Sustainable management based on biological control and ecological restoration of an alien invasive weed, *Ageratina adenophora* (Asteraceae) in China

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Summary

Crofton weed, *Ageratina adenophora* (Sprengel) R. King and H. Robinson, originally from Central America, was introduced into China in the 1940s. The weed spreads rapidly and is seriously damaging grasslands and hindering livestock production in southwestern China. To tackle the weed problem and allow the sustainable use of pastures, an integrated strategy, based on biological control and habitat restoration, is being explored. In 1983, a gall fly *Procecidochares utilis* Stone, originating from Mexico, was introduced from Tibet into Yunnan Province for the control of crofton weed. The current efficacy of this agent was investigated, but no significant control effect was found due to more than 60% parasitism by native parasitoids. Surveys were undertaken to identify any indigenous fungal pathogens infecting the weed. At least six strains of *Alternaria alternata* (Fr.) Keissler and a *Pestalotiopsis* sp. were isolated from leaves. One strain of *Alt. alternata* was selected for further study as a prospective mycoherbicide. Field trials on ecological restoration using competitive native plants and forages showed that *A. adenophora* was less interspecifically competitive than *Setaria sphacelata* (Schum.) Stapf. ex Massey cv. Narok.

Keywords: crofton weed, natural enemies, competitive weed replacement, IPM.

Introduction

The crofton weed *Ageratina adenophora* (Sprengel) R. King and H. Robinson (Asteraceae) (Synonym *Eupatorium adenophorum*) from Central America was introduced into China in the 1940s. The weed has distributed rapidly and is seriously damaging grasslands and livestock production in the southwestern China provinces of Yunnan, Guizhou, Sichuan, Guangxi and Tibet (Xiang, 1991; Qiang, 1998). Its successful invasion can be attributed to its strong adaptability, competitive ability in new invaded areas, abundant seed production and paucity of natural enemies, compared with its native range (Qiang, 1998; Wang, 2005). *A. adenophora* is still continuing to spread with an average expansion rate of 20 km/year throughout the south and middle subtropical zones, and 6.8 km/year in north subtropical areas (Wang and Wang, 2006). It has invaded meadow, forest and wetland, forming single dominant communities over a short period of time and thus has caused the decline and disappearance of the original plant community. It releases allelopathic substances into the soil, via the roots, which can inhibit seed germination of neighbouring plant species (Tripathi *et al.*, 1981; Baruah *et al.*, 1994; Zheng and Feng, 2005). However, allelopathic effects on susceptible plants, such as *Chromolaena odorata* (L.) R.M. King and H. Robinson, *Bidens pilosa* L., *Ageratum conyzoides* L. and *Gynura* sp., were not significant at the seedling stage of *A. adenophora* in shaded plots (Wang and Feng, 2006). This weed also exhausts arable soil fertility due to its strong absorption of soil nutrients (Liu *et al.*, 1989). Moreover, *A. adenophora* threatens the health of livestock as the branches and leaves are poisonous to domestic animals, particularly horses (O'Sullivan, 1979; Kaushal *et al.*, 2001; Wang, 2005).

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A. adenophora has become one of the worst invasive alien species (IAS) in China. In 2003, *A. adenophora* was one of 15 IAS listed in the 'White Paper of Primary IAS', released by State Environmental Protection Administration of China. Enormous efforts have been made by Central Government (through the Ministry of Agriculture) and local government, to control and/or eliminate *A. adenophora* in newly invaded areas, and control methods have been relying on chemical herbicides and mechanical removal. However, *A. adenophora* continues to spread, expanding its range principally toward the vast area of southern and southcentral China (Wang and Wang, 2006). This paper summarizes a sustainable management approach, based on biological control and ecological restoration, currently being developed for crofton weed in China.

Sustainable management measures for *Ageratina adenophora*

Classical biological control with a gall fly, *Procecidochares utilis* Stone

Procecidochares utilis, originating from Mexico, is a gall fly that forms galls in the stem of *A. adenophora.* It lays eggs on the stem apex and on hatching the larvae tunnel into the stem. In response to larvae presence, a gall forms in the stem, which may contain from 1 to 23 larvae (Bennett and Van Staden, 1986). Galls have been shown to cause severe stunting, a reduction in flowering and seed set and may result in ultimate death of the plant when they occurred in large numbers (Bennett and Van Staden, 1986). In 1984, *P. utilis* was introduced from Nienamu county Tibet into Kunming, Yunnan Province, for the control of crofton weed (Wei *et al.*, 1989). Since its introduction, field populations of *P. utilis* have been successfully established in the introduced areas in Yunnan, Guizhou and Sichuan provinces (Dai *et al.*, 1991; Chen and Guan, 1994; Li *et al.*, 2006; Wang *et al.*, 2006). The gall fly is multivoltine with the number of generations varying across the weed's invaded range in China (four in Kunming, Yunnan Province; five in southwest Guizhou Province; and six generations in the warmer lowlands of Sichuan).

A field study in 1990–1994 showed that infestation rate of *P. utilis* in the released area was approximately 10–37% on average, but could reach up to 85–96%. The average annual dispersal rate of *P. utilis* was 20–25 km (max. 40 km) from original release sites, facilitated by the southwest monsoon (Chen and Guan, 1994). Infected plants had a significantly decreased flower number, as well as seed weight, size and percentage germination (Wang *et al.*, 2006). It was concluded that the gall fly plays an important role in suppressing population growth of crofton weed as well as reducing its rate of spread (Chen and Guan, 1994; Wang *et al.*, 2006).

However, the dispersal of the gall fly has been lagging behind the spread of *A. adenophora* (Li *et al.*, 2006). In addition, the overall impact on the weed in the field has been disappointing, and a number of contributory factors have been investigated.

- *P. utilis* shows highly selective oviposition behaviour, leading to a restricted population size in the field. The gall fly will only oviposit on the stem apex, showing a preference for younger plant branches. This results in a reduction in eggs laid during the flowering season of the plant, when only less optimal oviposition sites are available (Wei *et al.*, 1989; Li *et al.*, 2006).
- Li *et al.* (2006) argued that *P. utilis* had no significant effects on the number of blossom branches, capitula and seeds produced by *A. adenophora*, which indicated limited impact on reproduction and spread of the weed.
- Significant differences were found by Li *et al.* (2006) in the infestation rates based on individual plants (71.7%) and plant branches (17.3%). Since *A. adenophora* produces a mean of 21 branches per plant, this suggests that *P. utilis* is unlikely to have a significant impact on the whole weed population.
- Recent field surveys have also revealed that *P. utilis* is parasitized by indigenous parasitoids; *Torymoides kiesenzuetteri* (Mayr), *Eupelmus urozonus* Dalman, *Bracon* sp., *Eurytoma* spp., *Sphegigaster* spp. and *Pteromalus* spp., which might also explain its lower-than-anticipated control effect. B.P. Li (2006, personal communication) observed heavy parasitism of more than 60% in the field.

Biological control with fungal pathogens

Fungal pathogens of *A. adenophora* have been studied since the first report of *Phaeoramularia eupatorii-odorati* (Yen) Liu and Guo (= *Cercospora eupatorii* Peck) in Australia in 1954 (Auld, 1969). This fungus was accidentally introduced, probably carried by *P. utilis* adult flies when they were introduced from Hawaii. This leaf-spot fungus is widespread and is responsible for significant premature leaf abscission, and is particularly prevalent in cleared areas. It is believed that the impact of the weed in Australia is considerably lessened by the pathogen (R.E. McFadyen, 2007, personal communication). It was released in South Africa in 1987, but although it has established, its impact on weed populations is minimal (Julien and Griffiths, 1998).

In Yunnan province, *P. eupatorii-odorati* is a common disease of *A. adenophora* and reaches epidemic levels during June and July. It causes reductions in the photosynthetic rate, transpiration rate and chlorophyll content, thus reducing plant height and number of leaves and flowers (Yang and Guo, 1991; Guo *et al.*, 1992). In laboratory studies, the optimal temperature for conidia germination of *P. eupatorii-odorati* was 25°C and the optimal pH was 5.0, and, like most pathogens, it requires free water on the plant surface to develop infection (Guo *et al.*, 1992). This study recommended that the ideal time, considering temperature and water requirements, to release this pathogen into the area where it does not occur in Yunnan province, was July and August.

In China, indigenous fungal pathogens infecting *A. adenophora*, which may have potential as mycoherbicides to control the weed (Qiang, 1998), have also been investigated. At least six strains of *Alternaria alternata* (Fr.) Keissler and a *Pestalotiopsis* sp. were isolated from leaves of *A. adenophora* (Wan *et al.*, 2001; W.X. Liu, unpublished data). Necrotic leaf spots on *A. adenophora* leaves were observed 24 hours after treatment with a toxin extract produced by *Alt. alternata*, at a dosage of 50–300 μg/ml (Dai *et al.*, 2004). Recent work by Qiang *et al.* (2006) has found that mycelial preparations of *Alt. alternata* are more effective infection propagules than conidia. The assessment of the potential of these local fungal pathogens is at the early stages of laboratory research and small-scale field trials.

Ecological restoration by competitive replacement with native plants and forage grasses

Ecological restoration involves the re-establishment of the structure and function of an ecosystem, primarily to achieve a pre-disturbance state. In China, studies have focused on restoration of both natural habitats with the native flora, and pastureland with forage grasses. The selection of alternative plants has been based on a number of factors:

- *A. adenophora* has a strong allelopathic effect on other plants, and degrades the soil; therefore, replacement plants need to be tolerant of the prevailing soil conditions, as well as being strongly competitive.
- Seeds of crofton weed are very sensitive to sunlight during germination and demonstrate less interspecific competitive ability at the seedling stage. Therefore, the chosen alternative plants should be easy to grow, with a high rate of growth, and a canopy density that can reach 70% within a short period.
- In the pasturelands of southwestern China, it is also critical to consider field application and technology dissemination within the rural communities. Therefore, to enhance development in rural areas, it would be favourable to choose alternative plants that have a high economic value.

Following these criteria, the candidate species selected were *Brachiaria subquadripara* (Trin.) Hitchc, *Cajanus cajan* (L.) Mjllspaugh, *Lolium perenne* L., *Pennisetum clandestinum* Hochst. ex. Chiov., *Pennisetum sinese* Roxb., *Setaria sphacelata* (Schum.) Stapf. ex. Massey cv. Narok, *Setaria viridis* (L.) Beauv. and *Trifolium repens* L.

In a greenhouse study using plants grown in pots, crofton weed was shown to be less interspecifically competitive than *S. viridis* and *S. sphacelata*, when comparing their shoot height and biomass at seedling stage (Jiang, 2007). The addition of nitrogen enhanced the relative competitive ability of the forage species, which indicated that improvement of fertilization could be of additional benefit to the restoration of the pasture. Field plots studies by Jiang (2007) confirmed that the growth (i.e. biomass) of *A. adenophora* was heavily suppressed by *S. sphacelata*, when both species were planted in a mixture at different densities, but no impacts were observed on the growth of *S. sphacelata*. Compared with the biomass produced in its monoculture plots, the biomass of *A. adenophora* decreased by over 70% in the mixed plots. The relative competitive ability of *S. sphacelata* was still higher than that of *A. adenophora* after 16 months in the field. This approach has been widely used and recommended in the invaded areas for pastures and animal farming.

Discussion

Field management of *A. adenophora* in China has been practised extensively using chemical and mechanical control, and hand removal. However, these methods are not sustainable, result in environmental problems, are labour-intensive and expensive, and still fail to contain the weed. Classical biological control was not effective probably due to the impact of the indigenous parasitoids on *P. utilis*. Biological control using fungal pathogens as mycoherbicides is still at the research stage and it is too early to say how effective they will be in the field. Recently many efforts have been made on ecological restoration of invaded pastures by native plants and forage grasses. However, ecological restoration itself is also not a sole solution to resolve the weed problem since it would not be feasible to restore all of the vast areas already invaded by the weed.

Studies on the mechanisms involved in invasion biology have also shed light on sustainable management of *A. adenophora*. It appears that *A. adenophora* colonizes human-altered environments (i.e. roads and streams) to which it is better adapted than native species, rather than invading undisturbed habitats and displacing locally adapted native species (Sax and Brown, 2000; Lu and Ma, 2006). Its invasion success is significantly negatively correlated with native plant diversity, and reduced native species cover appears to facilitate the invasion. Management to control *A. adenophora* in southwest China should also focus on habitats along roads and streams, which provide a significant source of seed and facilitate the spread of the weed into other habitats. Increasing canopy cover of native species could help control *A. adenophora* invasion in these area (Lu and Ma, 2006).

The biological control programme against mist flower, *Ageratina riparia* (Regel) R. King and H. Robinson (Asteraceae) in Hawaii is considered one of the most successful undertaken anywhere in the world (Morin *et al.*, 1997). The most important control agent for *A. riparia* in Hawaii appears to be the fungus *Entyloma ageratinae* Barreto and Evans, followed by the gall fly *Procecidochares alani* Steyskal and then the plume moth *Oidaematophorus beneficus* Yano and Heppner. It is interesting to note that a range of parasitoids destroyed up to 50% of *P. alani* in galls in Hawaii and parasitism was the main factor limiting its effectiveness in Queensland (Morin *et al.*, 1997). Morin *et al.* (1997) suggested that the fungus and the gall fly were complementary in their activity, and that both should be introduced into New Zealand for a biological control of *A. riparia*.

With all these experiences, we believe that a sustainable management programme could be established for *A. adenophora* in China using an integrated approach, underpinned by classical biological control. New agents need to be sourced from the centre of origin of the weed (Mexico), which are complementary to the two agents already impacting (albeit mildly) on *A. adenophora*. For example, a lepidopterous and a curculionid stem borer have been identified from Mexico (Osborn, 1924) as well as *Baeodromus eupatorii* (Arthur) Arthur, a rust fungus from Central America (Buriticá and Hennen, 1980). In high value land, the use of indigenous fungal pathogens as mycoherbicides may be economically viable. Ecological restoration with native plants and forage grasses, integrated with other measures such as mechanical removal, fire and chemical control, may provide the optimum approach. Over the vast areas of natural habitats, classical biological control will need to form the foundation of the integrated approach.

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