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Review Article

Current status of Parthenium (*Parthenium hysterophorus* Linn.) biological control in Australia

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ABSTRACT: Parthenium (*Parthenium hysterophorus* Linn.), an annual herbaceous plant native to the tropical Americas, is a weed of national significance in Australia. A major biological control program against parthenium in Australia commenced in 1977 and since then nine insect species and two rust fungi have been introduced into Australia. The stem-galling weevil, *Conotrachelus albocinereus* Deejan, the root-feeding clear-wing moth, *Carmenta* near *ithacae*, and the summer rust *Puccinia xanthii* var. *parthenii-hysterophorae* were the last three agents released. All agents established at some localities and seven are now widespread. Only the stem-galling moth *Epiblema strenuana* (Walker) is both widespread and damaging, occurring in all parthenium-infested areas in Australia at high population levels. In central Queensland the leaf-feeding beetle, *Zygogramma bicolorata* Pallister and stem-boring weevil, *Listronotus setosipennis* (Hustache) are also widespread and effective, while *C.* sp. nr. *ithacae* is at the early stages of field establishment and dispersal. In northern Queensland, *E. strenuana* and *P. xanthii* var. *parthenii-hysterophorae* are the only prominent agents. The combined impact of these agents has resulted in significant reductions in the abundance and impact of parthenium in most situations and seasons, though serious infestations can still occur. Not all potential agents have been properly investigated, and some additional agents known to be host specific in the native range warrant further investigation.

KEY WORDS: *Pathenium hysterophorus*, biological control. Australia

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INTRODUCTION

Parthenium hysterophorus L. (Asteraceae), commonly known as parthenium, is an annual herb native to the Gulf of Mexico region and central South America. Parthenium is a weed of global significance affecting many countries, including Australia, where it is a weed of national significance (Dhileepan and Strathie, 2009; Dhileepan and McFadyen, 2012). Parthenium was first identified in Australia in 1955 and proclaimed as a noxious plant in 1975 (Auld *et al.,* 1982–1983). In Australia, parthenium mainly occurs in Queensland, affecting 170,000 km^2 of prime grazing country (Chippendale and Panetta, 1994; McFadyen, 1992). Parthenium also causes human (McFadyen, 1995) and animal health (Tudor *et al*., 1982) problems, agricultural losses (Navie *et al*., 1996), serious environmental problems (Chippendale and Panetta, 1994) and also acts as a reservoir host for insect pests and plant pathogens of crop plants (Dhileepan and Strathie, 2009).

Management options for parthenium include chemical, grazing management, physical and biological methods (Dhileepan, 2009). Chemical control is the first line of defence, but high costs of herbicides preclude their long term use for parthenium management in grazing areas, public and uncultivated areas and forests. Physical methods such as grading, slashing and ploughing can provide some relief over the short term, but they are not effective in long term management. In grazing areas, management of parthenium can be achieved by maintaining sufficient levels of pasture grass growth to maximise competition against the weed. However, biological control is regarded as the most effective and economic method.

Biological control of parthenium was first considered for Australia in 1977 and since then nine species of insects and two rust fungi have been released (Dhileepan and Strathie, 2009). Field releases of biological control agents ceased in 2002, and recent research efforts have concentrated on monitoring the establishment and impact of the released agents (Dhileepan and McFadyen, 2012). In this review we report the current status of various parthenium biological control agents in Australia.

MATERIALS AND METHODS

Native range survey

Surveys were conducted in Mexico, USA, Brazil, Argentina, and the Caribbean Islands (Bennett, 1976; Evans, 1997; McClay, 1980; McClay *et al*., 1995; McFadyen, 1979). Based on field host range and preliminary host specificity tests in the native range, 10 species of insects and two rust fungi were progressed for detailed host specificity tests.

Host specificity tests

Detailed host specificity tests for the stem-galling moth, *Epiblema strenuana* Walker (McClay, 1987), the leaf-feeding beetle, *Zygogramma bicolorata* Pallister (McFadyen and McClay 1981), the seed-feeding weevil, *Smicronyx lutulentus* Dietz (McFadyen and McClay 1981), the sap-feeding planthopper, *Stobaera concinna* (Stäl) (McClay 1983), the leaf-mining moth, *Bucculatrix parthenica* Bradley (McClay *et al*., 1990), and the root-feeding clear-wing moth, *Carmenta* sp. nr. *ithacae* (Beutenmüller) (Withers *et al*., 1999), all from Mexico; the stem-boring weevil, *Listronotus setosipennis* (Hustache) (Wild *et al*., 1992) from Argentina and Brazil; and the stem-boring moth, *Platphalonidia mystica* (Razowski & Becker) (Griffiths and McFadyen, 1993) and the stem-galling weevil, *Conotrachelus albocinereus* Fiedler (McFadyen, 2000) from Argentina were carried out in the quarantine facility at the Alan Fletcher Research Station (AFRS) in Brisbane, Australia. The Mexican weevil, *Thecesternus hirsutus* Pierce was imported into Australia for host specificity-tests in 1982 and again in 1997. On both occasions no further progress was made as the insect could not be reared in quarantine. Host specificity tests for the winter rust, *Puccinia abrupta* Diet. & Holw. var. *partheniicola* (Jackson) Parmelee (Parker *et al*., 1994) and the summer rust, *Puccinia xanthii* var. *parthenii-hysterophorae* Seier, Evans & Romero var. nov. (Seier, 1999) from Mexico, were conducted at CABI (UK).

Field release and monitoring

The approved agents were mass reared in climate controlled glasshouses (20-30°C temperatures and 12:12 LD photoperiod) at AFRS in Brisbane (27°31’38.22"S; 152°58’31.43"E) and the Tropical Weeds Research Centre (TWRC) in Charters Towers (20°5’43.65"S; 146°16’6.28"E). Agents mass reared at AFRS and TWRC were field released in central and northern Queensland, respectively. All of the release sites were revisited at least annually (February to May) to monitor any signs of establishment. Non-release parthenium infested sites were also surveyed opportunistically to monitor the field dispersal of various biological control agents.

RESULTS AND DISCUSSION

Zygogramma bicolorata Pallister (Coleoptera: Chrysomelidae)

Zygogramma-bicolorata was introduced from Mexico into Australia in 1980. Between December 1980 and May 1983 at least 84,800 beetles were released in central Queensland at 20 sites from Moray Downs and Collinsville in the north to Mt Ogg south of Rolleston in the south, with several releases of >7000 beetles in each release. The insect became established on annual ragweed (*Ambrosia artemisiifolia* L.) in south-eastern Queensland and northern NSW within two years of first releases, but establishment on *P. hysterophorus* was much slower. Large numbers were then seen in the area in January 1990, and in 1993 a large outbreak occurred along Meteor Creek 10 km north of Peawaddy creek in central Queensland. Since then, due to both natural spread by the beetle and deliberate spread by farmers, the area with *Z. bicolorata* defoliation has increased to about 12,000 km^2, covering more than 50 properties in central Queensland where outbreaks of *Z. bicolorata* periodically cause complete defoliation. However, there has been no indication of field establishment in northern Queensland.

Smicronyx lutulentus Dietz. (Coleoptera: Curculionidae)

Smicronyx lutulentus was approved for field release in 1980. A total of 15,100 adults were released between January 1981 and February 1983 in 11 release sites in Queensland, ranging from Mt Nebo and Collinsville in the north to Mt Pleasant, south of Rolleston, in the south. All releases used young adults reared in laboratory cages in Brisbane. The weevil was initially thought to have failed to establish, as no insect was seen at release sites in the field. However, a large population of adults and larvae was found at a site in central Queensland in December 1995; subsequently the beetle has been found in many areas, including northern Queensland. In Australia, the incidence of *S. lutulentus* is sporadic, though very large populations can occur after rain.

Epiblema strenuana (Walker) (Lepidoptera: Tortricidae)

Epiblema strenuana was approved for field release in 1982. Field releases of 700 to 1500 pupae per site were made at 64 sites in Queensland from December 1982 to February 1984. These pupae were placed in absorbent paper in small wooden boxes protected from ant attack and with an exit hole for the adult moths. Subsequent field releases were made using galls collected from the initial establishment sites. The moth became established on *P. hysterophorus* from the first releases. It also now occurs on annual ragweed and Noogoora burr *(Xanthium*

occidentale Bertol.) and is widespread in all areas in Queensland and NSW where host plants occur.

Listronotus setosipennis (Hustache) (Coleoptera: Curculionidae)

Approval for the field release of *L. setosipennis* was obtained in 1982. A total of 23,800 adult beetles was released (1000 to 3000 weevils per site per release) between December 1982 and March 1985 at 21 sites in central Queensland, from south of Rolleston to Elgin Downs and Collinsville in the north. Additional field releases were made in northern Queensland (Cardigan Station and Burdekin River) from December 1991 to May 1992. Field establishment was first confirmed in 1983, and subsequent spread was quite rapid. However, current field incidence remains patchy and the population levels are usually low. The weevil appears suitable for regions with prolonged dry periods and an erratic rainfall pattern.

Stobaera concinna (Stal.) (Hemiptera: Delphacidae)

The sap-feeding planthopper, *Stobaera concinna* was approved for field release in 1983 and releases of several thousand individuals (5,000 to 10,000 adults and nymphs per site per release) were made at 26 sites in Queensland, from Townsville in the north to Pentland in the west, and Toogoolawah in the southeast, from October 1983 to April 1986. This agent did not establish on *P. hysterophorus*, though it has become established and is present at low levels on annual ragweed (*A. artemisiifolia*) in south-eastern Queensland. Non-establishment on parthenium is possibly due to the absence of a diapause stage, as there are long periods with no green parthenium available in central and northern Queensland.

Bucculatrix parthenica Bradley (Lepidoptera: Bucculatricidae)

Bucculatrix parthenica was released in sites in central Queensland from February 1984 to September 1985, in northern Queensland during August–September 1985, and in one site each in western (Charleville) and south-eastern (Toogoolawah) Queensland. Releases of plant material infested with pupal cocoons as well as adult moths were made. Field establishment in central Queensland was confirmed in 1987. The moth is now widespread on parthenium in Queensland, but is abundant only late in the summer and does not appear to have a major impact on the weed populations. No parasitoids have been reared from the larvae in Queensland.

Conotrachelus albocinereus (Razowski & Becker) (Coleoptera: Curculionidae)

The stem-galling weevil, *Conotrachelus albocinereus* was approved for field release in 1995, and over 15,000 weevils were released at several sites (from 40 to 800 weevils per site per release) in central Queensland between 1995 and 2000. A single release of 900 weevils was made at Greenvale in northern Queensland in 1999. Though recovered from a few release sites in central Queensland, there is no evidence of widespread field establishment of this agent.

Platphalonidia mystica (Lepidoptera: Tortricidae)

In 1992, after the approval of release of *P. mystica,* releases of potted parthenium plants infested with *P. mystica* larvae and pupae (20 to 80 potted plants per site per release) were made in central Queensland from 1992 to 1996. Occasionally, newly emerged adults were also released. Releases were made using stems containing large larvae and pupae from the laboratory colony, which were placed into field infestations of parthenium. Therefore, exact numbers of adults released are not known. Monitoring was complicated because of the universal presence of the stem-galling moth, *E. strenuana*, and the difficulty of distinguishing larvae in the field. However, adults of *P. mystica* have been reared from field collected stems on several occasions, and the species is believed to be established, though at a low level.

Carmenta sp. nr. *ithacae* (Lepidoptera: Sesiidae)

The root-feeding clear-wing moth *Carmenta* nr. *ithacae* was approved for field release in 1998, and field releases were made by planting or placing potted parthenium plants infested with larvae and pupae in the ground at 23 sites in central Queensland (40 to 513 plants per site) and 9 sites in northern Queensland (4 to 234 plants per site) from 1998 to 2002. Occasionally, newly emerged adults were also released directly in the field. This moth is now widely established in central Queensland (Dhileepan *et al*. 2012). However, there is no evidence of its field establishment in parthenium-infested areas of northern Queensland.

Puccinia abrupta var. partheniicola (Uredinales)

The parthenium winter rust, *Puccinia abrupta* var. *partheniicola* occurs naturally in Argentina, Bolivia, Brazil, Central America and Brazil and was collected from semiarid upland regions of Mexico (Evans, 1997). It is highly host specific to *P. hysterophorus* (Parker *et al*., 1994) and was the first pathogen to be approved

for release against *P. hysterophorus* in Australia. Field releases were made at 50 sites in central Queensland from 1991 till 1996. The winter rust established easily in southern Queensland, but in central Queensland it established only in a few localised areas with wetter winters and cooler temperatures. The spread and effectiveness of this pathogen has been hindered by frequent drought over the last 20 years. The rust has not established in northern Queensland where conditions are hotter and drier.

***Puccinia xanthii* var. *parthenii-hysterophorae* (Uredinales)**

The parthenium summer rust, *P. xanthii* var. *parthenii-hysterophorae*, previously known as *Puccinia melampodii* Dietel & Holway (Seier *et al*., 2009), was collected from low-altitude regions of Mexico and Texas, USA (Evans, 1997; Seier, 1999). It is highly host specific, virulent and adapted to areas with high temperatures and limited periods of humidity (Seier, 1999). The parthenium summer rust was approved for field release in 1999. Field release in Queensland commenced in January 2000 and continued until 2003. Releases were made at more than 50 sites in northern and central Queensland. Field establishment of parthenium summer rust was evident in most release sites soon after release (Dhileepan *et al*., 2006). The prevalence and intensity of parthenium summer rust varied widely between sites and between years, due to erratic nature of rainfall patterns and frequent dry summers.

Other potential agents

Some agents thought to be host specific in the native range were not reared and host-tested. The parthenium aphid, *Uroleucon* sp. near *ambrosiae* (Thomas) was tested in Mexico, where indications were that it was restricted to parthenium, but concerns regarding its relationship to similar aphids feeding on sunflower meant that further testing was not undertaken. The gelechiid moths, *Gnorimoschaema saphirinella* (Chambers) and *Helcystogramma chambersella* (Murtfeldt) and the noctuid, *Spragueia guttata* (Hodges), also from North America, might warrant further investigations.

Seven species of insects and two rust fungi have been successfully established as biological control agents against parthenium in Australia, and a further two insect species, *S. concinna* and *P. mystica*, have been recovered only occasionally in the field. Among the established agents, *Z. bicolorata*, *C.* nr. *ithacae*, *C. albocinereus*, and *P. abrupta* var. *partheniicola* continue to have restricted distributions which limit their overall impact on the target weed. The *C.* nr. *ithacae* is at the early stages of field establishment and dispersal. *S. lutulentus*, *B. parthenica*, *L. setosipennis* and *P. xanthii* var. *parthenii-hysterophorae* are widespread, but only seasonally present in large numbers causing significant damage. Only *E. strenuana* is both widespread and damaging, occurring in all parthenium-infested areas and frequently at high population levels.

The time taken for establishment of the different biological control agents varied widely, possibly due to the climatic differences between the countries of origin and introduction. In Australia, *Z. bicolorata* became established on *A. artemisiifolia* in south-eastern Queensland immediately and was visibly abundant within two years of introduction (McFadyen, 1992), but the same beetle took more than 12 years to become abundant on parthenium in central Queensland (Dhileepan and McFadyen, 1997). The seed-feeding weevil, *S. lutulentus* also took more than 14 years to become abundant in Australia (Dhileepan and McFadyen, 1997). In contrast, *E. strenuana*, *L. setosipennis* and *P. xanthii* var. *parthenii-hysterophorae* all became established almost immediately on field release.

The distribution and abundance of biological control agents and their interactions with their host plants are influenced mainly by timing of the onset of summer rainfall or the total summer rainfall. In central and northern Queensland, parthenium populations develop very rapidly in response to local rainfall events, and plants flower and senesce equally rapidly as the moisture dries up. Lack of suitable host plant material is therefore the main constraint on the populations of the biocontrol agents. In central Queensland, where early summer rainfall is more reliable, *Z. bicolorata*, *E. strenuana* and *L. setosipennis* are widespread and effective. In northern Queensland, *E. strenuana* and *P. xanthii* var. *parthenii-hysterophorae* are the prominent agents.

Cumulatively, biological control has had a significant negative impact on parthenium weed and its soil seed banks in Queensland, but the impact varied widely between years and between locations (Dhileepan, 2003). Overall, the impact was greater in central Queensland than in northern Queensland, and a significant increase in grass biomass production due to biological control was observed more often in central Queensland than in northern Queensland (Dhileepan, 2007). In economic terms, the benefit from increased grass production due to biological control was estimated to be $1.25 /ha/

year for buffel grass (*Cenchrus ciliaris* L.) in central Queensland, and $1.19 /ha/year for the Queensland blue grass (*Dichanthium sericeus* (R. Br.)) in northern Queensland (Adamson and Bray, 1999). In addition, biological control also resulted in the saving of $8m/year in health costs in treating allergic dermatitis and asthma in workers in infested areas, giving an overall benefit/ cost ratio for the program of 7.2 and a Net Present Value (in 2005) of $33.3 million for a total cost of $11.0 million (Page and Lacey, 2006).

Not all potential agents have been properly investigated, and there are still possibilities for further introductions. Some agents known to be host specific in the native range in North America (eg. McClay *et al.,* 1995) are yet to be screened. Detailed surveys in lowland Bolivia might also lead to discovery of additional agents (White 1994). However, at this stage there is no funding for further work for Queensland.

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