Challenges facing the successful management of widely distributed weeds: biological control of mesquite (*Prosopis* species)

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Summary Many weeds are widely distributed, frequently spanning several climate zones. This poses a serious challenge for biological control, because agents rarely perform equally well across the full distribution of their host. Mesquite (*Prosopis* spp.), a group of woody weeds that form dense thorn forests, is one such example. It is widely distributed in rangeland Australia, and forms dense infestations in five different regions, each with quite distinct climates. Two new biological control agents were released throughout Australia since 1998, a leaf-tying moth (*Evippe* sp.) and a sap-sucking psyllid (*Prosopidopsylla flava*). The psyllid is only tenuously established in south-west Queensland, which is most similar climatically to the native-range origin, and northern New South Wales. In contrast, the leaf-tier is established at all sites, but is most abundant in the Pilbara which, of all the Australian sites, is most dissimilar climatically to the native-range origin. In the Pilbara it is causing high levels of prolonged defoliation, which is greatly reducing growing seasons and seed production.

Suites of agents will probably be required to control mesquite throughout its distribution. The challenge remains to select new agents that are effective in regions where existing control strategies are inadequate. Better, but cost-effective, predictive tools are required to do so, because simple climatic-matching that do not account for the unique climatic requirements of individual species are an unreliable predictor of where agents will do best.

Keywords Biological control, mesquite, *Evippe*, Gelechiidae, *Prosopidopsylla flava*, Psyllidae, agent prioritisation, climate matching, climate modelling.

INTRODUCTION

Many weeds occur across diverse environments. This poses serious challenges for biological control, because agents will only rarely perform sufficiently well across all environments. Widely distributed weeds in northern Australian include parkinsonia (*Parkinsonia aculeata* L.), mesquite (*Prosopis* spp.), Noogoora burr (*Xanthium occidentale* Bertol.) and bellyache bush (*Jatropha gossypiifolia* L.). Where agents have been released they have not been universally effective. For example, on Noogoora burr the rust, *P. xanthii* Schweinitz, exerts complete control in eastern Australia, but causes little or no damage in northern Australia (Morin *et al*. 1996). Likewise, the moth, *Epiblemma stenuana* (Walker), is relatively abundant in Central Queensland, is generally rare in northern Australia, and has failed to establish in parts of the Kimberley (van Klinken and Julien 2000).

A challenge for agent selection is therefore to find agents that have broad environmental tolerances, and will do best in regions where the weed is most important, such as where existing control strategies are inadequate. The importance of agents being climatically adapted to the target region has long been recognised (Wilson 1949, in Huffaker 1964). In practice, however, agent prioritisation based on climatic adaptations is rarely done.

The primary technique used for identifying which agents are likely to be most suited to the target region is climate-matching. This method assumes that the best adapted agents will come from areas within the native range where the climate is most similar to the target region. Climate matching ranges in sophistication, from intuition, to comparing climate graphs (Wapshere 1993), to more quantitative comparisons using techniques such as the climate-matching function in CLIMEX (Kleinjan and Scott 1996).

Mesquite (Leguminosae) is one current example where the interaction between climate and agent effectiveness is likely to be particularly important. Mesquite is a widely distributed woody weed of rangeland Australia. It grows in diverse climatic conditions, with annual mean daily temperatures ranging from 10–15°C to over 25°C, and median annual rainfall from about 120 mm to 1200 mm (van Klinken and Campbell 2001). In this paper we briefly document the relative establishment of two agents on mesquite throughout northern Australia, and determine whether predictions based on climate-matching would have been useful at the resolution necessary for prioritising agents in northern Australia. We also discuss possible ways in which predictions of relative performance in different environments may be improved. Results are documented more fully in van Klinken *et al*. (in press).

METHODS AND RESULTS

Two agents, *Evippe* sp. (Gelechiidae) and *Prosopidopsylla flava* Burckhardt (Psyllidae) were approved for released against mesquite in 1998 (van Klinken and Campbell 2001). *Evippe* is a leaf-tier of mature foliage (van Klinken and Heard 2000), and *P. flava* is a sapsucker that feeds on immature foliage and causes dieback at high densities (van Klinken 2000). Both agents were sourced from the same part of central-north Argentina. This region has a semi-arid climate that is broadly similar to northern Australia.

Releases were made between 1998 and 2000. The release strategy for both agents was to make multiple, large releases at relatively few sites. Sites were selected within each of the six climatically distinct regions in which mesquite is a serious weed. *Evippe* was released in all six regions, and *P. flava* in five (Table 1).

Post-release evaluation was conducted at each site between 1998 and 2001 to determine relative abundance and spread at each site. A standardised survey method was developed for each agent that could be adopted by local collaborators across Australia (van Klinken *et al*. in press). Where possible, sites were visited at least twice a year for two to three years.

Evippe established at all release sites, although relative abundance after 2–3 years differed greatly between regions (Table 2). Highest densities were in the Pilbara, where high levels of prolonged defoliation are probably having a significant impact on reproduction and growth. Lowest densities were in northwest New South Wales, which is the coldest site. *Evippe* appears to reach highest densities in hot conditions, probably in part because generation times are shorter, particular in the months after the obligatory April–July diapause.

In contrast, the psyllid is only tenuously established in two regions, despite large releases elsewhere (Table 1). There are several reasons why *P. flava* failed to become established or abundant (van Klinken *et al.* in press). Ant predation is likely to be particularly important, as ants were abundant at all sites, and nymphs are free-living and do not exude secretions that might protect them from predation (van Klinken 2000). However, the relative importance of climate and predation in determining the distribution and abundance of *P. flava* remains to be determined.

The climates of each release region (represented by the meteorological station closest to the main release site) were compared with that from the native-range (represented by Santiago del Estero, the meteorological station closest to collection sites of both agents) using the climate-matching function in CLIMEX (Sutherst and Maywald 1999).

Table 1. Total number of each mesquite agent released in Australia between 1998 and 2000.

Region	*Evippe*		*P. flava*	
	No. sites	No. insects	No. sites	No. insects
Pilbara (WA)	3	9,975	15	49,014
Gascoyne (WA)	1	1,600	0	–
Barkly (NT)	3	9,925	4	26,223
Northern Qld	5	9,876	9	45,891
South-west Qld	2	14,133	3	27,142
Northern NSW	2	16,273	3	34,608
Total	16	61,782	34	182,878

Table 2. Establishment of the two mesquite agents in each region, and the climatic similarity of each release region with the native origin of the insects[A].

Region	Establishment		Climate match[B]	
	Evippe	*P. flava*	T°C	T°C+RF
Pilbara	Very abundant	–	35	51
Gascoyne	Common	–	35	51
Barkly	Common	–	38	61
Northern Qld	Common	–	52	**73**
South-west Qld	Common	Rare	**72**	**72**
Northern NSW	Rare	Very rare	55	55

[A] 0 (no match) to 100 (identical match). Values above 70 are in bold. [B] Climate matches based on just temperature (mean monthly min. and max. temperature), and temperature and rainfall (total annual rainfall and rainfall pattern).

Climate matches were compared for temperature only, and for temperature and rainfall (Table 2). South-west Queensland (and northern Queensland if rainfall is considered) was most closely matched to the origin, and the Pilbara and Gascoyne regions were the worst. Climate matching was therefore a poor predictor of where *Evippe* would do best, although it did predict that south-west Queensland was most suitable for *P. flava*.

DISCUSSION

Although both mesquite agents have the same origin, their relative performance differed dramatically across northern Australia. Climate matching, based on comparisons between the target region and the point of origin, gave incorrect predictions of where at least one of the agents would do best. Predictions from climate matching can therefore be misleading, because it does not take account of the individual climatic requirements of each species.

Better predictions are clearly required if agents are to be specifically targeted for particular environments, or given higher priority on the basis of wide environmental tolerances. Improved predictive power is particularly relevant when large lists of potential agents need to be prioritised, as is the case for many tropical woody weeds such as mesquite (>945 herbivores) (van Klinken and Campbell 2001) and *Mimosa pigra* L. (*c*. 417 herbivores) (Harley *et al*. 1995).

Techniques are already available in the literature, but have not been widely used or tested, have limitations, or have not yet been used for tropical weeds. Several authors have used climate modelling for predicting where agents will do best, with some success. Techniques include day-degree models (McClay and Hughes 1995) and the climate-modelling function with CLIMEX (Julien *et al*. 1995). Climate modelling has, however, not been used as a basis for prioritising agents. The main limitation to its use is probably the data requirements of climate models.

More cost-effective methods are therefore required to collect the necessary data for climate models. One potential source is native-range surveys, which have the advantage of providing data on the full fauna simultaneously. Data on species distributions (Julien *et al*. 1995), and even phenology and relative abundance (Scott 1992), can be used to infer physiological parameters necessary for modelling. However, native range surveys need to be designed to maximise the value and quality of data that is obtained. This might include careful site selection to represent the full range of climatic conditions in which the weed grows (replicated if possible), carefully timed surveys to optimise phenological data, and quantitative sampling to allow better inter-sample comparisons. Physiological data can also be determined directly in laboratory trials for individual species. Although this will always be more labour intensive, relatively rapid tests can be designed to determine most relationships necessary for climate modelling. The challenge remains to determine if climate modelling can provide sufficiently accurate predictions, and be sufficiently cost-effective, to become a realistic tool for agent prioritisation.

REFERENCES

Harley, K., Gillett, J., Winder, J., Forno, W., Segura, R., Miranda, H. and Kassulke, R. (1995). Natural enemies of *Mimosa pigra* and *M. berlandieri* (Mimosaceae) and prospects for biological control of *M. pigra*. *Environmental Entomology* 24, 1664-1678.

Huffaker, C.B. (1964). Fundamentals of weed control. *In* 'Biological control of insects pests and weeds,' ed. P. DeBach, pp. 631-649. (Reinhold, New York).

Julien, M.H., Skarratt, B. and Maywald, G.F. (1995). Potential geographical distribution of alligator weed and its biological control by *Agasicles hygrophila*. *Journal of Aquatic Plant Management* 33, 55-60.

Kleinjan, C.A. and Scott, J.K. (1996). Selection of *Cassida* spp. from southern Africa for the biological control of *Chrysanthemoides monilifera* in Australia. *Annals of Applied Biology* 128, 373-385.

McClay, A.S. and Hughes, R.B. (1995). Effects of temperature on developmental rate, distribution, and establishment of *Calophasia lunula* (Lepidoptera: Noctuidae), a biocontrol agent for toadflax (*Linaria* spp.). *Biological Control* 5, 368-377.

Morin, L., Auld, B.A. and Smith, H.E. (1996). Rust epidemics, climate and control of *Xanthium occidentale*. Proceedings of the Ninth International Symposium on Biological Control of Weeds, eds V.C. Moran and J.H. Hoffmann, pp. 385-391. (University of Cape Town, South Africa).

Scott, J.K. (1992). Biology and climatic requirements or *Perapion antiquum* (Coleoptera: Apionidae) in southern Africa: implications for biological control of *Emex* spp. in Australia. *Bulletin of Entomological Research* 82, 399-406.

Sutherst, R.W. and Maywald, G.F. (1999). 'CLIMEX: Predicting the effects of climate on plants and animals: user guide.' (CSIRO Publishing).

van Klinken, R.D. (2000). Host-specificity constrains evolutionary host change in the psyllid *Prosopidopsylla flava*. *Ecological Entomology* 25, 413-422.

van Klinken, R.D. and Campbell, S. (2001). Australian weeds series: *Prosopis* speices. *Plant Protection Quarterly* 16, 2-20.

van Klinken, R.D., Fichera, G. and Cordo, H. (in press). Targeting biological control agents across diverse landscapes: the release, establishment and early success of two mesquite (*Prosopis* spp.) insects in Australian rangelands. *Biological Control*.

van Klinken, R.D. and Heard, T.A. (2000). Estimating fundamental host range: a host specificity study of a biocontrol agent for *Prosopis* species (Leguminosae). *Biocontrol Science and Techonology* 10, 331-342.

van Klinken, R.D. and Julien, M.H. (2000). 'The Biological Control of Noogoora Burr in the Northern Territory: past attempts and future prospects.' (Unpublished Report, CSIRO Entomology).

Wapshere, A.J. (1993). Climate matching and the prospects for biological control of weeds: the contrasting examples of *Solanum elaegnifolium* and *Heliotropium amplexicaule*. *In* 'Pest Control and Sustainable Agriculture,' eds S.A. Corey, D.J. Dall and W.M. Milne, pp. 198-200. (CSIRO, Melbourne).