INTRODUCTION

The first biological weed control project in China was the successful control of dodder (*Cuscuta spp.*) in soybean fields with the native fungus *Colletotrichum gloeosporioides* f.sp *cuscutae* (Penzig.). Penzig & Saccardo (Coelomycetes) in Shandong Provinces in the 1960’s. In 1984, the exotic tephritid, *Procecidochares utilis* Stone (Diptera: Tephritidae), was successfully established in Yunnan Province for the control of *Eupatorium adenophorum* Sprengel (Asteraceae). The success of these two projects inspired the Biological Control of Weeds in 1985 and 1988, which subsequently resulted in a nation wide biocontrol program.

WEED PROJECTS

*Cuscuta spp.*, Dodder (Cuscutaceae)

Of the 11 species of dodder (*Cuscuta spp.*) present in China, three *C. maritima* Makino, *C. chinensis* Lam. and *C. australis* R. Brown cause large economic losses of soybean, vegetable, forage grass, peanut, potato and oilseed crops in many provinces (Teng, 1982). A 1979 survey of Heilongjiang Province showed that almost all the province’s 30,000 ha of soybean were infested with *Cuscuta spp.* resulting in losses of 20 to 95%.

Biocontrol of dodder was initiated in 1963 after a native fungal pathogen, *Colletotrichum gloeosporioides* f.sp. *cuscutae* was isolated in Jinan, Shandong Province. Studies of the biology and culture of the pathogen between 1963-1966 led to the development of a mycoherbicide called “Lubao 1” which was tested in soybean fields in five provinces in 1966 and by the end of the decade was being applied to 600,000 ha of soybean in 20 provinces (Liu & Zhu, 1980). Over 85% control was achieved resulting in yield increases of 30 to 50% (Gao & Gan, 1992). Currently, a granular formulation of Lubao 1 is produced commercially in two factories in Ningxia Autonomous Region.

However, since the late 1970s, the efficacy of Lubao 1 product has decreased considerably. The herbicide’s requirement for high humidity in the field and limited
shelf life (2-3 months), in addition to technical problems associated with its production have resulted in a dramatic decline in its use (Li, 1985). For example, in the last 10 years, only 18,000 ha of soybean in Ningxia have been treated annually (Gao & Gan, 1992).

Genetic analysis indicates the decline in efficacy was due to a change from diploid to monoploid phase during culture (Gao & Gan, 1992). A new strain of \textit{C. gloeosporioides} f. sp. \textit{cucutae}, called Lubao 1, S22 that was isolated in 1985 has much higher infectivity and productivity than the original culture. There has been no change in its virulence over 150 generations in culture over 5 years.

Currently, Lubao 1 S22 is produced by small-scale solid fermentation in two small factories and the total annual production of 10 tons does not meet the national need. It is likely that the ideal production system for Lubao 1 S22 will involve many small businesses, somewhat analogous to Western fast food franchises, each supplying their immediate area using local labour and thereby adding to the economic viability of rural areas. Additional research on production and storage methods and quality control is needed.

\textit{Eupatorium adenophorum}, Crofton weed (Asteraceae)

This South American perennial shrub was introduced inadvertently into southwest China about 1950, and has spread rapidly, invading many habitats and displacing the native flora, particularly in Yunnan, Sichuan, Guangxi and Tibet. In Yunnan province, 24 million ha of forest and agricultural land are infested and the weed is spreading northward at 10 km per year (He \textit{et al.}, 1988). It is poisonous to domestic animals, especially horses. In uncultivated habitats, chemical and mechanical control is impracticable and expensive. Indeed, Yiliang County, Yunnan Province spent 140,000 Yuan ($35,000) using these control methods in 1985 with little or no success (Anonymous, 1988).

In 1984, the Kunming Institute of Ecology, Academia Sinica found a gall-forming tephritid, \textit{Procecidochares utilis}, attacking Crofton weed near the Chinese/Nepalese border. This Mexican insect had been released in India for the biocontrol of Crofton weed in 1963 (Julien, 1992). Retesting of the tephritid’s host range in China confirmed that it was specific to the weed (He & Chen, 1987). It was mass propagated in the laboratory and released at 30 sites in Yiliang County, Yunnan Province, and by 1987 had spread to six adjacent countries with up to 75% of Crofton weeds being stem galled in an area of 100,000 ha (Chen & He, 1990). Unfortunately, the weed has not been noticeably suppressed (He \textit{et al.}, 1988).
In 1987, a fungus native to Yunnan, *Mycovellosiella* sp. was found to cause leaves of Crofton weed seedlings to wither within 35 days (Guo *et al.*, 1991). This fungus is currently undergoing field evaluation.

Although fungi causing leaf lesions are generally not particularly effective biocontrol agents, *Mycovellosiella* sp. may be more effective than the stem gall-inding tephritid. Other biocontrol insects are being investigated. *Eupatorium riparia* Regel, which is closely related to crofton weed, has been substantially to completely controlled in Australia and Hawaii by *Oidaematophorus beneficus* Yano & Heppner (Lep: Pterophoridae), *Procecidochares alani* Steyskal, and *Xanthaciura connexionis* Benjamin (Diptera: Tephritidae) (Julien, 1992). If these insects multiply on *E. adenophorum* integrated control may be possible with a complex of insect species, the fungus, *Meupatorii-odorati* and vegetation replacement with competitive grasses, forbs or trees. In developing an effective release strategy, close attention will have to be paid to the adaptability of the biocontrol agents to various climatic regions.

*Alternanthera philoxeroides* (Martius) Grisebach, Alligatorweed (Amaranthaceae)

The largely aquatic alligatorweed was introduced to eastern China from South America in the 1930s. During the 1950s and 1960s, it was regarded as “excellent pig forage” and cultivated in most of southern China. However, ten years later, it was out of control, invading citrus orchards, vegetables, rice fields, fish ponds, and irrigation canals (Wang & Wang, 1988). In most areas, terrestrial infestations cause the most economic damage. In Sichuan Province alone, alligatorweed infests 350,000 ha. Herbicides provide effective control in fields, but farmers are often discouraged by the cost of chemicals and rapid reinvasion by the weed.

The Biological Control Institute, CAAS, initiated the biocontrol of alligatorweed in 1986. No-host specific insects were found in China, but a flea beetle, *Agasicles hygrophila* Selman & Vogt (Coleoptera: Chrysomelidae) was introduced from Florida.

In southern China, the beetle has seven or eight generations a year and became sufficiently abundant to suppress aquatic infestations of alligatorweed. Between 1988 and 1991, a total of 50,000 beetles were released at Dongting Lake, Hunan Province and reduced the alligatorweed 90% over 1000 ha (Li & Wang, 1994). However, the beetle cannot survive winter without human intervention, so it is now collected in the fall and overwintered in greenhouses at 10-15°C. The beetle completes one or two generations in the green house, and in spring 3,000 beetles
per hectare are released. Release at the same site for 3 - 4 years in succession usually achieves complete control.

This capture-release method could be extended to other regions that are too cold for the beetle to survive over winter. A training program and manual for instructing farmers how to rear the beetles in winter and release them in spring will be necessary for successful use of this technology.

The puralid moth, Vogtia mallioi Pastrana (Lep.:Pyralidae), previously used in Australia and New Zealand (Julien, 1992), might be a more effective agent for control of the terrestrial infestations in China.

**Ambrosia artemisiifolia L. and A trifidaL., Ragweed (Asteraceae)**

*Ambrosia artemisiifolia* and *A. trifida*, two North American weeds that are now cosmopolitan in distribution, were probably introduced into China in the early 1930s. Both species have spread rapidly and by 1987 were present in 15 provinces, mainly along railroads and highways. *Ambrosia artemisiifolia* occurs throughout northeast, north, south and east China, infesting public parks, urban areas, residential communities, orchards, roadsides, highway shoulders and agricultural fields, while *A. trifida* is presently restricted to the northeast (Wan *et al.*, 1993). In the heavily infested areas, ragweeds are often found in dense, pure stands. The ragweeds are not yet a major agricultural problem, although dense infestations displace the native plant communities and cause economic losses in orchards and gardens. However, the primary problems is allergic “hay-fever” caused by the pollen. In Shenyang city 1.5% of the population is seriously affected (Xia, 1983) and this incidence is likely to increase unless the weed is controlled.

Two colonies of the defoliating beetle, Zygogramma suturalis (F.). (Coleoptera: Chrysomelidae) were imported from Canada and the former USSR in 1987 and 1988, respectively. In quarantine, it was confirmed that the beetle was specific to *Ambrosia* spp. and that it was a promising biocontrol agent (Wan *et al.*, 1993). Between 1988 and 1991, a total of 30,000 beetles were released in Changsha (South China), Nanjing (Southeast China ), Tieling, Shenyang and Dandong (northeast China), but only a few beetles have been recovered in Changsha and Dandong , and none in Nanjing, Tieling and Shenyang. However, when protected from predators by a cage, large populations of the beetle were produced in Beijing. Spiders, mantids, and reduvids prey on the eggs, larvae, and even the adults and appear to be the reason for the beetle’s failure to establish at field sites.
In habitats with low predator populations, *Z. suturalis* is an effective biocontrol agent for ragweed as has been the case in parts of the former USSR. Further research may identify such habitats in China.

Another insect, the stem galling tortricid, *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae) was introduced from Australia in 1990. Choice and no-choice feeding and oviposition tests conducted in quarantine and in field cages showed that *E. strenuana* completed its life cycle only on the closely related weeds *A. artemisiifolia*, *A. trifida*, *Parthenium hysterophorus* L. and *Xanthium* sp. and did not attack any of 37 species of crop plants or ornamentals. Because there was concern that this species might attack sunflower, which is in the same tribe as *Ambrosia*, additional tests were conducted with 60 sunflower varieties in pure sunflower stands, mixed sunflower and ragweed, and sunflower surrounded by ragweed during 1990-1992. In a field test with mixed sunflower and ragweed, 36 galls were found late in the season on dwarf, lodged and weak sunflower plants and five adult moths emerged from these galls. However no eggs had been laid on the sunflower plants. The heavily infested ragweed (10 to 20 galls per plant) had died prematurely and some immature larvae transferred to the adjacent, still-green sunflower stems and completed their development. However, in a field cage (10x12x3m) planted with sunflower only, introduced moths laid few eggs and those larvae that hatched did not feed or form galls (Wan & Ding, 1993). Apparently sunflower is not a suitable host for this species and it is unlikely to damage sunflower in nature. The effectiveness of *E. strenuana* in field plots indicates that it is an excellent biocontrol agent and largely immune from the predators affecting *Z. suturalis* (unpublished data, Wan). Generally, slight damage to adjacent non-host plants following sudden collapse of the host plants is fairly common in weed biocontrol, but the problem disappears as the weed density is reduced (Harris, 1990). *E. strenuana* does not infest sunflowers in either North America, where it is native, nor Australia, where it is introduced, (McFadyen, 1985; Julien, 1992). However, to be safe, it has been recommended that releases be restricted to the South of the Yangtze River where sunflower is not a major crop. In most parts of China, it appears that *E. strenuana* will be a more effective biocontrol agent than *Z. suturalis* for both *A. artemisiifolia* and *A. trifida*.

In northeast China, control of *Ambrosia* spp. along highways and railways is being achieved by replacement planting of economic and ornamental species such as indigo-bush, *Amorpha fruticosa* L., and crown vetch, *Coronilla varia* L., *Amorpha fruticosa* has been particularly effective in reducing ragweed growth and flowering (Wan et al., 1993; Guan et al., 1993).
Additional research is needed to evaluate other ragweed insects being used as control agents in other countries (Kovalev et al., 1989) and other native North America species (Harris & Piper, 1970; Goeden & Ricker, 1974a,b 1975, 1976a,b,c). *Liothrips* sp., *Tarachidia candefacta* (Hubner) Lep.:Noctuidae), *Stobaera concinna* (Stal) (Hemiptera: Delphacidae), *Euaresta* sp. (Diptera: Tephritidae), *Trigonorhinus tomentosus* (Say) Col.:Chrysomelidae) are potential candidates. Most of these have already been screened for specificity. If they can thrive in China it will be relatively cheap to use them to enhance ragweed biocontrol in China.

**Eichhornia crassipes** Solms, *Water hyacinth* (*Pontederiaceae*)

Water hyacinth, *Eichhornia crassipes* Solms, a southern American aquatic weed has posed a great threat to Dianchi Lake of Kunming City, Yunnan province in SW China. Based on researches and achievements of the weed biocontrol with *Neochetina* weevils in over 20 countries, a biocontrol project of waterhyacinth was initiated by BCI, CAAS in 1994.

Two weevils of *Neochetina bruchi* Hustache and *N. eichhorniae* Warner (Col.: Curculionidae) were introduced from USA and Argentina Nov. 1994. Host specificity test showed that the beetles only damaged water hyacinth. No damage was found on the other 45 plant species belonging to 24 families representing local economic, ecological and ornamental plants around Kunming region. The control effect test indicated that adults of the beetle could feed on the leaves and stems of the plants. For some of the plants the adult could eat about 60% of leaves. More than 200 scars could be found on one leaf of the plant. The larvae of the beetles bored the stem and made some stems decay and even the whole plant died. Compared with healthy plants, the rate of reproduction of the attacked plant was decreased by 32% after 40 days of releasing the beetles. The biomass of the plant was also decreased by 55% compared with the healthy plant. The height of the plant and the length of the roots were shorter than the no attack plant. The beetles occurred 2-3 generations in one year in Kunming area. The egg, larva, pupa and adult could develop normally in this area. Warmer winter in Kunming will be helpful for the overwintering of the beetle.

The above tests showed the beetle could been used to control the population of water hyacinth safely and effectively. It will be feasible to manage water hyacinth with biological control approach in Dianchi Lake.
BIOLOGICAL WEED CONTROL WITH FISH IN RICE FIELDS

The use of fish, *Ctenopharyngodon idellus* (C. & V.) and *Hypophthalmichthys molitrix* Val. to control weeds of rice was developed in Jiangsu, Zhejiang, Hubei, Sichuan & Anhui Provinces in the 1980s. As of 1985, 22 weeds including *Echinochloa* spp., *Cyperus difformi* L., *Ammannia* spp. and *Monochoria vaginalis* (Burm. fil)Presl. were controlled on one million ha of rice (Yu & Wu, 1988). The release of 30,000 fish (10-13 cm long) per ha at the beginning of rice growing season has been reported to reduce weed populations by 90% (Yu & Wu, 1988). This control method has doubled net returns from rice culture with the production of 300 kg per ha of edible fish and a saving of 450 Yuan per ha in herbicides (Wang & Rao, 1988). However, problems integrating fish culture, insecticides and agronomic practice remain.

INTERNATIONAL COOPERATION ON BIOLOGICAL WEED CONTROL

China is a source of natural enemies of weeds that are troublesome in North America. The Sino-American Biological Control Laboratory was established in Beijing in 1987 to seek biological control agents to control leafy spurge (*Euphorbia esula* L.), Eurasian watermilfoil (*Myriophyllum spicatum* L.), *Hydrilla verticillata* Bartr.) waterchestnut (*Trapa natans* L.) and tamarisk (*Tamarix* spp.) in North America. Some promising biocontrol insects have been collected and shipped to the USDA-ARS for screening tests.

In 1991 an agreement between Canada and China was approved for cooperative research on the biocontrol of Canada thistle (*Cirsium arvense* (L.,) Scop.). Several promising species found in the Xinjiang, a region of west China which is climatically similar to the Canadian prairies, are being studied, including a defoliating beetle, *Altica carduorum* Guer., and a stem-mining weevil *Lixus* sp. The screening tests of *A. carduorum* is currently being determined in the laboratory at Lethbridge and in field studies in Xinjiang.

PROSPECTS

Biological weed control is a recent development in China, and despite several successes, it is still, to a large extent, an art. A more systematic scientific approach will likely accelerate progress. There is an urgent need for well trained professionals and for increased understanding of the potential of weed biocontrol by both government and the public. In appropriate situations, biocontrol is the most economical and environmentally benign means of weed control.
Chemical herbicides will undoubtedly remain the means of weed control for the near future. The best return on research investment is likely to be from classical biocontrol of exotic weeds, but in many cases suitable agents can be obtained through cooperation with other countries. China is in the fortunate position of being able to capitalize on the experience of other countries. Some weed biocontrol agents that have been successfully used overseas have a high likelihood of success in China (Wang, 1986, 1989; Wan & Wang, 1991).

Conflicts between groups wanting weed biocontrol and those wanting to keep a high weed density for other purposes, such as bee culture, has received little attention in China. Stricter regulations for the release of weed biocontrol agents are needed in order to protect national interests and to provide guidelines for researchers.

China has just begun to explore the opportunities for weed biocontrol. Considerable progress has been made, but there is enormous scope for further work. Increased government and public support, closer international collaboration, more well-trained researchers are needed.

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