced range.

Occurrence of several native *A. nilotica* subspecies along with other native and non-native *Acacia* species (including species native to Australia) highlights the advantage of conducting surveys in India where the field host-specificity of potential agents could be determined. In Rajasthan, which has similar climatic conditions to western Queensland (hot and dry), two subspecies of prickly acacia (*indica* and *cuprissiformis*) and other *Acacia* species (*Acacia senegal* (L.) Willd., *Acacia leucophloea* (Roxb.) Willd. and *Acacia tortilis* (Forsk.) Hayne) co-occur in the field. In regions of Tamil Nadu with hot and dry climatic condition, prickly acacia subspecies (*indica* and *subalata*) co-occur with other *Acacia* species. In Chattishgarh, which has a hot and humid climate, *A. nilotica* ssp. *indica* is the only native subspecies, but it co-occurs with other *Acacia* species (i.e. *Acacia latifolia* Benth, *Acacia catechu* (L.) Willd.). Testing host use across such climatic gradients will allow us to determine which agents are likely to be effective in the different climatic regions of Australia that prickly acacia has invaded.

CONCLUSION

We propose that adopting such a systematic approach to native-range surveying and agent prioritisation that incorporates knowledge from plant population ecology and plant–herbivore interactions, and makes agent selection decisions explicit could allow more rigorous evaluations of agent performance and better understanding of success and failure of agents in weed biological control.

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