SUCCESSFUL BIOLOGICAL CONTROL OF CHROMOLAENA ODORATA IN GHANA: THE POTENTIAL FOR A REGIONAL PROGRAMME IN AFRICA

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BIOLOGICAL CONTROL OF Siam weed, Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), was revived in Ghana in 1989 after an initial failure in the 1970s. The arctiid moth Pareuchaetes pseudoinsulata was imported from Guam, USA in 1989 and, after quarantine studies, released in a pilot project in Kumasi in 1991. Establishment of *P. pseudoinsulata* was confirmed in Ghana in 1994. By 1999, the insect had spread to cover an area of about 81 501km², representing about 57.9% of the total area infested by *C. odorata* in Ghana. In areas defoliated by *P. pseudoinsulata*, the *C. odorata* cover has decreased from a mean of 85.0% to 37.0% within a decade. Correspondingly, there is an increase in density of grass and other broad-leaved weed populations from 2 and 13.0% to 26.6 and 36.4%, respectively, thus increasing the fodder base for domestic and game animals. Plant species diversity following control of *C. odorata* increased from three to six species per unit area. Results obtained in 1999 indicate that *P. pseudoinsulata* causes significant damage in about 57.5% of the present distribution area of the insect. Considering the continued spread of *C. odorata* through many parts of Africa and the similarity of the threats posed by it there, the success achieved in Ghana raises hope for a regional programme for biological control of *C. odorata*.

**KEY WORDS:** agent establishment and spread, biological weed control, impact on weed, *Pareuchaetes pseudoinsulata*, Siam weed

INTRODUCTION

Siam weed, *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae), was first discovered in Ghana in 1969 (Hall *et al.*, 1972). There are five schools of thought about its mode of introduction into Ghana (Timbilla and Braimah, 1996). Biological control of *C. odorata* was initiated in Ghana in the early 1970s but failed due to the lack of sustained effort (Greathead, 1989).

An international workshop was organized in Ghana in 1988 by the Ghana committee of the African Biosciences Network to examine the pest status of the weed and propose strategies for effective integrated control while maintaining its usefulness as a medicinal plant (Frimpong, 1992).

Subsequently, the Crops Research Institute of the Council for Scientific and Industrial Research initiated a biological control programme by importing the arctiid moth, *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) from Guam into Ghana in 1989. The objective of the study was to reduce the competitiveness and further spread of *C. odorata* and to thereby enhance biodiversity. *Pareuchaetes pseudoinsulata* was released in 1991, after two years’ quarantine for host-specificity and biological studies (Timbilla and Braimah, 1991), and it had established by 1994 (Timbilla and Braimah, 1996).

**MATERIALS AND METHODS**

A nationwide survey by questionnaire was conducted in 1991 to gather baseline information on the introduction, distribution and spread of *C. odorata*. Parameters recorded included the history of introduction, common names, and diseases and pests known to be associated with *C. odorata*. The importance of *C. odorata* to agricultural production in Ghana was also determined. Another survey was conducted in 1993 to rate the most important weeds in the study area.

The lifecycle of *P. pseudoinsulata* was studied in the laboratory using Kilner jars and wooden cages covered with grey-baft (30 x 30 x 30cm). Field releases of the control agent were done between 18h00 and 20h00 in *C. odorata* fields. Subsequent to the releases, monitoring was conducted to ascertain the field establishment and performance of the insect.

Using 5 x 5m² quadrats, the percentage of *C. odorata*, grasses and other broad-leaved plants in...
fields previously defoliated by *P. pseudoinsulata* was estimated. The number of plant species per unit area emerging from *C. odorata* fields after *P. pseudoinsulata* defoliation was also measured. These measurements have been ongoing since *P. pseudoinsulata* established in the fields.

**Figure 1.** Map of Ghana showing release sites and distribution of *Pareuchaetes pseudoinsulata* in 1999.
RESULTS AND DISCUSSION

Weed Status and Economic Importance of *Chromolaena odorata* in Ghana

In 1989 (20 years after the introduction of *C. odorata*), when the renewed effort to control *C. odorata* was initiated, in areas with optimal growth conditions the weed constituted about 85.0% of the vegetation outside of cultivation, in the form of dense thickets. The proportion of grasses and other broad-leaved weeds in the forest regions of Ghana had been reduced by *C. odorata* to about 2% and 13% respectively (Timbilla and Braimah, 1996). As a consequence, there was a reduction in fodder for domestic and game animals, thereby impacting negatively on animal production. There was also a substantial reduction of some native plant species such as *Aspilia africana* (Pers.) C.D. Adams (Asteraceae) and *Melanthera scandens* Schumach. (Asteraceae), which were prevalent fallow species before the introduction of *C. odorata*. Thus *C. odorata* impacted negatively on plant diversity. The damaging effects of *C. odorata* on plant diversity elsewhere have been documented (Pickworth, 1976; Liggitt, 1983; Macdonald, 1984; Erasmus, 1985, 1991; Byford-Jones, 1989).

By 1991 *C. odorata* had colonized about 60% of Ghana and was ranked as the most noxious weed in the forest regions (Timbilla and Braimah, 1996). In a study in 1992, *C. odorata* was ranked the most important weed in the Forest Savannah Transition Zone (Timbilla et al., 1996).

*Chromolaena odorata*, however, is claimed to be of use as a medicinal plant and in the improvement of soil fertility in Ghana (Timbilla, 1998). This notwithstanding, the ecological damage caused by the weed necessitated its control. In 1987, the government of Ghana signed an agreement for the control of the weed. Following the establishment of the insect, monitoring results have shown that *P. pseudoinsulata* is highly specific and an effective defoliator of *C. odorata*. Studies conducted in 1996 showed that the specificity and efficacy demonstrated by *P. pseudoinsulata* has reduced the competitiveness of *C. odorata* and species diversity has been enhanced.

Field studies conducted in 1998 indicated that, following the establishment of *P. pseudoinsulata*, the population of *C. odorata* had reduced from a mean 85.0% cover per unit area in infested fields to 36.4%. Grasses and other broad-leaved plants had increased from 2.0% and 13.0% in *C. odorata*-infested fields to 24.2% and 39.4% respectively. The study also showed an increase in the number of plant species per 1 x 1m² area from three in previously colonized *C. odorata* fields to six in areas where the insect has established and effected control of the weed.

Studies carried out in the Lama forest of Benin (O. Fischer, pers. comm.) indicate that many forest species are found growing under *C. odorata* thickets. These plants get smothered, however, if *C. odorata*...
is not controlled. Recent studies on the responses of tree seedlings in forests colonized by *C. odorata* show that there is great potential to restore the degraded areas by removing the competing *C. odorata* vegetation (Honu and Dang, 2000). Thus, effective biological control of *C. odorata* using *P. pseudoinsulata* would reduce the competitiveness of the weed, thereby enhancing the regeneration of African forests.

**The Need for a Regional Programme on Chromolaena odorata**

*Chromolaena odorata* is already a major weed in many parts of west, central and southern Africa, and results of studies conducted by Gautier (1992) and McFadyen and Skarratt (1996) indicate that there is potential for the further spread of the weed through much of the remainder of sub-Saharan Africa. Thus throughout the region there is a need to reduce the competitiveness of *C. odorata* to enhance biodiversity and save many rich African ecosystems from degradation. The present results on the activities of *P. pseudoinsulata* in Ghana are encouraging, with adequate baseline information and expertise both within the country and abroad for an effective biocontrol programme. The stage is therefore set for a regional programme to keep abreast with the rest of the world.

**CONCLUSIONS**

The field establishment of *P. pseudoinsulata* as an effective defoliator of *C. odorata* and its positive impact on plant diversity is without question in Ghana. There is however a need for other natural enemies to augment the activities of *P. pseudoinsulata*. Considering that *C. odorata* invasion poses similar ecological threats to agriculture, human health, forestry, game reserves and the environment throughout Africa, only a regional biological programme will be adequate to ameliorate the menace of the weed and salvage African ecosystems degraded by it.

**ACKNOWLEDGEMENTS**

The authors are very grateful to Prof. R. T. Awuah, Head, Crop Science Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana for pre-submission review of the manuscript. We are also grateful to staff of the Biological Control Unit, Crops Research Institute, Kumasi for their assistance in field data collection. Finally, the Technical Centre for Agricultural and Rural Co-operation (CTA), Netherlands, is thanked for sponsorship of the first author’s attendance at the workshop.

**REFERENCES**


CHROMOLAENA IN ASIA AND THE PACIFIC:
SPREAD CONTINUES
BUT CONTROL PROSPECTS IMPROVE

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Since the last Workshop, Chromolaena odorata has continued to spread to the south and east in South-East Asia and the Pacific, and to increase its distribution and density in areas where it is already recorded. It is increasingly abundant in Papua New Guinea (PNG) and eastern Indonesia, and in southern China. It is a major weed in natural grasslands and environmental reserves, as well as in grazing lands and plantation crops.

The biological control programme in Indonesia, PNG and the Philippines is being funded by the Australian Centre for International Agricultural Research. Through this project, the moth Pareuchaetes pseudoinsulata is now widely established in northern Sumatra, and in some sites in northern PNG. The gall fly Cecidochares connexa is now present at release sites in most Indonesian islands and is spreading well and giving good control of the plant 4 – 5 years after release. The fly is cleared for release in PNG, while the final release permit is awaited in the Philippines and Guam. A butterfly, Actinote anteas, is being released in Indonesia but has not yet successfully established there.

With the success of the gall fly in many areas, the prospects for biological control of this weed are good. More work is needed to spread the gall fly, and to make releases into all the countries of the region.

KEY WORDS: Actinote anteas, agent establishment and spread, biological weed control, Cecidochares connexa, Chromolaena odorata, distribution, impact on weed, Pareuchaetes pseudoinsulata, South-East Asia

CURRENT DISTRIBUTION AND SPREAD

On the Asian mainland, there has been no further spread to the north and west of India, where Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) has already reached its climatic potential, being limited by cold to the north and dry conditions to the west. To the east, it continues to spread into southern China, where it is now a major problem in Hainan and on the mainland in Yunnan and neighbouring provinces. In South-East Asia, it continues to increase in density and area in the eastern islands of Indonesia, and to spread east and south into southern Irian Jaya and northern Papua New Guinea (PNG). It is almost certainly present in Bougainville and probably in the Solomon Islands, but because of fighting in these areas, no reliable information is available. The only known infestation in Australia, in northern Queensland, is being eradicated with herbicides. Chromolaena is expected to continue its spread south and east across the Pacific, ultimately to affect all Pacific islands including Hawaii, Tahiti, northern New Zealand, and much of coastal east and north Australia (McFadyen and Skarratt, 1996).

METHODS OF SPREAD

The primary long-distance vector responsible for its spread is human activity. In Asia and the Pacific region as elsewhere, the direction of spread reflects human movements and not wind patterns (Fig. 1). The seeds bear minute hooks, and cling to animal hairs, clothing, and vehicles and machinery. Movement of military equipment and personnel are a major source of long-distance spread, and troop movements during World War II (WWII) were responsible for much of the spread through the region. Initial infestation sites were usually ports used as bases, by both Japanese and Allied forces. For example, Rabaul in New Britain and Jayapura in Irian Jaya were war-time bases and also the first sites of chromolaena invasion in these islands. Sri Lanka and the Western Ghats in India were probably infested by troops and their equipment returning from Assam and the Burma front in WWII. The initial infestation in the Marianas was at Rota island, also a Japanese base in the war.

It is noteworthy that the British South-East Asia Command HQ was in Sri Lanka, and movements of troops to and from the Burma front (an area already...
heavily infested with chromolaena) helped carry the weed to the area. Subsequent troop movements both by the British and the Japanese no doubt carried the weed into Java and Indochina. In contrast, the American HQ for the Pacific war was in Brisbane in north-east Australia, and there were significant movements of troops and equipment up and down the entire eastern Australia coast. However, these troops were fighting out of Hawaii and the Pacific islands, areas free of chromolaena at the time, and thus the weed was not spread into Australia. Had the American troops been fighting in Burma or Indochina and returning to Australia, it would have been a different story.

Figure 1. Spread of chromolaena in South-East Asia (a) by 1940 (prior to start of World War II), (b) by 1960 (spread during World War II). Shaded area: area infested by 2000.
In the same way, Indonesian army movements undoubtedly carried the weed into both West and East Timor after 1975. The importance of military vehicles and equipment in spreading seed is confirmed by the Australian experience with vehicles used in East Timor by Australian forces serving there. When the vehicles were cleaned prior to return to Australia, they were found to have up to 0.5kg of seeds in a single vehicle, primarily around the radiators and undercarriage (A.A. Mitchell, pers. comm.). The main seeding period is July and the vehicles were there from September 1999 onwards. Without the rigorous cleaning programme instituted for Australian forces and their equipment, the Timor operations would have resulted in massive chromolaena infestations at army bases throughout northern Australia (Waterhouse and Zeimer, this Proceedings).

Once established in a new area, seed continues to be spread by human activity, typically the movement of bulldozers and other heavy machinery associated with road-building, forest clearing, or the development of new agricultural areas. Unfortunately, tree clearing associated with logging, road-building, and increased agricultural activity creates the conditions in which chromolaena thrives, at the same time as the machinery spreads the seed into the newly-cleared areas. There are even instances where re-vegetation of road banks or mine sites has spread the weed, through the use of planting material or mulch contaminated with chromolaena seed. Villagers moving into new areas or working in forestry and along roads also carry the seed with them in their clothing and equipment. There is thus a progressive movement of the weed into previously clean areas along roads and tracks, which has been well documented in many countries.

Despite the conspicuous pappus on the seed, wind is the vector for purely local spread only, dispersing the seed away from the parent plants over distances usually less than 50m (Blackmore, 1998). Seed which falls under dense vegetation may lie dormant until the land is disturbed by clearing, fire or other causes. This can result in there being little visible problem in an area until trees are felled and land cleared, when there is a sudden massive germination. In grassland, whether natural or planted, the natural disturbance resulting from grazing in dry conditions and/or seasonal fires, both of which leave patches of bare soil, may be sufficient to stimulate germination. Seed germinates rapidly after rain and the seedlings quickly grow above the grass which is progressively shaded out. Grasslands in areas with a dry season are particularly vulnerable to invasion, and there is no easy control method in these situations. Valuable pasture is rapidly replaced by a dense growth of chromolaena, leaving the livestock to starve and the villagers deprived of their source of meat or cash income.

**BIOLGICAL CONTROL AGENTS**

Worldwide, three insects have been established and are now present in several countries. The eriophyid mite *Acalitus adoratus* Keifer (Acari: Eriophyidae) was host-tested in 1971 but never deliberately introduced anywhere. However, it was accidentally released in Sabah, Malaysia, from where it spread very rapidly throughout South-East Asia and is now present in all Asian infestations (McFadyen, 1995). It is particularly abundant in hot exposed sites but its impact on the plant seems to be minor. Nevertheless, it is completely host-specific, and might be worth introducing into areas such as West and Central Africa where it is absent.

The moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was the first agent to be deliberately introduced, from Trinidad into India and Ghana in the early 1970s (Bennett and Cruttwell, 1973). From India, where it was cleared of a very destructive nuclear polyhedrosis virus, it was introduced to Sri Lanka and Sabah, establishing in both countries but apparently not causing much damage to the plant. From Sabah, it spread naturally to Palawan in the Philippines and thence to Mindanao, where it is also not usually present at damaging levels. In 1985, it was taken to Guam, and subsequently to the other islands of the Marianas and adjacent countries, where it was very successful, giving excellent control of the weed (Muniappan and Marutani, 1988). From Guam it was imported into Indonesia in 1992, and has resulted in good control in north and central Sumatra (Desmier de Chenon et al. (a), this Proceedings), but has not established in Java or the other islands. It has also been introduced from Guam into PNG and Ghana, in both of which it established rapidly and is spreading (Orapa et al. (a); Braimah and Timbilla; both these Proceedings).

The erratic nature of success with this insect remains completely baffling. In some countries and areas, notably Guam, Ghana in 1995, north Sumatra, and PNG, it established rapidly, and
within 2 - 4 years was reaching outbreak populations which left large areas of weed completely defoliated. Persistent low-level populations and occasional outbreaks have resulted in adequate if not complete control of the weed, which has ceased to be a major problem in these areas. In other areas, establishment failed despite large releases of healthy larvae over a number of years. In others again, such as the Philippines, the population is present but at such low levels that the impact on the plant is insignificant.

There is no known reason for these differences. Parasitism is no higher in the Philippines, where the insect is not successful, than in north Sumatra where it is (McFadyen, 1997). Predation from whatever agency seems unlikely to be worse in Java, where it failed to establish, than in Palawan and Mindanao where it established unaided, presumably from only one or two mated females blown over the 50km crossing. It would be very useful to have a detailed population study of the moth in southern Mindanao, where it is known to be present but scarce in the midst of abundant chromolaena, to determine the factors which keep the population low. Unfortunately, resources for such a study are never likely to be available, unless a university in the USA or Europe decides to exploit this major opportunity to fund research into insect population ecology and factors affecting the success of weed biocontrol programmes.

The third insect released was the gall fly Cecidochares connexa Macquart (Diptera: Tephritidae). This was first reported from the Americas in 1970 (Cruttwell, 1974) but was not host-tested until 1993, and was first released in Indonesia in 1995. It established readily and has been widely released within Indonesia. It is now present in release areas in all the major Indonesian islands including Kalimantan and Irian Jaya (Desmier de Chenon et al. (b); Tjitrosemito; Wilson and Widayanto; all this Proceedings), and has been released and established in Palau in the Pacific (Esquerra, this Proceedings). It will be released shortly in PNG, Guam and the Philippines (Aterrado and Bachiller; Muniappan and Bamba; Orapa et al. (a); all this Proceedings), and possibly also in Thailand. It has not been tried in West Africa, India, or Malaysia, though it is likely that it will in time spread unaided across the Malaccan straits to peninsular Malaysia and thence throughout Indochina. In South Africa, the different strain of chromolaena found here is unfortunately not acceptable as a host to this very host-specific insect (C. Zachariades, pers. comm.).

Experience in Indonesia has demonstrated that the gall fly is limited only by a requirement for sunlight or high daytime temperatures (>27°C) for optimal adult feeding, mating and oviposition. Consequently it does not do well in areas with frequent cloud or mist cover, nor at sites over 900m altitude unless the area has particularly warm and sunny days. The fly survives the dry season well, diapausing as fully-grown pre-pupal larvae in the galls but without any emergence window. When the rains come and plant growth recommences, the larvae respond to the increased sap flow by cutting an emergence window and pupating, emerging as adults 11 - 14 days later. Unfortunately, dry season fires will destroy the diapausing larvae in the galls.

The fly is an effective biocontrol agent, taking about two years to reach population levels where every stem is galled. The following year, plants suffer increasing die-back and, by the fourth year after release, effective control of the weed is achieved. The fly is very good at locating isolated plants and seems able to maintain itself on a low plant population. The initial rate of spread, about 60km in 5 years or 3 - 4km per generation, implies that individual females may fly up to 4km. Parasitism in Indonesia remains very low (0 – 5%) even in areas where the fly has been present since 1994 (Desmier de Chenon et al. (b), this Proceedings).

NEW AGENTS

At present, a fourth agent, the butterfly Actinote antea, is being released in Indonesia (Desmier de Chenon et al. (c), this Proceedings). Successful establishment of this butterfly is not yet confirmed, but the initial indications are promising, and the butterfly has the additional advantage that it feeds on the closely-related plant Mikania micrantha (L.) Kunth (Asteraceae), another serious weed in South-East Asia and the Pacific.

CONCLUSION

On the negative side, chromolaena continues to spread east and southwards in Asia and the Pacific. Since the first Workshop in 1988, there has been a big increase in infestations in eastern Indonesia, and in PNG including New Britain (Orapa et al. (c), this Proceedings). The first infestation has been discovered in Australia, but is under control and should be eradicated soon. An infestation has also been found in the Cocos Island group west of Australia. There have been no reports of new infestations in Pacific island countries, but unfortunately it is likely that infestations do already exist, particularly in Bougainville and the Solomon Islands, but have not been discovered or recognised.

On the positive side of the ledger, the first of these
International Workshops, in Thailand in 1988, reported the first successful control of *Chromolaena odorata* in Guam using the moth *P. pseudoinsulata*. This was a great achievement, coming after 20 years of failures, and stimulated further efforts worldwide, as well as the continuation of the International Workshops and the inauguration of the IOBC Working Group on Chromolaena (Muniappan, this Proceedings). Now in this Fifth International Workshop 12 years later, we are reporting further successes achieved by a second very promising agent, the gall fly *C. connexa*. The gall fly seems to be both easier to establish and more consistently successful than the moth, though it is still too early to know how it will perform in the different ecological systems of mainland South-East Asia or the Philippines. However, the excellent results achieved in Indonesia should lead to increased use worldwide of the gall fly, together with the other agents reported at the Workshop.

**ACKNOWLEDGEMENTS**

The work reported in this paper was largely funded by the Australian Centre for International Agricultural Research (ACIAR) project for the Biological Control of Chromolaena in Indonesia, the Philippines and PNG, as was my attendance at this Workshop; I am very grateful for this continued support.

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Experiment Station, Guam, pp. 41-42.


Three neotropical insect species have recently been investigated for their potential as biocontrol agents of *Chromolaena odorata* in South Africa. The larvae of *Actinote thalia pyrrha* (Lepidoptera: Nymphalidae: Acraeinae), collected in Brazil, defoliate chromolaena plants, with young larvae feeding gregariously and older instars solitarily. Specificity testing indicated that this species oviposits and develops well on two southern African vines, *Mikania capensis* and *M. natalensis* and is unsuitable for release in South Africa. *Lixus aemulus* (Coleoptera: Curculionidae), also from Brazil, has larvae which tunnel along non-woody chromolaena stems. Pilot laboratory trials to assess the damage caused by larval tunnelling indicated a substantial decrease in stem length or stem die-back. Specificity tests indicated that *L. aemulus* adults preferentially feed and oviposit on *C. odorata* and this species is suitable for release in South Africa. The larvae of *Calycomyza* sp. (Diptera: Agromyzidae) from Jamaica form blotch mines under the upper surface of chromolaena leaves reducing their photosynthetic ability. *Calycomyza* sp. has a high potential rate of increase, although it is sensitive to humidity levels and temperature. Specificity tests indicated no larval development on any species other than *C. odorata* and this species is also suitable for release in South Africa.

**KEY WORDS:** *Actinote thalia pyrrha*, biological weed control, *Calycomyza* sp., *Chromolaena odorata*, host specificity, *Lixus aemulus*, South Africa

### INTRODUCTION

Three species of phytophagous insects, collected as biological control candidates from *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae: Eupatorieae) in various parts of the neotropics, have been extensively tested in the quarantine laboratories of the ARC-PPRI, South Africa, over the past 4 years, to determine whether they are restricted in their feeding and development to this weed. This paper summarises the results of these tests and also outlines the biology and likely effectiveness of these species as biocontrol agents. Some of this information has been described previously in Zachariades et al. (1999). The South African biocontrol programme on *C. odorata*, under which these studies were carried out, is more broadly described by Strathie and Zachariades (this Proceedings).

**ACTINOTE THALIA PYRRHA FABRICIUS**
**(LEPIDOPTERA: NYMPHALIDAE: ACRAEINAE)**

**Origin**

About 80 larvae of this leaf-feeding butterfly were collected in Salvador, Bahia State, on the east coast of Brazil (12.58 S 38.29 W), late in 1995 and brought into culture in quarantine in South Africa. This was an opportunistic collection, although *A. antea* (Doubleday and Hewitson) had previously been considered as a biocontrol agent for *C. odorata* in South Africa (Caldwell and Kluge, 1993).

**Identity and Description**

This species was initially identified as *A. parapheles* Jordan by G. Henning (South Africa) but was later re-identified by R.B. Francini (Brazil). Both larvae and adults are typical Acraeinae in appearance: adults are medium-sized butterflies with orange and black colouration, while the larvae have numerous processes. The larvae are distinctive in colouration, having a clearly demarcated dark brown anterior and pale brown posterior section.

**Biology**

The adult females lay batches of up to 500 eggs on the underside of leaves. These are initially yellow but turn red a few days before hatching. Young larvae feed gregariously, skeletonizing the leaves, while older larvae feed solitarily, eating entire leaves and defoliating the plant. There are 5 – 6 larval instars. In order to pupate, the larvae attach themselves to stems using silk, with the head pointing downwards. Adults lived for about 1 week in the laboratory, with females living longer than males. The total development time was about 85 days.

**Host Specificity**

Host specificity of *A. thalia pyrrha* was assessed using standard centrifugal testing principles (*sensu*...
Three Insects for Chromolaena Biocontrol in South Africa

Wapshere, 1974; Goeden, 1983). Thirty-three test plant species were selected, largely from the Asteraceae, and particularly the Eupatorieae, and included species indigenous to South Africa, some weedy American species, as well as some species of commercial value (ornamentals, crops) (Table 1). Larval starvation trials were conducted initially, using first-instar larvae on cut leaves in petri dishes, and measuring survival and feeding. If one or more larvae developed through to the pupal stage, adult oviposition choice trials were conducted with whole plants in a large 3 x 4 x 2m cage in the quarantine glasshouse. Plant species on which adults oviposited were then used in trials in which larval survival and development were compared against that on C. odorata. In accordance with the formula used by Maw (1976) to indicate host suitability for Cassida hemisphaerica Herbst (Coleoptera: Chrysomelidae), incorporating factors such as pupal weight, percentage of larvae that pupated, and development duration for female A. thalia pyrrha, an index of relative host suitability was obtained for each plant species on which eggs were deposited and larvae survived to adult stage (Table 2). The suitability index of C. odorata was assumed as the standard (100%) and test plant indices were compared against this.

Although larvae developed well on one sunflower variety (Asteraceae) (Table 2), very little oviposition occurred, and it was therefore not considered a suitable host. However, larvae on two species of indigenous Eupatorieae, Mikania capensis DC. and M. natalensis DC., developed as rapidly as larvae on chromolaena. In addition, in a choice situation adults oviposited on Mikania and chromolaena to a similar degree. Both Mikania species were calculated to have a similar host suitability index to that of C. odorata (Table 2). The genus Mikania is recorded as a host of Actinote butterflies in the neotropics. Mikania species, and especially M. natalensis, are at risk because both the geographic distribution and habitat preferences (forest margins) in South Africa are very similar to that of chromolaena, and thus no potential refugia exist for them. As a result of these factors we decided not to request permission from the regulatory authorities to release this agent.

Both A. thalia pyrrha and A. thalia L. (the latter was collected in Venezuela in 1996, is thought to be subspecies thalia (R. Francini, pers. comm.), and in preliminary specificity tests appeared to have a similar host range to A. thalia pyrrha), were forwarded to the Indonesian Oil Palm Research Institute, Marihat, Sumatra where at least one of them has been released under the name A. anteas (Desmier de Chenon et al., this Proceedings) because of discrepancies regarding the identification of Actinote species.

**LIXUS AEMULUS PETRI (COLEOPTERA: CURCULIONIDAE)**

Curculionids have a good record as biocontrol agents on weeds (Julien and Griffiths, 1999), and in addition a stem borer is considered a highly desirable element in the biocontrol strategy for chromolaena, particularly because the weed has photosynthetic stems that allow it to regenerate after defoliation.

**Origin**

Twelve adults were collected from a hairy form of C. odorata at Rio Branco, Acre Province, in the west of Brazil (9.59 S 67.49 W) in late 1995 and imported into South African quarantine.

**Identity and Description**

The species was identified by Dr C.W. O’Brien (USA, Florida A&M University) as L. aemulus (or near). The adult is an elongated black weevil (approximately 13mm in length), whose pronotum and elytra become covered with a yellow, waxy powder extruded from the cuticle soon after it ecloses. On the head and ventrally on the thorax this powder is a pink colour. Larval morphology is typical of a curculionid.

**Biology**

In the laboratory, adults feed on young leaves, particularly those of the tall, apical stems of C. odorata, causing minor damage. The females insert their eggs into a hole drilled in younger (non-woody but containing pith) stems, usually just above nodes, and protect them with a plug. Eggs hatch after about 1 week. The larvae tunnel up and down inside the stem, feeding mainly on the pith, and eventually pupate in a chamber in the stem. The adult progeny bore out of the stems 3 – 4 months after egg-laying, although they appear to diapause in stems through winter in the laboratory. Average adult longevity in the laboratory was 3 – 6 months, with a few living for up to one year.

**Host Specificity**

A total of 29 test plant species, consisting mainly of Asteraceae but including a few non-asteraceous crop species, was used for testing the host specificity of L. aemulus (Table 1). These were selected according to (i) standard centrifugal testing principles (Wapshere, 1974), (ii) host records for other Lixus species (Zachariades et al., 1999) and (iii) stem morphology. Plants were exposed to adults in a no-choice situation, and survival, feeding and oviposition were recorded over a 30-day period. Plants on which oviposition holes were found were isolated to check for the development of progeny. If any larvae developed into adults, the plant species was then used in a single-choice test with chromolaena, in which the
Table 1. Test plant list for candidate agents on *Chromolaena odorata*. Plant family and tribe are indicated in bold upper and lower cases respectively.

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<th>Test plant species</th>
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<tbody>
<tr>
<td></td>
<td><em>A. thalia pyrrha</em></td>
</tr>
<tr>
<td>ASTERACEAE</td>
<td></td>
</tr>
<tr>
<td>Eupatorieae</td>
<td></td>
</tr>
<tr>
<td><em>Chromolaena odorata</em> †</td>
<td>+</td>
</tr>
<tr>
<td>Adenostemma caffrum *</td>
<td>+</td>
</tr>
<tr>
<td>Adenostemma viscosum *</td>
<td>+</td>
</tr>
<tr>
<td>Ageratina adenophora †</td>
<td>+</td>
</tr>
<tr>
<td>Ageratina riparia †</td>
<td>+</td>
</tr>
<tr>
<td>Ageratum conyzoides</td>
<td>+</td>
</tr>
<tr>
<td>Ageratum houstonianum</td>
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</tr>
<tr>
<td>Campuloclinium macrocephalum †</td>
<td>+</td>
</tr>
<tr>
<td><em>Mikania capensis</em></td>
<td>+</td>
</tr>
<tr>
<td><em>Mikania natalensis</em></td>
<td>+</td>
</tr>
<tr>
<td>Stomatanthes africanus †</td>
<td>+</td>
</tr>
<tr>
<td>Helenieae</td>
<td></td>
</tr>
<tr>
<td><em>Tagetes sp.</em></td>
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</tr>
<tr>
<td>Heliantheae</td>
<td></td>
</tr>
<tr>
<td><em>Bidens pilosa</em></td>
<td>+</td>
</tr>
<tr>
<td><em>Bidens formosa</em></td>
<td>+</td>
</tr>
<tr>
<td><em>Dahlia rosea</em></td>
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<tr>
<td><em>Helianthus annuus</em> (sunflower)</td>
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</tr>
<tr>
<td>Variety unknown</td>
<td></td>
</tr>
<tr>
<td><em>CRN 1435</em></td>
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<tr>
<td><em>SNK 37</em></td>
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</tr>
<tr>
<td><em>HYSUN 333</em></td>
<td>+</td>
</tr>
<tr>
<td><em>Helianthus tuberosus</em> (Jerusalem artichoke)</td>
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</tr>
<tr>
<td><em>Xanthium strumarium</em></td>
<td>+</td>
</tr>
<tr>
<td><em>Chrysanthemum sp. 1</em></td>
<td>+</td>
</tr>
<tr>
<td><em>Chrysanthemum sp. 2</em></td>
<td>+</td>
</tr>
<tr>
<td>Arctotideae</td>
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<tr>
<td><em>Arctotis arctotoides</em></td>
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<tr>
<td><em>Aster novi belgii</em></td>
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<tr>
<td>Calenduleae</td>
<td></td>
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<tr>
<td><em>Calendula sp.</em></td>
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<tr>
<td>Carduaeae</td>
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<tr>
<td><em>Cynara scolymus</em> (globe artichoke)</td>
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<tr>
<td>Lactucoideae</td>
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</tr>
<tr>
<td><em>Lactuca sativa</em> (lettuce)</td>
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</tr>
<tr>
<td><em>Cichorium intybus</em> (chicory)</td>
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</tr>
<tr>
<td>Mutisiaceae</td>
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<tr>
<td>Seneconae</td>
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<tr>
<td><em>Senecio madagascariensis</em></td>
<td>+</td>
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<tr>
<td><em>Senecio sp.</em></td>
<td></td>
</tr>
<tr>
<td><em>Senecio tamoïdes</em></td>
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<td>Vernoneae</td>
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<td><em>Vernonia adoensis var. kotschyanana</em></td>
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<tr>
<td><em>Vernonia angulifolia</em></td>
<td>+</td>
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<tr>
<td><em>Vernonia cractigifolia</em></td>
<td>+</td>
</tr>
<tr>
<td>AMARANTHACEAE</td>
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<tr>
<td><em>Amaranthus sp.</em></td>
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same parameters were measured and, in addition, the position of the adults was regularly recorded.

*Lixus aemulus* is largely specific to *Chromolaena* (Table 3), although tests on many of the plant species have not yet been adequately replicated. The decision of the adult female on whether or not to insert an egg into a stem ('mother knows best') is the critical factor in determining use of a particular host species: once an egg is laid, the larva usually develops through to adulthood. On several test-plant species adults fed but did not try to oviposit; on several others they probed stems but did not insert eggs; and on a few they laid eggs in the probe holes. In general, stems must have a pithy centre, and be of a minimum diameter of about 5mm to accommodate a full-size larva; the plant must be phylogenetically close to *Chromolaena* for oviposition to occur; an upright growth habit is also an important criterion. Apart from *Senecio madagascariensis* Poir., from which a single deformed adult was obtained, the only plants supporting full development were South African weeds of American origin (Table 3). The Heliantheae, which includes *Bidens pilosa* L. and the Helenieae, are the closest tribes to the Eupatorieae. *Bidens pilosa* seems to be ‘chemically neutral’ i.e. has fewer deterrents, as other insect

<table>
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<tr>
<th>Test plant species</th>
<th>Insect species</th>
<th>A. thalia pyrrha</th>
<th>L. aemulus</th>
<th>Calycomyza sp.</th>
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<td>AMARYLLIDACEAE</td>
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<td>Allium cepa (onion)</td>
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<td>BRASSICACEAE</td>
<td></td>
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<td></td>
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<tr>
<td>Brassica oleracea var. capitata (cabbage)</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
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<tr>
<td>CAPRIFOLIACEAE</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Viburnum sp.1</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Viburnum sp.2</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>CHENOPODIACEAE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta vulgaris (beetroot)</td>
<td></td>
<td>+</td>
<td></td>
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<tr>
<td>CONVOLVULACEAE</td>
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<td></td>
<td></td>
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<tr>
<td>Ipomoea batatas (sweet potato)</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUCURBITACEAE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucurbita pepo (butternut)</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEGUMINOSAE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phaseolus vulgaris (bean)</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOLANACEAE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lycopersicum esculentum (tomato)</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indigenous species
† formerly in genus Eupatorium

Table 2. Results of host-specificity tests on *Actinote thalia pyrrha*, a candidate biological control agent for *Chromolaena odorata* in South Africa.

<table>
<thead>
<tr>
<th>Test-plant species</th>
<th>Larval feeding &amp; development (no-choice)</th>
<th>Oviposition (choice)</th>
<th>Comparative larval development (no-choice)</th>
<th>Relative suitability² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenostemma viscosum</td>
<td>Y</td>
<td>N</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ageratina adenophora</td>
<td>Y¹</td>
<td>Y</td>
<td>N</td>
<td>-</td>
</tr>
<tr>
<td>Campuloclinium macrocephalum</td>
<td>Y¹</td>
<td>N</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Helianthus annuus var. Hysun 333</td>
<td>Y</td>
<td>Y¹</td>
<td>Y</td>
<td>39</td>
</tr>
<tr>
<td>Mikania capensis</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>107</td>
</tr>
<tr>
<td>Mikania natalensis</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>110</td>
</tr>
</tbody>
</table>

¹ low numbers reaching pupal stage/low numbers of eggs laid
² calculated using: (pupal weight x % pupated)/development time of females
species collected on chromolaena have fed on it in the quarantine laboratory (ARC-PPRI, unpubl.) and it has accrued a number of herbivores in South Africa (C. Zachariades, pers. obs.). In the choice tests, the only species equivalent to chromolaena in terms of adult feeding and oviposition by L. aemulus was Ageratum conyzoides L. (Table 3). This American weed also seems ‘neutral’, as e.g. Pareuchaetes pseudoinsulata (Lepidoptera: Arctiidae) feeds on it as a secondary host in Indonesia (Desmier de Chenon et al., this Proceedings b).

Once adequate replicates have been completed, permission to release L. aemulus in South Africa will be sought from the regulatory authorities.

### Damaging Effects

Branches of chromolaena were each inoculated with 1 – 2 L. aemulus eggs (under laboratory conditions, a female often walks along a stem and lays several eggs, one per node). Growth rates of these branches were then measured against control branches. The preliminary results indicate that growth rates are decreased by up to 40% by the presence of a single larva and up to 65% if there are two larvae per stem. Stems sometimes die back due to larval boring. Significant damage occurs only when the larva is mature, and the hole created in the stem by the emerging adult weakens the stem structurally. Lixus aemulus thus appears to be a potentially damaging biocontrol agent for C. odorata.

### CALYCOMYZA SP.

**(DIPTERA: AGROMYZIDAE)**

**Origin**
A culture of Calycomyza sp. was brought into quarantine in South Africa from Jamaica (18.00 N 77.00 W) in late 1997. Host-specificity testing was partially completed before the culture died out early in 1999. The fly was re-collected late in 1999 from Jamaica and again brought into quarantine, and testing was resumed.

### Identity and Description

The leaf-mining fly recorded by Cruttwell (1974) on C. odorata in Trinidad was identified as C. flavinotum Frick, and it was thought that the culture imported into South Africa was the same species. However, Spencer and Stegmaier (1973) indicated that C. flavinotum is a nearctic species and they described tropical specimens previously included in this species and collected on C. odorata in Jamaica, as a new species, C. eupatorivora Spencer. Specimens from the culture in South African quarantine have been sent to Dr M. Tschirnhaus (Germany, University of Bielefeld) to confirm this identity.

Adult flies are large (wing length of 2.3 – 2.4mm) for agromyzids, shiny black with a distinctive, broad yellow-white area laterally on the thorax extending above the wing base. Larvae are typical, varying from transparent when young to bright yellow just before pupation.

### Biology

Adult flies live for about 2 weeks. The females, at least, make numerous small punctures on the leaf surface and feed from these. Adults also fed on water and dilute honey solution in the laboratory. Eggs, which are inserted into the tissue on the underside of the leaf, hatch after about a week. The larva forms a large (occupying up to half the leaf) blotch mine on the leaf during its 1 – 2-week development period. Several larvae may develop in a single leaf. The larva exits the leaf and pupates in the leaf litter. The pupation period is about 2 weeks in summer in the laboratory. The adult fly has a high potential rate of increase and appears to be a good disperser. However, it is quite delicate, in quarantine it was sensitive to pesticide residues and low humidities, the latter of which may prevent it from establishing in the seasonally drier areas in which chromolaena is a problem. In the field in South Africa it may also be prone to parasitism, as is the case with Calycomyza lantanae (Frick) released on Lantana camara L. (Baars and Nesar 1999).

---

**Table 3.** Test-plant species (all Asteraceae) from which adult Lixus aemulus progeny were produced in no-choice tests, and which were subsequently used in single-choice tests.

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Tribe</th>
<th>Single-choice test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ageratina adenophora</td>
<td>Eupatorieae</td>
<td>*</td>
</tr>
<tr>
<td>Campuloclinium macrocephalum</td>
<td>Eupatorieae</td>
<td>N</td>
</tr>
<tr>
<td>Ageratum conyzoides</td>
<td>Eupatorieae</td>
<td>**</td>
</tr>
<tr>
<td>Bidens pilosa</td>
<td>Heliantheae</td>
<td>N</td>
</tr>
<tr>
<td>Senecio madagascariensis</td>
<td>Senecioneae</td>
<td>Still to be conducted</td>
</tr>
<tr>
<td>Chromolaena odorata</td>
<td>Eupatorieae</td>
<td>**</td>
</tr>
</tbody>
</table>

1 N = no oviposition, * = little oviposition, ** = normal oviposition.
Host Specificity
Multi-choice tests were conducted in a glass cage in a glasshouse using 24 plant species, which consisted largely of Asteraceae but also included two non-asteraceous species recorded as hosts of C. flavinotum (Table 1). The fly is host specific; no mines developed on any other test species. There were a few adult feeding probe marks but these were insignificant. The fly is thus safe for release. However, it is recommended that no-choice tests be carried out on a limited number of the test plants used in the multi-choice trials to confirm specificity (R.E.C. McFadyen, pers. comm.) before permission for release is sought from the regulatory authorities.

DISCUSSION
Since the South African biocontrol programme on chromolaena was revived in 1996, three candidate insects have been tested to completion or near-completion. The first of these, A. thalia pyrrha, was considered unsuitable for release in South Africa due to its unacceptably wide host range. The second and third species, L. aemulus and Calycomyza sp., are adequately host-specific for release, and the damage that L. aemulus causes has been quantified in the laboratory.

Successful establishment of these two species in the field would signify a great step forward for the South African biocontrol programme on chromolaena, as no agents have yet been successfully established in the field. However, there are a number of possible reasons that these agents may not establish strong populations in the field, particularly (i) incompatibility with the southern African chromolaena, (ii) climatic mismatching and (iii) predation/parasitism (Table 4). It is now fairly certain that the southern African chromolaena originates from one of the islands of the northern Caribbean region (Jamaica, Cuba, Hispaniola, Puerto Rico or the Bahamas) (see also von Senger et al., this Proceedings). No quantitative climatic matching exercises have yet been conducted between South Africa and the neotropics, but it is generally accepted that the former has a more seasonal climate than many of the areas where C. odorata occurs naturally. Although the likelihood of predation and parasitism may be predicted beforehand to some extent, only post-release evaluative fieldwork will provide the full answers.

If these two agents do establish well in the field, indications are from preliminary laboratory tests that L. aemulus will cause substantial damage to chromolaena. The damaging effect that Calycomyza sp. has on the weed remains to be quantified in the laboratory.

Table 4. Predicted effects of several parameters on field establishment of Lixus aemulus and Calycomyza sp. on Chromolaena odorata in South Africa.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lixus aemulus</th>
<th>Calycomyza sp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromolaena biotype</td>
<td>Possible incompatibility; collected on hairy form. This can be tested in the laboratory using different C. odorata biotypes. There may be other suitable Lixus spp./biotypes within the area of origin of southern African chromolaena (von Senger et al., this Proceedings).</td>
<td>No incompatibility expected; collected within predicted area of origin of southern African chromolaena (von Senger et al., this Proceedings).</td>
</tr>
<tr>
<td>Climate</td>
<td>Overwinters in stems, so may be resilient to dry season. Adults are long-lived.</td>
<td>No diapause apparent, and short generation time, so may not establish well where chromolaena loses condition over winter.</td>
</tr>
<tr>
<td>Predators/parasitoids</td>
<td>May be susceptible to local ichneumonid parasitoid.</td>
<td>May be susceptible to the same local hymenopteran parasitoids that attack Calycomyza lantanae on Lantana camara (Baars and Neser, 1999).</td>
</tr>
</tbody>
</table>

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ACKNOWLEDGEMENTS

Thanks are due to Johannes Thusi and Lynnet Khumalo for assistance with culturing of insects and test plants. Stefan Neser and Mike Morris are thanked for collecting most of the initial insect cultures. Ernie Steenkamp and Eve du Preez assisted with some of the host-specificity tests. This programme has received substantial funding from the South African Department of Water Affairs and Forestry (Working-for-Water initiative), as well as WWF-SA and KZN Nature Conservation Services.

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BIological CONTROL OF Chromolaena Odorata IN South Africa: DEVELOPMENTS IN RESEARCH AND IMPLEMENTATION

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ARC-Plant Protection Research Institute, Private Bag X6006, Hilton 3245, South Africa

In 1997, nine insect species were prioritised for investigation in the South African programme against Chromolaena odorata, based on factors such as type and severity of damage caused, and ease of culturing. Host-specificity testing has been completed on the butterfly Actinote thalia pyrrha, and is almost complete on the stem-boring weevil, Lixus aemulus and leaf-mining fly, Calycomyzza sp., the latter two with encouraging results. The host range of A. thalia thalia has also been investigated. Rearing techniques and biology have been determined for the shoot-tip galling weevil Conotrachelus reticulatus and the root-mining flea beetle Longitarsus horni, and host-specificity testing of these species has been initiated. Following several failed attempts to breed the shoot-tip boring agromyzid Melanagromyza eupatoriella, C. reticulatus was substituted as it occupies a similar functional niche. Melanagromyza eupatoriella may be reconsidered in the future. Several other candidates that had not been prioritised were investigated on the merits of the damage observed in the field. The stem-galling fly Polymorphomyia basilica may be considered as a substitute for Cecidochares connexa, which seems incompatible with the South African biotype of C. odorata. Host-specificity tests on the sap-sucking bug, Leptocysta sexnebulosa, indicated that this candidate was not suitable for release. Difficulties were experienced with breeding of the stem-galling moth, Adaina sp. nov. and shoot-tip boring moth Mescinia sp. nr parvula, and cultures could not be established. Promising prospects include a sesiid moth, Carmenta sp. nov., that mines shoot-tips; aspects of its biology have been determined. Cooperative agreements have been signed with several countries in the neotropics to facilitate studies on candidate agents that have proved difficult to rear, and on flower- and seed-feeding species. In conjunction with the South African Department of Water Affairs and Forestry’s ‘Working-for-Water’ Programme, a mass-rearing initiative was set up in the Northern Province and more than 365 000 Pareuchaetes pseudoinsulata larvae were released. Despite early persistence in the field, this agent does not appear to have established. The introduction of another strain to overcome possible seasonality problems was complicated by disease. A similar programme is being set up in KwaZulu-Natal province to mass-rear P. insulata for the first-ever release of this agent. Several pathogens, collected on C. odorata in the Americas, are being examined for their potential as biocontrol agents. The origin of the South African biotype of C. odorata continues to be investigated and the recent discovery of a morphologically similar biotype in Jamaica suggests a northern Caribbean origin.

KEYWORDS: Actinote spp., biological weed control, Calycomyzza sp, Cecidochares connexa, Conotrachelus reticulatus, host range, implementation, Leptocysta sexnebulosa, Lixus aemulus, Longitarsus horni, mass-rearing, Melanagromyza eupatoriella, origin, Pareuchaetes pseudoinsulata, P. insulata, Polymorphomyia basilica, prioritisation of agents

INTRODUCTION

Since the inception of the biological control programme on Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) in South Africa in 1988, several surveys have been undertaken in 15 Central and South American countries (Argentina, Brazil, Costa Rica, Cuba, Dominica, Guatemala, Jamaica, Mexico, Paraguay, St Christopher, St Lucia, St Vincent, Trinidad, the USA and Venezuela) and a variety of insects and pathogens on C. odorata have been imported into the ARC-PPRI quarantine laboratories for further investigation. South African research on the insects and pathogens on chromolaena was reviewed by Zachariades et al. (1999) and Morris et al. (1999).

To date, chromolaena is not under successful biological control in South Africa. Two moth species, Pareuchaetes pseudoinsulata Rego Barros and P. aurata aurata (Butler) (Lepidoptera: Arctiidae), proved safe and were released in 1989 and 1990 but did not establish in the field. However, there are several promising insect candidates in quarantine. Pathogens such as Septoria ekmaniana Petr. & Cif. (Deuteromycotina: Coelomycetes), Mycovellesiella perfoliata (Ellis & Everh.) Munt.-Cvetk (Deuteromycotina: Hyphomycetes) and Pseudocercospora eupatoriiformosani (Sawada) J.M Yen (Deuteromycotina: Hyphomycetes) that were collected on C. odorata in the Americas are also being investigated and are discussed by den Breeyén (this Proceedings).
In 1997, several insect species on *C. odorata* were prioritised for investigation in South Africa (Kluge et al., 1997; Table 1). This exercise was conducted to ensure that the candidate agents being investigated in quarantine (i) were the most promising of those known at the time, and (ii) allowed for the most effective use of available resources. However, it did not preclude investigation of other insects that were encountered on later surveys in countries of origin. It was intended that this strategic planning exercise would be revised after about three years, to incorporate newly discovered candidate agents and results of investigations of prioritised agents.

Prioritisation and ranking of candidate agents was created on the basis of criteria such as monophagy, and extent and type of damage caused (agents affecting vegetative parts of the plant being preferred above those that affect reproductive parts, and those that cause tissue destruction (defoliators, borers) preferred over those that cause tissue modification (gallers) (Kluge et al., 1997). The candidates were prioritised according to guidelines set out in the literature (e.g. Harris, 1973; Goeden, 1983). The degree of control likely to be achieved, the likelihood of obtaining permission to release, and issues such as cost-effectiveness and practicalities were taken into consideration. At the time of prioritisation, more information was known about some candidate agents than others, as some agents had already been partially or entirely investigated while others had not yet been imported into quarantine.

**CANDIDATE AGENTS**

The following candidate agents are discussed in order of the stage of research that has been reached, and not necessarily according to their prioritisation ranking.

The butterfly *Actinote thalia pyrrha* Fabr. (Lepidoptera: Nymphalidae: Acraeinae) was collected in Salvador, Brazil in 1995, imported into quarantine in South Africa, its biology determined, and host-specificity testing completed. The larvae are very damaging and extensively defoliate chromolaena plants in the laboratory, but permission to release this agent was not applied for due to the suitability of two indigenous creepers, *Mikania capensis* DC. and *M. natalensis* DC. (Asteraceae), as hosts for oviposition, feeding and larval development (Zachariades et al., this Proceedings). These plants are in the same tribe, Eupatorieae, as *C. odorata* and have a similar distribution. Other indigenous, crop and ornamental plant species that were tested were unsuitable hosts. A decision was made not to apply for permission to release *A. thalia pyrrha* at this stage of the programme because of the attack on non-target plants and because there are several other potential agents, including other defoliators. The congeneric *A. thalia thalia* L., that was collected in Venezuela in 1996, was also deemed unsuitable for release after preliminary tests indicated a similar, unacceptably-wide host range. Starter colonies of these two agents were provided to the Indonesian Oil Palm Research Institute, as *Mikania* species are invasive in Indonesia.

Host-specificity testing of two candidate agents, a stem-boring weevil *Lixus aemulus* Petri (Coleoptera: Curculionidae), imported from Brazil in 1995, and a leaf-mining fly *Calycomyza* sp. (Diptera: Agromyzidae) that was collected in Jamaica in 1997 and 1999, is at an advanced stage (Zachariades et al., this Proceedings). *Lixus aemulus* larvae develop within chromolaena stems and each tunnels about 50cm, causing weakening or death of those stems. Pupation occurs in the stems. Adults feed on young shoot tips, although their feeding has minimal impact on plants. Due to the photosynthetic ability of chromolaena stems, which allows rapid regrowth of defoliated plants, a stem-borer is an important element in a suite of natural enemies. Thus, *L. aemulus* received high priority status (Table 1).

### Table 1. List of prioritised candidate insect agents on *Chromolaena odorata*, from Kluge et al. 1997.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Species</th>
<th>Order: Family</th>
<th>Mode of action</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Longitarsus horni</em></td>
<td>Coleoptera: Chrysomelidae</td>
<td>Root-miner</td>
</tr>
<tr>
<td>2</td>
<td><em>Melanagromyza eupatoriella</em></td>
<td>Diptera: Agromyzidae</td>
<td>Shoot-tip borer</td>
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<tr>
<td>3</td>
<td><em>Lixus aemulus</em></td>
<td>Coleoptera: Curculionidae</td>
<td>Stem borer</td>
</tr>
<tr>
<td>4</td>
<td><em>Cecidochares connexa</em></td>
<td>Diptera: Tephritidae</td>
<td>Stem galler</td>
</tr>
<tr>
<td>5</td>
<td><em>Actinote thalia pyrrha</em></td>
<td>Lepidoptera: Nymphalidae</td>
<td>Defoliator</td>
</tr>
<tr>
<td>6</td>
<td><em>Actinote thalia thalia</em></td>
<td>Lepidoptera: Nymphalidae</td>
<td>Defoliator</td>
</tr>
<tr>
<td>7</td>
<td><em>Pareuchaetes insulata</em></td>
<td>Lepidoptera: Arctiidae</td>
<td>Defoliator</td>
</tr>
<tr>
<td>8</td>
<td><em>Pareuchaetes pseudoinsulata</em></td>
<td>Lepidoptera: Arctiidae</td>
<td>Defoliator</td>
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<tr>
<td>9</td>
<td><em>Conotrachelus reticulatus</em></td>
<td>Coleoptera: Curculionidae</td>
<td>Shoot-tip galler</td>
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Calycomyza sp. was unknown to us at the time of prioritisation (Kluge et al., 1997), and was subsequently opportunistically collected. Eggs are deposited in the leaf, below the epidermis and, during their development, larvae cause blotch mines on the upper leaf surface, thereby reducing the photosynthetic ability of the plant. Host-specificity tests so far show that *L. aemulus* and *Calycomyza* sp. both display narrow host ranges and are suitable for release. Permission to release these agents will be sought as soon as testing has been completed.

A further two candidate agents, both of which were collected in Venezuela in 1998 and 1999, are in culture in quarantine. They are a root-mining flea beetle, *Longitarsus horni* Jacoby (Coleoptera: Chrysomelidae: Alticinae), and a weevil, *Conotrachelus reticulatus* Champion (Coleoptera: Curculionidae), that forms galls near shoot-tips. Both are likely to be suited to areas with a distinct dry season in South Africa, as they were collected in areas with a similar climate in Venezuela. The rearing techniques and aspects of the biology of both species have been investigated. R.E. Cruttwell McFadyen (pers. comm.) has favoured the use of both these insects as biocontrol agents for a number of years, especially in the drier and more fire-prone regions of South-East Asia, because they both have soil-dwelling developmental stages.

*Longitarsus horni* was ranked highest in the list of prioritised agents (Table 1) as the roots of *Chromolaena* are considered to be an important point of attack, with a potentially substantial impact on plant growth. Congeneric species have also been used with success in other weed biocontrol programmes e.g. ragwort flea beetle *L. jacobaea* Waterhouse on *Senecio jacobaea* L. (Asteraceae) (McEvoy et al., 1991). *Longitarsus hornii* eggs are deposited in the soil, near roots into which larvae tunnel. Larval tunnelling in roots may be particularly damaging to young seedlings. Adult feeding damage in the form of ‘shot-holes’ on the leaves probably has limited impact. Host-specificity testing has recently been initiated.

*Conotrachelus reticulatus* deposits single eggs, each with leaf trichomes packed over them, next to a hole created with the rostrum, on the underside of leaves usually near the tip of the stem. Each larva tunnels down the petiole into the stem and forms a gall at the node. This stunts further apical growth of that stem. Adults feed on axillary and apical buds, preventing growth of those shoot-tips. Host-specificity testing of *C. reticulatus*, using choice tests, has been initiated and preliminary results indicate a narrow host range.

Culturing difficulties have been experienced with *Melanagromyza eupatoriella* Spencer (Diptera: Agromyzidae), a shoot-tip boring fly that was imported from Florida in 1997 and on earlier occasions. There were problems in inducing mating and oviposition, and adults were short-lived; cultures were briefly established three times but were lost. The spiral tunnelling pattern of larvae causes shoot-tips to wilt and die. *Melanagromyza eupatoriella* was more highly favoured by Kluge et al., (1997) than *C. reticulatus* (Table 1) as, at the time, less was known about the latter in terms of its biology, breeding techniques and effectiveness. However, following the numerous failed attempts to breed *M. eupatoriella* successfully, *C. reticulatus* was substituted as it occupies a similar functional niche and was thought to be more ecologically resilient. *Melanagromyza eupatoriella* is still deemed to be sufficiently damaging to be considered for re-importation in the future, if culturing techniques can be improved.

Difficulties have also been experienced in culturing the stem-galling fly *Cecidocharaes connexa* Macquart (Diptera: Tephritidae) imported from Indonesia (originally from Colombia) in 1996 and 1998. This agent is being used with great success in South-East Asia, effectively stunting growth and reducing flowering of *Chromolaena* (Desmier de Chenon et al.; McFadyen; both this Proceedings). *Cecidocharaes connexa* is thought to be incompatible with the southern African biotype of *Chromolaena* as development on this biotype was more lengthy than reported elsewhere, few F1 galls were formed and the culture died out after a few generations. A possible substitute for *C. connexa* may be another stem-galling fly, *Polymorphismyia basilica* Snow (Diptera: Tephritidae), which is native to and widespread in Jamaica (S. Neser, pers. comm.) and Puerto Rico (McFadyen, 1988); *C. connexa* does not occur in Jamaica. *Polymorphismyia basilica* will be imported into quarantine for further investigation.

Kluge et al. (1997) listed several other insects that were not considered priorities. Some of these have been imported previously while others may still be considered for importation. A sap-sucking bug, *Leptocysta sexnebulosa* (Stål) (Hemiptera: Tingidae), that was opportunistically collected in Venezuela in 1998 was unknown at the time but damage observed in the field warranted its further investigation. Nymphs and adults are phloem-feeders on *Chromolaena* leaves, causing chlorosis. Preliminary host-specificity tests were conducted; in choice and no-choice tests on a few selected species, substantial feeding and survival occurred on *M. natalensis* and another indigenous species, *Distephanus angulifolius* (DC.) H. Rob. & B. Khan (Asteraceae). These results concur with similar host records reported in the literature (Silva et al., 1968), and as a result, this agent was not released.
A stem-galling moth, *Adaina* sp. nov. (Lepidoptera: Apionidae) was collected in Florida in 1996, and several galls per stem were observed. Difficulties with mating and larval development were experienced, so that a culture could not be established in the laboratory. A culture of the shoot-tip boring moth *Mescinia* sp. nr *parvula* (Zeller) (Lepidoptera: Pyralidae), collected in Florida in 1997 and in Venezuela in 1998 and 1999, could not be established as the females did not oviposit in the laboratory. Cruttwell (1977, pers. comm.) also reported problems with inducing mating in this species.

Another promising candidate agent that may be considered for re-importation is a shoot-tip mining moth *Carmenta* sp. nov. (Lepidoptera: Sesiiidae), collected in Venezuela in 1998. The damage caused by this insect is similar to that of *M. eupatoriella*, in that they both cause stem tips to wilt. Eggs are deposited in apical stems, near the tip, and larvae tunnel down the stems. Larvae were able to complete development on the southern African biotype of chromolaena but there were insufficient numbers to establish a culture as adult emergence was asynchronous and adults were short-lived.

The prolific number of viable, wind-dispersed seeds produced by chromolaena is one of the major factors in its success as an invader. A means of curbing seed-set will be highly advantageous, thus flower and seed-feeding agents e.g. *Apion brunneonigrum* Béguin-Billecocq (Coleoptera: Apionidae) will be investigated in the future.

**WORK IN COUNTRIES OF ORIGIN**

Since the inception of the chromolaena research programme, work in countries of origin has been characterised by brief exploratory and collecting surveys. Cooperative agreements have been or are being set up with relevant organisations in Mexico, Cuba, Venezuela, and Jamaica, to facilitate surveys and collection of agents, and alleviate delays and problems associated with obtaining export permits. It will also hopefully expedite studies on candidate agents that have proved difficult to rear and on potential new agents e.g. flower- and seed-feeders that are difficult to work on because of short flowering periods and different flowering times in the northern and southern hemispheres. It is envisaged that biotype preference studies and selected host-specificity testing (e.g. choice tests in open field conditions) could be conducted in countries of origin.

**IMPLEMENTATION**

In conjunction with the national Department of Water Affairs and Forestry’s ‘Working-for-Water’ (WFW) Programme, ARC-PPRI set up a pilot mass-rearing initiative in the Northern Province in 1997. This will now be expanded, with plans to set up WfW biocontrol mass-rearing centres on a province-by-province basis, nationwide. This cooperative venture enables mass-rearing and release of biocontrol agents that have been proven host-specific or are already known to be effective, to be released or re-distributed on a scale that was not previously achievable.

*Pareuchaetes pseudoinsulata* was released in KwaZulu-Natal (KZN) Province in 1989 but did not establish. However, following its successful establishment in places such as Ghana and Sumatra (Timbilla and Braimah, 2000; Desmier de Chenon et al., this Proceedings), another attempt was made to establish this agent in South Africa with releases in the Northern Province. A starter colony of 700 *P. pseudoinsulata* larvae was received from Indonesia in August 1998, and a culture was established at a mass-rearing laboratory that was set up at the Mamathola Forestry Station near Tzaneen, Northern Province. More than 350 000 larvae were released at two sites between November 1998 and April 1999, and a single release of 17 000 larvae was made at a third site in January 2000. Five releases, totalling 118 000 larvae, were made at the first site, in a 20 x 20m area within a chromolaena infestation on a fruit farm near Tzaneen. At the second site, close to the Mamathola Forestry Station, a total of 218 000 larvae (7 releases) and 2 700 adults (5 releases) were released along a 100m stretch of chromolaena. These sites were at different altitudes and had different climates, and the chromolaena infestations were dense and widespread.

The first survey was conducted two months after the last release and subsequent evaluations were conducted every two months for 10 months, thereafter twice a year, ongoing. Beating trays were used to count larvae at 10m intervals in the release areas. Sampling was conducted mostly during the daytime although some night-time sampling (up to 22h30) was also undertaken. The population persisted and larvae of subsequent generations were observed. It was estimated that there were 70 000 larvae in the 100m² area surrounding the release points at the first site in April 1999. The initial effects of larval feeding were dramatic, with plants completely defoliated at the release points. Although there was rapid regrowth, the plants only grew to about half their original height. The damage was evenly distributed up to about 200m from the release points but became more scattered further away. However, no larvae were seen at this site in July 1999, nor subsequently, and it is apparent that *P. pseudoinsulata* has not established, for unknown reasons. There was no establishment
at the other two sites, and the Mamathola release site was accidentally destroyed by WfW alien plant-clearing teams.

From mid-1999, the viability of the laboratory culture declined with reduced fecundity, low pupation success rates, high pupal mortality due to microsporidian (probably *Nosema* sp.) and viral infections. It was postulated that climatic incompatibility (Cock and Holloway, 1982) may have accounted for the lack of permanent establishment of *P. pseudoinsulata* in the field. Thus in November 1999, a new culture of *P. pseudoinsulata* larvae was collected in Venezuela, which experiences distinct wet and dry seasons similar to South African conditions. However, this culture also became diseased. The lack of a trained entomologist based at the Mamathola laboratory to timeously detect and rectify culturing problems, was considered to be a contributing factor in the problems experienced with the cultures. The *P. pseudoinsulata* mass-rearing and release programme was terminated 2000 due to the lack of establishment in the field, and because of the disease-contamination problems experienced in the laboratory.

In November 2000, *P. insulata* (Walker) was imported from Florida for mass rearing and release as part of the WfW Programme in KZN. These are the first releases of this insect as an agent on *C. odorata* in the world. Although the host-specificity testing of this agent was completed in 1990 and it was shown to be specific (Kluge and Caldwell, 1993), it was not released at that time because of previous problems in establishing *P. pseudoinsulata* and *P. aurata aurata* (Zachariades et al., 1999). The South African Sugar Association Experiment Station in KZN has been contracted to mass-rear *P. insulata* for two years; an extension of this programme will depend on whether or not *P. insulata* establishes in the field within this time frame.

DNA studies are being conducted to compare the southern African biotype of chromolaena to biotypes from elsewhere (von Senger et al., this Proceedings). A revision of the genus *Chromolaena* is being planned by researchers at the Royal Botanic Garden, Kew (D.J.N. Hind, pers. comm.).

In conclusion, despite several setbacks in previous years, the South African programme on chromolaena is progressing well and prospects for the biological control of this weed seem good, with prospective releases of three agents within the next two years, and several others pending. Determination of the origin of the South African biotype of the plant should alleviate biotype incompatibility problems that have been experienced and allow for the selection of better-adapted agents. In addition, ties forged with institutions in the countries in which chromolaena is native, will expedite research on new agents as well as agents which have been difficult to rear in the laboratory in South Africa.

**ACKNOWLEDGEMENTS**

We thank the Department of Water Affairs and Forestry ‘Working-for-Water’ Programme, World Wide Fund for Nature (SA), and KZN Nature Conservation Service for their financial support of this research programme. Stefan Nesser, Robert Kluge and Mike Morris (ARC-PPRI) are thanked for collection of insects, as well as for their advice and assistance to this programme. Johannes Thusi and Lynnet Khumalo are thanked for providing technical assistance. We thank the Indonesian Oil Palm Research Institute for providing starter cultures of *Cecidochares connexa* and *Pareuchaetes pseudoinsulata*.
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THE DISTRIBUTION OF SIAM WEED, CHROMOLAENA ODORATA, IN PAPUA NEW GUINEA

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In Papua New Guinea (PNG), increased surveillance associated with an Australian Centre for International Agricultural Research biological control project and with joint PNG – Australian quarantine activities has resulted in an increase in the reported or known infestations of Siam weed (Chromolaena odorata). Infestations are confirmed in the provinces of Morobe, East New Britain, West New Britain, Sandaun, Manus, Milne Bay, New Ireland and Oro. Infestations are suspected to be present in Western Province. In Sandaun there has been a substantial increase and spread of the weed since its discovery in 1992.

The major economic impact to date has been on the oil palm industry. However, invasions of subsistence food gardens and smallholder cattle pastures are being experienced and this could cause the greatest impact. Significant impacts are expected if the weed spreads to sugar- and coffee-growing areas.

The biological control agent Pareuchaetes pseudoinsulata was introduced from Guam in late 1998 and is established in Morobe province only. The introduction of Cecidochares connexa is planned. The presence of the mite Acalitus adoratus in PNG is reported for the first time.

KEY WORDS: Acalitus adoratus, agricultural plantations, biological weed control, Cecidochares connexa, oil palm, Pareuchaetes pseudoinsulata

INTRODUCTION

Siam weed, Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), is considered a potentially serious weed in Papua New Guinea (PNG). It is already a problem in many tropical and subtropical countries in Africa and Asia. In PNG the first recorded collection of C. odorata was made in 1970, near Rabaul on the Gazelle Peninsula of East New Britain province (Henty and Pritchard, 1973; Orapa, 1998). Increased interest in C. odorata in PNG by the PNG Department of Agriculture and Livestock and the Australian Quarantine and Inspection Service (AQIS) through the North Australian Quarantine Strategy (NAQS) led to the detection of further infestations (Waterhouse, 1992, 1998; Orapa, 1998). Up to 1996, C. odorata was known from the Malabunga and Kerevat areas on the Gazelle Peninsula (East New Britain Province); between Kimbe and Lake Lauli, and as far east as Bialla (West New Britain); between the Indonesian border and Vanimo and south to Bewani in Sandaun Province; and at Labu and in the Erap area in Morobe Province (Orapa, 1998).

Australian concern at the spread of C. odorata through South-East Asia to eastern Indonesia and

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PNG (McFadyen, 1991) led to the funding by the Australian Centre for International Agricultural Research (ACIAR) of a biological control project in Indonesia and the Philippines (McFadyen, 1998). McFadyen (1998) proposed the extension of the project to include PNG and this commenced in March 1998. The commissioned agency is the Queensland Department of Natural Resources, Alan Fletcher Research Station. The collaborating institution in PNG is the National Agricultural Research Institute (NARI). The leaf-feeding moth, Pareuchaetes pseudoinsulata Rego Barros (Lepidoptera: Arctiidae) was introduced in 1999 and has been released in four provinces. The importation of the gall fly, Cecidochares connexa Macquart (Diptera: Tephritidae), is planned (Orapa et al., this Proceedings). During inspections of C. odorata, the authors noted the presence of the chromolaena mite, Acalitus adoratus Keifer (Acar: Eriophyidae) in East New Britain, West New Britain, Sandaun, Manus, Morobe, Milne Bay, and Oro Provinces.

The authors investigated reports of new infestations of the weed, usually in the course of fieldwork associated with the ACIAR Chromolaena project, NAQS surveys or other projects. Further new records of infestations and extensions to previously known infestations have been made...
Figure 1. Distribution of Siam weed in Papua New Guinea.
through these inspections. Infestations of C. odorata were also reported by people who worked on other weeds, carrying out locust surveys and joint border quarantine surveys, and by people from areas infested by C. odorata. NARI weed awareness activities at the Lae Agricultural Show have resulted in reports by villagers.

**CURRENT DISTRIBUTION**

The presence of C. odorata is now confirmed in eight provinces: Morobe, East New Britain, West New Britain, Sandaun, Manus, Milne Bay, New Ireland, and Oro (Fig. 1). Its presence is suspected in the border region of Western Province.

**Morobe Province**

The initial infestation at Labu in this province (Orapa, 1998) probably originated as a garden escape after seeds collected in East New Britain Province in 1970 were planted for scientific study in a backyard garden at Abanaka, 1km away, (9km west of Lae).

In the Lower Markham valley, two further infestations have been found within 9km of the Labu infestation. In 1998, C. odorata was found growing beside a 2km section of a track leading east then south from the southern end of the Wau road bridge over the Markham River. The track is bounded on one side by steep mountainsides and the other by a sago swamp. A small infestation was found beside the Wau road approximately 8km towards Wau from the bridge over the Markham River during a roadside survey in February 1999. Seedling germination has been reported in soil collected from a secondary forest site near Oomsis about 13km SW of the bridge (Rogers and Hartemink, 2000).

A reported infestation on the road to Boana (Orapa, 1998) was confirmed by inspection in 1997. This infestation in the Erap Valley occurs along the riverbank, on river terraces, in village gardens, on steep lower mountainside slopes and in steep gullies. It was found along the Boana road for 11km from the Highlands Highway, through the villages of Munkip and Kasuka to the mountain village of Gaen. Since 1997, a considerable increase in the amount of C. odorata has been observed between Munkip and the Highlands Highway Bridge and downstream to the Erap Pastoral Research and Extension Station.

In 1998, scattered C. odorata was found from the Markham River floodplain to the road head in the village of Siara in the Rumu River valley. Steep banks and gullies near Siara were covered by dense C. odorata. In 1998 and 1999, scattered clumps of C. odorata were seen at Kaiapit and surrounding villages in the upper Markham Valley. These infestations are on the Markham Valley plains at the base of steep mountains. Chromolaena odorata plants were also found adjacent to the Highlands Highway at the bridge over the Leron River. About 10km across the Markham Valley from Kaimip, an isolated infestation of about 2ha of dense C. odorata was found in 1999 near the village of Oanga. A lack of roads on this southern side of the Markham Valley precludes more extensive land-based surveys.

During a survey undertaken in 2000 along the Leron River upstream from the highway, infestations were observed near the braided stream, along road verges, and in clearings and shifting cultivation areas on mountainsides near the village of Sira Sira. This infestation probably continues up the Leron Valley to Wantoot. On some hillslides in this area the exotic weedy shrub, Piper aduncum L. (Piperaceae) has overgrown C. odorata infestations.

The Leron, Rumu and Erap Rivers share common watersheds in the ranges on the northern side of the Markham Valley. Although it has not been possible to survey the upper valleys of these rivers, it is reasonable to assume that they are infested with C. odorata, as strong winds are common. There are paths between mountain villages in the upper valleys, along which seed may have been accidentally carried from one catchment to the next.

In 2000, C. odorata infestations were observed on Siassi Island, which lies between the Huon Peninsula and New Britain (J. Risimeri, pers. comm.).

**East New Britain Province**

Chromolaena odorata was first collected in 1970 from Malabunga near Rabaul (Henty and Pritchard, 1973) and has been reported around Kerevat (Orapa, 1998). In November 1999, C. odorata in the Gazelle Peninsula was inspected and local infestations were discussed with staff of the Cocoa and Coconut Research Institute (CCRI), Kerevat. One of the CCRI entomologists recalled playing in C. odorata thickets as a small boy in the 1960s (S. Laup, pers. comm.).

In 1999, C. odorata was found in most of the closely settled areas of the Gazelle Peninsula east of the Warangoi River. Significant stands occur on the ridges in the northern part of the peninsula between Rabaul, Kokopo and Kerevat. The weed is restricted to roadsides, road cuttings and very steep hillslides. In most of the peninsula, C. odorata occurs sparsely with few thickets, because of intense cultivation by villagers and the presence of continuous tracts of intercropped coconut and
cocoa plantations that reduce establishment of seedlings. Around Rabaul town, where a devastating volcanic ash eruption destroyed most vegetation in 1994, only small amounts of *C. odorata* occur. All vegetation is still recovering from the acidic ash falls.

To the west of the Warangol River there are few settlements in the rugged, heavily forested Bainings Range area but *C. odorata* is present along the roads between Malasaet and Raunsepena villages (G. Wiles, pers. comm.). This area has not been surveyed for the weed because of its remoteness. There is some logging in the Bainings area and as logging tracks are pushed into the forest we can expect *C. odorata* to follow.

In a number of locations on the peninsula, *C. odorata* was found growing down to the seashore. Near Tokua Airport, coastal *C. odorata* had leaves thickened by saline conditions.

**West New Britain Province**

In a previously reported survey (Orapa, 1998), *C. odorata* was found between Kimbe and Hoskins and for 40km towards Bialla. In surveys in 1999, *C. odorata* infestations were found for 20km north of Kimbe along the road to Talasea.

There are approximately 40 000ha of oil palms in company plantations and smallholders’ blocks in the Kimbe area. *Chromolaena odorata* is found around coconut and oil palm plantations, smallholders’ oil palm blocks, subsistence cultivations, pastures and reafforestation areas. *Chromolaena odorata* growth was reduced significantly in mature oil palm areas, and where herbicides had been used for programmed vegetation management in young oil palm areas on company plantations (S. Lord, pers. comm.). However, it is more widespread in poorly managed smallholder oil palm blocks, subsistence gardens, old fallow areas, newly cleared forest areas, poorly managed pastures, and clearings along river banks. In reafforestation areas, *C. odorata* inhibits tree growth, particularly during the establishment phase. Logging operations in the province are spreading *C. odorata* into rainforest areas (H. Kereteni, pers. comm.).

**Sandaun Province**

*Chromolaena odorata* was seen for the first time on mainland PNG in and around Vanimo by a Quarantine team surveying border areas for pests and diseases in 1992 (Orapa, 1998; Waterhouse, 1998). In 1994, the weed was found for 35km along the roadside from Wutung, near the Irian Jaya border, to Vanimo, along the road from Vanimo south to Bewani (40km), and along the road from Vanimo to the site of an old West Papuan refugee camp at Blackwater, 20km to the east (Orapa, 1998).

On successive visits to the province in 1992, 1994, 1997, 1999 and 2000, the senior author noticed a significant increase and spread of *C. odorata* along roadsides, in shifting cultivation gardens, near houses, along forest edges, on cliff faces, and on cleared hill slopes from Wutung to Vanimo. In many places along the road to Wutung, *C. odorata* grows adjacent to the seashore.

During a roadside survey in 1999, more isolated *C. odorata* patches were found up to 20km east of Blackwater along a road being developed to link Vanimo with Aitape and further east to the East Sepik Province. This road has been constructed through virgin forests. It crosses the Pual River, which drains the hinterland near Bewani. Logging operations are proceeding in this area. It is highly likely that people will settle along the road on previously inaccessible land, further clearing forests and bringing with them weeds including *C. odorata*.

In 2000, the senior author, examining a hillside infestation under disturbed forest at Wutung, noted severe local damage to the terminal buds caused by an unknown insect, effectively preventing formation of flower buds.

**Manus Province**

A 1997 visit to Manus Province, revealed a *C. odorata* infestation around the Lombrum Naval Base, and on roads from the base to Papitalai High School and to Momote Airport on Los Negros Island (M. Julien, pers. comm.). In 2000, Manus and Los Negros Islands were inspected.

*Chromolaena odorata* was found on roadsides and in clearings throughout Los Negros Island from Kitchapon Point to Momote Airport, Papitalai, Lombrum, and the bridge to Manus Island. The area between Kitchapon Point and Momote contained abandoned coconut plantations and two overgrown American airfields from World War II. The weed has been present since at least the end of World War II (P. Pokomu, pers. comm.). On Manus Island, roadside infestations were observed from the bridge from Los Negros Island through to Lorengau. Scattered clumps of *C. odorata* were found in and around Lorengau and for about 4km along the only road from Lorengau into the interior of the island. No *C. odorata* was found in the many clearings around Lorengau that were overgrown by vigorous native vines. Manus Island has frequent rainfall rather than separate wet and dry seasons. This allows native plants to compete successfully with *C. odorata*. Most travel in the province is by small boats between coastal villages on Manus Island and between Manus and Los Negros Islands.
and outlying islands. It is probable that infestations occur around coastal villages and on other islands.

**Milne Bay Province**

In 1997, infestations of *C. odorata* were found at Siagara on the northeast coast of Misima Island by the senior author. When first found, it covered a distance of nearly 5km of the north coast of the island and was never seen in the vicinity of Bwagaoia township, the Misima Gold Mine or on the southern coastal villages. During a weed survey in 2000, the weed was found in the southern coastal villages of the island. New areas of *C. odorata* were seen at the Misima Mine, around old quarry areas and clearings. The mine has a revegetation programme, and despite locals’ suspicions that the mining company sowed *C. odorata*, only seeds of two grasses and two legume species obtained from Morobe Province have been used to revegetate the mined sites (W. Benko, pers. comm.). The most likely means of introduction of *C. odorata* into the south of the island from the north are vehicles carrying shift workers from their villages. Now that the weed is established around the mine, it is spreading to nearby south-coast villages by road. Spread into subsistence gardens in the inland of the island reportedly occurred during the 1997 - 98 drought induced by the El Niño Southern Oscillation, when bushfires destroyed part of the island’s rainforests. These were subsequently quickly colonized by *C. odorata*.

An unknown insect was found to cause severe damage to the terminal buds of *C. odorata* in some parts of the northeast of the island, the damage symptoms being similar to those observed at Wutung in Sandaun Province.

**Oro Province**

Clumps of *C. odorata* were located on the banks of the Kumusi River during 1998 and later in 1999 during a helicopter survey for the weed *Mimosa pigra* L. (Mimosaceae) by the senior author. In 1999, large infestations were found in the upstream area of the Kumusi River in new oil palm groves, disturbed forest and old cultivation areas along the road between Popondetta and Kokoda. It is highly likely that the weed may have spread from West New Britain Province through equipment and people associated with the oil palm industry. During a weeds survey in 2000, the weed was not recorded in adjacent districts, indicating its recent arrival in the province.

**New Ireland Province**

*Chromolaena odorata* has been reported in and around Namatanai in New Ireland Province, along the roads leading north and south of the town (C. Maika, pers. comm.).

**Unconfirmed Reports**

A report of a suspected occurrence of *C. odorata* in the Bensbach region of Western Province near the Indonesian border remains unconfirmed. The threat of introduction from infestations around Merauke in West Papua (Indonesia) is very high (Waterhouse, 1998). Merauke is about 70km from the border with PNG’s Western Province. Infestations in this province will have a significant impact on the unique wildlife of the Tonda Plains.

**DISCUSSION**

Infestations of *C. odorata* in PNG are the result of several separate accidental introductions from outside the country, as well as accidental transfer within the country and escape from a temporary cultivation for scientific study. The possibility of wartime movement of the weed through the South-East Asian region was raised by McFadyen (1988). In West Papua near the border with PNG, a well-developed *C. odorata* infestation occurs at Jayapura on the site of a former World War II military base (Sipaying *et al.*, 1991). The Gazelle Peninsula infestation, as the oldest known infestation in PNG, is the one most likely to have started from an accidental introduction during World War II. Rabaul was one of the most important Japanese bases in New Guinea during the war. Other infestations near World War II bases include the Manus infestation near Momote Airport and the West New Britain infestations near Hoskins airfield. Apart from possible historical introduction around World War II military bases and by immigrants, it has been assumed that the more recent infestations have resulted from natural cross-border expansion, the movement of people, contaminated oil palm machinery and planting material, and contaminated logging machinery (Orapa, 1998).

The escape of *C. odorata* cultivated for scientific study probably led to its establishment in Morobe Province. While roads between provinces are limited, the extensive network of air routes has facilitated the movement of people around the country. Further spread of *C. odorata* by the movement of people, machinery and produce is expected. In South Africa, Blackmore (1998) found that mechanical transport of seed is more important than movement by wind in the long-range dispersal of *C. odorata*.

Downstream water-dispersal of seeds and short-range dispersal of the wind-blown seeds increase the size of infestations in Morobe Province, where river valleys separated by high hills and not connected by roads have *C. odorata* infestations.

The impact of *C. odorata* in PNG is varied. In Morobe Province, the impact on human activities is restricted to village food gardens, where manual
clearing is performed as necessary with the aid of fires. *Chromolaena odorata* is an important component of secondary vegetation at fallow sites. While only scattered plants have been found in cattle pastures so far, more severe infestation of pastures is forecast, with serious implications for cattle production. In West New Britain, young oil palm plantations are most affected. Commercial plantations are protected at a cost through programmed herbicide spraying. Some smallholders use herbicides to control the weed around young oil palms until canopy closure, but most do not, and suffer slower palm establishment and reduced production (S. Lord, pers. comm.). Reafforestation schemes east of Kimbe are severely infested with *C. odorata*. The establishment of new tree plantings is threatened. Village food gardens and some poorly managed pastures are also affected. In East New Britain, although widespread, the weed is largely controlled by permanent intensive cultivation of gardens and by shading in extensive intercropped cocoa and coconut plantations. Around Vanimo (Sandaun Province) and on Misima Island (Milne Bay Province) the major impact is in village food gardens. In these areas the weed is particularly robust and impedes access to and cultivation of food gardens. A possible future problem in Sandaun Province is the contamination of locally grown fodder for proposed cattle feedlots (B. Waterhouse, pers. comm.). Affected Misima villagers have complained of a reduced size of yams (*Dioscorea* spp., Dioscoreaceae) grown after clearing *C. odorata*, but this could not be verified. Large areas of cleared hillside that are now covered with *C. odorata* pose a fire risk to adjacent rainforests if the weed is burned during the dry season.

The increase in reported infestations since 1996 is mainly due to increased surveillance activities, although some increases in the size of infestations have been observed. Awareness of *C. odorata* remains low in most parts of the country, and with the difficult terrain and inaccessibility of communities, more unreported infestations are likely to exist. The weed will continue to spread, particularly out from the Markham valley into the surrounding ranges, into the Ramu Valley of Madang Province (where it will marginally affect the sugar industry), and into five highlands provinces that are important coffee-producing areas. Most commercial land traffic in PNG is on the highways from Lae to the Highlands and to Madang Province (Orapa, 1998). *Chromolaena odorata* will also spread along newly developed roads in Sandaun Province and eventually reach East Sepik Province. Western Province is likely to be infested by cross-border spread from Indonesia. The presence of the weed on islands such as Manus, New Britain, Misima and possibly New Ireland indicate that the sea is not an effective barrier. Many other islands of eastern PNG are under threat of infestation, as are other island nations of Oceania, as indicated by climate matching models (McFadyen and Skarratt, 1996).

*Chromolaena odorata* grows in coastal areas in East New Britain, West New Britain, Sandaun, Milne Bay and Manus Provinces. Although Doddamani et al. (1998) reported that saline coastal conditions in Karnataka, India, limited the growth of *C. odorata*, this effect was low in PNG. The low wind velocities and mostly calm sea conditions that prevail around northern PNG limit the amount of air-borne salt deposited on coastal land, and regular leaching of the thin soils on karsts by the high rainfall, may reduce the salinity close to shorelines in northern PNG.

The mite *A. adoratus*, which has not been previously recorded in PNG, was found on *C. odorata* throughout the country. McFadyen (1995) suggested possible mechanisms for the spread of *A. adoratus* in South-East Asia, such as phoresy and dispersion with foliage of *C. odorata* used as packing material by villagers and inter-island traders. Because of its widespread distribution in PNG, *A. adoratus* has probably been in the country for many years.

**ACKNOWLEDGEMENTS**

We would like to thank Rachel Cruttwell McFadyen for her efforts in promoting the project and Barbara Waterhouse for promoting and participating in weed surveillance in PNG. We would like to thank Pascal Pandau, Francis Oken, Cornelius Aumie, Jeffrey Binifa, and Peter Pokomu for providing local knowledge and assisting in *C. odorata* surveys, and Mic Julien, Pascal Pandau, Jimmy Risimeri, Geoff Wiles, and Charles Maika for providing information from surveys. We thank Rachel Cruttwell McFadyen, Dane Panetta, Bill Palmer, Geoff Wiles and Roy Masamdu for reviewing the manuscript. Acknowledgement is due to ACIAR for funding the biological control of Siam weed project in PNG and AQIS NAQS for funding joint border surveys and a weed survey of Oro and Milne Bay provinces.
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Chromolaena odorata continues to spread through the subtropical regions of southern Africa and to become denser where it is already present, leading to major vegetation changes. The manner of its introduction remains uncertain, but probably occurred directly from the West Indies, as the southern African biotype differs from that invasive elsewhere in the world. First recorded as naturalised around Durban, South Africa in the 1940s, chromolaena spread rapidly throughout the coastal region of KwaZulu-Natal province between the 1950s and 1980s. In the past two decades it has reached other provinces: southwards into the Eastern Cape and northwards into Mpumalanga and Northern Province, while the neighbouring countries of Swaziland, Mozambique and possibly Zimbabwe have also been invaded. The southern African biotype of chromolaena is likely to be spreading northwards towards Tanzania, while the Asian biotype is already present on the Indian Ocean island of Mauritius.

In South Africa, chromolaena mostly threatens conservation areas, but also impacts negatively on forestry, pastoral agriculture and other land-uses. Although public awareness of the weed is now much higher than it previously was in this country, its spread has proceeded largely unchecked until recently. Few private landowners were committed to clearing chromolaena in the early stages of invasion, or have had the resources to clear it later. Several herbicides are registered for use on chromolaena, and integrated control strategies, together with land management plans, have been implemented in a few areas. Historically, the conservation body Ezemvelo KZN Wildlife has expended the most resources on chromolaena control in South Africa. Since the mid 1990s, however, the Working-for-Water (WiW) Programme, a national strategy aimed at removing alien plants to increase water run-off and stream flow, has taken the lead. The WiW Programme oversees several large chromolaena clearing operations in KwaZulu-Natal and Northern Province. Control operations in other southern African countries are less advanced, although in Swaziland the sugar industry and conservation bodies run limited clearing initiatives.

Actions required to reduce chromolaena to manageable levels in southern Africa include (i) the release of a suite of biological control agents, (ii) increased awareness and funding and (iii) the development of a coordinated clearance plan.

KEY WORDS: biodiversity, biological weed control, chemical control, integrated weed management, water conservation

ORIGIN AND SPREAD OF CHROMOLAENA ODORATA IN SOUTHERN AFRICA

Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) was first recorded as naturalised in South Africa around Durban, KwaZulu-Natal (KZN) province, in the late 1940s (Liggitt, 1983). Henderson and Anderson (1966) suggested that it may have been imported as an ornamental (C. odorata was recorded growing in the Cape Town Botanic Gardens in the 1850s (Wells et al., 1986)), while Pickworth (1976) suggested that it was accidentally introduced via Durban harbour late in World War II, as seeds in packing material from the West Indies. South African chromolaena is distinct from West African and Asian biotypes, thus ruling out those regions as sources of invasion. Recent surveys in the neotropics indicate that, out of a wide native range which stretches from Florida, USA to northern Argentina, Jamaica or one of the other islands of the Greater Antilles is the most likely origin of southern African chromolaena (von Senger et al., this Proceedings).

During the next 30 years, chromolaena spread southwards and northwards throughout the coastal, subtropical region of KZN (Liggitt, 1983; Goodall and Erasmus, 1996). By the 1980s its distribution stretched from the Eastern Cape to Northern Province in South Africa, and into neighbouring Swaziland. It is estimated that C. odorata has infested 326 000ha, or 43 000 condensed ha, in KZN (Versveld et al., 1998). The weed is certainly present in Mozambique as infestations occur throughout the Ubombo/Lebombo mountains, where South Africa, Swaziland and Mozambique share a common border. The chromolaena infestations in South
Africa, Swaziland and Mozambique probably all originate from the initial population around Durban, as the plants are morphologically identical. There is an isolated herbarium record from northern Zimbabwe (Gautier, 1992), and the weed is also present in Mauritius (L.W. Strathie, pers. comm.). The origin of the Zimbabwean record is unknown and the Mauritian plants are morphologically identical to those in Asia and West Africa.

A climatic matching exercise (McFadyen and Skarratt, 1996) indicated that virtually all of eastern Africa is highly suitable for chromolaena. It thus seems likely that this region will be invaded from both southern and western Africa.

**IMPACT OF CHROMOLAENA ODORATA IN SOUTHERN AFRICA**

**Characteristics of Invasion**

Chromolaena is restricted to the frost-free areas of South Africa (Goodall and Erasmus, 1996). However, the weed's range will probably increase with climatic warming (Bond et al., 2001). Chromolaena has also spread to regions of lower rainfall (ca. 500mm per annum) than initially predicted, but occurs mainly along watercourses in these areas. During the dry season chromolaena suffers from water stress, and may die back or lose its leaves, but populations recover rapidly with the onset of the summer rains.

The southern African biotype of chromolaena displays high plasticity both in the habitat types invaded and in its growth form. It invades grassland, savanna and forest, and varies from a 3m self-supporting shrub in the open to a 10m scandent creeper in forest. Chromolaena takes advantage of both disturbance and neglect but is susceptible to fire (Macdonald and Frame, 1988; Goodall and Zacharias, this Proceedings). Chromolaena grows particularly well on forest margins and rapidly colonises forest gaps created by dead trees and tree-falls (J.M. Goodall, pers. obs.). Anecdotal evidence suggests that the biology and ecology of the southern African biotype is different to that of the biotype that invades Asia and western/central Africa, particularly with respect to its susceptibility to fire and its growth habit (Gautier, 1996; Goodall and Zacharias, this Proceedings; R.E. Cruttwell McFadyen, pers. comm.). Given these differences, it remains to be seen how the two biotypes will interact should they converge in eastern Africa.

**Land-uses Threatened**

The end of apartheid in South Africa in 1994 led to significant changes in the land-use patterns typical of the previous 150 years. The period prior to 1994 was characterised by the expropriation of black-owned lands for white-owned commercial agriculture (e.g. plantations of sugarcane, fruit and timber trees) or for proclamation as conservation areas. Black rural communities were transferred from expropriated lands to the ‘homelands’, fragmented political entities which were usually of low strategic importance. Homelands were also created in regions with historically large black populations. These communities were generally impoverished and their social structure was disrupted by the migrant labour system, which left women and children to manage the land. High numbers of cattle, which indicate wealth in black African culture, together with the relocation of too many people into inadequate areas, resulted in widespread land degradation through overgrazing, erosion and invasion by weeds.

South Africa thus has significantly different land-use patterns to most other countries in which chromolaena is invasive. It is considered to be an industrialised nation, whereas most other countries in which chromolaena is invasive have largely subsistence economies (Wilson and McFadyen, 2000). In South Africa, the weed is primarily viewed as a threat to biodiversity conservation and secondarily to commercial agriculture and forestry (Liggitt, 1983; Goodall and Erasmus, 1996). In contrast, elsewhere in the Old World tropics and subtropics, chromolaena is considered primarily a threat to both commercial and subsistence agriculture. No useful attributes have so far been recorded for chromolaena in southern Africa, in contrast to the situation in West Africa and other countries where chromolaena is used as a fallow crop (De Foresta, 1996; Akobundu and Ekeleme, 1996; McFadyen, 1996). However, this status may change in South Africa with the increasing emphasis on small-scale farming systems, where problems of low soil fertility and insufficient organic matter prevail.

Chromolaena negatively affects biodiversity in several ways. Apart from suppressing indigenous grassland and savanna vegetation through physical smothering and allelopathy, it also forms a higher plant biomass than the indigenous vegetation on forest ecotones. The increased fuel load causes seasonal fires to burn with greater intensity in invaded ecotones, with consequent damage to indigenous forest. This facilitates the replacement of forest vegetation by chromolaena (Macdonald, 1983). Where it invades forest gaps, chromolaena suppresses natural plant succession and smothers neighbouring trees, eventually causing canopy collapse (Goodall and Erasmus, 1996). The weed poses a severe threat to forest biodiversity, given the small percentage of land covered by natural forests in South Africa, the highly fragmented
nature of these forests (resulting in a strong edge effect sensu Riitters et al., 2000) and the high degree of plant endemism within them.

Three centres of floral endemism (Cowling and Hilton-Taylor, 1994), ranging from grassland to forest, are threatened by chromolaena in South Africa. These ‘hotspots’ include (i) ‘Maputaland’, in northern KZN, a portion of which forms a recently proclaimed World Heritage Site; (ii) ‘Pondoland’, shared between southern KZN and the northern Eastern Cape; and (iii) ‘Wolkberg’, shared between Northern Province and Mpumalanga. Some of these areas also possess high degrees of endemism of animal taxa. High-profile species whose habitats are threatened by chromolaena in the Maputaland centre of endemism include the endangered black rhinoceros, Diceros bicornis (L.) (Mammalia: Rhinocerotidae) and the Nile crocodile, Crocodylus niloticus (Laurenti) (Reptilia: Crocodylidae) (Leslie and Spotila, 2001).

Chromolaena has several other negative impacts in South Africa. The ecotourism and trophy-hunting potential of conservation and game-farming areas has been reduced because of decreased game populations and reduced visibility. The weed has decreased the livestock carrying capacity of land in both large-scale (commercial) and small-scale (subsistence) farming situations. In commercial forestry, suppression of the growth of young pine and eucalypt trees through competition, has been recorded. Cropping agriculture is affected mainly via the reduction of profit margins due to infestation along drainage lines and field margins. Since commercial farms can afford the costs of sustained chemical control, the implications of chromolaena here are less serious than for subsistence cropping agriculture. Indeed, in the recent land redistribution programme, some under-utilized State farms that are being returned to small-scale farming communities have already been rendered unprofitable by the high levels of chromolaena infestation. Pressure is also being exerted on conservation areas by the surrounding communities for grazing lands in reserves, because they have lost their land to chromolaena.

South Africa is a water-stressed country and alien vegetation decreases the run-off in catchments by about 7% (Versveld et al., 1998; WfW URL), as a result of its greater biomass and higher rates of transpiration compared to the displaced indigenous vegetation. Chromolaena is not considered a high priority species in this regard, as nationwide it is estimated to be responsible for only 2% (68 million m$^3$) of the 3 300 million m$^3$ lost annually to alien invasive plants (Versveld et al., 1998). It grows mainly in areas with a rainfall of >800mm per annum and its biomass is similar to that of the indigenous vegetation (although its transpiration rate may be higher). It is nevertheless a major target of the clearing operations overseen by the Working-for-Water (WfW) Programme (Department of Water Affairs and Forestry), as it forms secondary infestations in areas cleared of other alien invasive species, thereby obstructing follow-up clearing operations. The maintenance costs of keeping service areas clean (e.g. road and railway margins, powerline conduits) are also increased by such secondary infestations. Finally, chromolaena has also reduced the availability of indigenous plant species that are used in traditional medicine (‘muthi’), some of which are already threatened by over-exploitation.

Factors Facilitating Spread

Very little in the way of control was done by landowners in the early stages of the invasion, when the problem may have been contained, despite repeated warnings about the dangers of chromolaena dating back to the 1960s (reviewed in Goodall and Erasmus, 1996; Macdonald and Jarman, 1985). This can be ascribed to a combination of apathy, ignorance and limited resources. In addition, a no-burning policy imposed by the Department of Agriculture and the Natal Parks Board (now Ezemvelo KZN Wildlife) over the past few decades has resulted in encroachment by both indigenous and alien invasive woody species, including chromolaena. In some cases, e.g. conservation areas for black rhinoceros, bush encroachment was encouraged to provide forage for specific animal species. The isolated infestations of chromolaena that appeared in Northern Province, the Eastern Cape and Mpumalanga indicate long-distance dispersal mechanisms, for example seed attaching to vehicles. This has also been shown to operate on a more local scale (Blackmore, 1998).

Other Countries in Southern Africa

Information about the impact of chromolaena in neighbouring countries is limited. Swaziland has recorded similar problems to South Africa in terms of land-uses threatened. The situation in Mozambique, both in terms of invasion and the negative impacts, is unknown. Although chromolaena is naturalized in Mauritius, this country does not consider it to be of particular importance (P.L. Campbell, pers. comm.).

PROSPECTS FOR INTEGRATED CONTROL AND MANAGEMENT

Public awareness of chromolaena, and alien invasive plants in general, has increased markedly in South Africa in recent years. This can largely be attributed to the high profile of the WfW Programme and its awareness campaigns.
Several effective herbicides are registered for chromolaena in South Africa (Goodall and Erasmus, 1996) and no further research on chemical control is currently justified. These herbicides are either applied to the cut stumps of slashed plants or to the leaves of seedlings and coppice growth. Seedlings and young plants can also be removed by hand-pulling. The WfW programme implements follow-up clearance of chromolaena every 2 - 3 months because of rapid regrowth, compared to 6 months for other woody subtropical weeds. An annual burning regime effectively controls chromolaena in grassland situations by killing mature plants and preventing new seedlings from establishing (Goodall and Zacharias, this Proceedings).

Although the critical need for biological control of chromolaena in South Africa has long been recognised (Goodall and Erasmus, 1996), this has not yet been achieved and none of the three agents that have been released so far have become established. Nevertheless, the long-term prospects for biocontrol are still good and several promising agents are currently under evaluation (Strathie and Zachariades, this Proceedings). Biological control is envisaged to supplement, rather than replace, other control procedures by decreasing the growth and reproductive potential of chromolaena to a level where an integrated control programme would be cost-effective. At present, such integrated programmes are only effective in limited areas.

Several models have been proposed for the development of a land-unit based approach to controlling alien plant invasions in South Africa (e.g. Kluge and Erasmus, 1991; Goodall et al., 1996). In addition, integrated management plans, designed to incorporate all major weed species in an area, have been drawn up for some farms, nature reserves, mining areas and catchments (e.g. Goodall and Naudé, 1993; Goodall and Morley, 1995). These strategies recommend the removal of light weed infestations before the treatment of dense infestations as well as the use of integrated control operations to suit different land-users and vegetation types. However, these recommendations and models are often not implemented due to a lack of commitment or shortage of resources on the part of responsible land-managers.

Two organisations in South Africa have undertaken large-scale clearing of chromolaena. The first of these, Ezemvelo KZN Wildlife, undertook clearing operations within protected areas under their jurisdiction. For example, in 1997, this organization spent an estimated US$ 370 000 on chromolaena clearance (N.P. le Roux, pers. comm.). However, continuous seed pollution from outside the reserve boundaries necessitated repeated follow-ups and rendered these actions unsustainable. This organisation also conducted research on the ecology and impact of the weed (e.g. Blackmore, 1998; Leslie and Spotila, 2001). Recently this organisation’s operational budgets for *inter alia* alien plant control have been dramatically cut, and chromolaena has resurfaced. However, in some reserves of strategic importance (e.g. Mkuze Game Reserve) co-operative clearing operations with the WfW Programme have been initiated against several weed species including chromolaena. This latter programme was initiated in the mid-1990s as a consequence of an earlier cost-benefit analysis that indicated that a national initiative to clear catchments of alien plants would be cheaper than building more dams to alleviate predicted water shortages. It has been estimated that about US$ 27 million is required for clearance of *C. odorata* in KZN (Versveld et al., 1998). This programme is by far the largest weed control initiative in South Africa’s history, and has also been internationally acclaimed. Clearing operations use water catchments or sections of riparian zones as ‘land-units’, and include a programme of initial clearing, follow-up treatments and maintenance control. The programme’s other aims include (i) improvement of ecological integrity, (ii) restoration of the productive potential of land, (iii) promotion of sustainable use of natural resources and (iv) investment in the most marginalised sectors of South African society. Although the WfW Programme is focused on poverty alleviation and social upliftment by the employment of unskilled workers to carry out mechanical and chemical control procedures, it has recognised the logistic and financial importance of biological control as a sustainable back-up for its efforts. Consequently, the WfW Programme has invested considerable funds into the research and implementation of weed biocontrol in South Africa (Olckers, 1999) and chromolaena is a high priority species in this regard.

Several other stakeholders have shown a financial commitment to chromolaena clearing programmes and research. These include private companies in the forestry and sugar industries, government and private conservation organisations, the National Department of Agriculture, local municipalities and other service-based corporations (e.g. electricity suppliers) that are affected by chromolaena. Control operations are considerably less advanced in other southern African countries. In Swaziland, private companies in the sugar and citrus fruit industries and State conservation bodies have undertaken clearing operations. In Mozambique it is unlikely that any clearing of chromolaena has been or is being undertaken at an organisational level.
CONCLUSIONS

If the spread and impact of chromolaena in southern Africa is to be slowed and eventually reversed, several initiatives for control and management are required at both national and regional levels. These include: (i) the implementation of large and sustained releases of approved biocontrol agents; (ii) continued research on new biocontrol candidates (Strathie and Zachariades, this Proceedings; Zachariades et al., this Proceedings); (iii) sustained awareness of the problem, especially in areas that are sparsely infested or in uninfested areas which have the potential to become infested and (iv) the development of a co-ordinated clearing plan.

ACKNOWLEDGEMENTS

We thank Terry Olckers and Robert Kluge for comments on earlier drafts of the manuscript. The Working-for-Water Programme of the Department of Water Affairs and Forestry, South Africa is thanked for their generous funding of research on biological control of chromolaena.

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Working-for-Water URL: http://www.dwaf.pwv.gov.za/wfw/


INTRODUCTION

Dense thickets of the South American scrambling shrub *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae) have come to dominate rural landscapes across eastern Indonesia. The normal succession back to secondary forest in shifting slash-and-burn agriculture is halted by *C. odorata* invasion (de Foresta and Schwartz, 1991; de Rouw, 1991), leaving villages surrounded by vast infestations of the weed. Some subsistence farmers apparently prefer *C. odorata* to *Imperata cylindrica* (L.) Raeusch (Poaceae) (alang-alang grass) as it is said to be easier to control with fire and to improve soil quality (Tjitrosoedirdjo et al., 1991), but *C. odorata* is not eaten by cattle and shades out valuable pasture grasses (Sipayung et al., 1991).

In January 1993 the Australian Centre for International Agricultural Research (ACIAR) began funding a 3-year project on ‘Biological control of *Chromolaena odorata* in Indonesia and the Philippines’ covering the eastern provinces of Indonesia between the island of Bali and Papua New Guinea. This region is largely undeveloped and difficult to access, with little infrastructure and few trained personnel to facilitate a biological control programme. The project has seen a plant- and insect-rearing facility established at Nusa Cendana University in Kupang, west Timor, and training provided. Attempts to establish *Pareuchaetes pseudoinsulata* have so far been unsuccessful, but are continuing. The gall fly *Cecidochares connexa* established readily in the field near Kupang and subsequent efforts have been directed towards releasing it more widely. It is now established and spreading at many sites in west Timor and on major islands throughout the region. A reduction in density of the weed is already becoming evident in some wetter areas. Future work will concentrate on rearing, releasing and monitoring the butterfly *Actinote anteas*.

THE PROBLEM

The region covered by this part of the project stretches approximately 3 000km from the island of Lombok in the west to the Papua New Guinea
border in the east and encompasses thousands of individual islands. There has been no systematic survey for *C. odorata* here, but it is known to occur on all of the major islands (Lombok, Sumba, Sumbawa, Flores, Timor, Rote, Alor, Sulawesi, Irian Jaya) and probably occurs on the majority of smaller islands as well. Wherever it grows, *C. odorata* creates difficulties for humans.

Most people in the region are dependent upon small-scale traditional agricultural systems, usually involving shifting and permanent cropping (mainly maize, cassava and rice), home gardens, mixed tree gardens and animal husbandry (mainly goats, chickens and pigs) (Monk *et al.*, 1997). Free-range and tethered grazing of cattle is also widely practiced. Cropping farmers are limited to the area of land that can be hand cleared and maintained weed-free, while opportunities for grazing animals are reduced as valuable pastures are displaced by *C. odorata*. Fire is frequently used to clear infested lands, but this creates problems of its own by threatening villages, gardens, forests and plantations that are surrounded by the highly flammable weed. *Chromolaena odorata* recovers quickly following fire, shooting vigorously from the root crown and undamaged axillary buds (McFadyen, 1989).

Kupang is approximately 700km northwest of Darwin, the capital of Australia’s Northern Territory, and the two cities are connected by a regular air service. Kupang is the hub of a transport network that extends across the region, linking most of the major islands by ferry and/or aircraft, albeit sometimes infrequently. Other major centres are Mataram on the island of Lombok, Ujung Pandang in southern Sulawesi and Jayapura in north-eastern Irian Jaya, but outside of these cities the region is still largely undeveloped and difficult to access, with little infrastructure and no trained personnel to facilitate a biological control programme. Also, parts of eastern Indonesia are periodically beset by political, religious or racial turmoil, which can interfere with the free movement of project staff.

Undana in Kupang was the logical base for the project in eastern Indonesia due to its proximity to Darwin, pre-existing links with institutions in Darwin and the regular air connection. Establishing separate agent-rearing operations across the region would have been impractical and fraught with major difficulties. It was decided to carry out initial rearing of all agents at Undana and to distribute them from this base to sites across west Timor and to other islands in the region. Once an agent was established at a site, local redistribution could proceed using field-collected material. Undana initially lacked suitable facilities for mass-rearing a biological control agent. There was, and remains, a critical shortage of water at the campus, with only a single reticulated outlet available. Shadehouses were in disrepair and rearing was carried out in a small room with poor lighting and ventilation, using small plastic boxes. ACIAR made funds available for large rearing cages, technical assistance and transport to release and monitoring sites. Eventually, a shadehouse was refurbished and an adjacent water supply, filled by truck, installed. This enabled a greatly accelerated programme of mass rearing.

**THE BIOLOGICAL CONTROL AGENTS**

*Pareuchaetes pseudoinsula* Rego Barros (Lepidoptera: Arctiidae)

The moth *P. pseudoinsula* had already been introduced, host-tested and released in the field in Indonesia, in northern Sumatra, prior to 1993 when the ACIAR project began (McFadyen, 1998). A small batch of larvae was sent to Undana in 1993 from Biotrop in Bogor, Java, and further consignments were sent from the Indonesian Oil Palm Research Institute (IOPRI) in northern Sumatra in February 1994 and at irregular intervals since. Various difficulties in rearing the insect at Undana were overcome, including infertile eggs, pupal parasites, ant invasion and lack of water during the winter dry season.

Field releases began in August 1994 with a small number of larvae at Kolhua, a village near Kupang. In January 1995, 2,000 larvae and 300 adults were released at Kolhua, resulting in extensive defoliation and yellowing over the ensuing weeks, but no lasting establishment was observed. During July 1997, 3,000 larvae and 2,000 adults were released at a new site near the village of Bipolo, approximately 40km north east of Kupang. During September and October 1997, 4,000 larvae were released at the site, and a further 4,500 during January and February 1998. No establishment was observed during monitoring of the site in April 1998 or since.

With the recent provision of greater resources to Undana from the ACIAR project, a final attempt is being made to establish *P. pseudoinsula* by concentrating releases at a single site near the village of Camplong, approximately 60km east of Kupang, where spring-water ensures *C. odorata* plants remain green for most of the year.

*Cecidochares connexa* Macquart (Diptera: Tephritidae)

The Indonesian government granted a permit to release *C. connexa* in June 1995. In November 1995 the first field release in eastern Indonesia was made.
at Bipolo using mature galls collected from the field in northern Sumatra (Wilson and Widayanto, 1998). At the time, no parasites had been detected in field populations of the fly and hence it was considered relatively safe to transport fresh galls to a distant region. A survey of the Bipolo site in April 1996, two fly-generations following the initial release, revealed successful establishment. Using the methods described in Wilson and Widayanto (1998), mature galls were redistributed to 29 sites across west Timor, and to the islands of Lombok (2 sites), Sumba (3 sites), Sumbawa (1 site), Flores (4 sites), Rote (1 site), Alor (1 site) and southern Sulawesi (2 sites) (Fig. 1). A laboratory colony was briefly maintained at Undana, but was found to be unnecessary as field releases of as few as 200 mature galls quickly led to establishment, and an absence of parasites enabled relatively safe redistribution from field collections. S. Tjitrosemito and B. Waterhouse (pers. comm.) successfully released C. connexa at Jayapura in northeastern Irian Jaya. We subsequently redistributed galls from there to two sites in southeastern Irian Jaya. R. Desmier de Chenon (pers. comm.) also made a successful release at a site in southern Sulawesi (Fig. 1).

Establishment has been successful at every monitored release site, but several recently-established sites in remote areas have not yet been revisited (Fig. 1). Spread from release sites has also been rapid, reaching up to 5km per year. Five years after its first release in the region, C. connexa is established throughout the lowlands of southwestern west Timor to about 80km from Kupang, and several places beyond. We also know it to be established on Lombok, Sumba, Flores, Alor, Sulawesi and Irian Jaya. Despite its rapid establishment and spread, C. connexa does not yet appear to be having a major impact on C. odorata infestations in west Timor. Most of eastern Indonesia experiences a relatively low and highly seasonal rainfall (Monk et al., 1997). It is possible that the long dry season limits the ability of C. connexa to reach damaging levels in many areas. On Lombok and near Jayapura in northeastern Irian Jaya, where rainfall is higher and less seasonal, galls were found at levels of hundreds per plant less than two years after the first releases. At both places, heavily galled C. odorata plants were prematurely moribund with few flowers or seeds, and plant density appeared to be declining.

Figure 1. Release sites of Cecidochares connexa in eastern Indonesia. (▲ = release sites created by the authors, establishment confirmed; ■ = release sites created by the authors, establishment not yet confirmed; ★ = release sites created by others, establishment confirmed). Note that closed triangles in Timor represent a total of 28 separate release sites.
Local redistribution of field collected mature galls is a quick, easy and effective way of speeding the spread of *C. connexa* (Wilson and Widayanto, 1998). The technique should not be used for redistribution to other biogeographic regions unless it is certain that the galls are free of parasites. The best way of ensuring this is to rear *C. connexa* for one generation on potted plants in sealed cages.

**Actinote antees Doubleday and Hewitson (Lepidoptera: Nymphalidae)**

Eggs of *A. antees* were sent from IOPRI in northern Sumatra to Undana in May 2000. Survival was low due to desiccation during transport. Mature larvae and pupae were carried to Undana in July, and more eggs were sent during August 2000. At the time of writing, field releases have not commenced. It is proposed to concentrate releases initially at a single site near the village of Camplong in west Timor. A major effort will be made to establish *A. antees* in the field during the last year of the project.

**ACHIEVEMENTS AND OUTLOOK**

This project has delivered a number of important benefits to eastern Indonesia, including provision of equipment and facilities, training and extension, and establishment of a potentially effective biological control agent.

There are strong indications that *C. connexa* alone may provide substantial control of *C. odorata* in areas with a less severe dry season. If they can be successfully established, *P. pseudoinsulata* and *A. antees* may combine to provide substantial control of *C. odorata* in west Timor, where *C. connexa* appears to be less effective. Achieving this will be the main focus for the remainder of the project. Unfortunately, it is unlikely that such benefits can be extended to other islands in the region. Lepidopterans in large numbers are difficult to carry over long distances and extended time periods, and transport to other islands is expensive, infrequent and sometimes unreliable. Experience elsewhere suggests that *P. pseudoinsulata* requires continuous releases of many thousands of individuals at a site before establishment is achieved. Without significant additional funds, it will not be possible to release sufficient numbers of either agent to ensure establishment at any site away from west Timor.

In spite of the many significant achievements of this project, it is likely that *C. odorata* will continue to be a major problem for plantation crops, forestry, livestock, traditional agriculture and the environment in drier and more remote areas of eastern Indonesia.

**ACKNOWLEDGEMENTS**

The Australian Centre for International Agricultural Research (ACIAR) funded the work reported on here. The senior author is grateful to ACIAR for funding his attendance at the International Workshop in Durban to present this paper.

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INTRODUCTION

Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), a perennial hexaploid weed of neotropical origin, flourishes in the humid open forest areas of the Malnad region (hilly, forested land forming part of the Western Ghats) in Karnataka, India. A pilot survey for the present study revealed that the species preferred open sunny habitats in the Malnad and that its incidence on the plains around Bangalore, to the south-east, was extremely low. Existing data on the climatic conditions prevailing in two locations (Shimoga and Mercara) in the Malnad supporting luxuriant growth of the weed, and in Bangalore where it is sparse and less vigorous, revealed that the rainfall and relative humidity are higher in the Malnad than at Bangalore (Table 1). Hence, it was considered that an investigation on the growth responses of the weed under varying light intensities, available soil moisture regime, relative humidity and temperature would help in understanding the causes for the observations recorded during the pilot survey. Such an investigation was undertaken and the findings are discussed.

MATERIALS AND METHODS

Mature cypsellas of C. odorata were collected from teak plantations from Shimoga District, Karnataka, during March and April. These were stored dry in polythene bags placed in cardboard boxes, in the laboratory, at temperatures varying from 22 - 32°C and a relative humidity (RH) of 45 - 90%. They were drawn from periodically for experimentation.

Test 1: Seedling Emergence and Growth in the Laboratory at Different Light Intensities

This test was carried out in growth chambers. Plastic pots 7cm in diameter and 5.5cm deep were filled with a medium composed of red soil, sand and farmyard manure (2:1:1) and seeded with C. odorata cypsellas. The light source was arranged in such a way that the first row of pots received 3000 – 3,500 lux, the second row 2000 – 2,200 lux, the third row 1000 – 1,300 lux, the fourth row 500 – 600 lux and the fifth row 150 - 200 lux respectively. The interior temperature was maintained at 27°C, RH at 70 - 80% and available soil moisture between 85 and 95%.

Data on seedling emergence, plant height, root depth, the number of leaves, and dry weight of shoots and roots of the 45 day-old plants were recorded.

Test 2: Growth of Chromolaena odorata Seedlings under Different Light Conditions in the Field

Chromolaena odorata seeds were germinated and the seedlings grown for 45 days on Bangalore University campus, in (i) shade under the canopy of the tall trees, (ii) partly open and (iii) completely exposed areas during August and September. The seedlings were grown in three rows of five plants each. The light intensity under these three conditions varied, respectively, from 10 - 150 lux, 500 - 3,500 lux and 500 - 10,000 lux. During the growth period, the temperature and RH ranged from 20 – 28°C and 60 – 80% respectively. The available soil moisture ranged between 60 and 100%.

KEY WORDS: Asteraceae, ecophysiology, India, light intensity, mulching, Relative Growth Rate, relative humidity, root/shoot ratio, soil moisture
The 45 day-old seedlings were studied as in Test 1.

Test 3: Influence of Available Soil Moisture

Chromolaena odorata plants were raised from seeds during August and September in plots divided into four blocks of 2m² each separated by 1m. Each block had five rows of ten plants, each with an inter-row distance of 30cm and inter-plant distance of 20cm. The first block was maintained in a waterlogged condition. The second and third were watered frequently to maintain the available soil moisture at 95% and 70% respectively, whereas the plants in the fourth were grown at 50% available soil moisture by watering them once every three days.

The light intensity in these plots ranged between 500 and 10 000 lux. The atmospheric temperature varied from 20 – 28˚C and the RH from 60 - 80%.

Plants harvested after 30 days were studied as in Test 1.

### Table 1.
The range of temperature, relative humidity (RH), light intensity and rainfall from June – August in the forests of Shimoga (S) and Mercara (M), both in the Malnad, and in Bangalore (B), on the plains.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Place</th>
<th>Light intensity (lux)</th>
<th>Temp. (˚C)</th>
<th>RH (%)</th>
<th>Mean rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully open</td>
<td>S</td>
<td>500 – 10 000</td>
<td>22 – 26</td>
<td>82 ± 7.5</td>
<td>2 348.7</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>300 – 8 000</td>
<td>21 – 24</td>
<td>86 ± 8</td>
<td>2 465</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>800 – 10 000</td>
<td>25 – 29</td>
<td>76 ± 14</td>
<td>383.8</td>
</tr>
<tr>
<td>Partially open forest</td>
<td>S</td>
<td>200 – 5 000</td>
<td>23 – 26</td>
<td>78 ± 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>130 – 4 000</td>
<td>21 – 23</td>
<td>80 ± 14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>300 – 10 000</td>
<td>25 – 28</td>
<td>75 ± 10</td>
<td></td>
</tr>
<tr>
<td>Beneath the forest litter</td>
<td>S</td>
<td>35 – 670</td>
<td>22 – 23.5</td>
<td>77 ± 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>30 – 600</td>
<td>22 – 23</td>
<td>80 ± 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>200 – 1 000</td>
<td>24 – 26</td>
<td>70 ± 10</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2.
Dry weight and root/shoot (R/S) ratio of field-grown Chromolaena odorata seedlings under different light conditions and levels of soil moisture.

<table>
<thead>
<tr>
<th>Growth conditions</th>
<th>Mean dry weight (g)</th>
<th>R/S ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light conditions</td>
<td>Root</td>
<td>Shoot</td>
</tr>
<tr>
<td>Shade</td>
<td>1.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Partly open</td>
<td>2.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Fully open</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Soil moisture level (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 ± 5</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>70 ± 5</td>
<td>2.4</td>
<td>3.2</td>
</tr>
<tr>
<td>95 ± 5</td>
<td>3.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Water logging</td>
<td>0.7</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### Table 3.
Root/shoot (R/S) ratio and Relative Growth Rate (RGR) of Chromolaena odorata grown under Bangalore field conditions.

<table>
<thead>
<tr>
<th>Growth period (days)</th>
<th>Mean dry weight (g)</th>
<th>R/S ratio</th>
<th>RGR (g/100g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Root</td>
<td>Shoot</td>
<td>Root</td>
</tr>
<tr>
<td>30</td>
<td>2.3</td>
<td>4.4</td>
<td>0.52</td>
</tr>
<tr>
<td>90</td>
<td>4.4</td>
<td>9.8</td>
<td>0.45</td>
</tr>
<tr>
<td>150</td>
<td>6.0</td>
<td>13.6</td>
<td>0.44</td>
</tr>
</tbody>
</table>

The 45 day-old seedlings were studied as in Test 1.
Figure 1. Emergence and growth of *Chromolaena odorata* seedlings over a 45-day period under light intensities (lux) of 150 – 200 (A), 500 – 600 (B), 1 000 – 1 500 (C), 2 000 – 2 200 (D) and 3 000 – 3 500 (E). Numbers in parentheses are standard deviations.

Figure 2. Growth of *Chromolaena odorata* seedlings over a period of 30 days in the presence of varying available soil moisture: 50 ± 5% (a), 70 ± 5% (b), 95 ± 5% (c) and water logging (d). Numbers in parentheses are standard deviations.

Figure 3. Emergence and growth of *Chromolaena odorata* seedlings over a 30-day period at different relative humidities: 50 ± 5% (A), 65 ± 5% (B), 80 ± 5% (C), and 95 ± 5% (D). Numbers in parentheses are standard deviations.
**Figure 4.** Influence of mulching on the emergence and growth of *Chromolaena odorata* seedlings over a period of 45 days, where A = control and B = mulched with chromolaena twigs. Numbers in parentheses are standard deviations. Asterisks (*) denote significance (p < 0.05).

**Figure 5.** Rate and growth of *Chromolaena odorata* under field conditions. Numbers in parentheses are standard deviations.
Test 4: Influence of Relative Humidity

*Chromolaena odorata* seeds were raised from the seeds in plastic pots as for Test 1 and placed on the floor of the growth chamber. The RH values maintained in the chamber were 50, 65, 80, and 95%. The pots were watered sufficiently to maintain the available soil moisture between 85 and 95%. The temperature ranged between 20 and 28°C while the light intensity ranged between 2 000 and 3 000 lux.

The data on emergence and growth of the 30 day-old plants were studied as in Test 1.

Test 5: Influence of Mulching

*Chromolaena odorata* plants were raised from seed in five rows in 1m² plots. One of the plots was covered with twigs of *C. odorata* and the other one was left open to serve as the control. The plots were watered twice daily for 45 days. During the experimental period the temperature, RH and light intensity in the control plot were 30°C, 54% and 500 - 10 000 lux respectively, and the corresponding values below the mulch in the treatment plot were 25°C, 65% and 500 – 5 000 lux.

Data on seedling emergence and the growth performance of the plants grown for 45 days under these conditions were recorded as in Test 1.

Test 6: Rate of Growth of *Chromolaena odorata* Plants under Field Conditions

*Chromolaena odorata* plants were raised in plots, as described in Test 3, between June and November. The available soil moisture was maintained in the range of 80 – 95% at the rooting depth in the soil (2.0 - 6.5cm). The variation in the light intensity, temperature and relative humidity prevailing during the growth period are indicated in Table 2.

Ten plants each were harvested after one, three and five months. Data were collected as in Test 1 and the Relative Growth Rate (RGR) of shoots and roots was calculated.

RESULTS

Tests 1 and 2

Light intensity up to 1 500 lux favoured good seedling emergence in *C. odorata*. Growth and dry matter production were better at light intensities above 1 500 lux (Fig. 1). The growth performance of the seedlings under the different light conditions in the field (Table 2) also conformed to the trends evident in the laboratory trials. R/S ratios decreased with increasing light availability (Table 2).

Test 3

*Chromolaena odorata* seedlings grew in soils with the available moisture ranging from 45 - <100% and also survived in waterlogged soil. However, maximum growth occurred in soils with moisture availability ranging from 90 ± 5% (Fig. 2). Plant height, the number of leaves and dry weight decreased significantly with reduced available moisture (Fig. 2, Table 2). In drier soils, lateral root spread was poor although root depth increased slightly. In the waterlogged soil the growth was very poor and the seedlings remained slender, developed a trailing habit and produced adventitious roots from the internodes. The shoots of waterlogged plants had elongated internodes with very small leaves. No branching was seen. The R/S ratio remained the same irrespective of soil moisture, apart from at the lowest, where it increased (Table 2).

Test 4

*Chromolaena odorata* seeds were able to germinate over a wide range (50 – 100%) of relative humidities. The percentage of emergence was maximum over an RH range of 60 – 70% (Fig. 3).

Test 5

Seeding emergence doubled on soil surfaces mulched with *C. odorata* twigs, and plant height, number of leaves and dry matter production increased by 22 - 34% compared to the control (Fig. 4). Mulching reduced the soil surface temperature by 4 - 6°C, raised RH by 9 – 18%, and cut down the light intensity by more than 50%.

Test 6

The dry weights and R/S ratios of seedlings of different ages are presented in Fig. 5 and Table 2. The R/S ratio was highest (0.52) in the 30 day-old plants, declining slightly in the older ones. The RGR for shoots at the end of 30-day growth was much higher than for the roots. The RGR of the roots, which was quite high in the early stages, had declined dramatically after five months (Table 3).

DISCUSSION

In the Malnad, *C. odorata* seedlings start emerging from late June (early in the rainy season). The data on the RGR for the weed show that the growth rate of the seedling is quite high during the first thirty days, decreases considerably during the next two months and the decline is greater in the subsequent period. The decline in the rate of growth is slower in the roots. In the 3 – 5-month period of the rainy season, the species grows to a height of more than a metre. The weed is reported to grow in regions with an annual rainfall of around 1 500mm (Moni and George, 1959; Ivens, 1974).

The findings from the laboratory studies on the influence of light on seedling growth in *C. odorata* show that although germination was favoured by
low intensities of light, higher intensities (above 3,000 lux) were required for the optimal growth of the seedlings. With the decrease in the intensity from 3,000 - 150 lux, the mean dry matter content of the shoots was reduced by almost 95%. This dramatic effect also found expression in the plant height, leaf number and root depth, all of which were reduced to a significant degree. Marked reductions in the root depth become understandable when considering that its growth depends on the quantity of carbohydrates and other requirements normally supplied by the foliage. The reciprocal influences between the shoot and root systems of plants are well known (Mayer et al., 1973). Plants grown under different light conditions in the field showed similar responses. Mean dry root weight was reduced by 16% and 52% when seedlings were grown in partly open areas and under shade respectively, while the corresponding reductions in shoot dry weight were 31% and 65%. The effects were also evident in the root/shoot ratio of the plants. Similar effects of reduced intensities of light on the plant growth were studied by Mayer (1973). The results of experiments show that C. odorata seedlings grew well at 30°C, and on mulched soils (25°C) even better. Mulching also increased the RH significantly when compared to non-mulched plots. These conditions prevail in the Malnad during the growth of C. odorata and hence the seedlings grow vigorously, but in Bangalore, these conditions tend to be not so favourable.

Thus, it may be concluded that bright sunlight, high soil moisture and RH would favour vigorous growth of C. odorata. As these conditions are met in the Malnad areas, the weed grows luxuriantly here, whereas in plains habitats, like Bangalore, inadequate rainfall and relatively drier weather inhibit the growth of the weed, confining it to thickly vegetated areas.

ACKNOWLEDGEMENTS

I acknowledge Dr. D. Sivaramakrishna, Professor and Head, Department of Botany, Bangalore University, Bangalore for giving me the facilities and the necessary encouragement to carry out this work. Thanks to the Commonwealth Science Council and the workshop organizers, who provided funding for attending the Fifth International Workshop.

REFERENCES


CHANGING FALLOW VEGETATION FOLLOWING THE INTRODUCTION OF PAREUCHAETES PSEUDOINSULATA TO CONTROL CHROMOLAENA ODORATA IN SOUTHERN GHANA

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Chromolaena odorata was introduced to western Africa in the first half of the 1900s. Its rapid vegetative development and its massive production of air-borne seeds have allowed it to spread to large parts of the region. The plant has become an important component of the natural succession in the traditional slash-and-burn bush-fallow cropping systems of the humid forest and transition zones. Many farmers perceive C. odorata to be a major weed. However, there are some strong indications that the species can improve soil fertility in short-cycle fallows. It provides rapid ground cover, produces a lot of biomass, and appears to accumulate calcium and potassium. Furthermore, it has been shown to out-compete the noxious weed Imperata cylindrica in short-term fallow systems. This paper reports on the impact of the introduction of Pareuchaetes pseudoinsulata in southern Ghana on the composition of fallow and plantation undergrowth vegetation and its potential implications for the farmers of the region.
FEEDING BEHAVIOUR OF PAREuchaetes PSEUDOINSULATA

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²Regional Agricultural Research Station, Kumarakom, Kottayam, India

In laboratory studies to assess the relative preference of Pareuchaetes pseudoinsulata larvae for tender, mature, insect-induced semi-yellow and yellow leaves, maximum larval weight was registered for the seventh instar feeding on mature leaves. First and second instar larvae did not feed on semi-yellow and yellow leaves and they died of starvation when these leaves were offered for feeding. The indices for leaf consumption decreased as the age of larvae advanced. Maximum Relative Growth Rate was realised during the transition of larvae from the fourth to fifth instar on a mature leaf diet. From the third instar onwards, larval growth and development took place even when fed semi-yellow and yellow leaves, but in such cases adult emergence was curtailed considerably and they showed malformed and crinkled wings.

KEY WORDS: Arctiidae, biological weed control, Chromolaena odorata, Relative Growth Rate, Consumption Index

INTRODUCTION

In Kerala, the aggressive weed species Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) grows widely, causing severe problems. Pareuchaetes pseudoinsulata Rego Barros (Lepidoptera: Arctiidae) is a biological control agent of the weed. Metabolic changes were reported in plants exposed to larval feeding as an adaptive mechanism favouring the survival of the weed (Marutani and Muniappan, 1988). Both damaged and healthy leaves of the plant turned yellow after insect attack, and the chlorophyll content was much lower in insect-infested leaves than leaves from artificially defoliated plants. Artificial defoliation could not induce the same type of yellowing in leaves. McConnell et al. (1991) studied the changes in leaves due to insect feeding and found that the amount of chlorophyll and rate of photosynthesis were reduced in yellow plants. The present investigation on the feeding behaviour of the insect is to study the impact of such changes in plants on insect development.

MATERIALS AND METHODS

Feeding trials were conducted by feeding the larvae with tender, mature, insect-induced partially yellow and fully yellow leaves. For distinguishing tender and mature leaves, thin longitudinal sections of the leaves were taken and the intercellular spaces of the collenchymatous tissue were measured. It was found that in the first to third pair of leaves from the top, the intercellular space was negligible. These leaves were light green in colour and delicate in texture. From the fourth to eighth pair, the intercellular space ranged from 0.66 – 3.30µ in thickness. These leaves were deep green in colour. Leaves from the eighth pair downwards showed yellowing, a sign of senescence and in this case, the thickness recorded was above 3.50µ. The leaves taken on the seventh day after release of the larvae were considered as semi-yellow leaves and on the 12th day as yellow leaves.

The indices of larval food consumption and growth were calculated following Waldbauer (1968) and Scribe (1977). The early stages of the larvae were too delicate and small and produce inconspicuous feeding marks on the lamina. Therefore five larvae were placed together on a leaf for studying their feeding habits. From the sixth day onwards, they were placed individually. The experiment was carried out in plastic containers of size 12cm height and 8cm diameter with 20 replications, under laboratory conditions. The weight and area of leaves offered as well as the weight of larvae were recorded at 24-hour intervals. On each occasion, the cut ends of the leaf petioles were covered with wet cotton to prevent drying. The area and weight of leftover food were recorded, the containers cleaned and then fresh leaves were introduced. Natural weight loss from the leaves was determined after 24 hours, using separate sets of leaves. The area of the leaf was measured by using a leaf area meter and weights determined on an electronic balance.

RESULTS AND DISCUSSION

Leaf Consumption

Higher leaf consumption was found in the later instars, irrespective of the types of leaves offered (Table 1). According to Wolcott (1937), 97% of the total food consumption occurred during the last two instars in Bombyx and Protoparce, two
Table 1. Leaf consumption by *Pareuchaetes pseudoinsulata*.

| Instar | Weight of leaf consumed (g)
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tender</td>
</tr>
<tr>
<td>I</td>
<td>0.024 e</td>
</tr>
<tr>
<td>II</td>
<td>0.020 e</td>
</tr>
<tr>
<td>III</td>
<td>0.014 e</td>
</tr>
<tr>
<td>IV</td>
<td>0.063 e</td>
</tr>
<tr>
<td>V</td>
<td>0.108 cd</td>
</tr>
<tr>
<td>VI</td>
<td>0.155 c</td>
</tr>
<tr>
<td>VII</td>
<td>0.238 b</td>
</tr>
<tr>
<td>VIII</td>
<td>0.352 a</td>
</tr>
</tbody>
</table>

1 Means compared by One-Way ANOVA; those followed by the same letter are not significantly different ($p > 0.05$; Duncan’s Multiple Range Test).

Table 2. Mean larval weight and Consumption Index on consumption of tender, mature, semi-yellow and yellow leaves.

<table>
<thead>
<tr>
<th>Instar</th>
<th>Larval weight (g)</th>
<th>Consumption Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tender</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0.004 j</td>
<td>2.155 cd</td>
</tr>
<tr>
<td>IV</td>
<td>0.010 hij</td>
<td>2.143 cd</td>
</tr>
<tr>
<td>V</td>
<td>0.041 fg</td>
<td>0.484 g</td>
</tr>
<tr>
<td>VI</td>
<td>0.112 e</td>
<td>0.452 g</td>
</tr>
<tr>
<td>VII</td>
<td>0.163 c</td>
<td>0.370 g</td>
</tr>
<tr>
<td></td>
<td>Mature</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0.004 j</td>
<td>1.533 def</td>
</tr>
<tr>
<td>IV</td>
<td>0.013 hi</td>
<td>1.683 de</td>
</tr>
<tr>
<td>V</td>
<td>0.039 g</td>
<td>2.297 bc</td>
</tr>
<tr>
<td>VI</td>
<td>0.134 d</td>
<td>0.526 fg</td>
</tr>
<tr>
<td>VII</td>
<td>0.230 a</td>
<td>0.801 efg</td>
</tr>
<tr>
<td></td>
<td>Semi-yellow</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0.004 j</td>
<td>3.143 abc</td>
</tr>
<tr>
<td>IV</td>
<td>0.010 hij</td>
<td>3.784 a</td>
</tr>
<tr>
<td>V</td>
<td>0.034 g</td>
<td>0.646 fg</td>
</tr>
<tr>
<td>VI</td>
<td>0.142 d</td>
<td>0.471 g</td>
</tr>
<tr>
<td>VII</td>
<td>0.193 b</td>
<td>0.564 fg</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0.004 j</td>
<td>2.500 bcd</td>
</tr>
<tr>
<td>IV</td>
<td>0.002 i</td>
<td>2.498 bcd</td>
</tr>
<tr>
<td>V</td>
<td>0.049 f</td>
<td>0.671 fg</td>
</tr>
<tr>
<td>VI</td>
<td>0.109 e</td>
<td>0.641 fg</td>
</tr>
<tr>
<td>VII</td>
<td>0.141 d</td>
<td>1.046 efg</td>
</tr>
</tbody>
</table>

1 Means compared by One-Way ANOVA; those followed by the same letter are not significantly different ($p > 0.05$; Duncan’s Multiple Range Test).
lepidopterous leaf feeders. Ramdev and Rao (1979) reported that food intake of *Achaea janata* L. (Noctuidae) on castor increased with age. Ranjith (1981) also stated that consumption increased with the age of *Pericallia ricini* Fb. (Arctiidae) larvae. These findings are in consonance with the present result. Here tender leaf consumption was much higher than mature leaf consumption in the first instar. The preference for tender leaves at the early stage of the larvae has thus been established. From the second instar onwards, maturity of the leaf is not found to be a factor that determines leaf consumption.

When semi-yellow and yellow leaves were offered to the first-instar larvae, they did not feed at all and died due to starvation. This may be due to either the presence of phagodeterrents or the absence of phagostimulants in the leaves which have turned partially yellow. From the nutritional point of view these leaves were found to be inferior. The mandibles of early-stage larvae are not sufficiently developed to feed upon tough, mature leaves, and a lack of feeding by first- and second-instar larvae on these leaves could be due to this. The colour of a substrate also influences host-selection behaviour of phytophagous insects (Maxwell and Jennings, 1980). Marutani and Muniappan (1988) reported on the toughness and low nitrogen content of semi-yellow and yellow *C. odorata* leaves. Gross changes from the normal texture and colour of leaves could be the reasons for not accepting these leaves as feed in the early, delicate stages of the larvae. However, from the third instar onwards, the larvae were found to feed on such leaves in no-choice situations. According to Marutani and Muniappan (1988), the caterpillars favoured green leaves in both young and older stages, but when they were in the third or later instars, they also consumed the partially yellow leaves. The above observation is in conformity with the present studies.

**Larval Weight**

When weights of third, fourth, fifth, sixth and seventh larval instars were compared by feeding the larvae with tender, mature, semi-yellow and fully yellow leaves, it was found that the seventh instar had significantly higher larval weight when it consumed mature leaves (Table 2). Higher water and nitrogen contents in the host plants encourage the best growth of larvae (Waldbauer, 1968; Scriber, 1977, 1978, 1979). Of the four types of leaves, the mature leaves had higher total nitrogen and chlorophyll content, and the increase in larval weight in such cases is on the basis of favourable nutritional factors. Lowest larval weights were registered when they consumed yellow leaves. Yellow leaves are found to be tough in nature and with lower total nitrogen and chlorophyll contents.

Tanton (1962) stated that feeding rates and larval growth were retarded when the larvae were fed on relatively tough turnip, kale and brussels sprout leaves. Thus, a lower body weight attained on consumption of tough yellow leaves is expected as a result of adverse biophysical and nutritional factors.

**Consumption Index**

Consumption Indices were found to decrease as larval age advanced, and thus early instars recorded high indices for all four kinds of leaves. For castor semilooper *A. janata*, Ramdev and Rao (1979) observed a decreased Consumption Index as age increased. Dandapani and Balasubramanian (1980) stated that the Consumption Index decreased with an increase in age in *Heliothis armigera* Hubner (Noctuidae). These reports are in general consonance with the present findings. The highest Consumption Index was for the fourth instar larvae when they consumed semi-yellow leaves (Table 2). Consumption Indices were also higher when the larvae consumed yellow leaves. Yellow and semi-yellow leaves are low in total nitrogen and chlorophyll contents (Marutani and Muniappan, 1988) and therefore to obtain an adequate level of nutrients, the larvae must have resorted to increased feeding as a compensatory activity. However, even though there was more feeding, weight gain in larvae was less when they fed on these two types of leaves as compared to tender and mature leaves. This might be due to the inadequate quality of the yellow and semi-yellow leaves as compared to the tender and mature leaves.

**Relative Growth Rate**

The Relative Growth Rate of larvae was higher during the fourth and fifth stages when they consumed mature, semi-yellow and yellow leaves (Table 3). Muniappan *et al.* (1989) also recorded maximum growth rates in fourth and fifth instars. When tender leaves were supplied, the Relative Growth Rate was higher during first to second instar (1.650) than when mature leaves were supplied (0.881). This shows that for the first and second instar larvae, tender leaves were the most suitable food material. The Relative Growth Rate was maximum when the larva grew from the fourth to fifth instar on a mature-leaf diet and it was lowest when the larva grew from the sixth to seventh instar on semi-yellow leaf diet. The present findings are in consonance with that of Marutani and Muniappan (1988), who recorded that the growth rate of the larvae was greater when they consumed green as compared to yellow leaves.

Even though growth and development occurred in a normal manner when the larvae consumed partially yellow and fully yellow leaves from the third instar onwards, adult emergence was reduced.
Table 3. Relative Growth Rate of various instars when supplied with tender, mature, semi-yellow and yellow leaves.

| Instar   | Relative Growth Rate
d | Tender   | Mature   | Semi-yellow | Yellow   |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>III – IV</td>
<td>1.002 cdef</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV – V</td>
<td>1.075 bcde</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V – VI</td>
<td>0.549 fghi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI – VII</td>
<td>0.208 hi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III – IV</td>
<td>0.964 cdefg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV – V</td>
<td>1.581 a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V – VI</td>
<td>0.645 efgh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI – VII</td>
<td>0.214 hi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III – IV</td>
<td>0.763 defg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV – V</td>
<td>1.297 abc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V – VI</td>
<td>0.842 cdefg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI – VII</td>
<td>0.124 i</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III – IV</td>
<td>1.209 abcd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV – V</td>
<td>1.527 ab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V – VI</td>
<td>0.474 ghi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI – VII</td>
<td>0.176 hi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Means compared by One-Way ANOVA; those followed by the same letter are not significantly different (p > 0.05; Duncan’s Multiple Range Test).

Table 4. Effect of leaf consumption on duration of different stages of the insect.

<table>
<thead>
<tr>
<th>Type of leaf consumed</th>
<th>Developmental period (days)</th>
<th>Larva</th>
<th>Pupa</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tender</td>
<td>22.45 a</td>
<td>10.40 a</td>
<td>7.900 a</td>
<td></td>
</tr>
<tr>
<td>Mature</td>
<td>19.68 c</td>
<td>9.500 b</td>
<td>6.300 b</td>
<td></td>
</tr>
<tr>
<td>Semi-yellow</td>
<td>19.09 c</td>
<td>9.200 b</td>
<td>6.300 b</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>20.68 b</td>
<td>9.800 ab</td>
<td>5.600 b</td>
<td></td>
</tr>
</tbody>
</table>

1 Means compared by One-Way ANOVA; those followed by the same letter are not significantly different (p > 0.05; Duncan’s Multiple Range Test).

Table 5. Effect of leaf consumption on weight of different stages of the insect.

<table>
<thead>
<tr>
<th>Type of leaf consumed</th>
<th>Weight (g)</th>
<th>Larva</th>
<th>Pupa</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tender</td>
<td>0.260 a</td>
<td>0.141 a</td>
<td>0.052 a</td>
<td></td>
</tr>
<tr>
<td>Mature</td>
<td>0.277 a</td>
<td>0.158 a</td>
<td>0.059 a</td>
<td></td>
</tr>
<tr>
<td>Semi-yellow</td>
<td>0.229 a</td>
<td>0.139 a</td>
<td>0.036 b</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>0.238 a</td>
<td>0.095 b</td>
<td>0.029 b</td>
<td></td>
</tr>
</tbody>
</table>

1 Means compared by One-Way ANOVA; those followed by the same letter are not significantly different (p > 0.05; Duncan’s Multiple Range Test).
considerably. Most of the adults emerged were found to be malformed, with crinkled wings. This phenomenon might be due to severe nutritional imbalances in yellow leaves characterised by low total nitrogen, increased nitrate nitrogen and lower chlorophyll contents (Marutani and Muniappan, 1988). It has been reported in several plant species that previous non-lethal insect infestation can lead to changes in the resistance and palatability of plants (Haukioja and Niemela, 1976, 1977; Schultz and Baldwin, 1982; Edwards and Wratten, 1983; Edwards et al., 1985). The growth of larvae of the geometrid moth, *Epirrita autumnata* Borkhausen was retarded when they were fed on previously grazed birch trees (Haukioja and Hanhimaki, 1984). Damaged birch leaves (*Betula* spp., Betulaceae) were less palatable than undamaged leaves for the larvae of *Spodoptera littoralis* (Boisduval) (Noctuidae) and *Orgyia antiqua* L. (Lymantriidae) (Wratten et al., 1984).

The colour and shape of plants indirectly influences the host-selection behaviour of phytophagous insects (Maxwell and Jennings, 1980). In the present studies the larvae were forced to feed on yellow leaves in the absence of green leaves. On yellow *C. odorata* leaves, the feeding rhythm was of an irregular nature from the third instar onwards. On yellow leaves the presence of dark-coloured larvae may be more striking, and this situation is likely to be favourable to natural enemies, due to improved visual stimulus. A decline in field populations of the insect is therefore quite likely.

**Effects on Larval, Pupal and Adult Periods and Weights when Fed Tender, Mature, Semi-Yellow and Yellow Leaves**

When tender and yellow leaves were consumed, the larval period was longer than when mature and semi-yellow leaves were consumed (Table 4). Even though the early instars preferred the tender leaves, quickest development of the different stages took place when the larvae consumed mature leaves. This may be due to there being insufficient amounts of nutrients available in tender and yellow leaves. Purohit and Deshpande (1991) reported that the larval period of *H. armigera* was significantly reduced when they fed on sunflower leaves having a high nitrogen content. Marutani and Muniappan (1988) found that the duration of instars of the insect increased when they fed on yellow leaves, and according to them it may be due to insufficient amounts of nutrients available for caterpillars consuming yellow leaves.

The larvae which consumed tender leaves recorded less weight than those fed on mature leaves. An analysis of the larval weights shows that it was maximum when mature leaves were consumed in all the stages and minimum when yellow leaves were consumed, although these differences were not significant (Table 5). Pupal and adult weights were lowest for larvae which had fed on yellow leaves.

The extension of larval duration when fed tender and yellow leaves could be an adaptation for obtaining adequate nutrients for proper growth and development. The irregular rhythm of feeding on yellow leaves during the daytime is perhaps an adaptation for extending the consumption period when unsatisfactory food was available.

The present results are in conformity with the trends reported by Marutani and Muniappan (1988).

**Leaf Area and Leaf Weight Consumption**

The mature leaves were consumed in greatest mass by the larvae. Since the mature leaf is the most suitable food, more leaf weight consumption can be expected here. Leaf area consumption was maximum for tender leaves. In order to get sufficient nutrients, bulk feeding became necessary and the larval duration was extended for this purpose.

**ACKNOWLEDGEMENTS**

This paper forms a part of Ph.D. thesis of the first author submitted to the Kerala Agricultural University in 1995. The authors are grateful to the Kerala Agricultural University, Vellanikkara for providing the necessary facilities for the study.
REFERENCES


INTRODUCTION AND ESTABLISHMENT OF THE GALL FLY 
CECIDOCHARES CONNEXA FOR CONTROL OF SIAM WEED,
CHROMOLAENA ODORATA, IN JAVA, INDONESIA

Soekisman Tjitrosemito

BIOTROP, P.O. Box 116, Bogor, Indonesia

A shipment of 48 pupae of the gall fly Cecidochares connexa was imported and reared from July to December 1995 on its host plant Chromolaena odorata in the laboratory at BIOTROP. Subsequently, field releases were made in West and East Java and its life table was studied in the laboratory. The generation time was 71.1 days with a net reproductive rate of 14.2 offspring and an intrinsic growth rate of 0.0369 in the laboratory. The fly readily established in West Java but there was a delay in establishment at East Java. The population buildup of C. connexa was affected by the availability of oviposition sites on the C. odorata host plants, and these decreased in the dry season. In West Java C. odorata produced more vegetative shoot tips than that in East Java.

KEY WORDS: agent establishment and spread, biological weed control, climatic influences, field releases, Tephritidae

INTRODUCTION

With the decree of the Minister of Agriculture No. 588/kpts/TN.120/9/93, A. Sipayung and R. Desmier de Chenon of the Indonesian Oil Palm Research Institute (IOPRI), Medan, imported a colony of Cecidochares connexa Marquart (Diptera: Tephritidae) from South America. The first consignment of 100 galls arrived in December 1993 from Tucuman, Argentina (Sipayung and Desmier de Chenon, 1995), but failed to produce any flies. Further consignments were received from Colombia from February to June 1994 (R.E. Cruttwell McFadyen, pers. comm.), from which a culture was successfully established. Host-specificity testing, carried out by the Indonesian Oil Palm Research Institute using 58 species of plants in 18 families, showed that this gall fly developed only on Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae). Subsequently its release in the field was permitted.

The first colony of C. connexa for Java, in the form of 17 stem cuttings bearing mature galls, was collected by the author from the Marihat Research Station of IOPRI, North Sumatera in July 1995. The galls were dissected and 48 pupae were obtained. The pupae were placed in petri dishes lined with moist tissue paper, and these were left in a rearing cage measuring 0.4 x 0.4 x 0.4m, consisting of a wooden frame with fine plastic mesh. The pots were 5 litres in capacity and contained soil mixed with worm castings in a 1:1 ratio as a medium to support the growth of C. odorata. After the flies had died (about 7 days) the potted C. odorata were taken out of the cage and placed in the direct sunlight, where they were watered and fertilized adequately.

After the third generation the colony reached a size of more than 3 000 flies and field releases were subsequently initiated. The field releases were carried out in Parung Panjang, West Java in December 1995, Parung Kuda (close to Bogor), West Java in May and June 1996, and in Saradan, East Java in December 1996. In Parung Panjang the fly established readily but in Parung Kuda and in Saradan no establishment was recorded. More releases were made at the Saradan site in 1998. This paper presents the results of biology and life table studies conducted in the BIOTROP laboratory at Bogor, and the population dynamics of the fly in the field in relation to plant phenology and environmental factors.

MATERIALS AND METHODS

Biology and Life Table Investigations

Descriptions and measurements were made of the various developmental stages of C. connexa. Cohorts of C. connexa were established by confining 100 pairs of C. connexa flies for one day in a cage measuring 3 x 3 x 2m and containing 40 potted C. odorata plants, each with at least 10 actively growing shoot tips. The eggs laid in the growing shoot tips by these flies constituted a
cohort of a *C. connexa* population. Four replicates were used.

Observations using gall dissection were made to determine egg hatching rates and the mortalities and durations of the immature stages. After allowing the flies to oviposit, 10 shoot tips were harvested and the number of eggs was determined under a binocular microscope. Fourteen days later, 10 galls were harvested, dissected and the number of larvae was determined. This process was repeated at 10-day intervals up to 64 days after oviposition.

Observations without gall dissection were also made, to determine adult fecundity and longevity. When a window was noticed on a gall, the gall was wrapped with white nylon cloth to confine the emerging adults. To estimate their fecundity, the emerged male and female flies were collected, paired up and released onto a potted *C. odorata* plant in a cage. At the end of the day the flies were transferred to a new plant while the growing tips of the previous plant were harvested. The number of eggs in these tips was counted under a binocular microscope. This procedure was repeated every day until all the flies died.

Data from these observations were also used to obtain the values of the life table parameters of Generation Time (*T*), Net Reproductive Rate (*R₀*), and Intrinsic Growth Rate of the population (*r*), calculated using the following formulae (Gotelli, 1995):

(i) Net Reproductive Rate

\[ R₀ = \sum l(x)m(x) \]

where *x* is the age of the individual, *m(x)* is the fertility schedule i.e. the average number of offspring born to an individual female of a particular age, and *l(x)* is the survivorship schedule i.e. the probability that an individual survives from birth to the beginning of age *x*.

(ii) Generation Time

\[ T = \frac{\sum l(x)m(x)x}{R₀} \]

(iii) Intrinsic Growth Rate

\[ r = \frac{\ln(R₀)}{T} \]

and should satisfy the following equation:

\[ 1 = \sum x e^{-r(x)m(x)} \]

**Population Dynamics of *Cecidochares connexa* in the Field**

The adult fly population in the field is difficult to estimate, so population growth of *C. connexa* was determined using the percentage of growing tips carrying eggs and the abundance of galls on the shoots at the release sites at Parung Panjang, West Java and Saradan, East Java. These parameters were estimated by sampling the infected area using line transects from the release point i.e. permanent plot (Tjitrosemito, 1998) in the four cardinal directions. Quadrats of 2 x 2m² were established at intervals of 20m along the 100m transect lines. In each quadrat all growing tips and galls were counted, and 20 growing tips were collected at random. These were taken to the laboratory for egg counting under the binocular microscope. The flowering and fruiting phenology of *C. odorata* was also recorded.

**Effect of the Environment**

Environmental variables such as temperature, relative humidity and rainfall were collected from the weather stations nearby the experimental plots, and related to the population dynamics of *C. connexa* and *C. odorata*.

**RESULTS AND DISCUSSION**

**Biology and Life Table Investigations**

**Adults**

The adults of *C. connexa* are black with transparent wings banded with a blackish pattern, and pinkish eyes. The thorax as well as abdomen also showed a banded, blackish pattern. Females were differentiated from males by their conspicuous ovipositor, besides being larger than males. Females had a wingspan of 11.2mm and body size of 6.9 x 2mm; males had a wingspan of 10mm and a body size of 5.6 x 1.8mm.

In the laboratory, females laid a lifetime average of 58.0 eggs, of which 46.4 or 80% were laid in the first three days after the females emerged (Table 1). It is therefore recommended that the adult flies be released as soon as they emerge. Females laid their eggs by inserting the ovipositor into the tissue of the hairy apical tips of *C. odorata*, and deposited them in clumps.

The longevity of the adults was 5.3 days for males (*n* = 54) and 5.9 for females (*n* = 55) (Table 2). The ratio of males and females in the cohorts was 1:1.

**Eggs**

The eggs of *C. connexa* are creamy white, 0.7mm long by 0.2mm in width. The duration of the egg stage was determined using 67 eggs held at room temperature. The newly laid eggs were extracted from the growing tips of *C. odorata* in the morning, after which they were placed on wet tissue paper in petri dishes and examined daily for hatching. The eggs started to hatch on the sixth day and all eggs had hatched by the ninth day. The average duration of the egg stage was 6.9 days. When another set was examined for hatching in petri dishes lined with wet tissue paper, 76.3% of the total of 96 eggs hatched.
Observations were also carried out on eggs still inserted in the growing tips, by sampling ten growing tips in the laboratory for inspection under the binocular microscope. The ten growing tips contained 51 eggs. Sampling of 10 galls, 14 days after oviposition, indicated that there were only 32 larvae i.e. about 62.8% of the eggs had hatched. However, newly hatched larvae may die and disappear before being counted, thus giving an underestimate of hatchability compared with eggs extracted from *C. odorata* tips and held on wet tissue paper.

**Larvae**

Determination of instars was difficult as larvae dissected from galls moved and the oesopharyngeal apparatus was retracted under the folded segment of the larva. The size of a newly hatched larva was 0.7 x 0.2mm (n = 41). It grew to reach a size of 1.3 x 0.9mm 17 days later. Thereafter it grew faster, and the size doubled to 2.8 x 1.9mm in ten days. The size of the mature larva was up to 4.2 x 2.1mm.

The duration of the larval stage, determined indirectly by subtracting the durations of the egg and pupal stages from that of the immature stage, was about 35 days.

Galls were detectable about 2 weeks after oviposition. Measurement of the diameters of 50 galls at weekly intervals yielded data with the regression line $Y = -0.0525 + 1.349 X$ ($r^2 = 0.99$), where $Y$ = age of gall in weeks, and $X$ = diameter of gall in mm.

**Pupae**

The size of the *C. connexa* pupa was 4.2 x 2.1mm. It was yellowish white when young and turned dark brown when mature. The first pupation took place 44 days after oviposition, and after 64 days no larvae were present in the galls examined. The length of the pupal period, which varied greatly between individuals, was estimated by extracting larvae from galls dissected 54 days after oviposition. These larvae pupated quickly, whereas some of the larvae dissected out prior to this time were too young to pupate normally. When the time of onset of pupation was known and the adult emergence date was recorded, the duration of the pupal stage could be averaged at 19 days.

Only 21 pupae were obtained compared to the 51 eggs recorded at the beginning of the trial. The survival rate of eggs to pupae was thus only 41%.

**Duration of the Immature Stage**

The duration of the immature stage, determined using 54 adults, was 61 days on average, with 7, 35, and 19 days for the egg, larval and pupal stages respectively.

**Net Reproductive Rate, Generation Time and Intrinsic Growth Rate**

The mean length of the Generation Time was 71.1
days (n = 109) with a Net Reproductive Rate of 14.2 offspring (Table 2). This means that in a year this population of *C. connexa* will be able to produce about five generations, and in each generation the population will increase by a factor of 14.2 with respect to the female population under laboratory conditions. In the field, conditions will probably be different.

### Table 3. The number of growing tips and flowers of *Chromolaena odorata* (number/4m²), eggs of *Cecidochares connexa* (% of tips infested) and galls (% of tips infested) in 1998/1999, outside the permanent plot in Parung Panjang, West Java.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1998</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>Tips</td>
<td>64.6</td>
<td>-</td>
</tr>
<tr>
<td>Flowers</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Eggs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Galls</td>
<td>30.2</td>
<td>-</td>
</tr>
</tbody>
</table>

1Not recorded.
2*C. odorata* in the area was slashed.

### Table 4. Growth of (a) *Chromolaena odorata* plants (numbers of plants, shoot tips and flowers), (b) the *Cecidochares connexa* population (numbers of adults and galls released and numbers of galls found in field), (c) teak trees, in the 5 x 5m² permanent plot in Saradan, East Java.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1998</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>M</td>
</tr>
<tr>
<td>(a) <em>C. odorata</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stems</td>
<td>-</td>
<td>32</td>
</tr>
<tr>
<td>Shoot tips</td>
<td>1065</td>
<td>865</td>
</tr>
<tr>
<td>Flowers</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(b) *C. connexa* | | | | | | | | | | | | |
| Adults released | - | 16 | - | - | - | - | - | - | - | - | - | - |
| Galls released | - | 100 | - | - | - | 250 | - | - | - | - | - | - |
| Galls in field | 0 | 0 | 0 | 8 | 11 | 6 | 6 | 5 | 2 | 5 | 4 | 3 |

(c) Teak | | | | | | | | | | | | |
| Trunk diam.(mm) | 50.1 | - | - | - | - | 64.6 | - | - | - | - | - | 76 |
| Tree height (m) | 5.7 | - | - | - | - | 7.2 | - | - | - | - | - | 10 |

### Table 5. Growth of *Chromolaena odorata*, in terms of shoot tips and flowers (number/4m²), and of the *Cecidochares connexa* population, in terms of galls (number/4m²), outside the permanent plot in Saradan, East Java.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1998</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>J</td>
</tr>
<tr>
<td>Shoot tips</td>
<td>83.0</td>
<td>97.3</td>
</tr>
<tr>
<td>Flowers</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Galls</td>
<td>1.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Population Dynamics of Cecidochares connexa in the Field
Parung Panjang, West Java

Growth patterns of C. odorata in the permanent plot in Parung Panjang up to 1997 were reported by Tjitrosemito (1999a, b). The permanent plot was damaged by fire in 1997, but C. odorata regrew. The attack by C. connexa on this regrowth was very high, and by the end of 1998, the C. odorata in the permanent plot was severely affected. Chromolaena odorata plants growing in the partly open forest nearby remained green throughout the year, while shoots in the open areas (including the permanent plot) flowered, fruited and dried out in the dry season. The green shoots of C. odorata in the forest may have permitted the fly to survive and to infect the new growth of C. odorata in the open area at the beginning of the wet season.

Outside the permanent plot, the growth of C. odorata was estimated from the change in the number of growing shoot tips of C. odorata sampled monthly (Table 3). From March to May 1998 (the wet season) these increased considerably, and then decreased from 120.3 tips/4m² in May to 62.8/4m² in June because some developed into flower buds. The development of each inflorescence is independent from others on the same plant. It was common, therefore, that on one plant the apical inflorescence was already dispersing its fruits, while the lower shoot tips were only initiating flowering or did not develop flower buds at all.

The development of flower buds into flowers and then fruits coincided with the onset of the dry season. This further reduced the number of growing tips, and by November 1998 there were only 30.6 tips/4m². This number increased with the onset of the wet season to reach a density of 75.8 tips/4m² in January. The area was slashed to grow crops in February, resulting in another decrease in shoot tip density.

The percentage of shoots that developed into flower buds was 41.3% in June and 47.7% in July. It then decreased until, after October 1998, no more flower buds were observed. By July, some of the flowers were turning into fruits (cypselas pale yellow), and some fruits were beginning to mature (cypselas turned dark brown). In the following months, the bract opened, allowing the fruits to disperse. Inflorescences then died back.

The population growth of C. connexa, as measured by the number of shoot tips carrying eggs and the density of galls (expressed as % of the total number of growing tips/4m²) was affected by the growth of C. odorata. During the wet season, when tips of C. odorata are abundant, the population of C. connexa was high, and it decreased during the dry season. The percentage of shoot tips carrying eggs was 26.1% in May 1998, and remained relatively constant up to July. However, it decreased steadily during the dry season, and in November only 11.8% of the tips had eggs. The percentage of shoots with galls increased to 61.0% in January 1999 and 83.5% in February, but thereafter the plot was slashed for crop cultivation.

Saradan, East Java

The growth of C. odorata from 1996 – 1998 was reported by Tjitrosemito (1999b). Between May 1998 and March 1999, the number of C. odorata plants declined by more than 75% in the permanent plot (Table 4). A reduction of almost 97% was shown by the shoot tips. The reduction in the population of C. odorata may be attributed to shading by young teak trees. The build up of the C. connexa released in December 1996 was initially very promising. However, the area experienced a very dry season from June to October 1997 and was also damaged by fire. Even when the rains started in November 1997 and C. odorata began to regrow, no galls were recorded in the permanent plot. Fly releases were made in May 1998 with 100 galls and 16 pairs of adults. Another release was made in September with 250 galls. Afterwards galls were found in low densities (Table 4).

After galls had disappeared from the permanent plot in 1997, they were still frequently observed outside it, along the road. Observations were therefore carried out systematically outside the permanent plot (Table 5).

The growth of shoot tips showed a similar pattern to that in Parung Panjang, increasing during the wet season. However, the number of shoot tips peaked in June (97.3/4m²), one month later than that in Parung Panjang. The shoot tip density in Saradan was lower than that in Parung Panjang, reflecting the drier conditions in the former. The onset of flowering in Saradan was also one month behind, in July instead of June. This resulted in a reduction in the number of vegetative tips, which continued until the following wet season began. In the early part of 1998 the gall numbers were low, but gradually increased even during the dry months of June to September, and reached 23.6% in March 1999.

Adult C. connexa were frequently observed in open areas, both along the road and elsewhere where teak growth was poor.

Effect of the Environment

The climatological data on rainfall, relative humidity, and temperature of Parung Panjang, Bogor and Saradan are presented in Figs 1 – 3.
Table 6. Average increment in vegetative tip length of *Chromolaena odorata*, and estimated period of lifecycle of *Cecidochares connexa*, in three regions of Java, Indonesia.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parung Panjang</th>
<th>Bogor</th>
<th>Saradan</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tip increment</td>
<td>9.1 b(^1)</td>
<td>3.3 a</td>
<td>4.8 a</td>
<td>0.05</td>
</tr>
<tr>
<td>Lifecycle (days)</td>
<td>44.6</td>
<td>43.9</td>
<td>46.2</td>
<td>NS</td>
</tr>
</tbody>
</table>

\(^1\) Numbers in a row with different letter differ significantly at 5% level.

Figure 1. Average monthly rainfall in 1996 and 1997 in (a) Bogor, (b) Parung Panjang and (c) Saradan.
Figure 2. Average temperature (°C) in Parung Panjang, Bogor and Saradan.

Figure 3. Average relative humidity (RH) in Parung Panjang, Bogor and Saradan.
The three areas showed different climatic conditions. Bogor has a high rainfall, well above those of Saradan or Parung Panjang (Fig. 1). It is clear that Saradan has a very low rainfall which may constitute a constraint on the growth of *C. odorata*, and limit the availability of shoot tips for *C. connexa* oviposition.

In Parung Panjang the length of vegetative tips increased by a factor of 9.1 from April to May, while in Bogor it was 3.3 and in Saradan 4.8, indicating the differences in growth rates of *C. odorata* in these three locations (Table 6). The figure for Bogor was low because it was recorded from *C. odorata* plants grown in pots, which were suspected to be suffering from nutritional and/or water constraints, but those of Parung Panjang and Saradan were recorded from the field. However, the length of the lifecycle of *C. connexa* in the three locations, measured by tagging 50 galls of 3mm diameter and inspecting them 5 weeks later for emergence, did not differ significantly (Table 6).

The release of *C. connexa* in Parung Panjang at the end of 1995 occurred at a time of good rainfall, and although the area was swept by fire, there were sufficient fresh *C. odorata* tips remaining for *C. connexa* to oviposit and to maintain its population. On the other hand, when the Saradan release was made at the end of 1996, despite there being good gall production immediately after its release (Tjitrosemito, 1999b), no galls were later observed in the permanent plot. However, they were present in low numbers outside it. The data on temperature and relative humidity indicate more extreme conditions at Saradan (Figs 2, 3), leading to a low availability of tips for *C. connexa* to maintain its population, as supported by data from Table 6. However, following additional releases of *C. connexa* in 1998, the population of galls has become more abundant, again emphasizing that it was more the availability of *C. odorata* shoots that affected the establishment of this agent rather than the direct effect of climate on the flies.

In conclusion, it appears that the growth of the *C. connexa* population is affected by the availability of vigorous shoot tips of *C. odorata* for oviposition, which is reduced during the dry season when the plant flowers, fruits, senesces, and the axes of inflorescences die. It is concluded that the best time for release of flies is at the beginning of wet season, when the availability of vigorous *C. odorata* plants is assured.

**ACKNOWLEDGEMENTS**

This research has been partly funded by the Australian Centre for International Agricultural Research through the project Biological Control of *Chromolaena odorata* in Indonesia, Papua New Guinea and the Philippines (Project No. CS2/96/91).

**REFERENCES**


INTRODUCTION AND ESTABLISHMENT OF THE TEPHRITID GALL FLY CECIDOCHARES CONNEXA ON SIAM WEED, CHROMOLAENA ODORATA, IN THE REPUBLIC OF PALAU

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Since its introduction into Palau in the early 1980s, Chromolaena odorata (Siam weed) has invaded agricultural lands. As a result, thickets of the weed have reduced the amount of land in Palau available for cultivation, particularly in Airai, Ngatpang, Aimeliik and Ngaremlengui States. This study was conducted to introduce, determine host specificity of, and establish the tephritid gall fly, Cecidochares connexa, to control C. odorata in the Republic of Palau.

A culture of C. connexa was imported from Guam and reared for seven generations on potted Siam weed enclosed with muslin cloth sleeves in a rearing shed. Host-specificity tests, conducted on three root crops and four medicinal plants, revealed that the gall flies did not attack root crops such as taro, cassava and sweet potato. The flies also did not attack Coleus blumei, Phyllanthus sp., Physalis sp. and Mimosa sp. Adult gall flies were subsequently released in an area infested with Siam weed in Nizimatz, Ngaremlengui. Shoots of the weed were enclosed with muslin cloth sleeve and the adult flies were released inside. The sleeves were removed after three days. The fly was released on four occasions at the same site, and had established 8 months after the first release. By this stage numerous galls were present on the shoots and stems of C. odorata, even 4km from the release site. Adult gall flies will be collected from the release site and released in other areas of Palau where Siam weed is abundant.

KEY WORDS: agent establishment and spread, biological weed control, field releases, host specificity

INTRODUCTION

Siam weed, Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), a native of South and Central America, was introduced into Palau in the early 1980s. Since then it has invaded many areas and has become a dominant weed in Babeldaob, particularly in Airai, Aimeliik, Ngatpang, Ngaremlengui, and Koror States (Muniappan et al., 1999). The weed has occupied roadsides, vacant lands, pasture areas, and cultivated lands. Because C. odorata is an aggressive, fast-growing, scrambling perennial shrub, it is likely that it will continue to spread throughout Palau if left uncontrolled.

The weed has a rapid growth rate, profuse branching and prolific seed production, enabling it to impede access to croplands. Besides, the weed can withstand slashing and burning, as regeneration from the deep roots is rapid. During a dry spell, it becomes a fire hazard. Furthermore, the weed has allelopathic chemicals that suppress the growth of surrounding vegetation, so that some economic plants do not grow in areas infested with Siam weed (Muniappan, 1996).

Chromolaena odorata can be controlled by spraying herbicides such as picloram and triclopyr, but because of its rapid recolonization, this method of control is expensive and uneconomical. Also, herbicides can harm the fragile ecosystems of Palau. Hence, the use of effective, host-specific biocontrol agents is an ideal approach to controlling Siam weed.

In Indonesia, with the assistance of Australian and French entomologists, a biological control agent, Cecidochares connexa Macquart (Diptera: Tephritidae), was introduced and established on Siam weed (ACIAR, 1993). The gall fly produced galls on stems and shoots of C. odorata, thereby reducing the formation of flowerheads and seeds (Desmier de Chenon et al., this Proceedings). Thus, C. odorata is prevented from spreading to noninfested areas.

In 1998, Dr. R. Muniappan of the University of Guam received shipments of the gall fly from Indonesia. The gall fly has since been reared for several generations at this university. Palau Community College Cooperative Research and Extension received a shipment of a pure culture of the gall fly from Guam, and since then it has been successfully reared on C. odorata in a rearing shed in Ngaremlengui State.

This paper reports on the rearing, release and establishment of the gall fly, C. connexa, on C. odorata infestations in several areas in Palau.
MATERIALS AND METHODS

Importation and Rearing
A shipment (26 females and 23 males) of adult *C. connexa*, packed in test tubes, was received from Guam in February 1999. Flies were provided with honey to serve as food while in transit. Three male gall flies were dead upon arrival of the shipment. Live adults were released from test tubes onto potted *C. odorata* plants which had been individually enclosed with a frame of mesh wire covered with a muslin cloth sleeve. Gall flies in copula could be seen on each plant. The plants were kept in the rearing shed and watered twice a week.

Host-Specificity Testing
*Cecidochares connexa* has been shown to develop on only *C. odorata*. Despite its confirmed safety to economically important crops, it was decided to test it further on three commonly grown root crops (taro, cassava and sweet potato) and four medicinal plants (*Coleus blumei* Benth., *Phyllanthus* sp., *Physalis* sp., and *Mimosa* sp.) occurring in Palau (Table 1).

One plant of each of the three root crops and medicinal plants was grown in pots. The plants were individually enclosed with a mesh wire frame covered with muslin cloth sleeve. Five newly-emerged gall flies (one male and four females), collected from the existing culture, were released onto each plant. A *C. odorata* plant, treated in the same way, was used as a control. The plants were watered twice a week. After 1.5 months, the frame and muslin sleeve were removed from each plant, and the number of galls was counted.

Field Releases of the Gall Flies
Four field releases of adult gall flies were made from August 4 to October 5, 1999, with a total of 26 flies (7 males and 19 females). The flies were released in an area in Nizimatz, Ngaremlengui where *C. odorata* was growing abundantly. For each release, young shoots of *C. odorata* were enclosed with a muslin cloth sleeve and adult flies were released into the sleeve. The end of the cloth sleeve was tied to the stem with twine to prevent the flies from escaping. The cloth was removed after three days, allowing time for mating and oviposition.

RESULTS AND DISCUSSION

Rearing of Gall Flies
The gall flies, originally from Colombia and received via Indonesia and Guam, were reared successfully for more than one year on potted *C. odorata* in the rearing shed. The flies produced large, prominent galls on the shoots and shoot buds of the weed.

Host-Specificity Tests
Sweet potato, cassava, taro and the medicinal plants tested had produced no galls 1.5 months after exposure to adults. On one *C. odorata* plant, however, five prominent galls were evident (Table 1). This indicates that the test plants were not suitable as alternative hosts for the flies. Consequently it would not be possible for *C. connexa* to maintain a population on other plant species.

Field Releases of Gall Flies
When released as adults in areas infested with *C. odorata* in Nizimatz, Ngaremlengui, the flies established readily (Tables 2, 3), especially where young *C. odorata* was growing vigorously. Despite the fact that much of the release site was burnt a few days after the release, some *C. odorata* shoots that regrew had galls. This indicates that the adult female flies that escaped the fire were readily attracted to young succulent shoots and laid their eggs on them. By December 1999, less than 3 – 5 months after releases, an average of 23% of the plants in the area was infested with a mean of 1.7 galls per plant (Table 2). In April 2000, the percentage of galled *C. odorata* plants increased to 46%, with an average of 1.34 galls per plant. *Chromolaena odorata* plants with galls could be observed as far as 4km from the release site (Table 3).

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**Table 1.** Number of galls formed on each plant species 1.5 months after release of adult gall flies onto them.

<table>
<thead>
<tr>
<th>Plant species (crop name)</th>
<th>Family</th>
<th>No. of galls</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Chromolaena odorata</em></td>
<td>Asteraceae</td>
<td>5</td>
</tr>
<tr>
<td><em>Colocasia esculenta</em></td>
<td>Araceae</td>
<td>0</td>
</tr>
<tr>
<td>(<em>taro</em>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ipomoea batatas</em></td>
<td>Convolvulaceae</td>
<td>0</td>
</tr>
<tr>
<td>(<em>sweet potato</em>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Manihot esculenta</em></td>
<td>Euphorbiaceae</td>
<td>0</td>
</tr>
<tr>
<td>(<em>cassava</em>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Phyllanthus</em> sp.</td>
<td>Euphorbiaceae</td>
<td>0</td>
</tr>
<tr>
<td><em>Coleus blumei</em></td>
<td>Lamiaeae</td>
<td>0</td>
</tr>
<tr>
<td><em>Mimosa</em> sp.</td>
<td>Mimosaceae</td>
<td>0</td>
</tr>
<tr>
<td><em>Physalis</em> sp.</td>
<td>Solanaceae</td>
<td>0</td>
</tr>
</tbody>
</table>

**Plant species (crop name) Family No. of galls**

| *Chromolaena odorata* | Asteraceae | 5 |
| *Colocasia esculenta* | Araceae    | 0 |
| *Ipomoea batatas*    | Convolvulaceae | 0 |
| *Manihot esculenta*  | Euphorbiaceae | 0 |
| *Phyllanthus* sp.    | Euphorbiaceae | 0 |
| *Coleus blumei*      | Lamiaeae    | 0 |
| *Mimosa* sp.         | Mimosaceae  | 0 |
| *Physalis* sp.       | Solanaceae  | 0 |
Therefore, in a short period of 8 months, the flies dispersed rapidly and attacked the weed within a 4 km radius of the release site, despite the presence of some predatory arthropods. Both non-web- and web-forming spiders were observed preying on adult gall flies in the field. Black ants also broke the ‘windows’ (a paper-thin layer of epidermis created by larval tunneling before pupation in order to facilitate the adult’s escape) on galls and fed on larvae and pupae of the flies.

Since the gall fly aggressively attacks *C. odorata* and causes stunting of young plants, it can be used together with other biological control agents to reduce the rate of establishment of the weed in other areas of Palau.

### Table 2. Number of *Chromolaena odorata* plants, average plant height and number of galls in a 2 x 3m quadrat at different distances from the release site in Nizimatz, Ngaremlengui, on December 20, 1999.

<table>
<thead>
<tr>
<th>Distance from site (m)</th>
<th>Average plant height (m)</th>
<th>Total no. of <em>C. odorata</em> plants</th>
<th>No. of plants with galls</th>
<th>Total no. of galls</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (release site)</td>
<td>0.4</td>
<td>23</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>0.8</td>
<td>16</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>0.6</td>
<td>40</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>30</td>
<td>0.7</td>
<td>34</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>0.8</td>
<td>21</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>50</td>
<td>0.8</td>
<td>20</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>1.2</td>
<td>18</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>172</td>
<td>40</td>
<td>69</td>
</tr>
</tbody>
</table>

### Table 3. Number of *Chromolaena odorata* plants, average plant height and number of galls in a 2 x 3m quadrat at different distances from the release site in Nizimatz, Ngaremlengui, on April 26, 2000.

<table>
<thead>
<tr>
<th>Distance from site (m)</th>
<th>Average plant height (m)</th>
<th>Total no. of <em>C. odorata</em> plants</th>
<th>No. of plants with galls</th>
<th>Total no. of galls</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (release site)</td>
<td>1.2</td>
<td>17</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>100</td>
<td>1.4</td>
<td>16</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>200</td>
<td>1.3</td>
<td>17</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>300</td>
<td>1.4</td>
<td>14</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>400</td>
<td>1.5</td>
<td>17</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>500</td>
<td>1.5</td>
<td>19</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>600</td>
<td>1.6</td>
<td>19</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>700</td>
<td>1.4</td>
<td>22</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>800</td>
<td>1.5</td>
<td>20</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>161</td>
<td>75</td>
<td>101</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

This project is supported by the T-STAR programme of the United States Department of Agriculture. Dr R. Muniappan, Professor Emeritus, University of Guam College of Agriculture and Life Sciences was the Principal Investigator. The author acknowledges, with thanks, the help provided by Messrs Thomas Taro, Flavius Paul and Benjamin Ueda, and all PCC-CRE staff for their assistance in this project in Palau. Ms Geraldine Rengiil, of PCC-CRE, typed the manuscript. Furthermore, the author recognizes, with thanks, Dr. Aurora G. Del Rosario, Researcher, PCC-CRE for editing the manuscript.

REFERENCES


PARTICIPANTS OF THE FIFTH INTERNATIONAL WORKSHOP ON BIOLOGICAL CONTROL AND MANAGEMENT OF CHROMOLAENA ODORATA


Chromolaena odorata is a neotropical plant and it is not a problem in its place of origin. The spread of *C. odorata* in Asia took place in the early 1800s when it was introduced as an ornamental plant to the Botanical Garden in Calcutta, India. It was accidentally introduced to Nigeria in 1937. Currently it has established in most of the humid tropical and subtropical regions of Africa, Asia and Micronesia.

The Commonwealth Institute of Biological Control (now CABI Bioscience) initiated a biological control programme for *C. odorata* in 1966 with the support from the Nigerian Institute for Oil Palm Research. An outcome of this project was the introduction of *Pareuchaetes pseudoinsulata* to Ghana, Nigeria, India, Sri Lanka and Malaysia during 1970-78. In 1983 a project was initiated in Guam to introduce *P. pseudoinsulata*. In 1990 the European Community supported a Chromolaena biocontrol project in Ivory Coast and Indonesia.

Based on the encouraging results of the introduction of *P. pseudoinsulata* into the Mariana Islands, the first International Workshop was conducted in Bangkok, Thailand in 1988. The success of this workshop led to succeeding workshops in Bogor, Indonesia (1991), Abidjan, Ivory Coast (1994), Bangalore, India (1996) and Durban, South Africa (2000). In the Bangkok workshop a Chromolaena network was set up at Guam and after the Bogor workshop the IOBC Chromolaena working group was organized. Thirteen Chromolaena odorata Newsletters have been published and distributed. The Australian Centre for International Agricultural Research initiated a Chromolaena biocontrol project in Indonesia and the Philippines in 1993. In 1996 it was extended to Papua New Guinea. This project has introduced and established the natural enemy *Cecidochares connexa* in Indonesia and assisted in the establishment of it in Palau. A biological control programme for *C. odorata* has been in operation in South Africa since 1988. A regional programme initiated by FAO for West Africa has been blocked.

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1 *Cecidochares connexa* has been referred to as *Procecidochares connexa* in the biocontrol literature (Muniappan and Bamba, this Proceedings), but was accepted as the former by the workshop.
CHROMOLAENA ODORATA INFESTATION IN HLUHLUWE GAME RESERVE: HISTORY, IMPACTS, MANAGEMENT AND PROSPECTS FOR THE FUTURE

O.E. Howison and D.A. Balfour
Ezemvelo KZN Wildlife, P.O. Box 25, Mtubatuba 3935, South Africa

Chromolaena odorata was first identified in Hluhluwe Game Reserve (HGR) in the early 1970s and its distribution first mapped in 1983. This indicated that approximately 50ha contained light, dispersed infestations. Control programmes were also initiated at this time.

By 1985, C. odorata had spread to such an extent that budgets were insufficient to perform control operations throughout the reserve. A decision was taken to concentrate alien plant control programmes on a catchment contained within HGR. Control work was carried out between 1985 and 1997. However, diminishing budgets for alien plant control led to smaller areas of the catchment being cleared during this period. In the rest of the reserve C. odorata spread unchecked within areas of suitable habitat.

In 1998, an alien plant control programme was re-instated with the aid of State funds, and the distribution re-mapped, using similar methods as those used in 1983. This mapping exercise indicated that, by 1998, approximately 2 100ha were densely infested in HGR. GIS techniques were used to determine which habitats are currently being invaded by C. odorata, and to determine the area of potential invasion (approximately a further 10 000ha).

The impacts of such an infestation on aspects of the conservation of biodiversity in HGR will also be discussed.
INTRODUCTION

Siam weed, *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae) was introduced to Guam in the mid-1960s (Seibert, 1988). It is not a problem in its native habitat in the tropical Americas where it is attacked by more than 200 insects (Waterhouse, 1994). In Guam, however, it is highly invasive, forming thickets and suppressing native vegetation.

To suppress *C. odorata*, an arctiid moth, *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was introduced and established in Guam in 1985 (Seibert, 1988). *Pareuchaetes pseudoinsulata* was effective when this weed was in contiguous thickets, but its effectiveness was reduced by the insect-induced defense exhibited by *C. odorata*. *Pareuchaetes pseudoinsulata* defoliates *C. odorata* and is effective when the weed occurs in thickets, but less effective when it is sparse in distribution. *Cecidochares connexa* would be able to attack *C. odorata* both when it is thickly and sparsely distributed. Host-specificity test results have been submitted to the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture, and we are awaiting permission for field release of *C. connexa*.

KEY WORDS: biological weed control, Guam, host specificity, Siam weed, Tephritidae

MATERIALS AND METHODS

All the experimental work was carried out in the USDA-approved quarantine facility at the University of Guam, with natural light, a temperature of 22˚C and RH of 65 – 85%. A laboratory culture of *C. connexa* was established in the quarantine facility from the shipment received from Indonesia. Both male and female adults were kept in 29 x 2.5cm test tubes, the open end covered with a muslin cloth-enclosed cotton plug, for a 24hr period, to ensure mating. The flies were fed with a 50% honey solution. Mated flies were released in cages with potted *C. odorata* plants. These cages consisted of a cylindrical wire-mesh frame, 1m high and 50cm in diameter, covered by a muslin cloth sleeve. Adult flies lived for about 10 days but the plants were kept in the cages for a month from the time of release of the flies. Afterwards all the plants with galled shoots were individually covered with muslin cloth sleeves of 30 x 15cm. The open ends of the sleeves were secured to the stem to prevent escape of the emerging adults. The bags were examined daily for emergence of flies. Emerged flies were collected in the test tubes, sexed, recorded and fed with a 50% honey solution.

Host-Specificity Tests

Test-plant selection was based on the suggestions of Wapshere (1974) and also included plants in the family of an endangered species in Guam. Both ‘choice’ and ‘no-choice’ tests were conducted. In
the choice tests C. odorata was included with the test plant and in the no-choice tests only the test plant was provided.

Test plants of about 20 – 30cm height were either transplanted into or grown in the 25cm-diameter pots. The plants were covered with the cages mentioned earlier and exposed to C. connexa for oviposition. One adult male and female were released in each cage. All plants were kept in the cages for a month and then the number of galls formed was counted and recorded. The galls were covered with small cloth sleeves to collect the adult flies upon emergence. Emerged flies were sexed and recorded. Each test was replicated four times.

RESULTS

The species in the genus Cecidochares are highly host specific and many are specific to a single plant species. Museum records indicating that specimens collected on C. odorata and C. laevigata were C. connexa may not be correct. Cecidochares connexa reared from C. laevigata in Bolivia did not accept C. odorata as a host (McFadyen, 1998). Zachariades et al. (1998) reported that C. connexa collected on C. odorata in Indonesia would not multiply on the South African form of the weed. This might mean

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**Table 1.** Host-specificity test results of *Cecidochares connexa* in Guam.

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Family</th>
<th>No. of galls formed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No-choice</td>
</tr>
<tr>
<td></td>
<td>Test plant</td>
<td>C. odorata*</td>
</tr>
<tr>
<td>Ageratum conyzoides</td>
<td>Asteraceae</td>
<td>0</td>
</tr>
<tr>
<td>Bidens pilosa</td>
<td>Asteraceae</td>
<td>0</td>
</tr>
<tr>
<td>Cosmos sulphureus</td>
<td>Asteraceae</td>
<td>0</td>
</tr>
<tr>
<td>Helianthus annuus</td>
<td>Asteraceae</td>
<td>0</td>
</tr>
<tr>
<td>Mikania scandens</td>
<td>Asteraceae</td>
<td>0</td>
</tr>
<tr>
<td>Brassica oleracea</td>
<td>Cruciferae</td>
<td>0</td>
</tr>
<tr>
<td>Citrullus lanatus</td>
<td>Cucurbitaceae</td>
<td>0</td>
</tr>
<tr>
<td>Phaseolus sp.</td>
<td>Fabaceae</td>
<td>0</td>
</tr>
<tr>
<td>Zea mays</td>
<td>Gramineae</td>
<td>0</td>
</tr>
<tr>
<td>Abelmoschus esculentus</td>
<td>Malvaceae</td>
<td>0</td>
</tr>
<tr>
<td>Citrus aurantifolia</td>
<td>Rutaceae</td>
<td>0</td>
</tr>
<tr>
<td>Capsicum annuum</td>
<td>Solanaceae</td>
<td>0</td>
</tr>
</tbody>
</table>

* Mean of 4 replications

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**DISCUSSION**

The species in the genus Cecidochares are highly host specific and many are specific to a single plant species.
that the specimens of *C. connexa* used in the host-specificity tests in Indonesia and Guam were highly host-specific biotypes or that two different species were involved (Horner, 2002).

In host-specificity tests conducted in Indonesia, *C. connexa* deposited no eggs on any of the 55 species of plants in the choice tests. In the no-choice tests, females laid eggs on *Austroeupatorium inulaefolium* (H.B.K.) R.M. King and H. Robinson, and *Ageratum conyzoides* L. but the maggots did not develop and no galls were formed (Sipayung and Desmier de Chenon, 1994). *Austroeupatorium inulaefolium* does not occur on Guam. No galls formed on *A. conyzoides* in either choice or no-choice tests on Guam.

The results of the host-specificity tests conducted in Guam have been submitted to APHIS, USDA, and drafts of Environmental and Biological Assessments have been prepared. Regulatory officials seem to be satisfied with the tests conducted on plants belonging to the same family of the endangered species, *Serianthes nelsonii* Merrill (Fabaceae). However, the plant *Tabernaemontana rotensis* (Kanehira) Fosberg (Apocynaceae) has been recently listed as a candidate for endangered species on Guam. Regulatory officials prefer that we conduct host-specificity tests on a related species *Tabernaemontana divaricata* (L.) before the Environmental and Biological Assessments are completed.

Currently host-specificity tests are being conducted on *T. divaricata*. Should the tests prove that *C. connexa* does not attack this plant, we would be one step closer to obtaining a permit to field release the fly.

ACKNOWLEDGEMENTS

We would like to thank Dr R. Desmier de Chenon for supplying us with the culture of *C. connexa*, Dr R.E. Cruttwell McFadyen for providing valuable unpublished information on *C. connexa* and Mr Junard Cruz in assisting with the host-specificity tests. This work was supported by the Tropical and Subtropical Agricultural Research of the CSREES, USDA.

REFERENCES


IMPACT OF CECIDOCHARES CONNEXA ON CHROMOLAENA ODORATA IN DIFFERENT HABITATS IN INDONESIA

R. Desmier de Chenon, A. Sipayung and P. Sudharto

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The stem-galling fly Cecidochares connexa was imported into Indonesia from South America in 1993 and first released in North Sumatra in 1995. It is able to establish after a few mated adults have been released, or a few hundred galls with adults ready to emerge have been placed on Chromolaena odorata plants. This species is therefore already widely distributed in Indonesia, and releases have started in the Philippines and Guam, from cultures obtained from the mass-rearing centre at Marihat, North Sumatra.

The relatively short lifecycle of C. connexa (54 – 59 days) and a fecundity of 52 eggs per female make it possible for the population of this insect to increase rapidly. In their 6 – 10 day lifespan, adult females oviposit on C. odorata plants up to 900m from where they have eclosed. The fly established up to 5km away in 479 days. However, in the insectary the lifecycle of this insect is from 54 – 98 days. In the latter case the final (third) larval instar remains in the gall for 45 – 60 days before pupation due to adverse conditions during the dry season, with lower temperatures at night and a reduction in the growth of the plant. The spread and impact of C. connexa in the field also varies markedly depending on ecological conditions. The fly is able to establish and its population to increase up to 1 200m above sea level if the growth of C. odorata is not interrupted (e.g. Toba Lake, Samosir). But in Aceh, in a valley in the Sumatran mountain range with several months of drought and a temperature below 18°C at night, although the insect has established, it has not spread and its population has not increased. During the dry season here the weed produces few new shoots, thus diminishing oviposition sites. In consequence the larvae remain in their galls for several months and pupate only at the beginning of the next rainy season, when the plants start to produce new shoots. A limiting factor in rocky locations is the presence of a pseudomyrmecine ant that destroys the last larval instars and pupae after entering the galls through the pupal ‘window’.
RELEASE AND IMPACT OF PAREUCHAETES AURATA AURATA ON POPULATIONS OF CHROMOLAENA ODORATA IN KWAZULU-NATAL, SOUTH AFRICA

D.E. Conlong

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From April 1992 until July 1993, close to 148 000 Pareuchaetes aurata aurata larvae were released at 17 sites infested with Chromolaena odorata along the KwaZulu-Natal coastal belt from the Sezela River in the south, to Mkuze Game Reserve in the north. One site received one release of 257 individuals, five received one release of 1 000 individuals, another one a release of 10 000 larvae and another one a release of 11 184 larvae. The remaining sites had a number of releases of varying numbers of individuals over time. Three sites received between 3 000 and 6 500 individuals, two between 14 000 and 20 000, and three sites from 23 000 to 24 000. The maximum number of releases at any one site over the release period was nine. The impact of this defoliator on leaf and flower production was measured at six sites where 10 000 or more individuals were released, one month after releases were terminated. Three sites showed no significant difference between the release and control areas, one site showed a significant reduction in floral biomass, another a significant reduction in leaf biomass, and two a significant reduction in both leaf and floral biomass. High populations of P. aurata aurata thus did have an impact on the host plant at one month after completed releases, but at high plant densities this impact was not as clearly evident as at lower plant densities. Unfortunately, no establishment has been recorded at any site.
It is a great pleasure for me to be able to address you at this, the Fifth International Workshop on Biological Control and Management of *Chromolaena odorata*. *Chromolaena* has been one of my personal obsessions for over twenty years so it’s great to have a captive audience to whom I can expound on this matter.

Talking of captive audiences, I am reminded of a university buddy of mine who late one night in the laboratory told me his life’s plan: he was planning to do one really good piece of research for his PhD and then he was going to get a comfortable lecturing position in a medium sized university and bore successive generations of students with the results of his PhD research! Now it just so happens that the only research I ever did on invasive alien species was many years ago and I did get a PhD for it. So possibly I should take advantage of today’s captive audience...

In my questionnaire survey of alien invasive plants of protected areas in South Africa over the period 1983 to 1985, *Chromolaena odorata* had the highest percentage frequency of occurrence of any invasive alien plant species in the protected areas of any one biome: 61% of protected areas in the forest biome. The next highest, 59%, was that for *Opuntia ficus-indica* in the protected areas of the savanna biome.

In the rapid field surveys of protected areas that I carried out to check the validity of the results of these questionnaires, *Chromolaena odorata* once again turned out to have the highest percentage frequency of occurrence of any invasive alien plant species in forest reserves sampled (67%). This same percentage occurrence was also obtained for *O. ficus-indica* in savanna and grassland reserves and for *Ricinus communis* in savanna reserves and was only exceeded by *Argemone subfusiformis* in karoo reserves (75%). In this questionnaire survey I asked reserve managers to estimate the number of 1 x 1km grid cells covering their protected areas that were known to be invaded by *C. odorata*. The results were, in savanna, a mean of 47% (x = 4) and, in forest protected areas, a mean of 50% (x = 15). I further asked them to estimate the percentage of grid cells actually invaded (as distinct from known to be invaded) the comparable two percentages were then 60% (x = 4) and 57% (x = 15). In my own rapid field surveys I estimated the percentage of grid cells infested as 35% for a savanna reserve and a mean of 76% for two forest reserves. The survey showed that *C. odorata* was primarily a forest edge invader in protected areas in South Africa.

The species had been estimated to have invaded 8 000km² in South Africa by Liggitt (1983). I estimated, based on extrapolation from the results of these surveys of protected areas, that the total area invaded in South Africa by *C. odorata* was 3 250km². This compares with the *Opuntia aurantiaca* estimate of Zimmermann and Moran (1982) of a total range of 15 000km² in South Africa and the extrapolation from this survey to 16 665km². I must emphasize that in the early 1980s when Liggitt and I carried out the above surveys, *C. odorata* had been in the country less than 40 years and the invasion was still in its exponential growth phase. Since then I would guess the species has at least doubled its range in South Africa.

On the other hand, rather than just bore you with my thesis, I think it might be more productive if I share some thoughts with you on why I think the battle to control chromolaena is going to turn out to be one of the ‘flagship’ battles of the new millennium.

In structuring my talk I am firstly going to lay out why I think the battle against chromolaena is such a good indicator of our ability or inability to manage the world successfully. Secondly I am going to highlight why I think these first few decades of the new millennium are going to be decisive in the struggle to come up with a sustainable world. And finally I am going to say why I am optimistic that we will in fact win the battle against chromolaena and in turn will go on to work out a ‘new order’ in which mankind once again learns how to live in harmony with nature.

Why is the struggle against chromolaena such a good ‘flagship struggle for the new millennium’?

The struggle to control invasive alien plants is increasingly being recognised as one of the essential battles in the fight to achieve long-term sustainability - an essential component of the bid to bring mankind into some sort of harmony again with the natural world. Invasive alien species are now recognised by the IUCN (the World
Conservation Union) to be the third or fourth biggest threat to the maintenance of biodiversity on the planet: ecosystem transformation is the biggest, extinction of species the second biggest, and man-induced climate change or invasive alien species the third or fourth biggest. The threat to biodiversity is now enormous: some of the world’s top conservationists say we could well lose half of all the world’s species this century. People are talking about us already being well into the sixth (or seventh) great extinction wave. We know from the fossil record that it takes millions of years for the world to regain its diversity following such a mass extinction event. The 2000 IUCN Red List of Threatened Species released at the end of last month showed the following shocking statistics: among the world’s mammal species it is now known that one in four is currently threatened with extinction (24%), among birds one in eight (12%), among reptiles the estimate is one in four (25%) and among fish (mainly freshwater species) one in three (30%). For the well-known mammals and birds the comparison of the 2000 Red List with the 1996 Red List shows how rapidly the extinction crisis is worsening. The number of critically endangered species in these groups increased from 337 to 362 over these four years while endangered species increased from 550 to 661. Summing both categories of endangerment gives an overall increase of 887 to 1 023 species - and this in just four years!

Why do I think that the struggle to control chromolaena in particular is such a good flagship battle for the new millennium? Firstly, chromolaena has all the characteristics of one of the world’s worst invasive alien species: dispersed by wind, man and by many other agents; incredibly fast growing; capable of vegetative regeneration; quite difficult to detect; allelopathic; promotes fires and is itself promoted by fire (a positive feedback mechanism); shows numerous genetic strains; has many close relatives; fairly catholic in the habitat it can grow in; an incredibly prolific seeder. Therefore I believe that if you can beat chromolaena, then you can virtually be assured that you can beat any invasive alien plant species. Secondly, it is an invader of the tropical and subtropical forested areas of the world. This is important, as (i) these areas are the repository of most of the world’s biodiversity, and (ii) they are mostly found in the Less Developed Countries of the world, and have some of the world’s most rapidly increasing human populations and concomitant increases in human pressures. Therefore if we can beat chromolaena this will be a good indicator that we can come to grips successfully with many of the underlying problems that affect conservation in the tropics. If we can do this, we can be optimistic that the vast treasure trove of biodiversity that these areas hold can be secured. Amongst other considerations it will be indicative of (i) the ability of the Less Developed Countries to co-operate to mutual benefit in solving a common environmental problem, and (ii) the effectiveness of skills transfer and resources transfer from the Developed Countries to the Less Developed Countries (e.g. through mechanisms such as the Global Environment Facility that were set up specifically to assist such transfers after the 1992 Rio Earth Summit).

Just how perilous the times we live in can be assessed by reference to a few examples

- Human population increase: mankind has never before been increasing in numbers as fast as he is currently doing. It took all of human history until about 1652 to reach the first \(\frac{1}{2}\) billion (500 million) mark. Depending on when you take modern man as having originated, this is somewhere between 100 000 or 1 million years ago. The next \(\frac{1}{2}\) billion was added in 170 years i.e. the first billion people by 1820. The next 1 billion was added in 110 years i.e. 2 billion by 1930. The next 1 billion was added in 34 years i.e. 3 billion by 1964. The next 1 billion was added in 18 years i.e. 4 billion by 1982. The next 1 billion was added in 9 years i.e. 5 billion by 1991. The next 1 billion was added in 8 years i.e. 6 billion by 1999. Therefore the last \(\frac{1}{2}\) billion addition was made in about 4 years, whereas the first \(\frac{1}{2}\) billion took at least 100 000 years to add. Most of this most recent addition was in the Less Developed Countries.

- Global warming: the cases of the north pole, coral reefs, and extreme climatic events.

- Destruction of the earth’s forests: at least 50% were gone by 1975 and since then 12% of the remaining forest cover has been destroyed.

- Destruction of the stratospheric ozone layer.

- WWF’s Living Planet Index (LPI) indicates that 30% of the earth’s natural wealth has been lost in the last 25 years. The loss to forest ecosystems amounts to 12%, to marine systems 35% and to freshwater, 45%.

- Fresh water is now the earth’s most threatened natural resource. In South Africa, 50% of our freshwater wetlands have been completely destroyed.

- What is the safe carrying capacity of the earth for humans? The Stanford Group of Ecologists calculated 2.2 billion people i.e. we exceeded this threshold sometime in the early 1940s, fittingly during the Second World War. More recently WWF has calculated an area-based Human Footprint in which all of mankind’s impacts on the environment are converted to the area of natural ecosystems that would be
needed to use/absorb/provide the service. According to this much more anthropocentric measure, mankind exceeded the earth’s carrying capacity in 1976. The world is literally bursting at the seams with humans. Crucial decisions on human numbers, human desires and human impacts will have to be made in the next few years or there is simply no point pretending to be striving towards sustainability at e.g. the Climate Change Convention negotiations at The Hague next month.

Finally, why am I optimistic?

• This is the fifth such workshop on the control of chromolaena i.e. the Less Developed Countries involved have been able to work together on this common problem.
• The abstracts of the papers to be presented show that progress is being made all over the world.
• In particular I am optimistic that so much effort focuses on the ecologically sustainable solution which is biological control rather than the more symptomatic approaches such as chemical control.
• Big moves are afoot internationally e.g. the Global Invasive Species Programme (GISP), supported by SCOPE, CBP, CABI, UNEP and IUCN-SSG, and now other important bodies are also getting involved. The Ramsar Convention on Wetlands of International Importance, the World Trade Organisation, FAO, World Maritime Organisation, UNEP, UNDP and GEF are all taking much more interest in solving the invasive alien species (IAS) problem than ever before.
• Practical successes are being made in this field e.g. the order on IAS issued by the US President last year, the South African Working-for-Water Programme which has received its first R1 billion and employs 40 000 people in the biggest IAS control programme ever.

For all the above reasons I believe that what you are doing here at the Fifth International Workshop on Biological Control and Management of Chromolaena odorata is of enormous importance for the future of the world. I wish you all the very best for a most successful meeting.

Dr Ian Macdonald
Chief Executive: WWF (South Africa)
Umhlanga Rocks

23 October 2000

REFERENCES


MANAGING CHROMOLAENA ODORATA IN SUBTROPICAL GRASSLANDS IN KWAZULU-NATAL, SOUTH AFRICA

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Chromolaena invades subtropical grasslands that are not burnt regularly. Grasslands not burnt for 20 years succeed naturally to secondary forest or savanna, depending on soil type and aspect. Chromolaena, however, has recently become a key component of woody plant succession in subtropical grasslands. Chromolaena density affects grassland species composition, with dense stands in grassland being monospecific. Forest succession in grassland also ceases once chromolaena becomes thicket-forming. Fire-induced mortality of the weed depends on grass fuel loads. Sparse to moderate infestations with more than 30% grass cover are killed by fire. Running head-fires from adjacent grasslands into thickets kills dense infestations. Under conditions where head-fires cannot be used for killing dense stands, infestations must be slashed and burnt at the height of the dry season. Seedlings are killed during annual veld-burning in sparse and moderate infestations. The suppression of seedlings in dense infestations requires chemical control until grass cover is sufficient to effect uniform burning. Grasslands under moderate and dense stands cannot be restored once their original composition and structure have been altered. Depending on chromolaena density, soil type and aspect, grasslands can be rehabilitated and managed in multiple states, namely as grassland, savanna or forest communities. Chromolaena biocontrol has limited potential in grassland and savanna ecosystems except in dense infestations to facilitate grass establishment. Agents are unlikely to survive in systems with annual to biennial fire cycles. Biological control has a major role in rehabilitating grassland to secondary forest or in forest ecosystems that have become invaded.

KEY WORDS: alien invasive, grassland, fire, vegetation change, succession, integrated weed management, land use

INTRODUCTION

Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), commonly known as chromolaena, invades and transforms forest, grassland and savanna ecosystems in a variety of frost-free bioclimatic regions of South Africa (Liggitt, 1983; Macdonald, 1983; Henderson, 1989; Erasmus, 1991; Goodall et al., 1994; Wilson, 1995; Goodall and Erasmus, 1996). The weed is most abundant and destructive in the province of KwaZulu-Natal (KZN), where it has been present since the mid-1940s (Egberink and Pickworth, 1969). The KZN coastal plain up to an altitude of 450m is more infested than the adjacent hinterland (450 – 900m), a region of transition between the tropical climate of the coast and the temperate midlands. With respect to plant species the native vegetation along the coast and hinterland are similar, the main differences being relief, geology and spatial vegetation patterns.

Landscape transformation has been the main cause of ecosystem fragmentation. Metropolitan areas, urban sprawl, and sugarcane and forestry plantations have contributed the most to the reduction of natural forest, grassland and savanna ecosystems in the coastal and hinterland regions. Alien plant invasions have capitalised on the reduced resilience inherent in patchy habitats. Chromolaena is one of many weed problems threatening KZN’s subtropical ecosystems; however, its relative plasticity makes it unrivalled amongst the other contenders. The South African form of chromolaena can abide full sun or shade, survive in mesic and semi-arid climates and still grow and reproduce at a rate unequalled by other species.

Of the main vegetation categories in KZN, i.e. forest, grassland and savanna, grasslands are the most threatened by alien plant invaders and land conversion (Scott-Shaw, 1999). The association between threatened plants and ecosystems shows disproportionately high representation in grassland (58%). Grasslands remain vulnerable because they are the cheapest and easiest ecosystems to convert, e.g. ploughing. Coastal grasslands account for 14% of the threatened species in grassland, excluding Pondoland (previously the Transkei Wild Coast) coastal grasslands (18%), which are considered more protected. Uncontrolled or inappropriate ecotourism development, unsustainable agricultural expansion, exploitation of forest resources and permanent heavy grazing are additional threats to coastal ecosystems (McKenzie, 2000).
ECOLOGICAL DEVELOPMENT OF SUBTROPICAL GRASSLANDS

Approximately 2 000 years ago Iron Age communities from East Africa arrived in South Africa and over the next 1 000 years settled along the KZN and Eastern Cape coast and adjacent interior (Feely, 1980; Hall, 1981, 1987; Prins, 1993). At the time this region was covered by forests and closed woodlands (Axelrod and Raven, 1978; van Zinderen Bakker, 1978). Grasslands emerged as secondary communities from the ‘slash and burn’ practices of early Iron Age farmers, who grew grain crops in small plots in forest clearings (Hall, 1981). These plots were occupied for two to three seasons until soil fertility failed to sustain crop production levels. Shifting agriculture was the only farming system that could sustain crop production demands under increasing human influx. Small plots for growing subsistence crops were cut into the forest at frequent intervals, causing rapid deforestation. Infertile fields were abandoned and these returned to secondary grasslands under increasing grazing pressure and fire.

During the Late Iron Age (1 000 BP to early 19th century) forest clearing had progressed to such an extent that secondary grasslands were extensive. Besides shifting agronomic practices, Nguni cattle, goats and game grazed on these ‘man-made’ rangelands. Hall (1981) hypothesised that early Iron Age agronomic practices affected the very structure of the biota, rather than merely extracting a living from it, while late Iron Age pastoral practices opened the savanna and forest and kept them in this state. Coastal grasslands are strongly seral to forest in the absence of fire (von Maltitz et al., 1996). The interactions of man, fire and grazing therefore determined the spatial extent of grassland and savanna, whilst the topography and geomorphology influenced the variation in species composition. As a rule, regic sands of aeolian and marine origin along the coast supported forest and secondary grassland, while glacial deposits in the hinterland were covered with closed woodlands that were modified by pastoral management to open savanna.

Although the subtropical grasslands evolved as secondary vegetation, pastoralists had maintained them as such for over 1 000 years. Over this period these ecosystems accumulated a heterogeneous flora dependant on fire. For example, 214 plant species comprising 39 families were found in six 25m² belt transects located in relic grasslands (Goodall, 2000), of which seven species were endemic. Small-scale diversity was also high, with an average of 19 – 23 species/m² and grass production of 6 – 15 ton/ha.

By the time Europeans began settling in the province in the 1800s, Iron Age farmers had modified the vegetation so profoundly that the forest-savanna-grassland mosaic was ubiquitous (Henkel et al., 1936; Bayer, 1938). It is believed sugar planting converted more virgin grassland and savanna (Hoffman, 1996) than forest, which was expensive to clear for arable land (Watson, 1932). Meanwhile, Iron Age agricultural practices, presumed by Hall (1981) to be the main culprit of deforestation, have not desisted in KZN (Weisser and Marques, 1979; Weisser and Muller, 1983). Ongoing deforestation (see URL:http://www.hsf.org.za/Briefing_15/forest.htm) in an age where alien plants are more likely to colonise disturbed areas than native species, provides perfect conditions for the establishment of chromolaena instead of grassland.

PAST MANAGEMENT OF SUBTROPICAL GRASSLANDS

During the past 50 years grasslands throughout South Africa were managed along Clementsian rangeland principles. Stock farmers and game ranchers manipulated the vegetation in ways that best suited their rangeland objectives. Grazing intensity forced natural succession away from the climax state (Stoddart and Smith, 1955; Ellison, 1960), which in KZN would be forest or closed woodland. Once the veld was rested, natural succession would resume its function in bringing it back to a stable climax state. As a result, grazing strategies were used to direct grassland condition towards states that were preferable for livestock farmers. What transpired was the implementation of selective grazing strategies with minimal burning. This practice continued for many decades in KZN and resulted in gross vegetation changes in the savanna biome; essentially it was the reversal of a two thousand-year-old Iron Age succession.

Subtropical grasslands on the coast and hinterland have a relatively low potential for livestock production, and then only suitable for Zebu-type cattle and goats (Hardy and Hurt, 1999). Their main value is their high floral diversity and the wildlife associated with them. The no-burning policies of the past 50 years (Hall, 1981) in subtropical grasslands have reduced their spatial extent through bush encroachment, secondary forest establishment and chromolaena invasion. The former states are merely indicators of the environmental determinants of Quaternary vegetation in this region. Chromolaena, however, has the capacity to transform all natural vegetation and poses the single biggest threat to terrestrial biodiversity in KZN.
EFFECTS OF CHROMOLAENA DENSITY ON SPECIES RICHNESS

Between 1990 and 1999 research was conducted in subtropical grasslands to determine how fire and chromolaena influenced grassland communities over time (Goodall, 2000). The following sections discuss some of the highlights of this study. Small patchy grasslands on regic sands or glacial deposits, with chromolaena ranging from being absent to dense thickets, were chosen for the investigation.

Chromolaena invades moribund grassland, i.e. not burnt for 3 years, and forms monospecific thickets after 10 years (Goodall, 2000). Species richness is inversely related to chromolaena density (Fig. 1). Grasslands that were not invaded had a greater number of species, forbs in particular, than sites with sparse (moribund grassland) to dense infestations. The population and average height of chromolaena in each transect (25m²) was variable, viz. 30 x ≤1m plants in the sparse stand, 130 x 2m plants in the moderate stand and 393 ≥3m plants in the dense stand. The interactions of density and height were heavily influenced by soil type. Thickets on regic sands were shorter than thickets on glacial deposits. As a rule, sparse and moderate stands caused significant reductions of both forbs and grasses, while the dense infestations eliminated the grass layer (monospecific). Grasses were generally more resilient than forbs to the competitive effects of chromolaena.

Each site was subjected to an intensive veld-burning programme in which sites were burnt annually over a period of 7 years (a minimum of five burns per site). Species richness in the invaded sites remained lower throughout the study period, proportionate to weed density, compared with pristine grassland (Fig. 1), despite the susceptibility of chromolaena to fire. Natural processes of plant succession did not restore plant diversity within the time constraints (8 years) imposed by management. The use of the term ‘diversity’ is used in a numerical sense and does convey any information pertaining to changes in species composition.

Figure 1. The effect of chromolaena (≥1m tall) density on species richness (forbs, grasses and total) in fixed belt transects (25 ± 1m) in coastal grasslands, before (B) and after (A) the implementation of a fire regime, in which a minimum of 5 burns occurred at each site over a 7-year period. Density classes are: nil, sparse (sp), moderate (mo) and dense (de). The amounts in brackets on the x-axis give the mean number of rooted plants/m². The graph also shows before and after trends in mean richness/m² (Mean-B, Mean-A) and linear fits of total richness per transect (L.R. T-B, L.R. T-A).
EFFECTS OF FIRE ON CHROMOLAENA AND FUEL LOAD DYNAMICS

Trends
Coastal grasslands on well-drained soils yield between 5 and 8 ton/ha of dry matter per annum, provided they are not overgrazed or infested with chromolaena. Grasslands on alluvial soils have a high sedge fraction and yield double that of grasslands on slopes and crests. Chromolaena had a negative influence on grass production. Dry matter production declined with increasing chromolaena density. Dense stands of chromolaena taller than 3m did not support a grass layer. Soil type had a strong influence on the height of chromolaena thickets and their relative susceptibility to fire towards the end of the dry season (August).

The Importance of Soil Type
Chromolaena infestations on regic sands were sensitive to fire at any height. Thickets in open sandy grassland did not grow taller than 1.5m and dense stands (>17 plants/m²) supported a grass layer. Initial burns across the density gradient caused high mortalities (75 – 95%) of parent infestations. Subsequent burns killed seedlings and regrowth from surviving stumps. No herbicides or other mechanical methods were required. Annual burning eliminated chromolaena in six years and grass fuel loads reverted to around 6 and 15 ton/ha on slopes and bottomlands respectively.

Sparse to moderate chromolaena stands on glacial soils were susceptible to fire. Moderate infestations (5 plants/m², 75% frequency, 2m tall) in the process of becoming thicket-forming (monospecific) still supported remnant grassland (30% cover, 2.7 ton/ha). Fires set in August killed 75 – 95% of standing shrubs and grass cover and fuel loads increased to 45% and 4.2 ton/ha. After five annual burns chromolaena was eliminated from the sward and replaced by dense ruderal grasses that produced fuel loads of 8 – 9 ton/ha.

Dense infestations (16 plants/m², 100% frequency, ≥3m tall) on glacial soils replaced the open grasslands they invaded in the 1970s (evidence gained from aerial photographs) and proved more resilient to fire. Fires cannot easily be started in dense chromolaena infestations because of the lack of fine fuels (grasses and herbs); however, under certain conditions chromolaena is highly flammable. Dense infestations lacking grass cover were most combustible if burning occurred when rainfall over the past month was less than 8% of the previous 12 months’ accumulated rainfall. Under these conditions, head fires that converge on chromolaena thickets burn with intense heat for a short period and kill the shrubs without sterilising the soil. Under normal circumstances, however, when grass cover is less than 30%, dense infestations must be slashed and dried in situ before they are burnt. This results in over 80% mortality of stumps in soils with clay contents below 25%. Grasses took several years to establish on denuded sites, which were initially occupied by annual weeds. Chromolaena, bugweed (Solanum mauritianum Scopoli (Solanaceae)) and lantana (Lantana camara L. (Verbenaceae)) invaded and formed mixed stands where ‘slash and burn’ was not integrated with chemical or mechanical control.

Guidelines for Controlling Chromolaena in Grassland
Five to seven years of annual burning will effectively control sparse and moderate infestations in grassland and increase grass production. Dense infestations taller than 1.5m must be controlled by integrating burning with other methods of control. These methods include slashing shrubs, applying imazapyr (100g/litre) to stumps and foliar sprays of selective herbicides, e.g. metsulfuron methyl (600g/kg) or triclopyr (480g/litre), to seedlings and coppice.

Herbicides are registered on target weeds if they cause ≥80% mortality under trial conditions. In terms of cost-effectiveness, fire is free. If mortality exceeds reinfection rates then fire is an effective method of control, no matter how low the degree of fire-induced mortality. Fire can be used effectively in grasslands with fuel loads ≥1.5 ton/ha to reduce chromolaena, provided the weed is burnt when it is most flammable, i.e. at the height of the dry season.

EFFECTS OF CHROMOLAENA ON SPECIES COMPOSITION

Trends
Soil type had an important bearing on the herbaceous and woody community dynamics in subtropical grasslands. Pristine and moribund grasslands on regic sands and glacial deposits both had similar indicator grass species (Poaceae). Themeda triandra Forsk. – Aristida junciformis Trin. & Rupr. associations dominated veld that was regularly burnt. Moribund grasslands were characterised by turpentine-wire grass communities (Cymbopogon sp. and A. junciformis). As chromolaena density intensified the entire herbaceous component decreased. Grasses tolerated chromolaena more effectively than forbs.

Soil Type and Resilience in the Grass Layer
The restoration dynamics of coastal grasslands differed according to soil type and the density of parent chromolaena infestations. Themeda triandra, a decreaser species (sensu Dyksterhuis, 1949), was
found in relatively high abundance (64% frequency) under short chromolaena thickets (18 plants/m², 100% frequency, 1.5m tall) in sandy grassland. No herbaceous species were found under tall (≥3m) chromolaena thickets on glacial soils. Chromolaena height therefore had a synergistic effect when it came to the formation of monospecific stands, but soil type had an overriding influence in the formation of tall thickets of chromolaena.

Grasslands on regic sands proved to be more resilient to the effects of chromolaena than grasslands on soils of glacial origin. Irrespective of chromolaena density, sandy grasslands reverted to open grasslands dominated by many palatable species (T. triandra, Diheteropogon amplectens (Nees) Clayton, Ischaemum fasciculatum Brongn., Panicum dregcamun Nees and Setaria sphacelata (Schumach.) Moss). Grasslands on glacial soils, however, did not revert to T. triandra – A. junciformis grassland, but shifted to other states dominated by thatch-love grass communities (Hyparrhenia tamba (Stapf and Eragrostis curvula (Schrad.) Nees) and concomitant fire-resistant native and alien woody plants.

**EFFECTS OF CHROMOLAENA ON WOODY PLANT SUCCESSION**

For centuries, the grassland, savanna and forest mosaic on the KZN coast existed as discrete stable states driven by specific conditions (e.g. fire, grazing, soil type, rainfall), in a system possessing an affinity towards a stable forest domain in the absence of fire (Figs 2, 3). The fragmentation of coastal rangelands during the 19th and 20th centuries by sugarcane and forestry saw many thousands of hectares of grasslands transformed to an assortment of irreversible wooded communities

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**Figure 2.** State-and-transition diagram (*sensu* Westoby *et al.*, 1989) for subtropical grasslands on regic sands in KwaZulu-Natal. Stable states (S1-S3) on the left side persist under burning regimes (S1) or are protected from fire (S2 and S3). Transitions (T1-T4) are transient states that are triggered by divergence in principle determinants (arrows) – viz. fire or absence of fire). *Chromolaena odorata* in fire-excluded grassland forms stable monotypic states, provided fire-exclusion remains constant, introducing a new dimension to the non-equilibrium dynamics of plant succession in sandy grasslands. Integrated control will determine the persistence of forest on regic sands in future. Fire is needed to preserve remnant coastal grasslands.
through inappropriate veld management. The appearance of alien plant invaders has added new dimensions to the dynamics of plant community succession. At the moment natural enemies do not suppress chromolaena and it forms ubiquitous stands in rangelands that are protected from fire. These infestations persist for as long as the determinants (e.g. neglect) governing their stability retain the status quo.

Grasslands on regic sands do not succeed to forest as rapidly as grasslands on glacial soils. On regic sands fire was effective at reversing succession away from a chromolaena thicket domain to an open grassland state (Fig. 2). The successional process towards open grasslands becomes irreversible once fire-resistant forest precursor species (*Phoenix reclinata* Jacq. (Arecaceae) – wild date palm, *Strelitzia nicolai* Regel Koern. (Strelitziaceae) – Natal wild banana and *Syzygium cordatum* Hochst. (Myrtaceae) – water berry) become established with chromolaena. Once this unstable transition is reached, integrated control must be implemented against alien weeds and fire-prevention strategies used to direct succession towards a stable forest state. Grasslands on regic sands showed resilience to chromolaena at high densities because thicket height in the open was restricted, possibly by the lack of other woody species for support.

The successional tendency from grassland to forest on soils of glacial origin is through a secondary woodland sere (Fig. 3). At this point succession back to grassland is irreversible, unless bush control strategies are implemented. This is because savanna species have numerous defences against fire (Hochberg *et al.*, 1994). Secondary woodlands were made up of both forest and savanna precursor species. Fire and integrated control strategies targeting fire-resistant species are essential for range management.

**Figure 3.** State-and-transition diagram (*sensu* Westoby *et al.*, 1989) for subtropical grasslands on glacial deposits in KwaZulu-Natal. Stable states (S1-S4) on the left side persist under burning regimes (S1 and S2) or are protected from fire (S3 and S4). Transitions (T1-T4) are transient states that are triggered by divergence in principle determinants. *Chromolaena odorata* in fire-excluded grassland forms stable monotypic states after passing through a woodland transition. Chromolaena introduces new dimensions to non-equilibrium plant successions on structured soils. Integrated control will determine the persistence of forest on soils of sedimentary origin. Fire and integrated control strategies targeting fire-resistant species are essential for range management.
species. Fire-intolerant forest indicator species included *Hippobromus pauciflorus* (L.f.) Radlk. (Sapindaceae), *Maytenus undata* (Thunb.) Blakelock (Celastraceae) and *Protorhizus longifolia* (Bernh.) Engl. (Anacardiaceae). Savanna indicators included *Combretum molle* R. Br. ex G. Don (Combretaceae), *Dichrostachys cinerea* (L.) Wight Arn. (Mimosaceae), *Euphorbia triangularis* Desf. (Euphorbiaceae) and *Heteropyxis natalensis* Harv. (Heteropyxidaceae). The sustained exclusion of fire led to the sequential replacement of shade-intolerant savanna species by taller forest pioneer trees. The introduction of fire at the secondary woodland stage caused sudden mortality of forest tree species and the domain of attraction shifted away from a forest succession towards a savanna state. Grasslands on glacial soils were not resilient to chromolaena and were irreversibly transformed in the absence of fire by a host of both native and alien woody species. The use of fire in moderate and dense stands can also lead to chromolaena being replaced by fire resistant alien species, viz. *Psidiium guajava* L. (Myrtaceae), *L. camara* and *S. mauritianum*.

State-and-transition diagrams (sensu Westoby et al., 1989) (Figs 2, 3) are useful visual aids for vegetation management, including integrated weed control. The diagrams should include descriptive and causal information about the respective states and transitions. In so doing, state-and-transition diagrams help managers (i) identify desirable and undesirable vegetation patterns, (ii) provide indications of transitions and the reasons for change, (iii) list routine operations for maintaining desirable stable states and (iv) prescribe remedial measures for restoring desirable vegetation.

**CONCLUSIONS**

Chromolaena invades grasslands that are not routinely burnt. Once chromolaena has become established it suppresses existing vegetation and natural succession. Chromolaena has the ability to reduce grassland, savanna and forest to monotypic vegetation, irrespective of the system properties, i.e. soil type, climate, hydrology and relief (slope, aspect and elevation). It is the single greatest threat to terrestrial biodiversity on the KZN coast and hinterland, a region roughly 500km long by 50km wide.

Subtropical grasslands that have become invaded by chromolaena are indicative of poor range management. Routine burning will prevent chromolaena from establishing in grassland and savanna, while integration with herbicide and mechanical methods will effectively control infestations in rangeland. Grasslands are modified by numerous biotic and abiotic factors into multiple stable states, some of which are unacceptable, e.g. chromolaena thicket. Grasslands prone to chromolaena invasions must be managed adaptively. Since subtropical grasslands are strongly seral to forest, managers need to be flexible in their regard to the choice of habitat, paying close attention to species composition and vegetation structure. The loss of decreaser grasses to tough unpalatable species, alien weeds and indigenous woody pioneers may be motivation enough to allow succession to progress towards a stable forest state, assisted by integrated control. The prospects for managing and conserving forests indefinitely, however, are poor; unless biological control efforts can provide agents that are effective on the South African form of chromolaena.

**ACKNOWLEDGEMENTS**

We thank the Working-for-Water Programme of the Department of Water Affairs and Forestry, South Africa for research funding.

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INTRODUCTION

The invasive Siam weed, *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae), is increasingly becoming a significant weed of agriculture, disturbed forest margins, pastures and planted forest areas in Papua New Guinea (PNG). It was first recorded in PNG in 1970 (Orapa, 1998) but was seen much earlier on the Gazelle Peninsula of the island of New Britain (S. Laup, pers. comm.). The occurrence of the weed near a major wartime Japanese airfield on Manus Island suggests its introduction during World War II when there was movement of war machinery from South-East Asia. These and the other outbreak areas and their probable sources of outbreaks are discussed by Orapa et al. (this Proceedings).

The increasing importance of *C. odorata* as an invasive weed in PNG and the need to control it as a matter of urgency was noted only after it was discovered in the Vanimo area near the PNG-Indonesia border in May 1992 (Orapa, 1998; Waterhouse, 1998). It threatens subsistence and semi-commercial farming activities practiced by 85% of the population of PNG. It is present close to grazing areas in the Markham Valley of Morobe Province, where dense thickets of the weed have increased, largely through the wind dispersal of seeds over steep hillsides. *Chromolaena odorata* also threatens crops such as coconuts and coffee, which are grown largely by smallholder growers, while cocoa and oil palm are threatened only during the canopy establishment stages. These crops alone account for 30% of the national export income annually.

Natural succession and biodiversity in fallow and other sites disturbed by logging are threatened by the presence of invasive species such as *C. odorata* in the initial stages of forest regeneration. In fallow land northeast of Lae, in Morobe Province, seed bank levels of *C. odorata* were reported to be higher than that of native plants, but at levels lower than another weed, *Piper aduncum* L. (Piperaceae) (Rogers and Hartemink, 2000). However, we suspect this as a case of mistaken identity as *C. odorata* does not occur at the same location where the study was done.

MANAGEMENT OF CHROMOLAENA ODORATA IN PAPUA NEW GUINEA: STATUS OF A BIOLOGICAL CONTROL PROGRAMME

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Siam weed (*Chromolaena odorata*) is naturalised in Papua New Guinea and is viewed as a weed with potentially serious implications for subsistence food growers, smallholder grazing areas, and to important plantation crops like coconuts, cocoa, coffee and oil palm. It also threatens agroforestry and may affect natural succession in disturbed tropical rainforest areas. Since 1970 control recommendations of approved herbicides have been available but these have rarely been followed except on some oil palm estates. Control of *C. odorata* in shifting cultivation situations is generally achieved using simple cultural and physical methods that are targeted at all weeds present. Where infestations are serious, control is chiefly by manual slashing, uprooting and burning of dried plant matter and hand weeding after the crop has been planted. Biological control efforts began in 1998 as part of regional biological control project funded by the Australian Centre for International Agricultural Research. The moth *Pareuchaetes pseudoinsulata* was introduced from Guam in December 1998 but died off, possibly due to egg fertility problems. After a second shipment of the moth was obtained in March 1999, an insectary colony was successfully established and releases of larvae have since been made in several outbreak areas. Establishment of *P. pseudoinsulata* on the weed has been achieved only in one area, which is relatively drier than the other release areas. It is suspected that predation of larvae has prevented establishment of the moth at some sites. Introduction of the stem-galling fly *Cecidochares connexa* is planned. The mite *Acalitus adoratus* is present through accidental introduction and natural spread but its effects are not significant.

KEY WORDS: *Acalitus adoratus*, biological weed control, *Cecidochares connexa*, *Pareuchaetes pseudoinsulata*, Siam weed

*Address for correspondence
conducted. In West New Britain Province, under areas of planted gum (*Eucalyptus* sp., Myrtaceae) forests, *C. odorata* is the most dominant understorey species but it is not known if its presence is damaging or beneficial to the trees.

The presence of *C. odorata* in PNG is seen as a likely source for new outbreaks in Australia where the only known outbreaks in North Queensland are being eradicated (Waterhouse, 1998). This impending danger of new outbreaks in Australia from seeds originating in PNG led to the commencement of a biological control project in PNG. The project is part of the Australian Centre for International Agricultural Research (ACIAR)-funded regional project also involving Indonesia and the Philippines. The biological control work in PNG began in March 1998. In this paper, we discuss non-biological control factors influencing *C. odorata* growth in PNG, and also report on the progress made with classical biological control using the moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) in PNG.

**NON-BIOLOGICAL CONTROL OF CHROMOLAENA ODORATA**

Early recommendations for control of *C. odorata* in PNG were to use the herbicide 2,4-D at 2.8kg/ha or 2,4-D plus 2,4,5-T at 5.6kg/ha for direct treatment or atrazine or diuron at 5% in water for pre-emergence treatments (Henty and Pritchard, 1973). It is not known if herbicides have been used according to these recommendations. In PNG, only commercial farmers in the prosperous tree-crops sector can afford herbicidal control, but there is no known use of any against *C. odorata* specifically. Cocoa, coconuts and oil palm are the most widely planted export crops in the two New Britain provinces where *C. odorata* was first found and where some control has been necessary. Most plantations tend to include all weedy species in a general vegetation control strategy (S. Lord, pers. comm.), resulting in reductions of *C. odorata* infestations in cropped situations. However, it persists in those areas not subject to such vegetation management practices.

In Sandaun, Manus, Oro, Morobe, and West New Britain provinces, the weed is becoming increasingly troublesome for many subsistence or smallholder cash crop farmers who have to use the traditional methods of slashing, burning and uprooting of rootstocks before growing crops. Many affected farmers in these areas are living with increasing Siam weed infestations as it invades shifting cultivation areas.

Fires are commonly used in the Markham Valley to clear vegetation during the dry season from June to December. *Chromolaena odorata* in the affected areas within the Markham Valley begins flowing in late May and by August the senescing plants are burnt as villagers set fires more indiscriminately than on purpose. This reduces plant biomass and possibly a proportion of the seed bank, but regrowth and seedling growth at the onset of rains quickly re-establish infestations. Some burnt-out areas are easily cultivated to grow bananas, cassava and a few other food crops.

In West New Britain Province, where large areas of oil palm are cultivated, shading is an effective method of weed suppression and *C. odorata* tends to have invaded largely unmanaged palm groves, replanted forest zones, and abandoned fallow land. On the Gazelle Peninsula of East New Britain, where intensive cultivation of cocoa and coconuts takes up a lot of the fertile lands, *C. odorata* is effectively suppressed by cocoa-coconut canopies shading out seedlings and by intensive cultivation for food crops. This has limited the impact of the weed, with small isolated stands found on unused peripheral land or areas of difficult terrain such as steep slopes.

Aggressive species like the creeper *Merremia peltata* (L.) Merr. (Convolvulaceae), the tall shrub *P. aduncum* and the tall grasses *Saccharum spontaneum* L. (Poaceae) and *Pennisetum purpureum* Schum. (Poaceae) are effective competitors with *C. odorata* in some areas. In secondary rainforest areas on Misima and Manus islands and near Lae we observed that the ecological succession process continues, with *C. odorata* being an important component only among the pioneering plant community after disturbances such as logging or shifting cultivation.

**BILOGICAL CONTROL**

**Regional ACIAR Project**

In 1996, arrangements were made to extend the regional biological control project involving Indonesia and the Philippines and supported by ACIAR to include PNG. *Pareuchaetes pseudoinsulata* and other biological control agents already released in the other countries against *C. odorata* were planned for release in PNG under this project. The project implementation is the responsibility of the National Agricultural Research Institute (NARI). Work commenced in April 1998 from a work base at Labu Research Station (06.40.27 S 146.54.37 E) near Lae, Morobe Province. During December 1998 and March 1999 two batches of *P. pseudoinsulata* were obtained from Guam and field releases are continuing.
Rearing of *Pareuchaetes pseudoinsulata*

The first batch of *P. pseudoinsulata* (65 eggs and 125 first instar larvae) was received from Dr. R. Muniappan, Agricultural Experimental Station, University of Guam, Guam (USA) during December 1998. Only one of the eggs hatched after arrival. The larvae were fed on cut foliage of *C. odorata* in petri dishes until the second instar, when they were moved to plastic food containers with windows of soft gauze in their lids. They were fed on cut foliage until they pupated. Upon emergence, the moths were all kept in one cage containing cut foliage. From a total of 8 438 F1 generation eggs laid, only 57 (i.e. 0.7%) eggs hatched. The rearing shed housing the rearing cages had no artificial lighting sources at night but it was thought that lights from nearby buildings may have affected mating at night, as was reported in studies from the Philippines (Torres *et al.*, 1991). However, hatching levels continued to decline even when the mating cages were covered with black plastic at night. In subsequent generations egg fertility declined until the colony was lost in March 1999 (Fig. 1).

A second colony was received from Guam in March 1999. On pupation, male and female pupae were separated by the patterns of the genital area on the ninth abdominal segment in males and the eighth segment in female pupae. These were kept in separate plastic containers until emergence of the moths, which were paired in mating cages containing potted plants. During subsequent generations, modifications to containers holding pupae to prevent desiccation were made. These included placing pupae on top of a layer of *C. odorata* leaves placed over a layer of soil in the plastic lunch boxes with their lids partially cut open and covered by soft gauze. The soil helped to retain moisture within the containers. All mating occurred in cages with potted *C. odorata* plants and all larvae fed on the foliage of these potted plants. Most larvae produced were released in the field, with only a manageable culture being kept for further rearing.

During November 1999, a large proportion of the culture was lost when two unidentified parasitic flies caused mortality among pupae. One of the parasitic flies was reared from *P. pseudoinsulata* larvae collected in a field population at Erap. The other flies emerged from pupae in rearing cages. As the rearing shed is not enclosed, it would not be difficult for a gravid tachinid to invade a rearing cage while it was open.

![Graph](image)

**Figure 1.** Observations on mating ratios (total females/male) and on egg hatching rates among *Pareuchaetes pseudoinsulata* reared at Labu, PNG.
Table 1. Field release sites, release details, and early impact of *Pareuchaetes pseudoinsulata* on *Chromolaena odorata* in September 2000 in Papua New Guinea.

<table>
<thead>
<tr>
<th>Release sites in PNG(province)</th>
<th>No. larvae released</th>
<th>Releases at site</th>
<th>Result</th>
<th>Habitat type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markham Valley (Morobe) Kasuka 1</td>
<td>13 630</td>
<td>5</td>
<td>Established. Some defoliation 500m from release point</td>
<td>Dry open area of mixed shrubs and grasses</td>
</tr>
<tr>
<td>Kasuka 2</td>
<td>4 425</td>
<td>3</td>
<td>Established. Moths spread 400m from release point</td>
<td>Dry open grassland with mixed shrubs.</td>
</tr>
<tr>
<td>Kasuka 3</td>
<td>1 540</td>
<td>2</td>
<td>Established and spreading on hillside infestations</td>
<td>Dry gully forest.</td>
</tr>
<tr>
<td>Erap</td>
<td>44 000</td>
<td>5</td>
<td>Established and damaging weed</td>
<td>Dry fallow sites on floodplain among <em>Leucaena leucocephala</em> and raintrees (<em>Samanea saman</em>)</td>
</tr>
<tr>
<td>Narawan</td>
<td>4 300</td>
<td>2</td>
<td>No establishment</td>
<td>Dry gully grassland/forest</td>
</tr>
<tr>
<td>Naramanki</td>
<td>1 800</td>
<td>1</td>
<td>To be confirmed</td>
<td>Under <em>L. leucocephala</em></td>
</tr>
<tr>
<td>Siara</td>
<td>177</td>
<td>1</td>
<td>To be confirmed</td>
<td>Open grassland with <em>L. leucocephala</em></td>
</tr>
<tr>
<td>Pussuatu, Labu</td>
<td>6 158</td>
<td>5</td>
<td>No establishment</td>
<td>Edge of wet tropical rainforest</td>
</tr>
<tr>
<td>Mushu, Vanimo (Sandaun)</td>
<td>15 900</td>
<td>2</td>
<td>No establishment from first release</td>
<td>Fallow site in tropical forest</td>
</tr>
<tr>
<td>Kapore (West New Britain)</td>
<td>8 800</td>
<td>2</td>
<td>No establishment from first release</td>
<td>Fallow site edge of moist forest</td>
</tr>
<tr>
<td>Buvusi (West New Britain)</td>
<td>8 800</td>
<td>2</td>
<td>No establishment from first release</td>
<td>Reforestation hillsides</td>
</tr>
<tr>
<td>Kalangra Point (West New Britain)</td>
<td>8 800</td>
<td>2</td>
<td>No establishment from first release</td>
<td>Open hillside infestation at edge of coconuts</td>
</tr>
<tr>
<td>Gazelle Peninsula (East New Britain)</td>
<td>8 000</td>
<td>1</td>
<td>To be confirmed</td>
<td>Steep open hillside nr coast</td>
</tr>
<tr>
<td>Misima Island (Milne Bay)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eaus</td>
<td>400</td>
<td>1</td>
<td>To be confirmed</td>
<td>Open clearings under coconut trees</td>
</tr>
<tr>
<td>Manlita</td>
<td>400</td>
<td>1</td>
<td>To be confirmed</td>
<td></td>
</tr>
<tr>
<td>Manus Island (5 sites)</td>
<td>15 000</td>
<td>1</td>
<td>To be confirmed</td>
<td>Roadsides at moist tropical forest edges</td>
</tr>
</tbody>
</table>
Hatching rates for *P. pseudoinsulata* eggs improved when adult mating sex ratios were kept close to 1:1 during the first five generations (Fig. 1). The rate of eggs hatching declined below 60% after the fifth generation, due more likely to the unequal mating ratios in separate mating cages than to inbreeding. At the end of the observation period (April 2000), egg hatching increased to 66.98% when the sex ratio was kept nearly equal during mating after the 11th generation (Fig. 1).

**Field Releases, Establishment and Impact of *Pareuchaetes pseudoinsulata***

Up to September 2000, *P. pseudoinsulata* was released at 21 sites in Sandaun, Manus, Morobe, Milne Bay and East and West New Britain provinces. Follow-up releases were also made in some of the areas to increase the chances of establishment. Successful establishment of the moth occurred at only four release sites in drier parts of the Markham Valley of Morobe Province (Table 1). The Markham Valley is characterised by dry conditions caused by a rain shadow effect, with areas further west of Labu progressively receiving less rainfall (883mm at Erap in 1999 compared to 2 427mm at Labu). Other release sites were in areas of high rainfall and in or near rainforest. Establishment of *P. pseudoinsulata* in high rainfall areas characterised by evergreen tropical rainforest had not occurred at the time of reporting. Since arthropod biodiversity in tropical rainforests is high with large ant populations (Erwin, 1983; Stork, 1988; Orapa, 1991), we suspect that high levels of predation by ants, spiders, and birds in these areas may have contributed to this lack of establishment. Parasitic flies reared from some larvae collected from the Erap release site indicate that parasitism by locally occurring arthropods may have been responsible for low field populations or non-establishment of *P. pseudoinsulata* even at the drier Markham Valley sites. At Mushu near Vanimo, we observed green ants, *Oecophylla smaragdina* (F.) (Hymenoptera: Formicidae), attacking larvae at the same time that field releases there were made during June 1999.

At the Kasuka sites (Markham Valley), flocks of mannikins, *Lonchura grandidis* Sharpe (Aves: Estrildidae), were observed living among the *C. odorata* thickets, probably feeding on the established *P. pseudoinsulata* population.

**Levels of Damage by *Pareuchaetes pseudoinsulata***

At the three field establishment sites at Kasuka in the Markham Valley, damage to *C. odorata* varied. At Kasuka Site 1, *P. pseudoinsulata* establishment was confirmed after the first three releases but damage levels were insignificant. *Chromolaena odorata* stands here have always been dense and villagers were requested to avoid setting fires to protect the moths and plant-monitoring sites. The moths had spread in a windward direction for about 500m, causing low levels of defoliation during the 6 months after the first release.

At Kasuka Site 2 (1km south), high levels of damage occurred within 100m of the release points in pockets of the weed while at Kasuka Site 3 (1km away) similarly patchy areas of feeding have occurred on plants growing on slopes. Local populations of the moth have persisted and heavy defoliation continued on plants growing on steep areas despite carelessly set fires that wiped out the plants at the release sites twice.

At a release site near Erap Research Station (5km south of Kasuka Site 1), *P. pseudoinsulata* established easily on a *C. odorata* infestation growing under secondary bush dominated by rain trees, *Samanea saman* (Jacq.) Merr. (Fabaceae). There has been no reduction in the weed attributed to this biological control agent. Seasonal flooding of the Erap River affected populations of the moth twice at the established site after a year of field establishment.

**Other Arthropods Attacking *Chromolaena odorata***

The mite *Acallitus adoratus* Keifer (Acari: Eriophyidae) was found on *C. odorata* at all areas in all the provinces where the weed occurs. However, visible damage by the mite has been insignificant in controlling the spread and growth of *C. odorata*.

Two unidentified weevils were found feeding on the leaves of *C. odorata* in Morobe Province. The adult weevils of both species made holes in leaves and occasionally damaged terminal buds. These weevils were very abundant on *C. odorata* plants growing at the forest edge near Lae but are believed to be oligophagous, with little impact on the weed. Another weevil causing similar damage was found on Los Negros Island in Manus Province. Occasionally, ant-protected aphids attack young plants growing in moist areas throughout the country, causing stunting of the terminal growth. Such aphid damage is restricted to a few plants, having little impact on the growth and spread of *C. odorata*. At Wutung (Sandaun Province) and on Misima Island, an insect, which was not observed but believed to be an hemipteran, caused significant damage to the growing tips of plants, stunting plants and reducing flowering in patches of *C. odorata*.

**Other Biological Control Agent Introductions***

In late 1999 and May 2000 two permits for the importation of the gall fly *Cecidochares connexa* Macquart (Diptera: Tephritidae) were issued, but
these permits are being renewed, as the flies were not imported as planned from Guam before the permits expired. It is planned that importation will be made in the near future from the Philippines or Indonesia.

ACKNOWLEDGEMENTS

We thank ACIAR for funding the biological control work in PNG and project leader Rachel Cruttwell McFadyen (Queensland Department of Natural Resources) for making it possible for two of us to attend this workshop in South Africa. We are grateful to Dr. Geoff Wiles (NARI) and Dr Bill Palmer (Queensland Department of Natural Resources) for making comments on the manuscript.

REFERENCES


MASS REARING OF *PAREUCHAETES AURATA AURATA*

D. E. Conlong and M. Way

*South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe 4300, South Africa*

In 1992, the Insect Unit of the South African Sugar Association Experiment Station (SAEX) was approached by Plant Protection Research Institute (ARC-PPRI) to mass rear *Pareuchaetes aurata aurata* for release in areas badly infected with *Chromolaena odorata* in KwaZulu-Natal. Rearing commenced in April 1992, and was terminated in July 1993. During that time, a total of 147 775 individuals were released in the field. These were produced from a stock culture which took 4 months to build up to a population level where 150 eclosed larvae could be inoculated onto fresh *C. odorata* cuttings per day.

Through separation of the rearing procedure into ‘clean’ and ‘dirty’ operations, attention to stocking rates, sterilisation and cleanliness of rearing rooms and rearing apparatus, work flow patterns, provision of high quality host plant sections and the use of a multi-roomed facility, high production was attained, with the minimum of diseases apparent in mass reared insect populations.

This paper describes the rearing protocol, procedures and apparatus used in the attainment of these results.
CHROMOLAENA IN MICRONESIA

Jesse Bamba

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Micronesia is comprised of the Mariana, Caroline and Marshall groups of islands located in the northwestern Pacific. The flora and fauna of Micronesia is mostly Asiatic, however, in recent years more and more neotropical flora and fauna have been invading this region.

The first documented record of *Chromolaena odorata* in Micronesia was from Guam in 1963. In the early 1980s, *C. odorata* became a serious weed on the island of Rota, which is located 40 miles north of Guam. Here, *C. odorata* invaded pastures and replaced grass. It also became a dominant weed in vacant lands and roadsides in Guam. In 1985, *Pareuchaetes pseudoinsulata* was introduced and established in Guam. The following year it was introduced to Rota, Tinian and Saipan. *Chromolaena odorata* established in Palau, Yap, Pohnpei and Kosrae in the late 1980s.

In 1988 *P. pseudoinsulata* was introduced to Yap, Pohnpei and Kosrae. It established in Pohnpei in 1988–90 and Kosrae in 1992. In Yap, it established in a small area in late 1988 but later on it died out. The moth was introduced to Palau in 1989 and 1997, but it did not establish. *Chromolaena odorata* spread to Moen island in Chuuk State during this period.

The gall fly *Cecidochares connexa* was imported to Guam from Indonesia in April 1998 and it is still in the quarantine facility awaiting permission from APHIS, USDA for field release. In 1999 *C. connexa* was introduced to Palau and established in the field.

The eriophyid mite *Acalitus adoratus* has established fortuitously throughout the Mariana and Caroline Islands.
A NEW BIOLOGICAL AGENT, ACTINOTE ANTEAS, INTRODUCED INTO INDONESIA FROM SOUTH AMERICA FOR THE CONTROL OF CHROMOLAENA ODORATA

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BIOLOGICAL CONTROL OF CHROMOLAENA ODORATA IN INDONESIA was initiated with the importation of Pareuchaetes pseudoinsulata in 1991 and later Cecidochares connexa, in 1993. A third biological agent, Actinote anteas, was imported in 1996 under a project of the Australian International Centre for Agricultural Research. A culture of this butterfly, originally collected in Costa Rica, was established in the quarantine insectary at Marihat, Indonesia. The biology and the behaviour of this insect were studied and host-specificity testing was carried out, using starvation and choice tests. A method of mass rearing was also developed.

The lifecycle of A. anteas, with six larval instars, is completed in 92 – 102 days in the insectary. The duration is reduced to 73 – 84 days in drier periods when the temperature increases. For specificity testing, 58 plant species belonging to 22 families and 54 genera were used. The insect only fed, was able to complete its lifecycle, and to reproduce on C. odorata and Mikania micrantha, another major asteraceous weed in Indonesia. Following the results of specificity testing, and in accordance with the release permit obtained from the Ministry of Agriculture in Indonesia, A. anteas was released in June 1999.

Initial field observations indicate that A. anteas is able to feed on C. odorata until it completely defoliates the plant. The caterpillars remove the entire stem epidermis. The young instars do not eat the entire leaf, petals or flowers, but these are fully consumed by the older ones, in consequence causing a characteristic drying of the upper part of the plant.

After initial releases, adults were found flying in shady and bushy locations. They appeared to scatter and disperse widely. Batches of eggs, which are difficult to find, are laid on the foliage of chromolaena plants growing in mixed vegetation on the borders of fields. At least in the first releases, predators, particularly reduviid bugs and wasps, reduced caterpillar populations. In order to obtain establishment, numbers released must be greater than the capacity of predators, and several releases must be made in the same location. In consequence, further studies are still being carried out, in order to better understand the behaviour of A. anteas and to obtain long-term establishment of this insect for the biocontrol of C. odorata.

In addition to C. odorata, this insect also feeds on M. micrantha in the field, and may therefore be a valuable biological agent for the control of both of these aggressive species.

KEY WORDS: agent establishment and spread, biological weed control, field releases, host specificity, Nymphalidae: Acraeinae, mass rearing, Mikania micrantha

INTRODUCTION

After the importation of Pareuchaetes pseudoinsulata Rego Barros (Lepidoptera: Arctiidae) into Indonesia in 1991, and Cecidochares connexa Macquart (Diptera: Tephritidae) in 1993, for the biological control of Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), a third biological control agent, Actinote anteas (Doubleday and Hewitson) (Lepidoptera: Nymphalidae: Acraeinae), was imported from Costa Rica in 1996, in continuation of a project funded by the Australian Centre for International Agricultural Research (ACIAR).

This insect was reported as a potential biological control agent by (Cruttwell, 1974; McFadyen, 1988), but could not be induced to mate or oviposit (R.E. Cruttwell McFadyen, pers. comm.). This species was reared and tested for specificity in South Africa (Caldwell and Kluge, 1993), but the laboratory colony died out after the third generation, possibly because the South African form of C. odorata was not a suitable host. Subsequently another species, A. thalia pyrrha Fabr., obtained from Brazil, was reared in South Africa, but not released for safety reasons regarding native Mikania species (L. Strathie, pers. comm.).

In accordance with permit No. 856/KPTS/TP.120/11/96 from the Ministry of Agriculture, a culture of A. anteas was imported to the Indonesian Oil Palm Research Institute at Marihat via the Alan Fletcher Research Station in Brisbane, Australia. This culture was dispatched at the egg stage, and

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consisted of 1,365 eggs, in 20 batches, from which 1,362 hatched. The culture was kept under quarantine conditions at the Marihat Research Station. Here a rearing method was established, the biology and the behaviour of the insect were investigated, and host-specificity testing (starvation and choice) was conducted. After evaluation of the tests, the Ministry of Agriculture and the Quarantine authorities approved the release of this butterfly in Indonesia under the release permit No. 689/KPTS/TP.120/6/99 on 17 June 1999. The results of biology, host-specificity and post-release studies are presented in this paper.

**IDENTITY AND BIOLOGY OF ACTINOTE ANTEAS**

*Actinote anteas* has been collected in Costa Rica several times (R.E. Cruttwell McFadyen and others), in Colombia during an ACIAR-sponsored survey (C. Garcia, pers. comm.), and in Venezuela and north-eastern Brazil in 1996 (S. Neser, pers. comm.). It has also been reported on *Ageratum* and *Mikania* in Trinidad (Barcant, 1970) and as far south as Brazil (Silva *et al.*, 1968) respectively. This species is considered to be *A. thalia thalia* L. in South Africa (L. Strathie, pers. comm.). However, the taxonomy of the genus needs revision and the material collected in Costa Rica and northern South America probably belongs to the same species. *Actinote anteas* occurs widely through Central and South America, although within the species there may be several biotypes with different host plants. For the purposes of the Indonesian programme therefore, we consider the species to be *A. anteas*.

The eggs of *A. anteas* are laid in batches. The larvae are gregarious, living in large groups until the fifth instar. In the sixth and final instar they tend to scatter, living in small groups of sometimes no more than two or three caterpillars. When confined in cages, they pulate in groups, but in a more dispersed fashion in the field. Many aspects of the behaviour of this insect differ between the caged population and those in the field in Indonesia.

**Lifecycle**

The lifecycle is completed in 92 – 102 days in the insectary, but decreases to 73 – 84 days with an increase in temperature. Under these conditions, the duration and even the number of larval instars (five instead of six, especially for males), decreases significantly.

The incubation of the eggs takes 10 – 15 days (12 on average), and the larval period lasts 52 – 73 days for males (63 on average) and 52 – 87 days for females (67 on average). Pupation lasts for 9 – 12 days, depending on the gender and the host plant.

On *Mikania micrantha* (L.) Kunth (Asteraceae), the lifecycle is slightly shorter: 90.7 and 96.7 days for males and females respectively, compared to 96.3 and 100.5 days for males and female reared on *C. odorata* under the same conditions. However, fecundity is similar. Also, after rearing separate cultures on the two plant species for 14 generations, the caterpillars are still able to feed on both chromolaena and *M. micrantha*.

**Description and Characteristics**

Eggs are pale yellow in colour and vase-shaped. They vary from 0.62 – 0.70mm in length and 0.48 – 0.50mm in width, depending on their age, increasing in size after 5 days and becoming brick red in colour before hatching.

Caterpillars are greyish in colour, with many prominent spines on each segment. As in other acraeid larvae, the caterpillar has six dark black spiny projections (scoli) with fine hairs and numerous bristles on the abdominal segments, and four scoli on the thoracic segments. The scoli are very thick and shiny black, and clear green at the base, where they attach to the body. The neonates and the first instar are yellowish, and the caterpillars turn greenish-yellow as soon as they begin feeding on the foliar cuticle. The head capsule is initially brownish, turning to dark brown in the third and following instars. Sizes and durations of each instar are indicated in Table 1. The total mean duration of the larval period is 59.7 days.

**Table 1.** Size parameters and duration of the larval instars of *Actinote anteas*.

<table>
<thead>
<tr>
<th>Instar</th>
<th>Head capsule size (mm)</th>
<th>Larval length (mm)</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.47</td>
<td>2.73</td>
<td>11.27</td>
</tr>
<tr>
<td>2</td>
<td>0.69</td>
<td>4.37</td>
<td>21.09</td>
</tr>
<tr>
<td>3</td>
<td>0.82</td>
<td>6.32</td>
<td>9.36</td>
</tr>
<tr>
<td>4</td>
<td>1.43</td>
<td>14.87</td>
<td>8.95</td>
</tr>
<tr>
<td>5</td>
<td>1.83</td>
<td>19.76</td>
<td>10.06</td>
</tr>
<tr>
<td>6</td>
<td>2.49</td>
<td>27.33</td>
<td>9.00</td>
</tr>
</tbody>
</table>
The fully-grown caterpillars are dark grey dorsally and browner laterally. The bases of the median pairs of dorsal scoli are surrounded by a nearly square area, green near the base and delimited outwardly by a narrow yellowish line. The lateral and ventral part of the caterpillar is well differentiated in colour and uniformly yellowish, and the legs are shiny and black.

Initially, pupae are greenish-white in colour, becoming pale greyish-yellow as they age. Ventrally, they have six rows of longitudinal, non-continuous, very narrow dark lines, with a pair of dark shiny scoli on each of the five abdominal segments. Dorsally, two rows are present, with some dark, longitudinal, narrow lines only on the upper part. The veins of the wing cases are well marked, and black in colour. Shortly before adult emergence, the wing cases become darker. Two small horns are present on the front and upper part of the head, which is blackish underneath. A narrow semi-circular black ring is present around the upper part of the eyes. The pupa varies in length from 19.56 – 20.52mm. Pupation lasts 11.0 – 11.5 days in the insectary.

Adults are large colourful butterflies, brownish orange-yellow with black spots, and with an average wingspan of 56.1mm for the males and 63.4mm for the females. The males are paler in colour than the females, especially on the underside of the wings. The adults live for 7.0 – 8.7 days under optimal conditions.

Behaviour and Circadian Activities

Eggs
Oviposition starts 2 – 3 days after emergence and takes place in the morning, with a peak between 08h00 to 10h00. The eggs are laid in batches under leaves near the top of the plant. The number of eggs per batch varies from 116 – 718 (470 on average). One female, if undisturbed, is able to lay all these eggs in 1hr 40min – 3hr 00min, or sometimes longer depending on the size of the batch. When the eggs are scattered in small batches they are generally not fertile.

Larvae
After consuming their eggshells, young caterpillars start feeding on the C. odorata leaf cuticle while forming a net of silk. When moving, the caterpillars extend this or build a new net. Their faeces stick to the silk, providing protection for the young colonies.

During the night and early in the morning, when the humidity is high, the young caterpillars eat the foliage on the upper part of the leaves. When the humidity decreases, they move to the undersides of leaves to feed. In consequence, they remove both the upper and lower leaf epidermis. After this, the young caterpillars generally cut through half of the leaf petiole. As a result, the feeding of the A. anteas caterpillars causes characteristic damage, with the leaves hanging completely dried and black in colour. These leaves also form a shelter for the colonies. On M. micrantha, the young instar caterpillars appear not to cut the petiole, although they scrape the epidermis on both sides of the leaf. Instead they bind several leaves together with silk threads to form a large shelter, which in cages houses thousands of caterpillars.

After eating the younger leaves completely, the caterpillars move as a group to the older, bigger leaves, causing the same damage. They are gregarious until the third or fourth instar, when they scatter and, instead of scraping the epidermis, consume whole leaves.

After 11h00, when the temperature reaches 30°C, the caterpillars stop feeding but remain under the leaves. They generally adopt a position where only their legs are in contact with the leaves, to avoid the heat.

Pupae
In the field, sixth instar (occasionally fifth instar, for some males) caterpillars move away from feeding sites to pupate on the surrounding shrubby vegetation, often in the shade. In order to pupate, the prepupal larvae suspend themselves from the underside of a leaf or stem, not necessarily of a chromolaena plant.

Adults
When light intensity and temperatures are insufficient, the adults are inactive, sitting under the leaves, on stems or on the walls of the cages, with their wings closed. In the field, adults congregate in groups when they are resting. When the temperature is warm enough (around 29 – 30°C) the butterflies fly rapidly and above the trees. In the insectary most mating occurs from 14h30 – 15h30, whereas outside it occurs from 08h00 – 13h00, depending on the temperature. In cages, due to the density of plants, oviposition occurs without preliminary exploration, the female apparently laying her eggs immediately on young leaves.

The caterpillars and butterflies exude a bitter, toxic fluid that may protect them from attack by parasitoids or predators.

MASS-REARING METHODS

Mating and Egg Production
Obtaining mating is the key to success in mass rearing A. anteas. For this, three important factors
must be achieved: males must meet receptive females, climatic conditions should be optimal, and there should be a sufficient mating period.

**Temporal Overlap between Adult Males and Females**

In the insectary, adult males always eclose earlier than the females. Often the emergence peak of males is so different that there is little overlap, with the consequence that only a few mating events occur. However, if the population is larger, there is always an overlap of 3 – 4 days or more during the peak of emergence. In this case there is no difficulty in obtaining mating. Therefore, in order to avoid this problem in the insectary, it is important to rear a large number of *A. anteas*. In cages outside the insectary, under more natural conditions, the adults drink dew and live longer, and the overlap is thus greater. In the insectary, flowers or sugar solution can increase the longevity of the butterflies.

**Optimal Temperature**

The effect of temperature is much greater than light or humidity. In the insectary, the peak of mating occurs from 14h30 to 15h30, with 32 – 34% of mating occurring when the temperature reaches 30°C at 15h00. Only a few mating events are observed before the temperature reaches 29°C. In contrast, in mass-rearing cages outside the insectary, the temperature reaches 29°C at 08h00, and 30°C at 09h00. In correlation, mating happens as early as 08h30, with 15.4% at 09h00, 37.8% at 11h00, and reaching a peak at 13h00 with 46.8% of mating events. For similar populations, the number of mating events in the insectary is only 56, compared to 143 in cages outside. To obtain adequate mating, therefore, it is necessary to increase the temperature in cages to the optimal for several hours, or to keep the adults in cages outside, directly in the sunshine in the morning.

**Duration of Mating**

Mating generally lasts several hours, and sometimes the whole night. It has been found that a shorter mating duration (<15min) is inadequate for obtaining good egg fertilization, thus only pairs that mate for a long time should be selected to continue the culture.

**Fecundity Potential**

On dissection, we found four ovarioles per ovary. After mating, each ovariole contains 25 – 40 completely mature oocytes. Therefore at least 200 – 320 eggs can be laid together in a single batch. But there are also as many as 48 – 50 immature oocytes in the germarium, which reflects a potential fecundity of 584 – 720 eggs per female.

**Fecundity in the Insectary**

The duration of egg laying varied greatly, and was a function of the number of mature oocytes in the ovaries and of whether mating has occurred. If the female was not disturbed, oviposition lasted from 1hr 30min – 4hr 15min (on average 2hr 50min). If oviposition started early in the morning (as early as 08h00 – 09h00) it lasted longer (3hr 23min) than if it began later, when it lasted 2hr 46 min. When oviposition began early in the day, 114 – 555 eggs were laid, with an average of 410. Often the oviposition period was shorter, however, and the number and fertility of eggs was reduced. In order to obtain maximum hatching, only large batches of eggs should be collected.

**Fertility**

Batches of eggs of an average size of 410 eggs have a higher percentage of hatching (90.1%) than smaller batches, which have a maximum fertility of only 23.6%. Also, the fertility of batches obtained in the insectary is greater (from 76.9 – 68.8%) for batches laid during days 4 – 7 of the adult female’s life, decreasing sharply to 13% thereafter. In cages outside, the hatching rate is always higher than 90%, similar to the best rate of fertility obtained in the insectary with large batches, as a result of successful mating. At least for mating, therefore, it is better to keep the adults outside during this period.

**Oviposition and Hatching**

The quality of the leaves is important for egg laying. In order to obtain suitable plants, chromolaena in polybags should be regenerated regularly by cutting the stems and applying fertiliser. It is important to place polybags with strongly growing *C. odorata* in the cages, leaving some space between the plants and the top of the cage.

The eggs of *A. anteas* are very fragile and the chorion is very thin, and they are therefore easily subject to dessication. To avoid this, it is necessary to keep the eggs on the leaves until they hatch.

**Feeding**

The young neonates and first instars are also very fragile. The young caterpillars should be left on the plant on which the eggs were laid until they reach at least the third instar.

If mass rearing is carried out in cages outside, reduviid bugs must be regularly destroyed when they occur. Part of the culture should always be kept in the insectary, to avoid too much of it being preyed on.
Pupation
Supports for pupation must be placed in the cages before pupation, in order to allow the prepupae to attach themselves to the stems. It is best to use either cuttings of C. odorata stems kept after defoliation or small bamboo branches for this purpose.

The butterflies, which are quite large, need to hang from branches to unfold their wings and eject their meconium. Adults which eclose from pupae on the ground are deformed and unable to fly. Unattached pupae should be glued onto supports in order to obtain adults in good condition.

HOST SPECIFICITY
Host-specificity testing was conducted on many plant species belonging, together with C. odorata, to the Asteraceae family, and also on plants of economic importance in plantations, fruit trees, forest trees, vegetables and ornamental plants.

Methods
A total of 56 plant species from 22 families and 54 genera were tested (Appendix 1). The Asteraceae, with 18 genera, and Leguminoseae, with eight genera, were the families particularly tested. Two instars of A. anteas caterpillars were tested on each plant species: newly hatched first instar larvae, and older, third instar larvae. All tests were replicated three times and data on survival and feeding were recorded every day. The foliage of C. odorata was changed every 2 days. The tests were conducted in the insectary in an isolated room, using 1.2 litre containers covered with a muslin cloth.

Results
Both first- and third-instar caterpillars were able to complete development until pupation on C. odorata and M. micrantha only. On these two plants the larval period up to the occurrence of the first pupae lasts 58 – 61 or 28 – 31 days and 28 – 31 or 26 – 29 days for the 1st and 3rd instars respectively. For the other plants tested, the caterpillars were either not able to feed, or made only a little exploratory feeding, dying after 3 – 9 days, except on Bidens, Dahlia and Zinnia. On these species, some of the larvae were able to survive longer, often without moulting (9 – 14, 8 – 9, 9 – 44 days for the first instar and 26 – 49, 11 – 89, 37 – 94 days for the third instar respectively) before finally dying. This abnormal longevity and moulting until death already shows that A. anteas cannot live on these three plants.

Nevertheless, for additional safety, choice tests were carried out over a 2-week period, using C. odorata as a control plant each time, for all the plants on which exploratory feeding, or long and abnormal development had been recorded in no-choice tests. Always, and even for Bidens, Dahlia and Zinnia, there was no feeding, which indicates that A. anteas is specific to C. odorata and M. micrantha.

FIELD RELEASES
Optimal Release Methods
Adults are difficult to release, especially after mating, as they immediately disperse widely, even in the morning. In consequence, it is better to mass-release caterpillars while they are still at a gregarious development stage. To reduce the impact of predators (wasps and reduvid bugs), thousands of larvae should be released at the same point in a single locality. Caterpillars released in large numbers are better protected, but several releases over a number of generations must be made at the same locality.

Wasps (mostly Vespidae: Polistinae) attack the caterpillars, especially the older instars which are scattered and less protected. Generally, wasps with short and broad mandibles feed on caterpillars in order to take them as provisions to their larvae in the nest. However, A. anteas caterpillars are not killed and not carried by the wasps to their nests, but left on the leaves. It seems therefore that the wasps try to feed on A. anteas caterpillars, but quickly become repelled by the nauseating fluid emitted by them. In consequence, although the initial release at a locality may be destroyed by wasps, later releases are not, as the wasps lose interest in the caterpillars. To prevent wasps having too great an impact, it is also better to release A. anteas far from housing or bridges, which often harbour wasp nests.

Assassin bugs, such as Sycanus dichotomus Stål (Hemiptera: Reduviidae) in Indonesia, seem less disturbed by the fluid produced by A. anteas and are able to feed on both the caterpillars and the butterflies. However, because the total lifecycle of this predator is 5.4 months, and the nymphs are only found at ground level, S. dichotomus only has an impact when in the adult stage, which can last up to 50 days. During these periods, many releases should be made, in order to saturate the assassin bugs. Also, when the caterpillars are more scattered the impact is reduced, and in such a case it is better to release final-instar caterpillars, which are less gregarious and immediately spread out.

Preliminary Results
Near the Insectary
Actinote anteas was released five times on C. odorata near the insectary, with three of these resulting in complete defoliation of the plants. With the additional effect of C. connexa, these plants and several in polybags died. During each outbreak, the
caterpillars moved onto nearby *M. micrantha* plants after they had defoliated chromolaena, and caused huge defoliation of this species as well. Both eggs and larvae of the following generation were found. Adults were attracted to cages with butterflies inside, indicating that some were flying around and that the females produce a pheromone to attract the males.

**Field Releases**

Several releases have been made near Marihat where *C. odorata* is becoming more scattered and rare. In consequence, it is difficult to evaluate the real impact of *A. anteas* on this weed. It is necessary to release caterpillars in more dense populations of *C. odorata* in order to obtain better establishment. At release sites, defoliation occurs and characteristic symptoms of feeding of the caterpillars of *A. anteas* can be found. Massive defoliation was found and the caterpillars were seen in large aggregations. The young leaves near the top of the plant are eaten first, but thereafter the larvae quickly move down to the older leaves on the bush. As a result, the whole plant may be defoliated. When they are ready to pupate, the caterpillars leave their feeding sites and search for suitable supports from which to suspend themselves, on climbing plants or the leaves of bushes or trees, sometimes as far as 10 – 20m away. The adults have not been seen flying around chromolaena plants or even the flowers, but like other nymphalid butterflies, they fly in the shade in bushy areas and under trees, especially at noon. They probably only return to *C. odorata* plants to oviposit. Therefore, if adults are released, they should be released not directly onto the weed but in shady, bushy areas nearby. It is likely that *A. anteas* is more active in bushy areas or forest margins, and probably moves to the weed in open areas only when outbreaks occur. Eggs were found on both chromolaena and *M. micrantha* soon after releases, although these were rare and mainly on the edge of bushy vegetation. Eggs laid in the field hatched and some adults of the F1 generation were observed, but no eggs, caterpillars or adults of the F2 or subsequent generations were found. It is thus likely that these adults dispersed to more suitable areas. To ensure better establishment of *A. anteas* on *C. odorata*, the dispersal behaviour of the adults and caterpillars needs to be investigated in the field, along with the feeding activities of the caterpillars throughout their development, in open compared to shaded locations.

Preliminary post-release results indicate that *A. anteas* may be a good potential candidate, with at least occasional outbreaks, for better control of *C. odorata*, in combination with the other agents already successfully established in the field.

**ACKNOWLEDGEMENTS**

We are grateful to the Australian Centre for International Agricultural Research for funding this work, which was carried out under project CS2/96/91 (Biological control of *Chromolaena odorata* in Indonesia, Papua New Guinea and the Philippines). We want also to particularly thank Dr Rachel Cruttwell McFadyen, leader of this project, for providing the insects and for her very helpful guidance. We also give our sincere thanks to Ms Lorraine Strathie for her kind advice during this study.

**REFERENCES**


Appendix 1. Families and genera of plants used in the host-specificity testing of Actinote anteas.

Amaranthaceae: Amaranthus
Anacardiaceae: Mangifera
Asteraceae: Ageratum, Aster, Austroeupatorium, Bidens, Blumea, Chromolaena, Chrysanthemum, Clademium, Cosmos, Dahlia, Gynura, Helianthus, Mikania, Pluchea, Sonchus, Tagetes, Tithonia, Zinnia
Caricaceae: Carica
Euphorbiaceae: Euphorbia, Hevea, Ricinus
Flacourtiaceae: Flacourtia
Labiatae: Pogostemon
Lauraceae: Cinnamomum
Leguminoseae: Albizia, Caesalpinia, Calopogonium, Cassia, Glycine, Parkia, Pueraria, Vigna
Malvaceae: Gossypium, Hibiscus
Myrtaceae: Eugenia, Psidium
Palmae: Cocos, Elaeis
Piperaceae: Piper
Portulacaceae: Portulaca
Rosaceae: Rosa
Rubiaceae: Coffea, Gardenia, Uncaria
Rutaceae: Citrus
Sapindaceae: Nephelium
Solanaceae: Capsicum, Solanum
Sterculiaceae: Theobroma
Theaceae: Camellia
Verbenaceae: Lantana
ALIEN PLANT THREATENS NILE CROCODILE BREEDING IN LAKE ST LUCIA, SOUTH AFRICA

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In a study from 1994 – 1997, we observed that the majority of Lake St Lucia’s nesting Nile crocodiles selected open, sunny, sandy areas in which to deposit their eggs. Nests were only found in shaded sites in the Mpate river breeding area and these nests were shaded primarily by the alien plant Chromolaena odorata. Shaded site soil temperatures at 25cm depth, were on average 5.0 – 6.0°C cooler than sunny site soil temperatures at the same depth. Shaded site temperatures were well below the pivotal temperature for St Lucia’s Nile crocodiles and as a result nests probably produced a female-biased sex ratio. Shaded site temperatures may also have prevented embryonic development altogether. We observed the behaviour of a number of breeding crocodiles in the Mpate river area during the study, and noticed that while digging their egg chambers many females encountered roots from C. odorata. Being unable to dig through the fibrous mat of roots, these sites were abandoned. In a mitigation experiment, where additional nesting sites were created, the percent of sites utilized increased, indicating that suitable nesting sites were in short supply. This alien plant is posing a very serious threat to the continued survival of the Nile crocodile in Lake St. Lucia and unless immediate action is taken, a female-biased sex ratio will result in eventual extirpation of the species from this recently proclaimed World Heritage Site.⁵

A DECADE OF BIOLOGICAL CONTROL AGAINST 
CHROMOLAENA ODORATA AT THE 
INDONESIAN OIL PALM 
RESEARCH INSTITUTE IN 
MARIHAT

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Over a 10-year period, three biological agents were imported to the Indonesian Oil Palm Research Institute (IOPRI) quarantine laboratory at Marihat, to control *Chromolaena odorata*. First, in 1991 a defoliating moth, *Pareuchaetes pseudoinsulata*, was obtained from Guam. A stem-galling fly, *Cecidochares connexa*, was obtained from Colombia in 1993, and finally a defoliating butterfly, *Actinote anteas*, was obtained from Costa Rica in 1996.

Rearing methods for these insects were determined, and their biologies and behaviours studied, at the quarantine insectary in Marihat. Host-specificity tests were also carried out through choice and no-choice tests. After evaluating these tests, the Ministry of Agriculture and the Quarantine authorities approved the release in Indonesia of *P. pseudoinsulata* in 1992, *C. connexa* in 1995, and *A. anteas* in 1999.

Methods of release and establishment in the field were developed for each of these insects. Two of them, *P. pseudoinsulata* and *C. connexa*, are now well established and surveys for assessing the establishment of *A. anteas* are continuing. The spread of these insects from the release sites has been recorded. The impact of *C. connexa* galls on the growth of *C. odorata* has been determined.

Observations on reduction in the growth of *C. odorata* due to the impact of these insects were made. Plants sometimes died after being defoliated several times by *P. pseudoinsulata*, which also fed on the stem epidermis at the base of the plant. If all the new shoots on a plant were galled by *C. connexa*, it would often die back completely.

*Pareuchaetes pseudoinsulata* has been established in many places in Sumatra, Kalimantan and Sulawesi, with repeated severe defoliations observed in Riau, Aceh and East Kalimantan. Such defoliation of *C. odorata* in oil palm plantations has considerably reduced the cost of weeding this plant. *Cecidochares connexa* generally reduces the spread of this weed rather than destroying it. The cumulative impact of these two agents has led to the gradual reduction in density of the weed.

IOPRI (Marihat) has provided these three biocontrol agents to agencies throughout Indonesia, including Java, Nusa Tenggara Timur, and Irian Jaya. *Cecidochares connexa* has been sent to the Philippines, Guam, Ghana, Ivory Coast and South Africa.

KEY WORDS: *Actinote anteas*, biological weed control, *Cecidochares connexa*, host specificity, *Pareuchaetes pseudoinsulata*

INTRODUCTION

Three biological control agents for the weed *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae), a native of South America but invasive in Indonesia, were imported to the Marihat Research Station of the Indonesian Oil Palm Research Institute (IOPRI), in order to create an effective complex of natural enemies. These agents were obtained within the framework of two biological control projects, first with the European Economic Community (EEC) - Institut de Recherches pour les Huiles et Oleagineux (IRHO) in the early 1990s and later with the Australian Centre for International Agricultural Research (ACIAR) (McFadyen, 1991, 1996). *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was imported from Guam (Seibert, 1989) in 1991, *Cecidochares connexa* Macquart (Diptera: Tephritidae) was obtained from Colombia in 1993, and *Actinote anteas* (Doubleday and Hewitson) (Lepidoptera: Nymphalidae: Acraeinae) was imported from Costa Rica in 1996.

These importations were made in accordance with the procedures established by the Indonesian Quarantine authorities and the Ministry of Agriculture. All three insects were cultured at the
Marihat insectary, recognized as a safe quarantine facility, under the supervision of the quarantine officers in Medan. Host-specificity tests were carried out for each of these insects using more than sixty species of plants, including many Asteraceae and economically important plants grown in the region (Sipayung and Desmier de Chenon, 1995; Desmier de Chenon et al., this Proceedings). On each occasion, choice and no-choice tests were conducted on two larval stages: newly hatched larvae, and those midway through development, with three replicates each. The tests showed that these biological agents were highly host specific. However, *P. pseudoinsulata* also fed on *Ageratum conyzoides* L. (Asteraceae) and *A. anteas* on *Mikania micrantha* (L.) Kunth (Asteraceae), both of which are weeds in Indonesia.

After evaluation by the Commission for Importation of Natural Enemies and the Quarantine authorities, the Ministry of Agriculture issued release permits for these three biological agents in Indonesia. Accordingly, *P. pseudoinsulata* was released in 1992, *C. connexa* in 1995 (Desmier de Chenon and Sipayung, 1996a) and *A. anteas* in 1999. Releases by IOPRI were made first in North Sumatra and later in many other places in Sumatra, Kalimantan and Sulawesi. These biological agents were also provided to several research institutions, especially Gajah Mada University, Nusa Cendana University and Biothrop, for releases in Java, Nusa Tenggara Timur and Irian Jaya (Tjitrosemito, 1996; Tjitrosemito and Kasno, 1999; Wilson and Widyanto, 1997).

The results of studies on the lifecycle and behaviour of each of these three insects are presented in this paper, along with mass-rearing techniques at Marihat, the impact of each agent on the weed after release, and their current distribution in Sumatra, Kalimantan and Sulawesi.

**PAREUCHAETES PSEUDOINSULATA**

**Description**

This moth, with a wingspan of around 35mm for the male and 43mm for the female, is uniformly pale yellow on the wings and thorax. The abdomen is a deeper yellow with a dorsal row of black spots. The typically arctiid caterpillars are very hairy, with long setae on verrucae interspersed with secondary ones of moderate length. They are blackish in colour, with narrow white stripes.

**Biology**

During the rainy period, the lifecycle of *P. pseudoinsulata* is completed in 37 – 59 days, with an average of 47 days. In the dry season the average duration decreased to 44 days. Eggs are 0.66mm in diameter, yellowish in colour, and are laid on the undersurface of the leaves in 2 – 7 batches of 40 – 196 eggs each (89 eggs on average). A total of 189 – 582 eggs is laid per female, with 437 eggs on average. The incubation period of the eggs is 3 – 5 days. The larval period, through six instars of 3 – 6 days each, lasts 17 – 30 days (23.5 days on average). By the end of the final instar, the caterpillars have grown to 40mm in length. Pupation lasts for 9 – 13 days. The pupae, dark brown in colour, are 13.5 and 15.4mm long and 4.5 and 5.3mm wide for males and females respectively. The adults live 8 – 11 days, with a pre-oviposition period of less than one day. Oviposition begins just after mating and continues for 6 days, with rarely more than one oviposition event a day. However, the first few batches account for the greatest proportion of the eggs.

**Mass-Rearing Methods**

Adults are kept in large cages of 50 x 50 x 150cm which consist of an aluminium frame and rustproof wire netting, and isolated from ants by small dishes filled with water and disinfectant. One or two polybags with *C. odorata* plants are placed inside the cage to allow the adults to oviposit. After oviposition, the egg batches are collected and kept in small containers of 11cm diameter and 400cm³ capacity, where incubation and hatching take place. Fresh leaves are placed in these containers each day. In large mass-rearing situations, the egg batches are sometimes kept inside the cages until they hatch. Later, the caterpillars are fed on fresh *C. odorata* branches whose cut ends are kept in bottles containing water (cf. Muniappan and Marutani, 1988).

To reduce handling of the caterpillars, new *C. odorata* cuttings are placed in contact with the older, almost eaten ones, to allow the caterpillars to move onto the new foliage. The old foliage is removed every two days, along with waste from the caterpillars. After completion of the larval period, the caterpillars pupate in leaves which have fallen to, or have been placed with branches on, the bottom of the cages. The pupae, which lack cocoons, are removed after sufficient hardening and kept in pails of 12 litres capacity, covered with muslin cloth, until emergence of the adults.

It is important to always keep the cages as clean as possible and provide fresh foliage regularly, in order to keep the colony healthy. After each generation the cages must be washed thoroughly and disinfected with bactericides.

**Release Methods**

For best results, it is preferable to release mated adults rather than caterpillars. For this purpose, the pupae can be easily separated into males and females on collection, using the morphological
Table 1. Percentage of *Chromolaena odorata* plants affected by *Pareuchaetes pseudoinsulata* defoliation on several oil palm estates in Indonesia.

<table>
<thead>
<tr>
<th>Estate</th>
<th>Dead</th>
<th>State of plants (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Drying</td>
</tr>
<tr>
<td>Sei Kopas (North Sumatra)</td>
<td>23.8</td>
<td>54.8</td>
</tr>
<tr>
<td>Manggala (Riau)</td>
<td>59.2</td>
<td>7.6</td>
</tr>
<tr>
<td>Gunung Batin (Lampung)</td>
<td>41.8</td>
<td>16.3</td>
</tr>
</tbody>
</table>

In the field, feeding by caterpillars causes leaves to turn yellow; this yellowing of the plants is characteristic of an outbreak of *P. pseudoinsulata*. At this stage the plant is no longer attractive to the moths, and they seek healthy plants some distance away. Over 54 months, *P. pseudoinsulata* was observed to spread and establish over a distance of 45 km, with 76, 99, 140 and 32 caterpillars per m² in *C. odorata* stands at 4, 15, 25 and 45 km respectively.

Damage to chromolaena plants was observed during major defoliation of *C. odorata* on several oil palm estates (Table 1). With such an impact, herbicide application was no longer needed. Only one slashing per year was carried out, instead of three to four per year. This reduced the maintenance cost by 75%. It is advisable not to slash *C. odorata* soon after defoliation, as higher mortality of the plants is obtained when caterpillars feed on the epidermis at the base of the plant.

**Impact on the Weed**

Observations on *P. pseudoinsulata* are difficult to make in the field, due to the nocturnal feeding habits of the caterpillars (Desmier de Chenon and Sipayung, 1996). However, leaves with large areas eaten in spots, or on the borders with only the midrib remaining, are characteristic of *P. pseudoinsulata* feeding. Such damage is easier to observe on new shoots of *C. odorata* after slashing, and on roadsides. Caterpillars are found around the bases of such damaged plants during the day, often feeding on the stem epidermis.

The leaf area consumed by a single caterpillar over its larval period of 20 - 22 days varies from 197.2 - 403.4 cm², with an average per caterpillar of 266.4 cm². In a cage with 40 of the 4th – 5th instar caterpillars, a plant of 1.4 m high was completely defoliated in 3 days. The caterpillars live gregariously, and even pupate near one another. Because they are gregarious, the young caterpillars are able to completely strip both the upper and lower epidermis of the leaves. After the leaves have been consumed, even the tips of new shoots and parts of the flowers are eaten. After attack by *P. pseudoinsulata*, only 21 – 26% of the shoots flower, compared to 88% for undamaged plants.

**Current Distribution of Pareuchaetes pseudoinsulata**

*Pareuchaetes pseudoinsulata* is well established in many locations in North Sumatra, Aceh and Riau, and is spreading into West Sumatra and Jambi. Major populations are also established in East Kalimantan and South Sulawesi, and these will help the dispersion of this biological agent around these two islands.

Massive defoliation has been observed in Aceh, North Sumatra, Riau, East Kalimantan and South Sulawesi. This is sometimes over hundreds of kilometers, as around Kutacane in Aceh, Manggala in Riau and Kuaro in East Kalimantan.

**CECIDOCHARES CONNEXA**

**Description**

This fly is strictly a gall-former on the stems of *C. odorata*. The adult males and females are 4.4 and 5.5 mm long respectively, and are blackish in colour with silver transverse bands on the posterior part of each tergite. The wings are partly transparent, with characteristic wide, oblique, dark stripes. The female has a long ovipositor.
Biology
The lifecycle of *C. connexa* is completed in 47 – 73 days, with an average of 60 days. The eggs are elongated (0.8mm long and 0.2mm wide) and translucent white in colour. The female inserts them into the stem-tips, after she has made a small incision with the chitinized tip of her ovipositor. Generally 3 – 5 eggs are placed together, but up to 16 have been found on the same growing point. A total of 53 – 69 eggs are laid by a female. The incubation period is 5 – 7 days. As the larvae or maggots develop, abnormal stem growth starts leading to the formation of a gall.

The larva has a developmental period of 20 – 30 days, with three instars. Each larva develops in a separate curved gallery in the gall. Mature larvae pulate in a tunnel behind an epidermal ‘window’ through which the adult later emerges. The final-instar larva grows to a length of 3.7mm and a width of 2.3mm.

Pupae are 4.1mm long, 2.0mm wide and rounded at the ends. They are yellow when newly formed, and turn red-brown later on. Pupation lasts for 15 - 25 days.

The adult emerges by breaking the epidermal window with its frontal bulb. Adults live for 5 – 11 days. They mate from 08h00 – 11h00, with a peak at 09h00. Oviposition takes place from 09h30 – 14h00, with a peak from 10h00 – 12h00. The female remains active in full sunshine.

Mass-Rearing Methods
Galls should be collected when an epidermal window is present, indicating that the larvae are at the end of their final instar or that the pupae have already formed. For optimal adult emergence, the galls must be incised at both ends and then split open down the middle, in order to collect the mature larvae and the pupae. These are kept in boxes to allow adults to emerge. The emerging adults are separated into males and females. Pairs are placed in glass tubes for mating and then released into cages of 50 x 50 x 150cm with a *C. odorata* plant in a polybag. Sufficient light is required for oviposition. The adults live for 5 – 11 days, with a maximum of eggs laid in the first 5 days. Mated adults can be moved onto new plants each day.

Release Methods
It is preferable to release adults to avoid spreading the pupal parasitoid, *Ormyrus* sp. (Chalcidoidea: Ormyridae). So far, the rate of parasitism by this species has not exceeded 5%. If galls are free of parasitoids they can be hung on *C. odorata* plants in the field, allowing the adults to emerge on their own. With this system, however, the pre-cut galls desiccate quickly and only a few adults are able to emerge. This method requires at least several hundred galls per release point, instead of only some tens of adults, for successful establishment of *C. connexa*.

Impact on the Weed
The galls cause distortion of the stems and reduced plant growth, especially when all the shoots are attacked. Gall size varies as a function of the meristematic activity of the growing point of the stems and not according to the number of larvae per gall. On average a gall is 16 – 17mm long and 11 – 12mm wide, but galls on lateral stems are generally smaller than galls on the main stem.

After three months, *C. odorata* plants in polybags, onto which five pairs of adults had been released on three successive occasions, showed a stem elongation of 70 – 85cm, compared to 224 – 244cm for the controls.

On an oil palm estate, the number of galls observed in 10 minutes increased from 11 at 110 days to 79 at 290 days and 212 after 628 days (10 generations) after release. On another plantation, the percentage of stems with galls at four localities, 14 months after release, was 30.4, 52.3, 31.7 and 32.3%, and 6 months afterwards 93.3, 90.2, 79.3 and 100% respectively. Sometimes several galls were present on the same stem, with new shoots often emerging from the gall itself. Frequently, however, under such conditions, such damage leads to a dieback of the plants.

An adult fly can reach plants as far as 500 – 800m from its natal plant during its lifetime. A *C. connexa* population can become established 90m from a release point in 110 days, 400m in 219 days, 2km in 330 days and 5km in 479 days. After 3 years it can be found up to 50km away, and after 5 years up to 200km.

Distribution of *Cecidochares connexa*
At present, after 5 years and intensive releases, *C. connexa* is well established in Sumatra (Aceh, North Sumatra, Riau, Jambi, West Sumatra and Lampung). Although a few galls (2 – 5%) are parasitised by *Ormyrus* sp., or sometimes damaged by a *Tetraponera* sp. (Formicidae: Pseudomyrmecinae), which destroys the larvae and pupae inside the galls, *C. connexa* continues, slowly but consistently, to spread. The species is also well established on *C. odorata* in oil palm plantations in South Kalimantan and South Sulawesi.

The insect has been released in Java, Lombok, Sumbawa, Flores, Timor and Irian Jaya, from cultures taken from Marihat. Despite the drier weather conditions on some of these islands,
C. connexa has established and appears to be spreading.

**ACTINOTE ANTEAS** (see also Desmier de Chenon et al., this Proceedings)

**Description**
This butterfly, with an average wingspan of 56.1mm in males and 63.4mm in females, is bright brownish-orange in colour with black spots. A black band is present on the costal border of the forewing. It is connected to a wide transverse black band on the distal two-thirds of the wing. The end of the wing is also completely black. The hindwing is orange in colour, except for the veins, which are black. It has a wide black band on its border. Males are paler in colour than the females.

**Biology**
The lifecycle of *A. anteas* is completed in 73 – 102 days, depending on the temperature. The oval eggs, which are initially yellowish-green, vary as a function of their age from 0.62 – 0.70mm in length and 0.48 – 0.50mm in width. They increase in size after 5 days and become reddish in colour. Eggs are laid in batches of 116 – 718 eggs (on average 470 eggs). The incubation period is 10 – 15 days, with an average of 12.

The caterpillars are yellowish in the first instar, becoming greyish in colour and spiny in the later instars. Young larvae live gregariously in colonies protected with a netting of silk until the fourth instar. In the fifth instar they tend to disperse. The larval period lasts from 63 – 67 days.

Pupation lasts for 9 – 12 days. The pupae are pale grey and spiny, and hang from leaves and stems.

When feeding on *M. micrantha*, *A. anteas* has a shorter lifecycle (90.7 and 96.7 days for males and females respectively). The fecundity is similar, and the caterpillars are able to return to feed on *C. odorata* and *vice versa* even after 14 generations.

**Mass-Rearing Methods**
As they emerge, adults are placed in a large cage with several *C. odorata* plants in polybags, to allow them to fly and to lay eggs directly on fresh leaves. Adults require bright light and high temperatures before they will mate, and oviposition peaks in the morning. Successful matings last several hours, or even throughout the night. Eggs which are laid in a scattered fashion rather than in compact batches are generally infertile and a consequence of unsuccessful mating.

The eggs are very fragile and should be left to hatch on the leaves on which they have been deposited. They desiccate easily if the leaf with the batch is removed from the plant. After the second instar they can be fed on *C. odorata* cuttings in smaller, 0.5 x 0.5 x 1.2m cages. Defoliated branches should be left in the cage to give the caterpillars a support to hang from when pupating.

For mass production it is best to keep the adults outside the insectary in large cages with 10 – 20 *C. odorata* polybags. The 1.5 x 1.5 x 1.2m cages are covered with brown plastic netting. Under high light conditions such as these, mating occurs more easily and the adults lay eggs directly on the plants in the cage. The caterpillars can also be reared outside in these or bigger (1.5 x 3.0 x 1.2m) cages, but predators which are able to penetrate the cages have to be destroyed regularly. As a precaution against losing the culture through predation, part of it should always be kept in well-protected cages.

**Release Methods**
The third to fifth instar caterpillars should be released in their thousands to overcome predatory pressure. Predators include the bug *Sycanus leucomesus* Walk. (Hemiptera: Reduviidae) and wasps, which attack both the caterpillars and adults.

Adults should be released early in the morning so that they do not disperse widely from their release locality. It seems that the caterpillars, after initially being attacked by wasps, are attacked less later on, probably because they produce a repellant, toxic liquid. More studies need to be done in order to understand the behaviour of *A. anteas* in the field. So far, only the establishment of this insect has been investigated in the field.

**Impact on the Weed**
In both the insectary and the field, defoliation of *C. odorata* plants by the young caterpillars is very characteristic. The upper and lower epidermis is stripped, and the leaves hang limply down. Massive defoliation is sometimes achieved in the field, allowing other plants to replace this weed. *Actinote anteas* thus appears to be a good candidate for the control of *C. odorata*.

However, establishing *A. anteas* has proved difficult. Although egg batches of the generation following release have been found on *C. odorata* leaves, the caterpillars or adults subsequently disappear. Adults have been found flying under bushy vegetation rather than in sunny areas, and some egg batches have been found on *C. odorata* growing in such places. In the field, pupation often does not take place at feeding sites, but on the higher branches of other plant species. The adults also seem to disperse widely.

**Distribution of Actinote anteas**
Field releases of this biological agent are in
progress. However, more studies have to be carried out in order to establish \textit{A. anteas} in large populations in the field and to compare its feeding activities on \textit{M. micrantha} (Desmier de Chenon et al., 2000).

CONCLUSIONS

We have succeeded in importing, rearing and releasing three biological agents. \textit{Pareuchaetes pseudoinsulata}, \textit{C. connexa} and \textit{A. anteas} have been tested under quarantine conditions, their biology and behaviour studied, and methods for mass rearing developed. Release methods have been established for the first two species. Therefore, with these three biological agents creating a wider complex of natural enemies, better control of \textit{C. odorata} can be obtained.

Massive defoliation by \textit{P. pseudoinsulata} has been observed in Sumatra and Kalimantan, but this is sporadic, in contrast with the consistent damage to the weed by the stem-galling \textit{C. connexa}. \textit{Pareuchaetes pseudoinsulata} and \textit{C. connexa} are now well established together in many localities in Sumatra with a major impact on \textit{C. odorata}, leading to the decrease or often the elimination of this weed. In plantations, this association of \textit{P. pseudoinsulata} and \textit{C. connexa} can result in avoidance of the use of herbicides against \textit{C. odorata}, reducing the cost of maintenance by more than 75\%. \textit{Actinote anteas} is also promising, but more field-based studies need to be undertaken in order to understand the behaviour of this insect and to obtain establishment.

Following the interesting and effective results achieved during 10 years of research on the biological control of \textit{C. odorata} at IOPRI, more releases of these three biological control agents are necessary and new insects (Cruttwell, 1974), which have a permanent rather than occasional impact, like \textit{C. connexa}, must be imported. Because IOPRI (Marihat) continuously mass-rears these three biological control agents, it can supply them to countries, research centres, plantations and other establishments with official import permits, for the biocontrol of \textit{C. odorata}.

ACKNOWLEDGEMENTS

Funding from ACIAR and the support of Dr Rachel E. Cruttwell McFadyen (Alan Fletcher Research Station), leader of this project on the biocontrol of \textit{C. odorata}, are gratefully acknowledged. We are pleased, as an oil palm institution, to have kept the tradition of oil palm research involved from the very beginning in the biological control of \textit{C. odorata}. It was initiated by the Nigerian Institute for Oil Palm Research (NIFOR) in 1966, later supported by IRHO in 1989, and finally by IOPRI during the past decade.
REFERENCES


Mr Chairman, honoured guests, ladies and gentlemen, welcome to this workshop and to KwaZulu-Natal – especially to those of you from overseas who are visiting us for the first time. I hope that your stay in our province and in South Africa will be memorable and enjoyable, and that we will have the opportunity of welcoming you back many times in the future.

I cannot overstress the importance to us of the subject matter you will be discussing while you are here. Chromolaena is a very serious problem for us in KwaZulu-Natal, impacting badly on both our agricultural output and the natural resources which are at the core of our nascent tourism industry. You may already have noticed the southern African form of chromolaena growing all around Durban and Umhlanga.

Agriculture and tourism are vital components in our quest to uplift the regional and national economy, and in turn create a better quality of life for our people. Chromolaena is a very real impediment to achieving those objectives. We will therefore be following the proceedings of your workshop with intense interest, in the justifiable hope that you will come up with new insights into how the scourge of chromolaena can be contained. Your four previous workshops have made an invaluable contribution to the achievement of this goal, and I have no doubt that this week’s proceedings will add further impetus. This is the second time you have elected to hold your workshop in Africa.

You are all too familiar with the threat that chromolaena presents internationally to agriculture and biodiversity, but I would like to touch briefly on the specific impacts here in KwaZulu-Natal, and then put this in the context of our vision for environmental and agricultural development in the province.

Chromolaena was first recorded around Durban in the 1940s and from there spread rapidly throughout the province. As a matter of interest, it has diverse names in our principal languages here. In English it is known as ‘triffid weed’ – after the walking, human-devouring plants in John Wyndham’s 1950s novel ‘The Day of the Triffids’; in Zulu, it is known as ‘isandansezwa’ – meaning smallpox; and in Afrikaans, it is ‘paraffienbos’, or ‘paraffin bush’ – due to its flammability.

Different names, identical problems. Chromolaena interferes with biodiversity and nature conservation, and consequently on agriculture, ecotourism and hunting. It smothers vegetation and thereby causes the collapse of ecosystem functioning in grassland, savanna and forest. It is considered to be one of the most serious environmental threats inside and outside our coastal region, and although we have spent many millions on control, we have been able to clear only relatively small areas. In agriculture, it impacts on pastoral farming – from commercial to small-scale and subsistence levels; on forestry plantations; on the margins of fields and along watercourses on cropping farms.

It is more of a problem for small-scale farmers and for rural communities in that they have neither the resources (the chemicals), nor the expertise to control it effectively. Farms which once belonged to the state or commercial farmers and which are now being taken over by community operators, are often so infested by chromolaena as to render them largely unusable. What we need is a more coordinated approach to clearing; more research funding; more education and awareness about the problem; and the introduction of a range of biocontrol agents that will restore the natural balance – without chromolaena as a prominent feature of the landscape.

The extent of our problem emphasizes the importance we place on your presence here this week and the faith we have in your workshop to make progress towards a lasting solution.

As I said earlier, chromolaena presents a very real threat to the realisation of my department’s vision for the agricultural and environmental future of this province. Let me explain to you what we have in mind, and you will understand my concerns about chromolaena. We have set as an objective a fourfold increase in overall agricultural production over the next 20 years. As commercial agriculture is already highly developed and productive, obviously we intend focusing strongly on small-scale producers because that is where the greater potential for expansion lies. We call this programme ‘Vision 2020’.

You may well ask if this is a realistic target – a fourfold increase in agricultural production in only 20 years. Let me put it this way. KwaZulu-Natal for the most part has good soils, high rainfall and a strong river system. Yet it produces way below its potential, mainly because proper development of the deep rural districts has been neglected over very many years. In this new political era we are...
determined to reverse that. Agronomists of my department calculate conservatively that if the area under traditional control, plus the state land in this province, were developed to the optimum, overall agricultural production could increase by 366% by the year 2020. That would increase the contribution of agriculture to gross geographic product to R 18 billion a year from its current R 5 billion. The benefits would obviously be enormous.

The question is: how do we get there from where we are today? The first principle was to adopt a calibrated approach, a step-by-step progression to the completion of a long journey. One of the first of those steps was to establish a programme which in Zulu we call ‘Xoshindlala’ – Chase Away Hunger. This has the dual objective of achieving food security through small production projects throughout the province, and of getting people in the deep rural districts into a mode of self-sufficiency through agricultural and agriculture-related projects. We have budgeted R 142 million for Xoshindlala over the next three years and already more than 1 000 projects are in production or close to it.

The next step is to stimulate cluster development. In natural nodes of human interaction – schools, clinics, trading stores for instance – we facilitate such activities as sewing or baking clubs, to generate modest economic activity. Where appropriate we will establish a departmental Information Centre. We intend also facilitating agreements between local communities and the tractor companies for the establishment – at the appropriate cluster – of mechanisation centres each to serve a somewhat wider community. Our intention is that, wherever feasible – the criteria mainly being quality and reliability of local production – agri-industry enterprises should be established, providing a market on the spot for small-scale growers plus some employment.

To meet the vital need for funding, my Department was instrumental last year in forming the KwaZulu Natal Agricultural Development Trust, a 50/50 partnership with influential private sector interests. The Trust is designed to be a reliable conduit for funding from overseas governments and the international donor community for particular projects in the province.

More recently, my department has been granted power of attorney to settle new farmers on substantial tracts of state land in this province, either by sale or lease. We also intend driving a process of farmer settlement on commercial farmland on the willing seller/buyer basis. This represents possibly the single most important development opportunity yet created for the emerging agricultural sector.

Ladies and gentlemen, you will have gathered from this broad overview that my department is taking its agricultural, environmental and developmental responsibilities very seriously. We are committed to the realization of our Vision 2020 programme, and if chromolaena represents an obstacle, then it is an obstacle we shall surmount.

We have the will. You have the expertise. Together we will succeed.

I thank you for your attention.

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23 October 2000
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Fifth International Workshop on Biological Control
and Management of Chromolaena odorata
ECOLOGICALLY SUSTAINABLE CHROMOLAENA ODORATA MANAGEMENT IN GHANA IN THE PAST AND PRESENT, AND THE FUTURE ROLE OF FARMERS’ FIELD SCHOOLS

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Chromolaena odorata was introduced into Ghana in the late 1960s and quickly established itself, infesting large tracts of arable land and becoming the worst weed problem for resource-poor peasant farmers. Early attempts at control were mainly manual. It was either cut to ground level and burnt or the stems and subterranean portions were uprooted and burnt. Few commercial and medium-size farmers attempted the use of weedicides.

Biological control of this weed in the 1970s was not successful. However, the project initiated in 1989 has established Pareuchaetes pseudoinsulata in the field. The objective of the project is to reduce populations of C. odorata to levels below economic damage. The biological control activities which have since remained the domain of research scientists are now set to embrace farming communities through the Integrated Pest Management/Farmer Field Schools (IPM/FFS) concept, recently introduced into the country. Already 106 extension agents and 2 470 farmers across the country have been trained and will facilitate further releases and monitoring. The involvement of farmers in the spread of the bioagent, P. pseudoinsulata, is comprehensively discussed, and will conform to the current policy of decentralization and focus of agricultural and rural development programmes of the government of Ghana.

KEY WORDS: agriculture, biological weed control, extension, Integrated Pest Management, Pareuchaetes pseudoinsulata

INTRODUCTION

Chromolaena odorata (L.) King and Robinson (Asteraceae), otherwise called Siam weed, was reported in Ghana in the late 1960s by Hall et al. (1972). The observation of this weed in the country generated a lot of controversy, with accusing fingers being pointed at various organizations for deliberately importing it either to check erosion or to suppress noxious weeds under high-tension electricity cables and telephone lines. Though the accusations were promptly denied by the institutions concerned, the impact of the introduction has been far-reaching.

Demerits and Merits

Chromolaena, however, has some agronomic benefits and impacts positively on soil fertility. Tie Bi (1995) indicated that the impact on maize production in the rainy season is comparable to that of mineral fertilizers; and farmers also have it that groundnut, tobacco and cassava crops grown on C. odorata fallow lands give higher yields. The indications are that the introduction of C. odorata has decreased fallow periods from 10 to 3 years.

The medicinal properties of C. odorata are also worth mentioning in that the fresh juice extract of
C. odorata leaves is said to cure eye and stomach diseases, heal wounds and stop excessive bleeding.

Despite some seemingly beneficial aspects of C. odorata, the ecological threats and hazards posed to farmers and the environment necessitate its control.

METHODS OF CONTROL

Past and Present

Manual
In the traditional farming systems, the major implements of cultivation have been the trusted companions of cutlass and the hoe. Two slightly different methods of manual control may be recognized in the case of C. odorata. One method simply involves using the cutlass to cut down the C. odorata plant. The weeded plants may then be heaped and burnt. This has been the traditional practice among cereals, legumes and vegetable cultivation including maize, millet, sorghum, cowpea, bambara beans, tomatoes, pepper, okra and eggplant. This type of land preparation also applies to cash crops such as tobacco, coffee and oil palm.

The other manual clearing practice is to cut down the C. odorata plant with cutlass and remove the subterranean portions with the hoe. Both the aerial cut portion and the uprooted roots are heaped and burnt. This has been associated with land preparation for mainly the cultivation of root and tuber crops, including cassava, sweet potatoes, yams and cocoyam.

On large-scale mechanized farms the stumps are ploughed, harrowed and uprooted. In all practices, farmers need between three and six rounds of maintenance per year. The initial clearing and subsequent maintenance is done either by a solitary farmer or the family. However, hired farm labour is engaged on large farms.

Chemical
Chemical control of C. odorata is mostly associated with the medium-scale and the large-scale, mainly commercial, farmers who cultivate more than 2ha. Herbicides used in C. odorata control in Ghana are mainly Gramoxone, Glyphosate and Atrazine. Other herbicides occasionally found in use include Folar and 2-4D amine. In all cases application dosage ranges from 2 – 5 litre/ha.

Biological Control
The ecological threats and hazards posed to farmers and the environment necessitated attempts at biological control. The beginnings of biocontrol attempts, initiated by the Crops Research Institute (CRI) of Ghana in the 1970s, were not very successful. However, a more purposeful project was started by the CRI in 1989, aimed at reducing C. odorata populations in infested regions of Ghana below economically damaging levels, as well as preventing its further spread and reducing its competitiveness with other flora to enhance biodiversity.

The main focus of the research work is on the mass breeding of the lepidopteran bioagent Pareuchaetes pseudoinsulata Rego Barros (Lepidoptera: Arctiidae) in the laboratory, field releases and post-release monitoring. The bioagent has since (1994/1995 onwards) been released into the open fields, and a national survey indicated that P. pseudoinsulata has spread to the Eastern, Central, Western, Volta, Ashanti and Brong Ahafo regions of Ghana, with considerable damage to C. odorata in some localities. The activity of P. pseudoinsulata in such localities have been found to reduce the competitiveness of C. odorata, giving rise to the growth of new plants (Timbilla et al., these Proceedings) and thus improving on biodiversity and reducing the cost of farm maintenance.

The major hindrance to further releases of P. pseudoinsulata in the field and its subsequent monitoring has been financial. Research has not been able to attract enough donor funding for further releases and for effective and sustained post-release monitoring. Attempts will therefore be made to involve farmers themselves in the further releases of the bioagent and the monitoring and evaluation of its spread and impact, through the recently introduced Farmers’ Field Schools (FFS).

FARMERS’ FIELD SCHOOLS

The FFS training methodology originated from the FAO Intercountry programme in Asia, where it has been used to train over one million rice farmers. The focus is on the production of a healthy crop without or with very minimal use of chemical pesticides. In Ghana, FFS has been embraced as an emerging extension tool, with the realization that future agricultural growth for resource-poor peasant farmers must be knowledge based, to deal with specific problems. Emphasis is placed on facilitating learning processes, continuous observation and feedback from the local environment, and enhancing the decision-making capacity of farmers.

Consequently, the Integrated Pest Management (IPM)/FFS training distinguishes itself from conventional extension packages by its participatory and farmer-centred approach. Farmers gain a fundamental understanding of the agro-ecosystem, on which they base their own crop management decisions.
TRAINING OF TRAINERS (TOT)

The IPM/FFS training methodology is dependent on season-long Training of Trainers (TOT) who then become expert facilitators in the training of farmers at FFS. The training starts basically, with the selection of a specific crop. For example, an initial pilot project on irrigated rice brought together 28 extension personnel who were camped in a school at an irrigation site and went through a season-long residential training. The facilitators were imported from Asia where the IPM/FFS concept originated. However, the season-long training has since been modified so that trainees are invited to the school at specific growth stages of the crop, in order to reduce cost.

Subsequently the concept is now being progressively applied to Ghana's agriculture. To date plantain, cassava, cowpea, tomatoes and cabbage have also been handled.

In the course of a TOT programme, participants collect baseline data which involves a survey of crop problems and farming practices, during which interviews are conducted among farmers, extension staff and research scientists. Researchers working on *C. odorata* are critical in the dissemination of information on the biological control of the weed.

The following are important components of the TOT programme:
(i) Trainees at a TOT programme on the biological control of chromolaena shall source available research information on *C. odorata* and *P. pseudoinsulata* from the research scientists to serve as reference material.

(ii) Researchers shall provide trainees with practical information on:
- Biology and habitats of *C. odorata*.
- Biology of *P. pseudoinsulata*.
- Mass breeding, field releases and monitoring of *P. pseudoinsulata*.

(iii) Study of indigenous natural enemies of *C. odorata* (insects and diseased samples). This involves:
- Observation and collection of insects from various parts of *C. odorata* (including collections from the leaves, flowers, stems and roots) into jars.
- Identification of the insects and diseases.
- Grouping of insects into pests and natural enemies.
- Setting up of insect zoos: seedlings of *C. odorata* are raised in pots and shielded with mesh. Individual insect species are placed on the plants in different zoos and observed. Daily recordings are made on the activities of the insects on the plants. This will establish any damage caused to the plant by any particular insect.
- Microbial pathogens collected from the field shall be identified in research laboratories and tested for host specificity and eventual mass production (long term project for research).

(iv) The lifecycle of *P. pseudoinsulata* taught to trainees should include information on:
- The egg mass
- Instar stages
- Pupae
- Adults

(v) Insect zoos containing potted *C. odorata* seedlings are then set up and the different stages of *P. pseudoinsulata* are introduced into different zoos; and daily observation of such processes will enable trainees to observe the damage inflicted by the larvae on *C. odorata*.

(vi) Insect zoos utilizing different plant seedlings are set up to enable trainees to note that *P. pseudoinsulata* is host specific and thus a good biological control agent.

AGRO-ECOSYSTEMS ANALYSIS

In IPM, the major concern is with the environment in which the crops are cultivated (Youdeowei and Akatse, 1999). Consideration is given to factors that influence the growth and development of the crop such as the soil, water, sunshine, rainfall, plant nutrients, pests, diseases and natural enemies.

An analysis of the interactions between these environmental factors is what has been referred to as Agro-Ecosystem Analysis (AESA) and provides useful and rational information at different growth stages of the crop. AESA thus provides a useful tool for farmers to take informed and appropriate crop management decisions.

In the FFS each group of farmers should ideally not exceed 25, and are put into five equal-sized working groups.

Each working group collects insects, spiders, diseased specimens and eggs on *C. odorata* thickets into vials for observation and preservation. The collection of insects could be facilitated by the use of sweep nets. Specimens collected in the sweep nets are transferred into polythene bags for further observation in the field school as follows:
- Place the eggs collected into vials and observe what will hatch out from the eggs.
- Identify the insect specimens in the polythene
bags and those that eventually hatch out from the eggs in the vials. It should be assumed that eggs, larvae and or adults of *P. pseudoinsulata* previously released into the field, would be observed and collected for identification. Otherwise vials containing eggs, larvae and adult specimens of *P. pseudoinsulata* should be added to the farmers' own collections.

- Insect zoos are then constructed and the identified insect specimens (including larvae of *P. pseudoinsulata*) are carefully introduced into different zoos and daily observations are made and recorded. Such daily observations will reveal the damage done to *C. odorata* by the larvae of *P. pseudoinsulata*.

**Releases and Monitoring**

Farmers shall carefully remove portions of stems on which larvae are feeding and carefully hang them on *C. odorata* thickets on their own farms or other fallow lands in their communities. Farmers are then encouraged to report their own introductions, and the names of new areas where eggs, larvae and or adults of *P. pseudoinsulata* have spread to and colonized, to their Agricultural Extension Agents. The data so collected could be fed into the established national networking system.

**TRAINED FACILITATORS/FARMERS**

A series of IPM Training of Trainers courses combined with FFS were organised under the FAO-

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**Table 1.** National distribution of IPM trainers.

<table>
<thead>
<tr>
<th>Region</th>
<th>Crop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice</td>
<td>Vegetable</td>
</tr>
<tr>
<td>Greater Accra</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Volta</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Ashanti</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Eastern</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Western</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Central</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Upper East</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Northern</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Brong Ahafo</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Upper West</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>39</td>
<td>52</td>
</tr>
</tbody>
</table>

**Table 2.** National distribution of IPM/FFS farmers.

<table>
<thead>
<tr>
<th>Region</th>
<th>Crop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice</td>
<td>Cassava</td>
</tr>
<tr>
<td>Greater Accra</td>
<td>405</td>
<td>-</td>
</tr>
<tr>
<td>Volta</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Ashanti</td>
<td>-</td>
<td>110</td>
</tr>
<tr>
<td>Eastern</td>
<td>120</td>
<td>45</td>
</tr>
<tr>
<td>Western</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>Central</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>Upper East</td>
<td>340</td>
<td>-</td>
</tr>
<tr>
<td>Northern</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Brong Ahafo</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Upper West</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1 085</td>
<td>300</td>
</tr>
</tbody>
</table>
funded pilot project and a UNDP-funded Agro Skills Development project as component of a National Poverty Reduction Programme (NPRP). Trained extension staff, after their TOT training, proceeded to their own operational areas to train farmers in FFS. By the end of 2000, some 106 extension agents had been trained in separate season-long training of trainers courses and 2,470 farmers (Afreh-Nuamah, 1999) passed through FFS (Tables 1, 2). Each trained facilitator is expected to conduct two FFS per season, whereas graduating farmers are to facilitate the transfer of the technology to their neighbouring colleagues. These IPM/FFS graduates, equipped with the appropriate knowledge through further training (at their normal regular periodic meetings), could assist in the transfer of the technology on the biological control of *C. odorata* to other farmers throughout the country. The involvement of the farmers themselves will thus greatly reduce the financial constraint on the execution of the programme.

**OTHER PROGRAMMES**

A number of ongoing programmes with IPM components had been identified and could assist in organizing more FFS. These programmes include the Root and Tuber Improvement Programme (RTIP), Lowland Rice Development Project (LRDP), Special Programme for Food Security (SPFS) and the Integrated Crop Protection (GTZ/ICP) programme. The combined efforts of such programmes, spread nationwide, will greatly enhance the national dream of expanding the programme on the biological control of *C. odorata*.

**CONCLUSION**

A national IPM Secretariat recently created at the Ministry of Food and Agriculture and headed by a National IPM Coordinator could greatly facilitate the national effort on the biological control of *C. odorata* through the FFS concept. Certainly the active involvement and participation of farmers, the ultimate stakeholders, in the further spread and monitoring of *P. pseudoinsulata* in the management of *C. odorata* is an untapped potential.

**ACKNOWLEDGEMENTS**

The Centre Technique de Coopération Agricole et Rurale (CTA) is thanked for providing funding for the author to attend the Fifth International Workshop.

**REFERENCES**


The gall fly, *Cecidochares connexa* has been imported to the Philippines from Indonesia for biological control of *Chromolaena odorata*. The fly oviposits into the tender shoots of the host plant. Galls start to appear within 12 – 15 days after oviposition. Windows appear on the gall one month after oviposition and attain a maximum width of 9.7mm and length of 13.7mm. Each gall contains from 2 – 10 pupae. Galls were harvested about a week after the appearance of windows. Adults start to emerge from the 51st day onwards. As many as 107 galls were recorded from a single *C. odorata* host plant. Host die-back was observed during heavy infestation. Host-specificity tests on selected plants showed no oviposition or galls formation.

**KEY WORDS:** biological weed control, lifecycle, host specificity, Tephritidae

**INTRODUCTION**

*Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae), known locally as ‘hagonoy’, has invaded agricultural fields, rangelands, forests, plantations and marginal areas of the Philippines. For rangelands and coconut and other plantations, the rapid invasion of the weed has had a severe impact in terms of decreased carrying capacity. It is unpalatable and, when ingested by cattle, causes diarrhoea. In extreme cases death has been reported (Sajise et al., 1974).

This weed was reported to have been introduced into the Philippines in the early 1960s (Pancho and Plucknett, 1971). It spread throughout the country from the southern provinces towards the north. Since then, control of *C. odorata* has been an integral component of agricultural cultivation.

In the Philippines, a serious attempt towards biological control of *C. odorata* was initiated in 1993 when the moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae), previously discovered on the Philippine island of Palawan, to which it had possibly been accidentally introduced from Sabah, was found to heavily defoliate the weed. However, later mass rearing and field release of this insect did not result in high field populations or much defoliation.

Biological control of *C. odorata* in Indonesia has been gaining ground since *Cecidochares connexa* Macquart (Diptera: Tephritidae), a gall-forming fly, was imported from South America into quarantine in North Sumatra in 1995. Since then it has spread widely, with significant galling and growth suppression of *C. odorata* (Desmier de Chenon et al., this Proceedings).

In this paper we report on the importation of *C. connexa* into the Philippines from Indonesia, and on host-specificity testing and other observations in the Philippines.

**MATERIALS AND METHODS**

**Importation of the Gall Fly *Cecidochares connexa***

An application for a permit for the importation of *C. connexa* was filed with the Plant Quarantine Service of the Bureau of Plant Industry with copies of all the available literature. The quarantine containment facilities were checked to ensure that safety measures were in place and conformed to safety standards and quarantine regulations.

**Mass Rearing of *Cecidochares connexa***

Emerging flies were immediately contained in small medicine vials for mating. Moistened cotton wool served as plugs to prevent escape. Mated flies were introduced in pairs into oviposition cages in the quarantine insectary. The cages contained from 2 – 4 host plants. Water, virtually the only substance the flies feed on, was sprayed regularly into the cage. Honey was occasionally offered as alternative food for adults. From six to 12 pairs of mated flies were introduced into each cage and kept in the cage for 2 – 3 days. After this time the potted host plants were taken out to the adjoining screen house for exposure to sunlight, to allow normal growth and development of the galls. As soon as the galls had enlarged, and ‘windows’ appeared (a
tunnel created by the mature larvae for the escape of adult flies during emergence, leaving only a parchment-thin layer on the gall surface), they were harvested and brought back to the insectary.

**Host-Specificity Tests**
Trials were conducted from August 1999 to March 2000 at the quarantine containment facilities of the PCA-Davao Research Center. No-choice and choice tests on the NCBP-prescribed host-plant species were conducted over a 6-month period. Tests were replicated 10 times, except for *Vitex negundo* L., with only six (Table 1).

**No-choice Tests**
Cages of 0.3 x 0.3 x 0.6m were used to contain, individually, the different host plant species. Three mated pairs of flies were introduced into each cage. They were kept in it for 3 days before being retrieved and either used for mass rearing or destroyed. *Chromolaena odorata* was placed in a separate cage as a control.

**Choice Tests**
An array of host plant seedlings of species prescribed for testing by the National Committee on Biosafety of the Philippines (NCBP), at most 0.51m high were placed all together in big cages measuring 0.6 x 0.6 x 0.76m. At least five pairs of flies were introduced into the cage each time. After the experiment was terminated, the flies were destroyed. *Chromolaena odorata* was always placed in the cage with the other plant species in this series of tests.

**Longevity Test**
Newly emerged flies were placed individually in medicine vials. Longevity was measured for (i) males only and (ii) females only, with twelve replicates.

**Preliminary Test on Control of *Chromolaena odorata* by *Cecidochares connexa* under Confinement**
To simulate field conditions, a preliminary test was set up using a 2.4 x 2.4 x 2.4m cage constructed inside a screen house. One hundred pairs of adult flies were introduced onto 15 healthy polybagged *C. odorata* plants. A similar set of untreated control plants was also set up inside the screen house.

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**Table 1.** Results of host-specificity tests on *Cecidochares connexa*.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Family</th>
<th>n</th>
<th>No-choice test</th>
<th>Choice test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hagonoy</td>
<td><em>Chromolaena odorata</em></td>
<td>Asteraceae</td>
<td>10</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Sambong</td>
<td><em>Blumea balsamifera</em></td>
<td>Asteraceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Damong maria</td>
<td><em>Artemisia vulgaris</em></td>
<td>Asteraceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manzanilla</td>
<td><em>Chrysanthemum indicum</em></td>
<td>Asteraceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sunflower</td>
<td><em>Helianthus annuus</em></td>
<td>Asteraceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ipil-ipil</td>
<td><em>Leucaena leucocephala</em></td>
<td>Asteraceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Narra</td>
<td><em>Pterocarpus indicus</em></td>
<td>Fabaceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mahogany</td>
<td><em>Sweitenia macrophylla</em></td>
<td>Meliaceae</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lagundi</td>
<td><em>Vitex negundo</em></td>
<td>Verbenaceae</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 2.** Results of preliminary trials on control of *Chromolaena odorata* by *Cecidochares connexa* under confinement.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean no. of branches per plant (n = 15 plants)</th>
<th>% branches galled</th>
<th>% die-back of total branches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed to flies</td>
<td>8.46</td>
<td>73</td>
<td>43</td>
</tr>
<tr>
<td>Flies excluded</td>
<td>6.80</td>
<td>0</td>
<td>4.4</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Importation of Cecidochares connexa
Having complied with all quarantine regulations, the gall fly was imported in May 1999. Four hundred and forty four galls containing pupae were collected on the outskirts of Marihat Research Station, North Sumatra. Only galls with windows were collected. The cargo was securely packed to prevent possible escape of flies en route to the containment facility. The cargo was properly documented at the quarantine office upon entry in to the Philippines. In the quarantine room, the cargo was unpacked inside an emergence chamber. The flies were provided with sprayed water. A total of 17 chalcid parasitoids was collected and preserved.

Mass Rearing
As early as 12 days after exposure to adults, galls started to form on the host plant. The growth of the shoot above the gall was considerably reduced. Rosetting of the terminal growth, an indication of slowed growth of the infested part, was apparent. Galls reached a maximum width of 9.7mm and length of 13.4mm, and each contained 2 – 10 pupae. It took about a month for a gall to develop windows. Harvesting of the galls was done a week after the appearance of windows, to anticipate early emergence. The galls were dissected and pupae kept in plates inside an emergence box.

First-generation flies appeared to have acclimatized easily, since nothing unusual about the population was noted, in terms of health, abnormalities, or death upon emergence. The flies were found to be so prolific that the population had to be regulated to limit oviposition, to allow for easier management under quarantine.

Host-Specificity Tests
In all trials of both no-choice and choice tests, gall formation occurred only on C. odorata (Table 1), with a range of 12 – 15 days before gall appearance on this species. The results of these tests confirm that C. connexa is highly host-specific on C. odorata, and are in conformity with the tests conducted by Sipayung and Desmier de Chenon (1994).

Longevity Study
Initial trials on the longevity of C. connexa showed that females outlived the males. Males lived from 4 – 9 days, with an average longevity of 6.41 days, while females lived from 6 – 14 days, with an average of 11.6. This study provides an indication of the number of egg-laying days available to female flies.

Control of Chromolaena odorata by Cecidochares connexa under Confinement
After a single release of 100 pairs of adult flies, results show that over 6 months, 73% of the branches developed galls and 59% of these branches died. On the other hand, the untreated plants had zero infestation and a die-back of 4.4%, which was due to natural causes (Table 2).

Conclusion
Colonization of C. odorata by C. connexa in the field and its subsequent suppression should eventually allow the regrowth of beneficial plants in coconut and other plantations and the grass to grow in rangeland used for livestock rearing. It will also reduce the fire hazard caused by C. odorata thickets during the dry season in these rangelands.

The costs of agricultural production would decrease correspondingly, since C. odorata would be relegated to a lower significance level and may not require priority action for control.

ACKNOWLEDGEMENTS

The Australian Centre for International Agricultural Research is thanked for providing funding for attendance of the first author at the Fifth International Chromolaena Workshop.

REFERENCES


**INTRODUCTION**

*Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae) is a bushy shrub that is invasive throughout the subtropical parts of South Africa (Henderson, 1995). It originates from South and Central America and forms dense impenetrable thickets that displace other vegetation and creates fire hazards due to its flammability. Until recently, biocontrol programmes on this weed have focused primarily on the use of arthropods with little or no consideration of fungal pathogens as biological control agents. In South Africa, a programme looking at biological control of *C. odorata* was initiated in 1988. Attempts to establish several insect agents have already been made and other potential insect agents are currently being investigated. Several pathogens have been reported on *C. odorata* in recent years and as a result several exploratory survey trips to south, north and central America were undertaken from 1988 until 1997 to record and collect pathogens on *C. odorata*. A number of isolates of several pathogens were collected and screened against South African *C. odorata* plants. The most important fungal species identified were *Pseudocercospora eupatorii-formosanii*, *Mycovellosiella perfoliata*, *Colletotrichum*-like isolates, and *Septoria ekmaniana*. This paper reviews the biological control programme against *C. odorata* using pathogens, including (i) the pathogenicity of the isolates on South African chromolaena; (ii) initial results of host range testing of selected candidates and (iii) the potential impact of the pathogens.

**KEY WORDS:** *Anhelia*, biological weed control, *Cionothrix*, *Mycovellosiella*, *Pseudocercospora*, *Septoria*

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**INTRODUCTION**

*Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae) is a bushy shrub that is invasive throughout the subtropical parts of South Africa (Henderson, 1995). It originates from South and Central America and forms dense impenetrable thickets that displace indigenous vegetation and create a fire hazard due to its flammability. It is a problem in forestry, agricultural and conservation areas and could become a problem in disturbed areas cleared of other weeds or vegetation. Although the plant is easy to control chemically and mechanically, the vast number of seeds it produces makes this economically infeasible (Zachariades et al., 1999). Biological control of chromolaena in South Africa was initiated in 1988, with three insect agents having since been released, and the evaluation of several other insect agents currently being undertaken (Zachariades et al., 1999). However, it is only during the past decade that the potential of using plant pathogens as biological control agents against chromolaena has been considered, even though this weed has been the subject of several biocontrol programmes worldwide for over thirty years (Evans, 1987; Elango et al., 1993; Barreto and Evans, 1994). Several pathogens with good potential as control agents have been identified in countries such as Brazil, Trinidad, Guam, India and others (Evans, 1987; Elango et al., 1993; Barreto and Evans, 1994). As a result, researchers from the ARC-PPRI Weeds Pathology Research Unit undertook several short exploratory survey trips to South and Central America between 1988 and 1997 to record and collect pathogens on *C. odorata*. A number of isolates of several pathogens were collected and screened against South African *C. odorata* plants. The most important fungal species identified were *Pseudocercospora eupatorii-formosanii*, *Mycovellosiella perfoliata*, *Colletotrichum*-like isolates, and *Septoria ekmaniana*. This paper reviews the biological control programme against *C. odorata* using pathogens, including (i) the pathogenicity of the isolates on South African chromolaena; (ii) initial results of host range testing of selected candidates and (iii) the potential impact of the pathogens.

**PATHOGENICITY TESTING OF EXOTIC PATHOGENS**

Several pathogens were collected on *C. odorata* and closely related species during these field trips (Appendix 1). These were isolated and inoculated onto the South African form of chromolaena, under strict quarantine conditions at ARC-PPRI laboratories, to determine their compatibility with the weed. The leaf-spot pathogens *Septoria ekmaniana* Petr. & Cif. (Deuteromycotina: Coelomycetes), *Pseudocercospora eupatorii-formosanii* (Sawada) J.M Yen (Deuteromycotina: Hyphomycetes), *Mycovellosiella perfoliata* (Ellis & Everh.) Munt.-Cvetk (Deuteromycotina: Hyphomycetes), and *Anhelia niger* (Viégas) Arx (Ascomycotina: Ascomycetes: Myriangiales), the rust fungus *Cionothrix praelonga* (Wint.) Arthur (Basidiomycotina: Urediniomycetes: Uredinales) and several less damaging pathogens (all collected during the 1988, 1994 and 1995 field surveys) were included in the screening process. With the exception of an isolate of *S. ekmaniana* (collected by Dr H. Evans, CABI Bioscience, U.K.) from diseased
material in Guatemala that came close to producing a compatible reaction against the South African chromolaena, none of the pathogens isolated produced any symptoms. Following a field trip to survey and collect pathogens in Guatemala and other South and Central American countries in 1997, several pathogens were isolated, with the most important being *P. eupatorii-formosani*, *M. perfoliata* and *S. ekmaniana*. Pathogenicity testing of these pathogens was completed at the end of 1999. Fourteen isolates of *P. eupatorii-formosani* from Jamaica, Mexico, Cuba, Florida and Costa Rica, and one isolate of *M. perfoliata* from Florida, were found to be the most compatible. The fifteen isolates were placed into three categories according to the severity and consistency of symptoms they caused on the South African form of chromolaena.

HOST-SPECIFICITY TESTING

Host-specificity testing of the three most pathogenic isolates of the leaf spot pathogen, *P. eupatorii-formosani*, all collected from Jamaica, is being undertaken in the quarantine laboratory. The list of test plants follows the centrifugal theory of host-specificity testing (*sensu* Wapshere, 1974; Goeden, 1983), starting with species within the tribe Eupatorieae and then expanding the testing to species in closely related tribes and including several economically important species (see Zachariades *et al.*, this Proceedings). As a measure of whether the isolates are pathogenic, inoculations of South African chromolaena are included as controls for comparison. Preliminary results showed that no symptoms developed on the species tested within the Eupatorieae a month post-inoculation, while the controls developed pin-point lesions.

CONCLUSIONS

The impact that these pathogens will have on chromolaena in South Africa remains to be seen, as this is the first time that isolates tested have shown the potential to cause disease on the South African form of chromolaena. It is interesting to note that the three most promising isolates originate from Jamaica, which is currently being considered as the possible centre of origin of South Africa’s chromolaena, as the result of morphological and genetic studies (Zachariades *et al.*, 1999; von Senger *et al.*, this Proceedings). The project is ongoing and further collections for other potential pathogens on chromolaena in Jamaica and on neighbouring islands need to be undertaken, as the possibility of finding one or a suite of pathogens that are compatible with the South African form of chromolaena, together with insect biocontrol agents, will maximise the likelihood of success of biological control of this weed in South Africa.

ACKNOWLEDGEMENTS

I would like to thank Mrs J.L. Markram and Ms G. Samuels for their technical assistance throughout the project. The Department of Water Affairs and Forestry’s Working-for-Water Programme provided research funding for the project.

REFERENCES


## Appendix 1

Pathogens collected on *Chromolaena odorata* and related species during surveys conducted between 1986 – 1997.

<table>
<thead>
<tr>
<th>Country</th>
<th>Pathogens isolated (date collected)</th>
</tr>
</thead>
</table>
| Argentina     | *Cionothrix praelonga* (1993)  
                | *Septoria ekmaniana* (1993)  
                | *Alternaria* sp. (1991)  
                | *Alternaria zinniae* (1991)  
                | *Anhelia niger* (1988)  
                | *Cercospora* sp. (1992, 1995)  
                | *Colletotrichum* sp. (1995)  
                | *Cionothrix praelonga* (1988)  
                | *Pseudocercospora* sp. (1995, 1997)  
                |                   |
| Brazil        | *Septoria* sp. (1991)  
                |                   |
| Colombia      | *Cionothrix praelonga* (1997)  
                | *Pseudocercospora eupatorii-formosani* (1997)  
                |                   |
| Costa Rica    | *Cionothrix praelonga* (1997)  
                | *Fusarium* sp. (1997)  
                |                   |
| Cuba          | *Pseudocercospora eupatorii-formosani* (1997)  
                |                   |
| Dominica      | *Cercospora* sp. 1 (1994)  
                | *Septoria* sp. 1 (1994)  
                | *Septoria* sp. 2 (1994)  
                |                   |
| Ghana (western)| *Cercospora* sp. 1 (1996)  
                | *Mycovellosiella* sp. (1996)  
                |                   |
| Guatemala     | *Cionothrix praelonga* (1997)  
                | *Mycovellosiella* sp. (1997)  
                | *Pseudocercospora eupatorii-formosani* (1997)  
                | *Septoria ekmaniana* (1997)  
                |                   |
                |                   |
| Ivory Coast   | *Septoria* sp. (1993)  
                |                   |
| Jamaica       | *Cercospora* sp. 1 (1994)  
                | *Cercospora* sp. 3 (1994)  
                | *Pseudocercospora eupatorii-formosani* (1997)  
                | *Septoria* sp. 2 (1994)  
                |                   |
| Mexico        | *Alternaria zinniae* (1997)  
                | *Cionothrix praelonga* (1997)  
                | *Pseudocercospora eupatorii-formosani* (1997)  
                | *Redbia trichomambusa* (1997)  
                | *Septoria ekmaniana* (1997)  
                |                   |
| Trinidad      | *Anhelia niger* (1994)  
                | *Cercospora* sp 1 (1994)  
                | *Cercospora* sp 2 (1994)  
                | *Cionothrix praelonga* (1994)  
                | *Mycovellosiella* sp 1 (1994)  
                | *Mycovellosiella* sp 2 (1994)  
                | *Septoria ekmaniana* (1994)  
                | *Septoria* sp 2 (1994)  
                |                   |
| USA (Florida) | *Cercospora* sp. 1 (1996)  
                | *Cercospora* sp. 2 (1995)  
                | *Cercospora* sp. 3 (1995)  
                | *Mycovellosiella perfoliata* (1997)  
                | *Pseudocercospora eupatorii-formosani* (1997)  
                | *Septoria* sp. (1997)  
                |                   |
| Venezuela     | *Anhelia niger* (1994)  
                | *Cercospora* sp. 1 (1994)  
                | *Cercospora* sp. 2 (1994)  
                | *Cercospora* sp. 3 (1994)  
                | *Cionothrix praelonga* (1994)  
                | *Redbia trichomambusa* (1994)  
                | *Septoria ekmaniana* (1994)  
                |                   |
This collection of papers was presented at the Fifth International Workshop on Biological Control and Management of Chromolaena odorata, held in Durban, South Africa from 23-25 October 2000. The Workshop was held under the auspices of the International Organization for Biological and Integrated Control of Noxious Animals and Plants (IOBC) and organized by the Plant Protection Research Institute of the Agricultural Research Council (ARC-PPRI), South Africa. The post-workshop trip to the north coast of KwaZulu-Natal province, to view chromolaena infestations, clearing operations, and biodiversity, was organized in part by the KwaZulu-Natal Nature Conservation Service. The workshop was attended by 50 delegates from 12 countries.

The Workshop was funded from several sources: BASF, Dow AgrSciences Pty (Ltd), IOBC, MTN, Novon Crop Protection Pty (Ltd), Sappi Forests, South African Sugar Association and Tongaat-Hulett Sugar. Attendance of international delegates was sponsored mainly by the Australian Centre for International Agricultural Research (ACIAR) and the Centre Technique de Coopération Agricole et Rurale (CTA). The production of this Proceedings was funded by Richards Bay Minerals, the University of Guam and the Working-for-Water Programme of the South African Department of Water Affairs and Forestry. We thank all sponsors for their contributions.

We are grateful to all those who assisted in the organization and running of the workshop, post-workshop tour and/or in editing the proceedings:

Dave Balfour, Peta Campbell, Milly Gareeb, Jeremy Goodall, Martin Hill, Owen Howison, Lynnett Khumalo, Rob Kluge, Peter le Roux, Andrew Mitchell, Terry Olckers, Nunez Pottie, Christian Shabalala, Johannes Thusi and Edith van Niekerk. Thanks are also due to the chairs of the sessions, and all who participated in the workshop.

This Fifth Workshop was imbued with a positive atmosphere. Considerable progress has been made on research into control of chromolaena around the world. In South-East Asia and the Pacific the stem-galling fly Cecidochares connexa is proving very successful. It establishes easily, spreads well, and damages chromolaena. ACIAR has been responsible for the building of capacity and the distribution of this agent in several countries. The defoliating moth Pareuchaetes pseudoinsulata is still spreading and causing great damage in Ghana and Sumatra. New insect and pathogen agents are being tested in South Africa. Finally, there appears to be progress towards resolving the conflict of interest surrounding chromolaena in much of West and Central Africa, opening the way to wider application of biological control. The post-workshop tour made the international delegates aware of the differences in the biotype of chromolaena invading southern Africa.

Costas Zachariades
R. Muniappan
Lorraine W. Strathie

August 2002
INTRODUCTION

Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) is commonly known as trifid weed, chromolaena, ‘paraffienbos’ (Afrikaans) and ‘isandanezwa’ (isiZulu) in South Africa (Kluge, 1990; Goodall and Erasmus, 1996). It is regarded as the worst alien invasive plant species in the subtropical regions of South Africa (Zachariades et al., 1999; Zachariades and Goodall, this Proceedings), and it poses the greatest threat of any invasive weed to the biodiversity of the KwaZulu-Natal province of South Africa (Liggitt, 1983). In southern Africa, C. odorata is primarily a problem in conservation areas, and Macdonald (1983) ranked C. odorata as the alien invader posing the greatest threat to the natural vegetation in the Hluhluwe-Umfolozi Game Reserve Complex in KwaZulu-Natal, where it suppresses the natural vegetation and reduces species diversity.

The Origin and Spread of Southern Africa’s Chromolaena odorata

Chromolaena odorata was first recorded in South Africa near Durban in the late 1940s, from where it has spread (McFadyen, 1988a). The exact route by which C. odorata arrived in South Africa is much discussed (Vos, 1989; C. Erasmus, unpubl. data), but as yet remains unconfirmed. It is possible that C. odorata was introduced to South Africa for horticultural reasons (Henderson and Anderson, 1966), or the plant may have arrived in seed-contaminated packaging materials unloaded in Durban harbour during the Second World War (Liggitt, 1983). Vos (1989) suggests that there is support for the idea that C. odorata may have been introduced to South Africa via ballast in cargo ships from the West Indies. The spread of C. odorata in southern Africa has been poorly documented, but the initial spread of C. odorata may have been along railways and roads, which have been good seed sources for infesting the surrounding countryside (Liggitt, 1983).

Biological Control

Of all the South African biocontrol programmes, that on C. odorata is the only one for which no biological control agents have yet been successfully established in the field (Ockers et al., 1998). This can primarily be contributed to the relative recentness of this programme, as well as problems with compatibility of some of the imported biocontrol candidates (insects and pathogens) with the South African C. odorata (Zachariades et al., 1999; Strathie and Zachariades, this Proceedings). This incompatibility is manifested in poor or non-development of the candidates on plants in the quarantine laboratory or in the field.

In its extensive native distribution in the Americas, C. odorata embraces a wide range of climatic conditions, and thus the chances of finding insect herbivores that are climatically pre-adapted to the intended forms and climates of introduction are considered good (Kluge, 1991).

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Some aspects of the biology of *C. odorata* make it a good candidate for biocontrol (Kluge, 1990). For example, the plant does not reproduce vegetatively (McFadyen, 1988b); the seedlings are weak competitors and there is high seedling mortality (Yadav and Tripathi, 1981); and the shallow fibrous root system of the South African *C. odorata* (Kluge, 1990) limits strong regeneration of cut or burnt stumps. Finally, there are many potential biocontrol agents (insects and pathogens) in the region of origin of chromolaena (McFadyen, 1988c; Barreto and Evans, 1996; Zachariades et al., 1999).

It is generally recognised that biocontrol remains the only way to bring chromolaena to manageable levels (Goodall and Erasmus, 1996). For those candidates that have done poorly in the laboratory or have not established field populations, compatibility with the southern African form may or may not be a factor – however it is desirable to rule it out as a variable. If the compatibility problem could be solved, the potential for biocontrol to play a pivotal role in the suppression of chromolaena would be considerably increased.

**Variation within Chromolaena**

*Chromolaena odorata* exhibits considerable morphological variation over its wide native range, which extends from the south-east USA and Mexico, through the Caribbean to South America, as far as northern Argentina (H. Robinson, pers. comm.). The form invasive in South Africa is distinct in its morphology and odour from forms that have been observed in other areas of the world (South America, the Caribbean and Florida in the USA) including other invaded areas (West Africa, Asia, Micronesia and Australia) (Neser, 1998). However, live plants imported from Jamaica in 1997 and grown in pots in quarantine in South Africa appear virtually identical in morphology to the southern African chromolaena, and this was corroborated by a field trip to Jamaica in 1999.

Table 1 highlights some of the differences between South African *C. odorata* and other forms of this plant.

The uniqueness of the South African form of *C. odorata* is believed to be the cause of compatibility problems with some biocontrol candidates, collected by necessity on other forms of *C. odorata* in the neotropics. It is hoped that there is a parent population to the South African *C. odorata* in the Americas that matches the latter. Such a match would include similarities in morphology and, hopefully, chemistry as the compatibility problems already experienced may be caused by both physical and chemical differences. It is hoped that this hypothetical parent population will harbour potential biological control agents that will be more suited to South African *C. odorata* than some of the previously used insects and pathogens.

It is important to note that there are several ‘morphotypes’ of *C. odorata* in Jamaica. These range in morphology from forms that are identical to South African chromolaena to forms that are very similar to the form native to Florida and invasive in W. Africa, and there are intermediate forms.

In order to narrow the search for the parent population of South African *C. odorata*, Vos (1989) investigated morphology, isozymes and cytology of various *C. odorata* samples collected world-wide. He reported that he had found only one haplotype of *C. odorata* in South Africa, yet each of his data sets indicated a different geographical origin for the South African chromolaena: the isozyme data indicated that South African *C. odorata* originated from Thailand, the morphology indicated Manaus, Brazil, and the cytology data pointed to India.

Several other attempts, using various techniques, have been made to determine the origin of the

| Table 1. Morphological comparison of *Chromolaena odorata* from South Africa and other countries. |
| --- | --- | --- | --- |
| **Feature** | **Country** | **Character** | **References** |
| | | | |
| Capitula | South Africa | Whitish to cream | Kluge, 1990 |
| | West Africa and Asia | Pale mauve or pale blueish-lilac | Holm et al., 1977 |
| | Trinidad | White or pale blueish-lilac | McFadyen, 1988b |
| | West Africa and Asia | Purple pigment | Sheldrick, 1968 |
| | South Africa | Red pigment | C. Zachariades, pers. obs. |
| | Trinidad | Shallow and fibrous | Kluge, 1990 |
| | India | Shallow and fibrous | McFadyen, 1988b |
| | Unspecified | Deep taproot | Chacko and Narasimham, 1988 |
| | South Africa | Deep taproot | Holm et al., 1977 |
southern African chromolaena (Zachariades et al., 1999), but have also not yielded consistent results. However, the north coast of South America and some of the Caribbean islands emerge repeatedly as possible origins (Table 2).

There is a possibility that the C. odorata invasive to South Africa is a species other than C. odorata (Zachariades et al., 1999), or that it is a hybrid with an undiscovered parentage (see Ellstrand and Schierenbeck, 2000). Confirmation of the identity of the South African Chromolaena is currently being sought from the Royal Botanic Garden, Kew and the Smithsonian Institution, Washington, D.C..

This study aims to use molecular fingerprinting techniques to determine the geographic origin of the South African C. odorata, in the hope that potential biocontrol agents collected from the area of origin will have a greater probability of successfully establishing on the South African C. odorata.

**Molecular Fingerprinting**

The term ‘DNA fingerprinting’ was originally used by Jeffreys et al. (1985, cited by Weising et al., 1995) to describe a method whereby numerous highly variable DNA loci could be simultaneously found and recorded. This was done by hybridisation of specific multilocus ‘probes’ to fragments of DNA that could be electrophoretically separated into distinct bands. One of the methods proposed for later use in the fingerprinting of C. odorata, ISSRs, yields fragments such as those mentioned above.

The method used in this study, gene sequencing, does not precisely follow the original use of the term ‘DNA fingerprinting’, as it does not yield distinct ‘bands’. Rather, the sequence of a particular gene is obtained, and then compared between samples.

Thus far, two genes have been sequenced: the ITS (Internal Transcribed Spacer region) and the ETS (External Transcribed Spacer region). Both of these genes form a part of the same 18S-26S nuclear ribosomal DNA (nrDNA) gene (Baldwin, 1992, 1993; Baldwin et al., 1995; Baldwin and Markos, 1998; Linder et al., 2000). They form spacers between DNA coding for ribosomal proteins. Because they have little or no function, the ITS and ETS regions are not highly conserved, and are subjected to relatively rapid mutation events. They are thus variable enough to be phylogenetically informative between species, the ETS region more so than the ITS region (Baldwin and Markos, 1998).

The ITS region has been proved to be phylogenetically useful for many angiosperm studies. Although it has not yet been found to be sufficiently variable to be useful for angiosperm studies at the intraspecific (single species) level (Schaal et al., 1998), studies in this regard are few, so this is largely untested. It is hoped that the longer and more informative ETS region (Baldwin and Markos, 1998) will be able to augment the ITS region to provide enough useful variation for C. odorata.

**Methods of Comparative DNA Sequence Analysis**

In any genetic study, there are several analytical approaches from which to choose. Two of the more commonly used approaches are Parsimony analysis and Distance-based methods. The first assumes that evolution proceeds along the shortest possible pathway, and so the ‘tree’ that has the fewest number of changes or mutations is considered the
correct tree. The second analytical approach, the distance method, describes the amount of evolutionary (or mutational) divergence between two taxa in a numerical manner, and then converts that into a proportional distance on the tree.

The above two analytical methods are commonly used for studies within genera or families, but it is emerging that these methods are not completely suited to single-species studies, which can (and often do) yield reticulate relationships. Therefore a new set of statistical analytical methods has been developed to analyse samples within one species. Some of these alternative methods include AMOVA (Excoffier et al., 1992), which has been adapted for use in population studies by Huff et al. (1993), and PCO, as used by Adams and Demeke (1993, cited in Bachmann, 1997).

**MATERIALS AND METHODS**

**Samples**
All chromolaena leaf samples were collected and dried using silica gel (Chase and Hillis, 1991). Samples were supplied by the Weeds Division of ARC-PPRI or collected by the senior author. Fig. 1 indicates where the South African samples were collected, and Table 3 gives details of all the samples.

**DNA Extraction**
Prior to extraction, a 4mm² piece of leaf tissue was rinsed in 100% ethanol, to remove surface contamination and assist in rehydration (Scott et al., 1998). DNA was extracted from the samples using a modified hot CTAB (hexadecyltrimethyl-ammonium bromide) method (Doyle and Doyle, 1987).

**DNA Amplification**
Polymerase chain reactions (PCR) were performed on either a Hybaid PCR Sprint Thermal Cycler, SPRT 001 (Hybaid Limited, U.K.), or a PC-960G Gradient Thermal Cycler, PC 960G (Corbett Research). Fifty-microlitre reactions were used during optimisation operations, whereafter PCR was performed in 100µl reactions. Varying magnesium (Mg) concentrations were used throughout the amplification of DNA, as each taxon had a different optimal Mg (though most samples amplified the most DNA at Mg concentrations of 2mM and 3mM).

Each 100 µl reaction volume contained 10mM Tris-HCl (pH 9.0 at 25°C), 50mM KCl and 0.1% Triton® X-100 (all from Promega Magnesium-free buffer), as well as ca. 0.2µM of each primer, 0.25mM of each dNTP, 2 units of Taq DNA polymerase, and 1, 2, 3, or 4mM MgCl. Six microlitres of template was used in the ITS reactions (100µl), and this was doubled in the ETS reactions. Reaction volumes were covered with mineral oil for molecular biology (Sigma).

The primers used to amplify the internal transcribed spacer region were ‘ITS1’ (forward) and

**Table 3. List of sample origins.**

<table>
<thead>
<tr>
<th>Country of origin</th>
<th>Locality</th>
<th>Coordinates</th>
<th>Voucher Accession Code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Native range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Salvador</td>
<td>12.58 S 38.29 W</td>
<td>AcCe 27</td>
</tr>
<tr>
<td>Guatemala</td>
<td>Near Amatilán</td>
<td>14.29.46 N 90.36.83 W</td>
<td>AcCe 35</td>
</tr>
<tr>
<td>Jamaica</td>
<td>Irish Town</td>
<td>18.03 N 76.43 W</td>
<td>AcCe 37</td>
</tr>
<tr>
<td>Jamaica</td>
<td>Guava Ridge</td>
<td>18.01 N 76.41 W</td>
<td>AcCe 04</td>
</tr>
<tr>
<td>Mexico</td>
<td>Near Actopán</td>
<td>19.30 N 96.37 W</td>
<td>AcCe 30</td>
</tr>
<tr>
<td>Trinidad</td>
<td>Blanchisseus</td>
<td>10.47 N 61.18 W</td>
<td>AcCe 19</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>Rolling Hills, Florida</td>
<td>26.04.30 N 80.15.09 W</td>
<td>AcCe 15</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Near Trujillo</td>
<td>09.27.10 N 70.34.36 W</td>
<td>CZ 98, WP 096, P1</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Near Trujillo</td>
<td>09.29.06 N 70.25.61 W</td>
<td>CZ 99, WP 011, P1</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Near Puerto la Cruz</td>
<td>10.13.59 N 64.31.21 W</td>
<td>CZ 98, WP 117, P1</td>
</tr>
<tr>
<td><strong>Introduced range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>Bangalore</td>
<td>12.59 N 77.35 E</td>
<td>AcCe 24</td>
</tr>
<tr>
<td>South Africa</td>
<td>Tzaneen area</td>
<td>23.50 S 30.10 E</td>
<td>-</td>
</tr>
<tr>
<td>South Africa</td>
<td>Durban area</td>
<td>29.51 S 31.01 E</td>
<td>-</td>
</tr>
<tr>
<td>South Africa</td>
<td>Port Edward</td>
<td>31.03 S 30.13 E</td>
<td>IvS 1</td>
</tr>
<tr>
<td>South Africa</td>
<td>Eshowe</td>
<td>28.53 S 31.27 E</td>
<td>IvS 4</td>
</tr>
<tr>
<td>South Africa</td>
<td>Mtnunzini</td>
<td>28.57 S 31.45 E</td>
<td>IvS 5</td>
</tr>
<tr>
<td>South Africa</td>
<td>Port Shepstone</td>
<td>30.43 S 30.17 E</td>
<td>IvS 6</td>
</tr>
<tr>
<td>West Africa</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
ITS4’ (reverse), first described for use in fungal applications (White et al., 1990). ‘ITS5’ (White et al., 1990) was later substituted for ‘ITS1’, due to poor sequence quality from the ‘ITS1’ primer, but the ‘ITS5’ primer produced even poorer results. These fungal ITS primers have been used with success on several Asteraceae before (e.g. Baldwin, 1992; Torrell et al., 1999; Schmidt and Schilling, 2000). The internal primers used were ‘Danth 5.8F’ (forward; 5’-GACTCTCGGCAACGG-3’) and ‘chromo 5.8R’ (reverse; 5’-GATTCTGCAATTCACACC), designed by one of us (NPB).

The PCR cycle programmes varied slightly between samples, but in general, they were as follows. The PCR cycle used for the ITS was: 40 cycles of 95°C for 45s, 52°C for 45s and 72°C for 2min 30s, followed by 10min at 75°C. The ETS PCR cycle was: 10 cycles of 95°C for 30s, 57°C for 30s and 72°C for 2min, followed by 10 cycles of 95°C for 45s, 55°C for 45s and 72°C for 2min 30s, followed by 15 cycles of 95°C for 60s, 55°C for 60s and 72°C for 3min. All of this was followed by 10min at 72°C.

Fifteen microlitres of each PCR product was run on a 1% agarose gel. All gels were made up with ethidium bromide. Gels were viewed using an ultraviolet transilluminator.

PCR reactions from each sample that yielded a single product (band), were pooled until a total volume of at least 200µl amplified product had been collected. The pooled PCR product was purified with a QIAquick Purification Kit, according to the manufacturers’ instructions.

DNA Sequencing

The sequencing reaction was carried out using an ABI PRISM BigDye™ Terminator Cycle Sequencing Ready Reaction Kit and reactions were done at half-volume using a 5x sequencing dilution buffer (PE Applied Biosystems). The sequencing product was precipitated according to Ethanol Precipitation Protocol 1 of the ABI PRISM™ Dye Terminator Cycle Sequencing Ready Reaction Kit. The dried DNA pellets were sequenced either on an ABI 377 or an ABI 3100 automated sequencer.

Sequence Analysis

Sequences were edited using Sequencher™ version 3 (Gene Codes Corporation, 1995). The sequences were then imported into the alignment package DAPSA (DNA And Protein Sequence Alignment; written by E. H. Harley, Dept. Chemical Pathology,
Figure 2. Jukes Cantor neighbour joining distance tree for ITS sequence data. Numbers in bold are bootstrap values above 50%.

Figure 3. Jukes Cantor neighbour joining distance tree, with superimposed bootstrap values above 50%.
University of Cape Town Medical School, Observatory 7935, South Africa). Aligned Sequences were analysed using PAUP 4.0b3a (Swofford, 2000). Both parsimony and distance analyses were attempted. The distance analysis used the Jukes-Cantor option, which corrects for superimposed mutations over time. One hundred bootstrap replicates were carried out using PAUP.

RESULTS

In total, 21 samples were sequenced for the ITS region, six of which are South African. Five samples were sequenced for the ETS region, none of which are South African.

ITS

The ITS region was found to be variable within the species *C. odorata*, with 38 out of a total of 775 bases being variable. Nineteen of these were parsimony informative.

The strict consensus tree of the parsimony analysis for the ITS data yielded very little resolution and was therefore considered to be uninformative. The results have therefore not been included. It is, however, possible that this lack of resolution could be a result of the reticulate nature of the data.

The Neighbour Joining tree produced from the Jukes-Cantor algorithm is presented in Fig. 2. The phylogram has been left unrooted, in the manner that many species trees are, as it is difficult to determine the temporal polarity of mutations, even with an outgroup (Castelloe and Templeton, 1994, cited in Schaal and Olsen, 2000).

Of particular interest in the ITS distance tree is the manner in which the South African samples have not been resolved together, as might have been expected if there were only one *C. odorata* genotype in South Africa.

It is worth noting that the Irish Town, Jamaica sample is morphologically identical to the South African chromolaena and resolves close to the South African chromolaena in the ITS tree, whereas the Guava Ridge sample looks similar to chromolaena from Florida and West Africa and resolves further from the South African sample.

ETS

Although only 653 bases of a possible total of 1700 bases were sequenced, the ETS region was found to be variable within the species *C. odorata*. Twenty-three of the 653 bases were variable, and 17 of the variable bases were parsimony informative.

Fig. 3 shows the Jukes Cantor neighbor joining distance tree of the ETS data that are currently available. The preliminary nature of these data prevents any conclusions being drawn. However, it is interesting to note that Brazil has not been resolved with the Mexican and Jamaican (Irish Town) samples, as it was in the ITS tree.

DISCUSSION

This is one of the first attempts to obtain variable information from ITS and ETS regions at the intraspecific level within angiosperms. Other attempts have been made at using the ITS region within a single species, but thus far intraspecific variation has not been found for the region. For example, Torrell *et al.* (1999) sequenced 33 populations of 31 species of the genus *Artemisia* s.l., in an attempt to delineate the limitation of the genus. They found 0% divergence between many of their species and populations, and a maximum divergence of 11.7% for the ITS1 region between some of their species. The variation in the complete ITS region in this study was 4.9%. That there is intraspecific variation within *C. odorata* is not completely unexpected, as the ITS region of at least one other genus of the Asteraceae (of which *C. odorata* is a member) shows intraspecific variation (Baldwin, 1993). It is therefore possible to suggest that the ITS and ETS regions of *C. odorata* are potentially phylogenetically useful within this species. The ETS data are very preliminary, and it is possible that more variation will become useful later in this study.

As mentioned already, *C. odorata* is thought to have entered South Africa only once, possibly through Durban harbour. There is no evidence of a second introduction. This belief, alongside Vos’ (1989) thesis, suggests that there is only one haplotype of *C. odorata* in South Africa. However, the distance data from the ITS gene does not appear to agree with this.

Genetically, the ITS genes of Eshowe, Mtunzini and Port Edward samples are identical, while the Port Shepstone ITS sequence is only one base different to these other samples. The remaining samples (Durban and Tzaneen) have several differences in the ITS sequence from the above-mentioned samples, Tzaneen being so different as to associate with Venezuelan samples (but note that only one sample has been taken from the Tzaneen area thus far). Nevertheless, this data would suggest that there are at least two genotypes of *C. odorata* in South Africa. Whether this implies (i) multiple introductions of chromolaena to South Africa, (ii) that there were several genetic varieties that all arrived in one introduction to South Africa, or (iii) whether there has been genetic diversification/evolution during the 50 years that it has been in South Africa, remains unknown.

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A word of caution is due here. Fig. 2 is a gene tree, that reflects the relationships between the genes of the samples, and it is only human extrapolation that has suggested that the gene trees approximate the species tree (Doyle, 1992; Avise, 1998). It is considered prudent in molecular systematics to find more than one gene tree from several different genes, and then combine, or find the consensus of, those data sets. Also the chromolaena in South Africa is to all intents and purposes morphologically homogeneous, especially when compared to that from other parts of the world, so the genetic variability that is currently being shown may be an artefact of the ITS gene.

The data presented are too preliminary to make any conclusive statements as yet as to the geographic origin of the South African *C. odorata*. However, if one combines the evidence from the morphological investigations (Tables 1, 2) with the genetic evidence thus far obtained, it would seem that all of the populations with morphological or genetic similarities to *C. odorata* in South Africa originate from the West Indies, northern parts of South America or Central America.

**Future Prospects**
This study will continue to collect samples from all over the world, but will focus on collecting samples from the above-mentioned areas, in the hope that the parent population of South African *C. odorata* will be encountered.

**CONCLUSIONS**
The South African form of *C. odorata* is morphologically unique to most other *C. odorata* plants investigated thus far in the world. However, morphological investigations indicate that the Caribbean region has plants with several morphological similarities to South African *C. odorata*. Of particular interest is one of the forms of *C. odorata* found in Jamaica that is identical in morphology and growth habit to South African *C. odorata*. Molecular data would seem to agree that South African *C. odorata* shares features with plants from the Caribbean.

It was previously thought that there is only one haplotype (and thus genotype) of *C. odorata* in South Africa. The preliminary data presented here suggests there may be several genotypes of chromolaena in South Africa. Future studies will continue to examine *C. odorata* from all over the world, but will also focus on more samples from the West Indies region, to compare them with the form of chromolaena invasive in South Africa.

**ACKNOWLEDGEMENTS**
The authors would like to thank Rhodes University Joint Research Council, the National Research Foundation and the Working-for-Water Programme of the Department of Water Affairs and Forestry for funding this research.
REFERENCES


RECOMMENDATIONS OF THE WORKSHOP

1. To change the name of the future workshops to ‘International Workshop on Biological Control and Management of Chromolaena’.

2. To adopt as the common name ‘chromolaena’ in future literature for Chromolaena odorata.

3. That other specialist tephritid taxonomists be approached to sort out the generic placement of (Pro) Cecidochares connexa Macquart and its relationship to Procecidocharides alani and P. utilis.

4. Cooperative international work should be encouraged especially in the aspects of foreign exploration and preliminary screening of candidates.

5. As a follow-up to the 1993 recommendations of the Chromolaena odorata workshop held in Abidjan, West and Central African stakeholders should hold a regional meeting in 2001 to assess the expansion of the biological control effort across the region. The recommendations of this meeting will be tabled to the regional governments.

6. That an integrated weed management strategy including eradication where applicable (countries where the weed has only been found), slashing, burning, cultural, chemical and biological control be developed for the management of C. odorata.
An integrated control approach to the reduction in extent and density of alien plant infestations should include the process of rehabilitation using a suitable ground cover after clearing. Information is available but not always in a form easily accessible to the land managers dealing with alien plant control. ARC-PPRI has developed a research project to collate the known expertise and ‘fill in the research gaps’ identified during five workshops. This was a multi-institutional approach, with local universities, nature conservation services, departments of agriculture and environmental affairs, the ARC-Range and Forage Institute and project managers of the Department of Water Affairs and Forestry’s Working-for-Water (WfW) programme having important contributions at the workshops. In addition, research trials to ‘fill in the research gaps’ have been completed e.g. best planting practices and comparison of suitable grass species.

The extension tools developed from this project are:
(i) Rehabilitation Recommendations Handbook
   Part 2: Selection of suitable grasses for rehabilitation in different areas.
   Part 3: Practical recommendations and guidelines for grass harvesting and planting methods suitable for rehabilitation after alien plant control.
   This has colour photos and diagrams to illustrate the text.
(ii) Grab-a-Grass dials
   This is a 7-step ready reckoner with planting guidelines. There are four dials:
   Dial # 1: GRAB-A-GRASS for KwaZulu-Natal
   Dial # 2: GRAB-A-GRASS for the Eastern Cape
   Dial # 3: GRAB-A-GRASS for Mpumalanga and the Northern Province
   Dial # 4: GRAB-A-GRASS for the Free State, Northern Cape, North West and Gauteng.

Target audiences for the products are farmers, municipalities, non-governmental organizations, conservation authorities, the forestry industry, WfW project managers and any other agencies actively involved with alien plant control.
SESSION SUMMARIES

Session 1: Country and regional reports
Chairperson: J.A. Timbilla

Rachel Cruttwell McFadyen touched on the history, spread, methods of control, future prospects and problems of Chromolaena odorata. She stated that there is a new infestation of C. odorata in Tully (Australia). Among methods of spreading of seeds of C. odorata is the movement of military vehicles (up to 0.5kg of seeds were found in one vehicle). Funding for the present project will end in 2001.

Graham Donnelly presented the distribution of C. odorata, in Papua New Guinea. He showed slides on infested provinces and talked about the origin of the outbreak and dispersal of C. odorata. As part of an extension programme, displays on weed awareness have been put in place. Logging activities, construction of new roads and mining were some of the factors leading to the spread of C. odorata.

Jesse Bamba talked about the distribution of chromolaena in the islands of the Pacific forming Micronesia. Pareuchaetes pseudoinsulata has established and effected control in Guam and has also established in Northern Mariana Islands, Yap, Pohnpei and Kosrae. Apion brunneonigrum did not establish in Guam. Currently, Cecidochares connexa has established in Palau.

Azmi Bin Man said that in Malaysia, nine major crops are of economic importance. Chromolaena odorata, also known as aeroplane plant, suppresses the growth of rubber. The weed, however, has uses as a green manure crop, helps reduce nematode populations in the soil while also having medicinal uses. These notwithstanding, farmers abandon coconut farms because of dense thickets of C. odorata. At the moment, control of chromolaena is by the use of herbicides and manual weeding. Very little research has been done on its ecology and biological control in Malaysia.

Barbara Waterhouse stated that the Tully District of North Queensland, Australia has scattered infestations of C. odorata. Australia wants to eradicate chromolaena and prevent invasion, however biocontrol may be implemented if methods planned for eradication of the weed fail.

Session 2: Country and regional reports (contd.)
Chairperson: R.E. Cruttwell McFadyen

Costas Zachariades talked about the weed’s introduction into Durban in about 1940 and its progressive spread along the coast and north into Northern Province, Swaziland and even Mozambique. He mentioned problems with management of the weed, resulting from initial failures to recognise the importance of the weed and then from lack of resources.

Warea Orapa summarised the impact of the weed in Papua New Guinea and the management methods used. The biocontrol programme commenced in 1998 and is ongoing, with the introduction and establishment of P. pseudoinsulata. The gall fly C. connexa will be introduced shortly.

Roch Desmier de Chenon then reported on the biocontrol programme in Indonesia carried out by the Oil Palm Research Institute in Sumatra over the last 10 years. Three agents have been introduced, tested and released, with both P. pseudoinsulata and C. connexa now widely established.

Colin Wilson reported on the programme in eastern Indonesia, where P. pseudoinsulata has not been successful but C. connexa is doing very well in moist areas.

Haruna Braimah summarised the biocontrol programme in Ghana over the last 10 years. Pareuchaetes pseudoinsulata is now spreading very widely and having a significant impact on the plant.

Session 3: Country and regional reports (contd.)
Chairperson: S.R. Ambika

James Timbilla said that P. pseudoinsulata was imported from Guam, USA and was established in Ghana in 1994/95. It could effectively defoliate and suppress C. odorata. The successful control of C. odorata with P. pseudoinsulata has had a positive impact on plant species diversity with an increase in plant species per unit area from three to six. He felt that the success achieved in Ghana could effectively be used for regional biological control of C. odorata.

Grégoire Bani spoke on activities of biological control and management of C. odorata in Congo-Brazzaville. Chromolaena was first collected in 1965 in the Congo. Later it started spreading, mainly via areas of disturbance. In sugar cane and oil palm plantations, the farmers use herbicides to control C. odorata. Fire is also used to clear the bush of C. odorata. Chromolaena odorata increases soil fertility when used as a compost and the local people use it for wound healing. Considering the pros and cons, the negative aspects prevail. Chemical, mechanical and biological control methods are being practised and integrated control projects started in 1996.
Lorraine Strathie said that the insect species on *C. odorata* were prioritised for investigation in the South African programme in 1997 based on severity and damage caused and ease of culturing. Host specificity testing has been completed on *Actinote thalia pyrrha* (butterfly), *Lixus aemulus* (stem-boring weevil) and *Calycomyza* sp. (leaf mining fly) with encouraging results. The host range of *A. thalia* has also been investigated. Rearing techniques and biology have been determined for the stem galling weevil *Conotrachelus reticulatus* and the root-mining flea beetle *Longitarsus horni*, and host-specificity testing has been initiated. *Pareuchaetes pseudoinsulata* larvae were released in the Northern Province of South Africa but did not establish, and another strain that was introduced to overcome possible seasonality problems became diseased. The origin of the South African form of *C. odorata* is being investigated and the recent discovery of a morphologically similar form in Jamaica suggests a Caribbean origin.

Peta Campbell stated that after the alien species are cleared, ground cover should be rehabilitated. The ARC-PPRI has developed a research project to collate the known expertise and fill in the research gaps identified during five workshops. Two extension tools developed from this project: (i) Rehabilitation Recommendations Handbook (ii) Grab-a-Grass dials

Target users for the products include farmers, municipalities, non-governmental organisations, conservation authorities, the forestry industry, WfW project managers and other agencies actively involved with alien plant control.

Rachel Cruttwell McFadyen explained the details of ACIAR biocontrol of *C. odorata* involving persons working in five different organisations in Indonesia, Papua New Guinea, the Philippines (Davao, Bogor, Bubia, Marihat and Kupang). Their different organisations used a leaf-feeding moth (*P. pseudoinsulata*), gall fly (*C. connexa*) and leaf-feeding butterfly (*A. anteas*).

**Session 4: Taxonomy, ecology and impacts of chromolaena**

**Chairperson: J.M. Goodall**

Elizabeth Retief spoke on the tribe Eupatorieae in southern Africa. Four genera, viz. *Ageratina*, *Ageratum*, *Campuloclinium* and *Chromolaena* are aliens. *Mikania* are indigenous to Africa but are important weeds in other tropical countries in the Asian Pacific. The tribe is made up of various growth forms including herbs (*Ageratum*), shrubs (*Ageratina* and *Chromolaena*) and suffrutices like *Mikania*. Features of the anthers, pappus and involucral bracts distinguish between different genera. Chromolaena is distinguished by achenes with pappi of many capillary bristles and involucral bracts with coloured tips.

Inge von Senger said that chromolaena in South Africa was morphologically different from other forms of the weed in Asia and Australasia. Accounts from entomologists on expedition in the Neotropics and of herbaria have led to much confusion regarding the exact home location of the South African form of chromolaena. Preliminary data from genetic fingerprinting shows that the KwaZulu-Natal (KZN) and Tzaneen infestations have different home ranges. KZN are close to the West Indian types and the Tzaneen type closer to the Venezuelan type.

Ambika covered environmental factors relating to seedling growth of chromolaena. Optimum growth conditions include high light intensity, high moisture availability and temperatures between 20 and 28°C. Growth is most rapid in the first 30 days after germination. Relative growth rate declines subsequently with increased effort put into root production.

Ed Witkowski discussed changes in density, biomass, seed production and soil seed bank of chromolaena in different age stands in sun, semi-shade and shade. Self-thinning occurs in older stands as a result of intra-specific competition. Consequently young infestations are denser. Biomass is greater in younger stands and infestations become more ‘inactive’ (moribund) with age. Seed production was much greater in plants in the open. Viable seed banks were, however, lower in full sun than in semi shade. Soil seed is sensitive to temperatures. Seedlings in the soil were killed at 100°C in ovens. Implications are that intense fires will be effective in killing the soil seed bank.

Alison Leslie spoke on the chromolaena infestations that threaten the breeding habitat of the Nile crocodile in the Greater St Lucia system. Crocodiles rely on open sand banks for egg-development and balanced sex ratios. Temperatures of nests under chromolaena stands are lower by 5–6°C and this is sufficient to induce female-biased sex ratios, but may also prevent embryonic development altogether. Chromolaena is also a barrier plant that reduced the spatial extent of potential breeding sites.

**Session 5: Impacts and management of chromolaena**

**Chairperson: S. Neson**

The impacts and management of *C. odorata* infestations in both natural and agricultural contexts were considered and the most useful
recommendations were made for both situations in lessening the adverse impacts of the weed.

In the first paper (Owen Howison), the dramatic increase in the incidence of the weed over a 15-year period was graphically demonstrated, as it occurred in spite of attempts to control it, and to keep up with follow-up work, and leaving the question whether the efforts should not have been concentrated on preventing spread, rather than attempting to ‘eradicate’ the weed at the densely infested areas.

The second paper (Jeremy Goodall), using clever interpretations of the natural plant successions in grassland, savanna and forest in the absence and presence of C. odorata, and the effects of fire under different situations, demonstrated that the use of regular fires, when a certain minimum grass cover is present, could lead to a return to chromolaena-free grassland/savanna situations, provided that management is judiciously directed.

Judicious guidance also proved to be of great importance in the last two papers, in the first (Paa-Kwesi Entsie) by specifically trained extension officers who could relay information to resource-poor farmers on the use of P. pseudoinsulata and their education through the Farmer Field School principle, and in the second (Stephan Weise), by not upsetting the traditional utilization of C. odorata during the short fallow period. This could be achieved by promoting the use of alternative plants, such as legumes, which were shown to be equally as good as, or better than chromolaena for this purpose. It would however be necessary to prevent undesirable complications should C. odorata be suppressed sufficiently by biocontrol agents to allow other, more undesirable weeds or pioneer plants to take its place.

The information in the four papers provides a useful basis for future integrated management of C. odorata, especially when additional biocontrol agents could be brought into play.

Session 6: Biological control of chromolaena
Chairperson: L. Strathie

Muniappan reported that the gall fly C. connexa was imported into Guam in 1998. A tephritid expert has re-identified this fly as Cecidochares connexa. Species in the genus Cecidochares are very host specific. Host-specificity testing of C. connexa showed that it is host specific and permission to release is being applied for.

Emmanuel Aterrado reported that P. pseudoinsulata had not established in many areas in the Philippines, thus C. connexa was imported. Host-specificity testing was conducted and C. connexa shown to be host specific. Permission to import has been obtained after much delay. The biology of the insect was reported. Chromolaena plants are heavily galled and approximately 60% of galled branches die.

Soekisman Tjitrosemito reported that C. connexa was imported into Indonesia in 1993. Where the fly has been released in 1995 in the eastern part of Java it has established slowly, whereas it has established more rapidly and readily in the western parts. Climate affects plant growth, determining the number of growth tips, which in turn affects the number of galls produced. Thus plants which grow better in the west have a higher degree of galling.

Roch Desmier de Chenon reported that C. connexa was released in Indonesia in 1995. The biology of the insect was reported on. Gall size is related to meristematic function of the plant (actively growing plants produce large galls). Spread of 900m occurred within one generation after release, and up to 200km 5 years after release. Up to 400 galls per plant have been observed. Growth, flowering and seeding are affected. Cecidochares connexa can occur up to 1200m altitude and particularly attacks plants which have been slashed and are resprouting.

Des Conlong reported on the techniques used to mass-rear P. aurata. He emphasised the importance of trained staff, division of the labs into clean and dirty rooms, distinct workflow, and high levels of hygiene with regular cleaning and the use of different disinfectants.

Session 7: Biological control of chromolaena (contd.)
Chairperson: C. Wilson

The five speakers, Costas Zachariades, Alana den Breejyen, Desmier de Chenon, Des Conlong and James Timbilla, followed a natural progression in biological control from testing potential insects and pathogens, looking at the biology of an agent being released, examining the impact of a released agent on flowering and foliage, and seeing the impact of an established agent on land management practices. A couple of significant issues to arise were the potential of pathogens, and the explanation for the failure in some circumstances of Pareuchaetes spp. moths to establish.
THE ROLE OF CHROMOLAENA ODORATA IN THE SHORT FALLOW-FOOD CROP SYSTEMS OF THE FOREST MARGINS OF SOUTHERN CAMEROON

S.F. Weise, S. Hauser, L-S. Koutika and N. Tchamou

Humid Forest Ecoregional Centre, International Institute of Tropical Agriculture, Yaounde, Cameroon

Chromolaena odorata is often the dominant fallow species in the short fallow-food crop systems which form the basis for subsistence as well as cash crop farming in the forest margins of southern Cameroon. Studies have been conducted over the past 5 years to identify the farmer’s perception of C. odorata as a weed in food crop fields, the impact of the removal of C. odorata from short fallows, and the possible advantages of planted fallows over C. odorata.

Farmers see C. odorata as an important weed in their food crop fields, but also identify others like Sida spp., Stachytarpheta cayennensis and Euphorbia heterophylla as being significantly more problematic forbes. In fallows where C. odorata was manually removed, these problem species increased substantially in the fallow vegetation. A planted fallow of Pueraria phaseoloides successfully suppressed C. odorata. The nitrogen content of particulate organic matter after a P. phaseoloides fallow was higher than after C. odorata on soils with low acidity and Al saturation, but the inverse was true on soils with high soil acidity and Al saturation. Time required for land preparation before planting does not vary between fallow types, however tree-based fallows need proportionately more time for clearing and burning. The maize yield of a mixed groundnut-maize-cassava system was higher after a P. phaseoloides fallow than after C. odorata. Cassava yields tended to be at least as great after C. odorata and lowest when C. odorata had been removed. In summary, where farmers are not ready to plant fallows, C. odorata is a valuable fallow species. General weed management measures need to be developed to ease the tedium of handweeding.
**INTRODUCTION**

The weed *Chromolaena odorata* (L.) R.M. King and H. Robinson (Asteraceae) was introduced into Congo more than three decades ago. The speed of its spread and growth permitted its easy establishment in disturbed landscapes, where it generally constitutes the dominant species. The noxious effects of *C. odorata* are felt in the domains of agriculture, stock breeding, forestry, and the natural environment.

At present, the practical methods of control are chemical and mechanical. Biological control, strongly recommended as a durable solution to the problem posed by *C. odorata*, is in its initial stages.

**ORIGIN AND DISTRIBUTION**

*Chromolaena odorata*, which originates in Central and South America and the Caribbean, was introduced into Asia in the 19th century. From Asia, *C. odorata* reached Africa in 1937. The date and means of introduction of *C. odorata* into Congo are unknown. In 1965 *C. odorata* was collected for the first time in the forested region of Mayombe (Gautier, 1992). It is probably at the end of the 1960s that *C. odorata* began to attract people’s attention. This period corresponds with the arrival of President Marien Ngouabi in power, which explains one of the names given to the plant. To date, *C. odorata* has been given several names, used mainly in the south and south-west of the country. The most well known are: lantana of Ngouabi (former president); Matapa mbala (the invader); Comilog (an allusion to the trains belonging to COMILOG, the mining company of Ougoué, which are made up of several wagons i.e. the idea of something never-ending); Kalamilebe; Kalamana; Diabantou (toxic); Yhombi (former president); Rwandais (name given in Odziba in 1977 following the mass arrival of Rwandan refugees after the genocide).

*Chromolaena odorata* is present in all regions of Congo. The south and south-western regions are the most infested. The centre of the country is colonized to an intermediate extent. In the north, *C. odorata* is present as pockets spread sparsely along roads, and in some fallows. *Chromolaena odorata* colonises various types of terrain (plateaus, valleys, lowlands). Its establishment is favoured by rural development (cultivation based on the fallow system, road construction, civil engineering works, electrical lines), and erosion also contributes significantly. In the towns, *C. odorata* grows in gardens, on buildings and along poorly maintained borders of canals. However, the weed is not fond of dry, sandy soils.

**NOXIOUS EFFECTS**

The speed of growth of *C. odorata* allows it to suffocate the naturally growing, indigenous flora in both forest and savanna. De Foresta and Schwartz (1991) indicated that *C. odorata* retards forest regeneration. The detrimental effects of *C. odorata* on the environment are considerable: it markedly reduces biodiversity, and as a consequence decreases the quality of pasturage. Effects at a population ecology level are equally noticeable: in the Mayombe, the proliferation of the grasshopper *Zonocerus variegatus* (L.) (Orthoptera: Pyrgomorphidae) has followed the invasion of fallow lands by *C. odorata* (Bani, 1990).

In palm and sugarcane plantations, *C. odorata* poses a dreaded fire risk. Large sums of money are spent on the purchase and application of herbicides to combat it. Furthermore, the farmers of the forested areas of the Chaillu massif fear to cultivate manioc in fields infested with *C. odorata*, as its presence results in a high incidence of tuber rot.

An anecdotal story from Sibiti tells how, at the end of the 1980s, a family died after consuming a plate of moussosso (leaves of *Solanum aethiopicum* L.)
USEFUL PROPERTIES

The farmers of the valleys of Niari and Pool recognize that *C. odorata* improves the fertility of the soils (e.g. boosting peanut production). These observations were confirmed by research conducted by Madembo and Ekouamvie (1993). *Chromolaena odorata* limits colonization by *Imperata cylindrica* (L.) (Poaceae) and allows a substantial reduction of the fallow period of land, which decreased from 6 – 7 years to 3 – 4 years in Kombé (Brazzaville region) and in the Niari valley. The stems of *C. odorata* are used as firewood. The repellant effects of *C. odorata* compost on phytoparasitic nematodes have been highlighted (Matondo et al., 1993) and essential oils extracted from the leaves of *C. odorata* (Lamaty et al., 1992) have insecticidal properties. Additionally, certain herbalists consider *C. odorata* to have many medicinal properties.

STATUS

*Chromolaena odorata* has officially received the status of a weed, and a national control committee was put in place in 1992. This committee brought together researchers, development agencies and herbalists.

CONTROL

The various control activities against *C. odorata* are practiced by different sectors and/or are at different stages of development:

- Mechanical control is practiced by small-scale farmers and by the Agro-Industrial Societies. It consists of clearing the thickets of *C. odorata* and burning them. The stumps of the plants are then removed, piled up and burned at the edge of the plantations.
- Chemical control is practiced exclusively by the Agro-Industrial Societies. It is not directed only at *C. odorata*, but at all weeds present in the plantations.
- Biological control against *C. odorata* began in 1996 with (i) a survey of local natural enemies. Seven species of insects cause damage to *C. odorata*. They are: *Z. variegatus*; *Anoplocnemis curvipes* (Fabr.) (Heteroptera: Coreidae); *Phenacoccus madeirensis* Green (Homoptera: Pseudococcidae); *Ferrisia virgata* (Cockerell) (Homoptera: Pseudococcidae); *Orthezia sp.* (Homoptera: Ortheziidae); *Aphis citricola* van der Goot (Homoptera: Aphididae); *Uroleucon compositae* Theobald (Homoptera: Aphididae), (ii) the upgrading of an insectary to receive exotic biocontrol agents. However, this insectary unfortunately suffered extensive damage during the sociopolitical events of 1998 - 1999.

An exotic plant, *Tithonia diversifolia* (Hemsl.) A. Gray (Asteraceae) affects *C. odorata* negatively. Under certain experimental conditions the elimination of *C. odorata* by *Mucuna* sp. (Fabaceae) has been observed.

DISCUSSION AND CONCLUSIONS

*Chromolaena odorata* is an exotic plant that was first observed in the Congo in 1965, in the Mayombe massif. The invasion of this forested zone, of the Niari valley, and of the massifs of Chaillu and Pool must have occurred during the 1970s and 1980s. The work of realigning the Congo-Ocean railroad, the construction of an electric line between Moukoukoulou and Pointe-Noire, the construction of numerous bridges on the national route No. 1, and the regular maintenance of routes for motor vehicles were the main factors in the extension of the infestation. The intensity of agricultural activities in these regions and the practice of shifting agriculture permitted the creation of numerous spaces favourable to *C. odorata*.

It appears that *C. odorata* colonized areas to the north of Brazzaville during the 1980s and 1990s. Two events seem to have been the determinant factors in this, namely the construction of the national route No. 2 and the opening up of large expanses for the cultivation of maize in Odziba. Odziba is the only place in these regions where large expanses of ground infested with *C. odorata* can be seen. Otherwise, *C. odorata* is only present at irregular intervals along the edge of the road. On the Koukouya plateau, for example, it was as recently as 1991 that *C. odorata* was first seen.

Most of the names given to *C. odorata* by the people evoke contempt or fear. This seems to be in keeping with their desire to get rid of the plant or at least to reduce its harmful effects.

Nature reserves constitute a domain of economic interest recognized in Congo. The reduction of biodiversity by the expansion of *C. odorata* is harmful to such areas. Similarly, the invasion of pastures by *C. odorata* hinders the development of stock breeding. No animal feeds on this plant. The regular consumption of palatable plant species allows *C. odorata* to colonise all the spaces among the pasturages and render them useless.

The clearing of *C. odorata* at the beginning of the
dry season (June – July) in the Niari valley plays a positive role in reducing the potential seed production by eliminating the stems of the weed as flowering starts. Fire is also an important means of reducing *C. odorata*. Bush fires are started by people for various reasons during the dry season (June – September). In June and July, the *C. odorata* thickets burn very poorly, but the fires in August, September and October are violent and can eliminate a large proportion of the seed produced by *C. odorata*.

The large-scale utilization of herbicides is an expensive control method, and damaging to the environment. *Chromolaena odorata* is now a component of the biological diversity of Congolese ecosystems; its eradication is almost Utopian. Nevertheless, to successfully control its spread, biological control is becoming the only adequate method. In its essence, biological control, instead of eliminating the target organism, aims to establish an equilibrium which maintains its population at a level of negligible harmfulness. In consequence, the rehabilitation of the insectary is a necessity. The effort to introduce exotic biological control agents and to evaluate their activities needs to be sustained.

**ACKNOWLEDGEMENTS**

I thank the Centre Technique de Coopération Agricole et Rurale (CTA) who supported my participation at the workshop. I give my sincere thanks to the ARC-Plant Protection Research Institute and particularly to Dr H. Zimmermann and his team for the facilities which were granted me during and after the workshop.

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STATUS AND BIOLOGICAL CONTROL OF CHROMOLAENA ODORATA IN MALAYSIA

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Chromolaena odorata is one of the major weeds in Malaysia, affecting a number of crops. The natural enemies Apion brunneonigrum and Pareuchaetes pseudoinsulata were introduced in the early 1970s. Only P. pseudoinsulata established.

KEY WORDS: Apion brunneonigrum, biological weed control, distribution, Pareuchaetes pseudoinsulata

DISTRIBUTION AND HABITAT PREFERENCES OF CHROMOLAENA ODORATA IN MALAYSIA

Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) was unknown in Malaysia until the 1914 - 1918 war (Henderson, 1974). It is now common on roadsides, open areas, pastures, abandoned gardens and forest clearings. In addition, it prefers well-drained soil. It normally grows in association with other weeds, such as Melastoma malabathricum L. (Melastomataceae), Clidemia hirta (L.) D. Don (Melastomataceae), Diodia ocimifolia (Willd. ex Roem. & Schult.) Bremek. (Rubiaceae), Borreria latifolia (Aubl.) Schum. (Rubiaceae), Asystasia gangetica (L.) T. Anderson (Acanthaceae) and Dicranopteris linearis BP (Cleicheniaceae). It can form dense bushes with tangled branches which are difficult to penetrate (Syed, 1979).

PROBLEMS AND USES OF CHROMOLAENA ODORATA

Chromolaena odorata is an important weed in 2 - 5 crops (including rubber, oil palm, coconut and tobacco) in peninsular Malaysia and in coconut plantations in Sabah and Sarawak, in eastern Malaysia (Holm et al., 1977; Syed, 1979).

In experiments at the Rubber Research Institute of Malaysia, C. odorata, when compared with ground covers of small grasses or recommended legumes, was found to suppress the growth of rubber trees (Anon., 1967). In Malaysia, leguminous plants are commonly planted in rubber and oil palm plantations during the replanting of new crops. These cover crops grow and spread very quickly, and prevent invasion of noxious weeds, including C. odorata. The planting of a cover crop during tree crop establishment could account for why this weed is not so widespread in the plantations.

The debris of C. odorata has been shown to produce allelochemicals, especially during its decomposition (Ismail, 1989).

Muhammad and Mustafa (1994) reported that C. odorata can be used to stop bleeding, by pounding the leaves until fine, and applying to the wound. Sometimes, during an emergency, the leaves are crushed by hand, mixed with some saliva and applied to the wound.

BIOLOGICAL CONTROL OF CHROMOLAENA ODORATA

Efforts towards the biocontrol of weeds in Malaysia started in the 1970s, when control attempts were made against C. odorata, which seriously infested coconut fields. To date biological control efforts have been made on five major weed species: C. odorata, Cordia curassavica (Jacq.), Roem & Schult. (Boraginaceae), Mikania micrantha (L.) Kunth (Asteraceae), Salvinia molesta D. Mitch. (Salviniaceae) and Eichhornia crassipes (Mart.) Solms (Pontederiaceae).

Biological control of C. odorata in Malaysia was first attempted in the early 1970s, when releases of Apion brunneonigrum Béguin-Billecocq, a seed-eating beetle, and the defoliating larva of a moth, Pareuchaetes pseudoinsulata Rego Barros, were made in Sabah. Apion brunneonigrum did not establish, while P. pseudoinsulata did establish but little follow-up work has been carried out (Ooi et al., 1988, 1991).

ACKNOWLEDGEMENTS

The Australian Centre for International Agricultural Research is thanked for providing funding for the author to attend the Fifth International Workshop.
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INTRODUCTION

The potential geographic range of *Chromolaena odorata* (L.) R.M. King and H. Robinson (chromolaena) in Australia is extensive. Much of the coastal margin and adjacent hinterland from north-west Western Australia through the Northern Territory and Queensland to northern New South Wales is climatically suitable for its establishment (McFadyen and Skarratt, 1996). In Australia, chromolaena is referred to by the common name ‘Siam weed’. Australia’s northern coastline closely abuts eastern Indonesia, East Timor and Papua New Guinea, where infestations of chromolaena are expanding rapidly. The recent history of its spread in neighbouring regions led experts to warn of its likely arrival in northern Australia (McFadyen, 1989; Michael, 1989). Chromolaena was subsequently declared a prohibited species throughout Australia and became a primary target of weed surveys conducted in northern Australia, Papua New Guinea and eastern Indonesia under the auspices of the Northern Australia Quarantine Strategy, a sub-programme of the Australian Quarantine and Inspection Service (Waterhouse, 1998). Early detection of new incursions (by weeds, pests or pathogens) offers the best opportunity for timely and cost-effective intervention. In Australia, national and state authorities are committed to preventing chromolaena from becoming a long-term problem.

The discovery of established infestations of chromolaena near Bingil Bay and along the lower reaches of the Tully River in coastal north-east Queensland in July 1994 and immediate commencement of an eradication campaign, were discussed by Waterhouse (1994, 1998). The present paper reviews subsequent progress in the eradication effort and reports on a previously unknown infestation in the Cocos (Keeling) Islands, one of Australia’s external territories. During the recent deployment of Australian military personnel and equipment to East Timor, the presence of extensive, heavily seed-bearing chromolaena infestations necessitated the adoption of rigorous quarantine measures to minimise the inadvertent introduction of seeds as contaminants of returning equipment. Minimisation of the risk of introduction of chromolaena through effective quarantine, early warning and public awareness measures must become a long-term commitment, because geographic and sociological factors dictate that northern Australia will remain on the brink of re-invasion of chromolaena for the foreseeable future.

**KEY WORDS:** alien invasive, Cocos (Keeling) Islands, early detection, East Timor, eradication, Queensland, Northern Australia Quarantine Strategy

ERADICATION EFFORT IN NORTH QUEENSLAND

**Detection of Further Infestations**

When chromolaena was first discovered in north-east Queensland in 1994, rapid but relatively superficial surveys of the entire region revealed numerous small to well-established infestations scattered throughout an area of hundreds of square
The herbicides of choice have been Grazon DS® in combination depending on local site conditions. Herbicide application, hand-pulling or fire, alone or previously unknown infestations.

Public, have also led to the reporting of many infrastructure providers (e.g. telephone, electricity authorities, rural landholders, service and awareness campaigns targeting local government or inaccessible infestations. Repeated intensive effective and useful for finding and treating isolated Annual helicopter surveys have proven both cost- increase the likelihood of recognition of any infestations outside the surveillance area. To ensure continuity of the eradication effort, a full-time team leader was appointed to the project.

From the outset, Department of Natural Resources is the agency responsible for the eradication campaign. From the outset, Department of Natural Resources personnel from all over the state were circulated through the eradication teams to become familiar with the appearance of chromolaena and thus to increase the likelihood of recognition of any infestations outside the surveillance area. To ensure continuity of the eradication effort, a full-time team leader was appointed to the project.

Annual helicopter surveys have proven both cost-effective and useful for finding and treating isolated or inaccessible infestations. Repeated intensive awareness campaigns targeting local government authorities, rural landholders, service and infrastructure providers (e.g. telephone, electricity and road maintenance field crews) and the general public, have also led to the reporting of many previously unknown infestations.

All known infestations have been treated using herbicide application, hand-pulling or fire, alone or in combination depending on local site conditions. The herbicides of choice have been Grazon DS® (picloram + triclopyr 1:300) or Starane® (fluoxyprpyr 1:250), in combination with a wetting agent. Grazon DS® is used where a residual action is desired. Prevention of further seed set is essential, so surveys to detect new plants and the major annual treatment programmes are conducted between March and June each year, before flower initiation is evident. Further spot checks are conducted throughout the year.

With eradication the ultimate goal, repeated follow-up is essential at all sites where chromolaena plants have been recorded. A comprehensive database containing approximately 600 individual site records has been developed and linked to aerial photographic layers on a Geographic Information System. Detailed photo-maps displaying the location of known individual plants or infestations enable the eradication teams to relocate and inspect previously treated sites, and apply spot-treatments as necessary. All new occurrences (including presence of seedlings where mature plants have been destroyed previously) are incorporated onto the database and subsequent maps (Zeimer and Bocking, 2000).

The eradication effort precludes establishment of long-term plots for studying the behaviour of chromolaena under local conditions. However, several sites have been selected throughout the infested district, where seedlings are counted in fixed plots every 6 months before being destroyed. The sites were selected to provide a range of dates since mature (seeding) plants were last recorded as present. In most cases the duration of the infestation at these sites (and therefore the period of accumulation of seeds in the soil) is unknown. It is often assumed that chromolaena seeds are relatively short-lived and that accumulation of a substantial soil seed bank is unlikely. We have observed a marked and relatively rapid decline in the numbers of seedlings emerging in the plots, but it has caused concern that occasional seedlings are still emerging at sites where the last (known) mature plants were destroyed 6 and 5 years earlier, respectively (in 1994 and 1995). The presence of viable seeds in the soil has also been demonstrated where seedlings appear in the wake of disturbances (e.g. trench-digging) at sites that had been recorded as free of chromolaena for several years.

Economic Analysis of the Eradication Campaign
To date the chromolaena eradication campaign in north-east Queensland has cost a little over AU$ 1.0 x 10^6. In 1999, Dr R.E. Cruttwell McFadyen and the Department of Natural Resources commissioned an economic evaluation of the eradication campaign in terms of costs and benefits to Queensland alone. The analysis considered the
potential economic impacts of chromolaena on a subset of Queensland’s major agricultural and horticultural commodities and concluded that the eradication effort is highly cost effective and of great benefit to present and future production. A net present value between AU$ 13.6 x 10^6 and AU$ 41.9 x 10^6, and a benefit/cost ratio of between AU$ 10.99 and AU$ 25.71 (per dollar spent on the eradication) were calculated; the variability depended on the assumptions used (Adamson et al., 2000). It should be noted that the analysis did not specifically include actual or potential costs to the natural environment or human health, nor did it consider the potential impacts on a range of less important commodities or the potential costs should chromolaena spread beyond Queensland.

Chromolaena in north-east Queensland occurs on land abutting Australia’s ‘Wet Tropics World Heritage Area’. In this region alone, the environmental consequences could be enormous if chromolaena was allowed to spread unchecked. An inevitable conclusion of the analysis was that it is most profitable to attempt eradication of weeds like chromolaena before the population (and geographic distribution) starts to expand exponentially, and preferably as soon as possible after its arrival (Adamson et al., 2000).

**DETECTION OF CHROMOLAENA ODORATA IN THE COCOS (KEELING) ISLANDS**

The two atolls comprising the Australian external territory of the Cocos (Keeling) Islands lie in the Indian Ocean about 900km south-west of Sumatra (Indonesia) and 2 100km north-west of the Australian continent (between latitudes 11.49 and 12.13 S and longitudes 96.49 and 96.56 E). There are approximately 30 low islands of coralline sand, rubble and algal limestone in the group. The natural vegetation is a relatively depauperate low forest containing species typical of strand and littoral communities throughout the Indo-Pacific region. Only North Keeling Island retains relatively undisturbed forest, now preserved as the Pulu Keeling National Park (AGPS, 1993). The islands were settled during the 1800s and most were cleared and extensively planted with coconuts. These plantations were abandoned in 1978. The present population of approximately 600 people is mostly of Malay origin. The Western Australian government administers the islands.

In May 2000, extensive infestations of chromolaena were recorded on many of the islands of the southern atoll during a Northern Australia Quarantine Strategy weed and plant health survey. Chromolaena was not found on North Keeling Island (A.A. Mitchell, pers. comm.). A subsequent search of herbarium records for the islands revealed that specimens of *C. odorata* had been collected, indicating that the plant was common as early as 1986, but had been misidentified and lodged in the National Herbarium as another species. Ironically, the voucher specimen was re-examined and misidentified a second time in 1990, so the presence of chromolaena on the Cocos (Keeling) Islands remained unrecognised until the survey in May 2000.

Delayed recognition of serious invaders reduces the options for mitigation. The most appropriate response is still being considered, but it is unlikely that eradication will be attempted in the Cocos (Keeling) Islands. Biological control seems to be the most logical choice in this case.

**THE THREAT FROM EAST TIMOR**

The risk of inadvertent re-introduction of chromolaena to mainland Australia has substantially increased through our peace-keeping and reconstruction role in East Timor’s transition to independence from Indonesia. Thousands of Australian personnel and associated vehicles and equipment have been deployed to East Timor since September 1999, and most personnel and equipment from other participating nations have transited through Darwin (Northern Territory) *en route* to and from East Timor.

When Australia’s role was announced the Australian Quarantine and Inspection Service instigated an assessment of the quarantine risks associated with movements between Australia and East Timor. The risk of introduction of *C. odorata* seeds was identified as a primary threat (AQIS, 2000). At the time of the initial deployment, abundant chromolaena seed was present on bushes as well as in the general environment of East Timor, and inspection of equipment, vehicles and personal effects revealed the presence of chromolaena seeds (A.A. Mitchell, pers. comm.).

In response to the threat posed by chromolaena and various other quarantine pests, up to 10 Australian quarantine officers at a time have been stationed in East Timor since late 1999 to oversee cleaning and inspection of vehicles and equipment before their return to Australia. A permanent rotational staff of two quarantine officers increasing to 10 at times of peak movement has been guaranteed for the next 2 - 3 years. The number of quarantine officers stationed in Darwin has also been doubled to cope with the increased workload in the foreseeable future.

Australian Defence Force personnel have made a major contribution to the quarantine effort. During the change-over from the original peace-keeping...
force to the United Nations Transitional Administration, more than 300 military and quarantine personnel operated 20 wash-stations up to 18 hours a day for 3 months. All clothing and personal effects are inspected for seeds, as are vehicles and machinery, the latter being stripped down for cleaning and inspection. Armoured personnel carriers that cannot be adequately dismantled in East Timor are brought back to Darwin under quarantine. Some of these have been found to contain large quantities of chromolaena seed in their radiators (A.A. Mitchell, pers. comm.), which is subsequently destroyed.

Given the small size of chromolaena seeds and seasonal increases of its availability in the East Timor environment, it is almost inevitable that some seed will remain undetected despite the application of rigorous quarantine measures. As a further adjunct, regular surveys for chromolaena and several other weeds not yet present or widespread in Australia will be undertaken at high-risk sites (e.g. military bases and training grounds) throughout Australia for at least the next 3 years.

**FUTURE REQUIREMENTS**

Paradoxically, Australia is on the brink of successful eradication of *C. odorata* from the mainland, and on the brink of its re-introduction from neighbouring islands. Vigilance and a sustained effort are required to keep Australia free of chromolaena.

It is now extremely difficult to find chromolaena in the Tully River and Bingil Bay districts, thanks to the dedication of the teams involved in the eradication effort. Ironically, as chromolaena plants become scarce and relatively harder to locate, the search effort required to find those plants before they flower and set seed has increased. While treatment costs have dropped, it is unlikely that there will be a significant reduction in overall annual expenditure on the eradication effort for at least several more years. Vigilance must be maintained and adequately supported for the eradication effort to succeed.

The huge logistical effort to minimise the risk of inadvertent re-introduction of chromolaena following deployment of Australian personnel to East Timor is very expensive. The response to date represents a high level of commitment at Federal, State and Territory levels to keep Australia free of chromolaena. Early detection of any new infestations is absolutely critical if this effort is to succeed. Implementation of a national public awareness programme clearly stating the threat posed by chromolaena and encouraging members of the public to report suspected outbreaks, is an essential adjunct to the quarantine and surveillance measures.

Biological control of chromolaena in the Cocos (Keeling) Islands should be investigated as a matter of urgency. Effective agents have been released and established in neighbouring Indonesia as part of the biological control programme funded by the Australian Centre for International Agricultural Research (ACIAR) (McFadyen, this Proceedings), and appropriately skilled personnel are available in Australia. Host-specificity testing could be completed more rapidly (than for mainland Australia) due to the relatively low floral diversity in the Cocos (Keeling) Islands and successful introduction and establishment of appropriate agents may reduce the likelihood of chromolaena’s spread to the Pulu Keeling National Park on North Keeling Island. Results of this work would also be useful should biological control ever be required for the Australian mainland.

**ACKNOWLEDGEMENTS**

I would like to thank my colleague Andrew Mitchell of the Australian Quarantine and Inspection Service for providing information relating to the discovery of chromolaena in the Cocos (Keeling) Islands and to the East Timor response.
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INTRODUCTION

Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae) is a major tropical weed worldwide and the most problematic non-native invasive plant species in the KwaZulu-Natal province of South Africa (Liggitt, 1983; Macdonald and Jarman, 1985; Henderson, 1989). Chromolaena odorata is a perennial semi-lignified herbaceous plant (Gautier, 1992). Its spread has been rapid, facilitated by the production of large numbers of wind-dispersed, light-weight (2.54 ± 0.11mg) seeds. In South Africa, C. odorata is mostly a problem in nature reserves and to silviculture during the establishment phase, and it was proclaimed a noxious weed in 1980. The leaves contain essential oils, resulting in flammable foliage and raised fire temperatures and hazard. It generally grows into dense stands along forest margins and riverine fringes and its flammability threatens the persistence of coastal forest patches, which are not resilient to burning (Pammenter et al., 1985). The availability of grazing and browsing to large herbivores is reduced by dense stands of C. odorata.

Biological invasions, the human-mediated breakdown of biogeographical barriers to species dispersal, are a consequence of global environmental change. Presently, biological invasions have caused more species extinctions than have resulted from human-caused climatic change, and only land-use change has probably caused more extinctions, but invasions interact strongly with land-use change (D’Antonio and Vitousek, 1992).

Chromolaena odorata is native to the neotropics from eastern USA, Central America and most West Indian Islands to Paraguay (Gautier, 1992; Goodall and Erasmus, 1996). In South Africa C. odorata occurs predominantly below 1000m a.s.l. and is virtually restricted to the frost-free zone (Henderson, 1989). Biological control in South Africa has been unsuccessful to date, but new candidate insects appear promising (Zachariades et al., 1999). Clearing in nature reserves is largely based on labour-intensive manual methods (A. Blackmore, pers. comm.) and the use of chemical herbicides (Goodall and Erasmus, 1996),
Witkowski: Invasion Intensity and Regeneration of Chromolaena

but overall success has been disappointing.

Chromolaena odorata has a phytochrome-mediated germination response, which is typical of many weeds and allows rapid colonization of disturbed areas (Erasmus and van Staden, 1986). Field trials show that seeds are rarely dispersed >80m by wind, with the majority dispersing <10m, but longer distance dispersal by vehicles (Blackmore, 1998) and exozoocyadry also occurs (Gautier, 1992). This suggests that rapid ‘reinvasion’ of cleared areas may largely be from seedlings establishing from an in situ soil seed bank.

The aim of this study was to determine the invasion intensity (density and biomass) and regeneration potential (seed production and soil seed banks) of C. odorata along a chronosequence of six sites spanning an invasion period of about 15 years.

METHODS

Study Sites
The study was centred within the landscape of a large conservation area and world heritage site, the Greater St Lucia Wetland Park, KwaZulu-Natal province, South Africa (henceforth referred to as St Lucia), and adjacent pine plantations. The six sites ranged in age of invasion (time since the last clearing of C. odorata for sites 1 - 4) of <1 to >15 years. Sites 1 - 5 were on the Western Shores of St Lucia (Charter’s Creek/Nyalazi Forest; 28.10 - 13 S 32.20 E) within a radius of 3km, while site 6 (>15 years) was on an island in the St Lucia Estuary (Honeymoon Bend; 28.23 S 32.24 E) 20km to the south. The natural vegetation comprises coastal dune forest and grasslands. Sites 1 and 2 at Charters Creek were cleared <1 and 3 years prior to the study, respectively. Sites 3 (5 years) and 4 (7 years) were situated in the Nyalazi plantation, where C. odorata is cleared for 3 years after planting. Site 5 (10 years old) occurs in an indigenous forest patch within the Nyalazi plantation. The 10 and >15 year old sites have never been cleared.

Altitudes range from <10 - 40m a.s.l. Mean annual rainfall for Fanie’s Island (closest to sites 1 – 5) is 921mm, with 61% falling between November and March and about 23% in the winter months of May to September. Mean annual rainfall for St Lucia Estuary (closest to site 6) is 1 192mm. Mean daily temperatures range from 10.9 - 22.6˚C in June to 20.6 - 30˚C in January. The sites are situated on the Zululand Coastal Plain. The soils are relatively deep and sandy (more details on soils, geomorphology and geology in Maud (1992) and Witkowski and Wilson (2001)). Within each site, a typical C. odorata invaded area of about 1ha along the edge of forest patches (or within the pines) was selected.

Density, Growth Form and Plant Size
In August – September 1994, 15 1 x 1m quadrats were placed at random within each of three microsites per site. These were ‘sun’ (<30% overstorey), ‘semi-shade’ (30 – 70%) and ‘shade’ (>70%) cast from indigenous forest or pine trees. Within each quadrat, the number of rooted C. odorata plants was counted. Plants were categorised into three growth forms: seedlings, etiolated shrubs, or bushy shrubs. Seedlings had from 1 – 3 stems, and were <1m in height. Etiolated shrubs were >1m in height, with few but long branches which tend to climb or lean against woody plants (a sparse canopy). Bushy shrubs were also >1m in height, but had many short branches (dense canopy). For each flowering plant in each quadrat, plant height (H), the widest canopy diameter (D1) and the diameter at right angles to the widest (D2) were measured. Canopy area [π x (D1/2) x (D2/2)] and volume [(π) x x (H/2) x (D1/2) x (D2/2)] were determined. Foliage projective cover of C. odorata within each quadrat was also visually estimated.

Allometric Relationships for the Determination of Chromolaena odorata Biomass
In order to assess the size of plants and the degree of invasion at a site, biomass per plant was selected as the most useful measure. Thirty-five seedlings, 23 etiolated shrubs and 17 bushy shrubs were randomly selected from the various sites to provide a range of sizes for allometric determination of plant biomass. Plant height and canopy dimensions were measured prior to cutting the stems at the soil surface. Plants were divided into live leaf, stem and dead material, and dried in a forced-draught oven for 7 days at 70˚C, and then weighed. The relationships between canopy dimensions (height, canopy area or canopy volume) and plant dry mass (live and total) were determined using the best fit of linear, logarithmic (In), exponential and power-curve regressions. The canopy dimensions of all the plants in the quadrats were then used to determine biomass per plant. For biomass per unit area, the mass of each plant per quadrat was summed.

Seed Production
The number of flower heads per plant was counted in plants with <100 flower heads. On plants with >100 flower heads, flower heads on three representative branches were counted, the total number of branches counted, and total number of flower heads determined. A subsample of 10 flower heads per plant were taken at random, or all flowerheads if the total was <10. The number of capitula per flower head was counted and the mean determined. The number of seeds (fruits) from three capitula per flower head was selected.
mean determined. Total seeds per plant was then calculated as follows:

\[
\text{Seeds/plant} = (\text{flower heads/plant})(\text{capitula/flower head})(\text{seeds/capitula})
\]

The number of seeds produced per quadrat (1m²) was determined by summing the seeds produced per plant rooted in the quadrat. Seed germinability was tested on a subsample of 50 randomly selected seeds per plant.

Seed Germinability in Relation to Light, Moisture Availability and Burial
A greenhouse trial was established in March 1994 using seeds collected from 20 \textit{C. odorata} shrubs from Charter’s Creek, St Lucia during August 1993. One hundred intact seeds were placed either at the surface, or at a depth of 1 or 8cm in pots of height 9cm and diameter 10cm. Pots were kept at two levels of light (full sun, 550 – 600mmol/m²/second; Li-cor Quantumsensor Li-185B) and shaded (200 – 300mmol/m²/second), and at two levels of watering, saturated daily (high) or biweekly (low). Five pots were assigned to each level of light, moisture and depth of burial. Once a week, the number of seedlings that emerged was counted, and then snipped off at the base with scissors to encourage other seeds to germinate. In August 1994 (after 5 months), the remaining ungerminated seeds were removed, counted and tested for germinability (see below for technique). Mean daily maximum and minimum temperatures in the heated greenhouse ranged from 24 – 35°C and 10 – 16°C respectively. Because no seedlings emerged in the pots with seeds buried at a depth of 8cm, only one set of replicate pots was used initially for seed recovery. In January and June 1995, after a further 5 and 10 months of treatment (10 and 15 months in total), the seeds were recovered from one and then the remaining three sets of pots respectively. Seed germinability was again assessed.

Soil Seed Banks
Five \textit{C. odorata} soil seed bank samples were collected from the sun and shade of sites 1, 2, 4 and 6 during 3 – 10 July 1994. Samples were thus collected just prior to the production and release of seeds during August/September. The seeds of the previous seasons’ cohorts had thus been in the soil >10 months. These represent ‘persistent seeds’ that had survived and not germinated through at least one growth season.

Seed Germinability and Viability
Germination trials commenced about 6 months after seed collection to satisfy after-ripening requirements, corresponding with the peak field germination period. Seeds were placed in petri dishes on moist Whatman No. 1 filter paper in full sun. Moisture was checked daily and fungi were controlled with Benlate. Seed germination (radicle emergence by 2mm) was monitored daily for 40 days, and germinants immediately removed. Chemical viability testing using 2,3,5-triphenyl-tetrazolium chloride (Mbalo and Witkowski, 1997) was undertaken on 22 of the samples.

RESULTS
Aerial Cover, Plant Size and Density of \textit{Chromolaena odorata} Infestations
Aerial cover was highest in the sun for all except the 1-year-old site, where it was similar in the sun and semi-shade. Only the 3-year-old site had a high cover of \textit{C. odorata} in the shade, with cover in the

Table 1. Best-fit allometric regression equations for the relationships between live or total biomass (g) with dimensions of individual \textit{Chromolaena odorata} plants.

<table>
<thead>
<tr>
<th>Growth form</th>
<th>Biomass (g)</th>
<th>(r^2)</th>
<th>(n)</th>
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<tr>
<td>Seedlings</td>
<td>Live and Total biomass = 0.00418 (height in cm(^{1.69915}))</td>
<td>0.803</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Live biomass = 44.475 + 206.65 (Canopy volume in m(^3))</td>
<td>0.780</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Total biomass = 53.490 + 225.93 (Canopy volume in m(^3))</td>
<td>0.691</td>
<td>22</td>
</tr>
<tr>
<td>Etiolated shrubs</td>
<td>Live biomass = 787.794 (Canopy volume in m(^3))(^{0.74992})</td>
<td>0.879</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Total biomass = 834.1862 (Canopy volume in m(^3))(^{0.73142})</td>
<td>0.874</td>
<td>17</td>
</tr>
</tbody>
</table>

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Witkowski: 
Invasion Intensity and Regeneration of Chromolaena

Figure 1. (A) Percentage aerial cover, (B) live biomass and (C) density of Chromolaena odorata in relation to invasion age (years) in the St Lucia region, South Africa.

- Percentage aerial cover: $\text{cover}_{\text{sun}} = 24.701 \cdot (\text{Invasion age})^{0.4539}$ ($r^2 = 0.68$)
- Live biomass (1-15 years): $\text{live biomass}_{1-15\text{yrs}} = 376 \cdot (\text{Invasion age})^{1.3325}$ ($r^2 = 0.72$)
- Live biomass (1-10 years): $\text{live biomass}_{1-10\text{yrs}} = 447 + 3240 \ln(\text{Invasion age})$ ($r^2 = 0.85$)
- Density in sun: $\text{density}_{\text{sun}} = 14.27684 \cdot e^{-0.2884054 \cdot \text{Invasion age}}$ ($r^2 = 0.91$)
- Density in semi-shade: $\text{density}_{\text{semi-shade}} = 12.33671 \cdot e^{0.1135706 \cdot \ln(\text{Invasion age})}$ ($r^2 = 0.79$)
- Density in shade: $\text{density}_{\text{shade}} = 9.02154 \cdot e^{0.2994097 \cdot \ln(\text{Invasion age})}$ ($r^2 = 0.79$)
Figure 2. Overall (all sites combined) size class distribution of *Chromolaena odorata* plants in terms of (A) canopy area and (B) canopy volume, in the St Lucia region, South Africa. The Y axis is a log$_2$ scale.
shade of <1% for the sites invaded for ≥5 years. The aerial cover of *C. odorata* was intermediate in the semi-shade in all sites ≥5 years old. There was an increase in aerial cover with invasion age in the sun, but not in the shade or semi-shade (Fig. 1). *Chromolaena odorata* shrub heights varied greatly, reaching a maximum of about 6m, but generally averaged 2 – 3m, with similar heights in the sun and semi-shade, and shorter plants in full shade. The size distribution of *C. odorata* is an inverse J (Fig. 2), typical of strongly recruiting self-thinning populations.

Harvested plant biomass ranged from 0.35g seedlings to 9.9kg bushy shrubs of 5m in height and canopy area 14.1m². The best-fit allometric regressions for live and total biomass are given in Table 1. Overall biomass of *C. odorata* was very low in the <1 year old site and rapidly increased thereafter in the 3-year-old site, with little change thereafter (Fig. 1). Seedlings represented a negligible proportion of total biomass (< 1%) in all sites (and microsites) except the seedling-dominated youngest site. A very small proportion of *C. odorata* biomass occurred in the shade, with the majority of biomass in the sun (66 ± 7% for all sites combined; range 45 – 95%).

Density of *C. odorata* tends to be highest in the semi-shade, followed by the sun and lowest in the shade. *Chromolaena odorata* density decreased with invasion age up to about 7 years of age, thereafter tending to level off (Fig. 1). Adult density was highest in the 3-year-old site and lowest in the most recently invaded site.

**Seed Production**

There were no differences between etiolated and bushy shrubs in seeds per plant, seed germinability or germinable seeds per plant, thus data for these
Figure 4. (A) Number of seeds produced per reproductive plant, (B) number of germinable seeds produced per reproductive plant, (C) total seeds produced per m² of invasion, and (D) total germinable seeds produced per m² of invasion, for Chromolaena odorata in relation to invasion age in the St Lucia region, South Africa. Data for sun and semi-shade microsites only (seed production in the shade was negligible).

Seed production/plant (1 - 10 years)$_{semi-shade}$ = 980 $e^{0.2408}\text{Invasion age}$ ($r^2 = 0.74$)
Seed production/plant (1 - 10 years)$_{sun}$ = 4096 $e^{0.4356}\text{Invasion age}$ ($r^2 = 0.98$).
Germinable seeds produced/plant (1 - 10 years)$_{semi-shade}$ = 245 Invasion age$^{1.1237}$ ($r^2 = 0.86$)
Germinable seeds produced/plant (1 - 10 years)$_{sun}$ = 1293 $\text{Invasion age}^{1.7288}$ ($r^2 = 0.98$).
Seed production/m² (1 - 10 years)$_{semi-shade}$ = -514 + (639 Invasion age) ($r^2 = 0.53$)
Seed production/m² (1 - 10 years)$_{sun}$ = 2162 (Invasion age)$^{2.1229}$ ($r^2 = 0.99$).
Germinable seeds/m² (1 - 10 years)$_{semi-shade}$ = 68.58 (Invasion age)$^{1.3837}$ ($r^2 = 0.61$)
Germinable seeds/m² (1 - 10 years)$_{sun}$ = 739.5 (Invasion age)$^{2.1659}$ ($r^2 = 0.99$).
Seeds produced per reproductive plant increased with invasion age in both the sun and semi-shade up to 10 years, and declined (by close to an order of magnitude) at ≥15 years (Fig. 4). Total seed production for the youngest site was <2% of that for the 10-year-old invasion.

Seed production/m² was very low in the shade and only found in early invasions, averaging 14 (<1 year invasion) and 279 seeds/m² (3 year), and representing <1% of production at these sites. Plants growing in the shade in the two oldest sites produced no seed. The vast majority of seeds were produced by plants in the sun (ranging 89.4 – 99.6%), with plants in the semi-shade intermediate (0.4 – 10%). Total and germinable seeds produced/m² increased with invasion age up to 10 years, and then declined greatly at ≥15 years (Fig. 4), peaking at almost 300 000 seeds/m²/annum at 10 years in the sun.

Seed Germinability in Relation to Light, Moisture Availability and Burial
No seeds emerged from the 8cm depth. After 5 months, germination was greater from seeds sown at the surface (ANOVA, d.f. = 1,32, P < 0.0001) and with higher levels of watering (d.f. = 1,32, P < 0.0001; Fig. 6). The percentage of seeds that did not emerge, but were still germinable, varied with depth of burial (d.f. = 1,32, P = 0.0469) and watering level tended to have an effect as well (d.f. = 1,32, P = 0.0720), with a higher proportion in the 1cm depth class and with biweekly watering. For seeds buried at 8cm for 5 months, 4.9 ± 1.8% were germinable. After 15 months 2 ± 2% were germinable (3 ± 3% by tetrazolium).
Figure 6. Percentages of *Chromolaena odorata* seeds that (A) germinated and (B) did not germinate but were still germinable (mean ± S.E.) in relation to light intensity (shade, sun), depth of burial (D0 = 0cm, D1 = 1cm depth) and water availability (Low = bi-weekly, High = daily watering) in a greenhouse pot trial.
DISCUSSION

Within a year after clearing *C. odorata* there is rapid colonization, with the majority of colonizers found in the sun, followed by semi-shade, and only a few plants in the shade. *Chromolaena odorata* biomass per plant and per unit area follows the same trends. Dense young stands of *C. odorata* are virtually mono-specific in the sun and self-thinning occurs as the stand matures. The presence of mature *C. odorata* plants and/or lack of disturbance suppresses seedling recruitment, especially after ≥7 years of invasion. The ≥15-year-old site, being on an island, excluded fire, although other disturbances such as hippopotamus trampling and flooding (e.g. cyclone Demoina, January 1984) occurred. Large senescent *C. odorata* plants with long trailing branches prevailed. They also exhibited very low total and germinable seed production and low germinability of seed banks relative to the other sites, consistent with plant senescence. At the same time there was considerable indigenous forest tree regeneration (M. Wilson, pers. comm.), which was absent from the ‘younger sites’. Ramakrishnan (1992) found that *C. odorata* fallows (after slash and burn agriculture) in north-eastern India were ‘senescent’ by the tenth year. Thus *C. odorata* plants, undisturbed by fire, become senescent. The onset of this appears to be more rapid in India relative to southern Africa. The commencement of flowering and seed production is also earlier in other parts of the world, probably due to higher rainfall and temperatures, especially in the very moist sites in north-eastern India (Ramakrishnan, 1992).

Seed production per plant and per unit area increased with invasion age for the first 10 years, declining at ≥15 years. Although seed production is relatively low in the <1 year old site in South Africa, the fact that seeds were produced shows the rapid attainment of reproductive maturity. Older stands produce enormous numbers of seed. Overall seed germinabilities were in the range of 20 – 46%, but probably represent underestimates because sampling of seeds prior to release is likely to include many that were not yet fully mature and thus not yet viable. Seed rain is one of the main factors responsible for the rapid spread of this species. Although the number of germinable seeds is only a small fraction of total seeds in the soil, and an even smaller fraction of annual germinable seed production, these still represent a sizeable number (12 – 385/m² and 158 – 511/m² in the sun and shade respectively) which can quickly establish after clearing, even before newly-dispersed seeds arrive. For example, in the <1 year old site, where even after clearing of *C. odorata* and establishment of a new cohort of plants from seeds in the soil, and prior to any dispersal of seeds to the site, there were still 12 and 279 germinable seeds/m² in the sun and shade respectively. Although <1% of seeds occurred below 5cm, a significant proportion (16%) were found at the 2 – 5cm depth, allowing survival in the soil for >1 year for many of these.

Both the field seed bank and greenhouse experimental data indicate that although the vast majority of seeds persist for <12 months, a small proportion survive longer periods in the soil, particularly in the shade and at greater depths of burial, forming a highly effective short-term persistent seed bank. The greenhouse trial provided conditions for accelerated seed ageing, with higher levels of water and humidity and consistently high temperatures (these decline in the field in winter), yet still 1 – 3% of seeds survived for >1 year under these conditions. These data suggest that a small proportion of seeds may persist in the soil for several years within sheltered microsites.

Alien plants change ecosystem processes, for example *Acacia saligna* (Labill.) H. Wendl. (Fabaceae) and *A. cyclops* A. Cunn. ex G. Don increase the rate of nutrient cycling in Cape fynbos (Witkowski, 1991a, b). In north-eastern India, the *C₃* *C. odorata* has been described as a nutrient-demanding early successional species (Ramakrishnan, 1992) which takes advantage of the flush of soil N that becomes available after a disturbance like fire or land clearing for agriculture and exhibited higher foliar N, P and K contents than other fallow species, especially *C₄* species (Saxena and Ramakrishnan, 1983). *N*- and particularly P-use efficiencies of *C. odorata* (dry matter production/nutrient absorbed) were much lower than for *C₄* fallow species (Saxena and Ramakrishnan, 1984). Schroth et al. (1995) in cleared West African forests found that a *C. odorata* spontaneous fallow had a higher N-mobilization ability than nine planted agroforestry tree legume species, including six *N*-fixers. Ramakrishnan (1992, and references therein) found that *C. odorata* was more prevalent in relatively nutrient-rich sites and was replaced by indigenous *C₄* grass species (inherently lower nutrient requirements) on more nutrient-poor fallows. Invasion by *C. odorata* is thus likely to have a marked affect on nutrient cycling, and more nutrient-rich sites may be favoured in southern Africa as well.

Considering that *C. odorata* infestations become senescent if protected from fire for about 15 years, fire exclusion is a possible management option if the goal is to conserve coastal forest patches (intolerant to fire). In contrast, savannas and grasslands are inherently fire-prone ecosystems. Temperatures at the soil surface in summer can be quite high (Bradstock and Auld, 1995). Greenhouse trials showed that *C. odorata* seeds are intolerant of
soil surface temperatures of 50 or 70°C for 4 weeks with only 9 and 3.2% surviving respectively (initial viability using tetrazolium = 72.8%), and showed no tolerance to fire temperatures (>100°C; 0% survival after >1 min; Mbalo and Witkowski, 1997). This suggests that fire under certain circumstances could be used to manage C. odorata. Chromolaena odorata survives mild fires but is killed by intense fires in South Africa (A. Blackmore, pers. comm.), West Africa (Ivens, 1975) and north-eastern India (Saxena and Ramakrishnan, 1983; Ramakrishnan, 1992). Even young plants may coppice after mild fires (B. Hart, pers. comm.; Ramakrishnan 1992), with rapid regrowth of up to 1.75m after 5 months (Ivens, 1975), yielding multistemmed shrubs. The use of high intensity fires as an initial clearing strategy to kill both plants and seeds in the soil seed bank should be explored. Fires during the period after flowering but before seed release (July – August) when the plants have presumably allocated a large proportion of stored reserves to reproduction, may be optimal. Developing seeds will be destroyed before they are dispersed and resprouting should be greatly reduced in vigour or even prevented. High intensity fires typically occur during this period due to high and dry fuel loads.

Biological control is probably the only long-term cost-effective means of controlling C. odorata. However, with the present poor success of biological control in South Africa, an effective integrated control programme needs to be developed. Clearing of recently invaded sites is more effective than starting with old invasions, particularly because in old senescent C. odorata invasions there is a decline in germinable seed production. Under these circumstances, follow-up seedling removal from cleared sites should be prioritized over tackling new sites. Maintenance of cleared sites involves removal of seedlings that establish from the soil seed bank and wind-blown seeds from adjacent sites. The relatively short distances that the vast majority of seeds disperse (Blackmore, 1998) suggests that systematic eradication of the germinable soil seed bank, through hand pulling or application of herbicides, is possible once other seed sources are fairly distant. Establishment of C. odorata seedlings occurs over many months during the wet season and thus follow-up clearing should not be too early in the year as more seedlings may still establish, assuming that only a single clearing per site per year is undertaken. The best time for hand pulling of seedlings is at the end of the rains (March – May), after as many seedlings as possible have established and while the moist soil facilitates removal (stems break in dry soil and thus may resprout; A. Blackmore, pers. comm.), but prior to seed production and dispersal (August/September). Once an area is cleared, no new plants must be allowed to establish and grow to the extent that seeds are produced and dispersed. In this way, the seeds remaining in the soil will germinate in the following year(s), and will be removed. With the possible future success of biological control, overall effectiveness will be greater within an integrated control strategy.

The landscape context of the St Lucia Reserve, with a long tortuous boundary adjacent to plantations, which serve as C. odorata seed reservoirs, results in continual reinvasion of C. odorata from outside. Under these conditions there is little chance of effectively controlling C. odorata. Clearing of plants (seed sources) on adjoining land is thus essential. Even with effective clearing, episodic long-distance dispersal means that vigilance to the presence of C. odorata cannot be relaxed. However, as long as new invasion nodes are identified at an early stage, clearing may be relatively inexpensive.

ACKNOWLEDGEMENTS

Melanie Asary, Andrew Blackmore, Bronwen Griffith, Bruce Hart, Justin Hodge, Gerhard Kruger, Thierry Regnier, Wayne Smith and Megan Wilson are thanked for field / laboratory assistance. Isabel Weiersbye is thanked for the tetrazolium tests and the figures. The National Research Foundation and Wits University funded the study.
REFERENCES


A DECADE OF SUCCESSFUL BIOLOGICAL CONTROL OF SIAM WEED, CHROMOLAENA ODORATA, IN GHANA: LESSONS AND FUTURE PLANS

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Siam weed (Chromolaena odorata) was first detected in Ghana in 1969 and spread to about 60% of the land area by the 1980s. Attempts to establish the arctiid moth Pareuchaetes pseudoinsulata from 1970 – 74 for the biological control of C. odorata were unsuccessful. A renewed effort to establish this moth, using a culture from Guam, was initiated in late 1989. After extensive laboratory studies, P. pseudoinsulata was mass-reared and released on C. odorata around experimental fields of the Crops Research Institute (CRI) in Fumesua, Kumasi in 1991. From 1992 to 1994, populations of P. pseudoinsulata at the release sites fluctuated from very high in the wet seasons to very low in the dry seasons with little spread into new areas. However, during the wet season of 1995, significant spread from the release sites was noticed and populations of P. pseudoinsulata were found on C. odorata in the dry season. By 1996, P. pseudoinsulata had spread to a radius of about 45km from the CRI station. By 1997 it had spread to a radius of about 100km, in 1998 it reached the Cape Coast area (210km) and in 1999 it was found across the Volta River in the remote Afram plains. The qualities of P. pseudoinsulata as an effective natural enemy of C. odorata have been amply demonstrated but local fauna, particularly parasitic tachinid flies, are adopting it as a host. Also, as a defoliator whose efficacy is limited by the physiological state of its host plant and other environmental conditions, it appears it would be difficult to use it alone for the suppression of C. odorata. It is planned to develop other sustainable weed management practices and introduce root and stem feeders as well as host-specific pathogenic organisms whose impact may complement P. pseudoinsulata.

KEY WORDS: agent establishment and spread, biological weed control, Pareuchaetes pseudoinsulata

INTRODUCTION

Siam weed, Chromolaena odorata (L.) R.M. King and H. Robinson (Asteraceae), a native shrub of South America and the Caribbean (McFadyen, 1988) was first reported in Ghana in 1969 (Hall et al., 1972). It has since spread to cover about 60% of the land area of the country (Timbilla and Braimah, 1996). It is particularly prominent in areas with an annual rainfall of about 2 000mm and has become a major weed of arable and plantation crops, forests and rangelands. Chromolaena odorata grows very fast and smothers other vegetation beneath it. It forms dense thickets that are difficult to penetrate. As a result it has earned several nicknames such as Acheampong, Busia and Abaafo across its range in Ghana (Timbilla and Braimah, 1996).

The management of C. odorata in plantation crops such as cocoa, oil palm and citrus is known to contribute to about a third of the cost of production of such plantations. The high cost of plantation maintenance and other problems associated with the management of the weed have forced some farmers to abandon their plantations (Timbilla and Braimah, 1996). Chromolaena odorata has also contributed significantly to the recent forest fires in the country because it produces large quantities of dry leaf litter, stems and twigs that contain chemicals which act as a fuel for fires (Braimah and Timbilla, 1991). A non-nutritive relationship that has developed between the weed and the variegated grasshopper, Zonocerus variegatus (L.) (Orthoptera: Pyrgomorphidae) is one of the causes of the increased populations and pestilence of the grasshopper in West Africa in recent times (Boppré, 1991). Thus, the introduction of C. odorata brought new challenges to bear on agricultural productivity in the country.

In order to cope with the new menace posed to them by C. odorata, farmers have adopted various methods to control the weed. These methods include the use of herbicides, hand hoeing, slashing and burning, and land rotation. The slash and burn method is the most popular method of control (Timbilla et al., 1996). These methods of control do little to limit the spread of the weed. Also, because of the ability of the weed to regenerate quickly and to produce large quantities of viable seed, these methods of control only provide temporary relief.

Consideration of the origin and biology of the weed, especially the facts (i) that it arrived without its complement of natural enemies, (ii) that it is not as prolific in its native home as in Ghana, and (iii) the absence of local natural enemies effectively adopting it, showed that the most viable option to manage it sustainably is through ‘classical’
biological control. The erstwhile West Africa Substation of the International Institute of Biological Control (now the Biological Control Unit of the Crops Research Institute) initiated efforts in the 1970s on a region-wide (West Africa) basis to control the weed. During the period 1970 - 1974, the moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) (originally misidentified as *Ammalo insulata* (Walk.) was imported, multiplied and released on *C. odorata* both in Ghana and Nigeria. Unfortunately, that effort did not succeed, probably because it was not sustained (Greathead, 1989). This paper reports on the recent success of the re-introduction of *P. pseudoinsulata* to suppress *C. odorata* in Ghana.

**MATERIALS AND METHODS**

**Survey of Distribution of Chromolaena odorata**

A countrywide survey of the extent of spread of the weed was conducted in 1990 (Timbilla and Braimah, 1996). This was necessary to establish the magnitude of the problem posed by the weed and to ascertain the perception of farmers in particular and the general public at large on the economic importance of *C. odorata*.

**Laboratory Cultures of the Natural Enemy Pareuchaetes pseudoinsulata**

The laboratory cultures of *P. pseudoinsulata* were started from a consignment of disease-free eggs and day-old larvae that were received from Guam. The cultures were maintained as detailed in Braimah and Timbilla (1991).

**Host-Specificity Studies**

After the successful establishment of *P. pseudoinsulata* cultures in the laboratory, studies were carried out to confirm its monophagous feeding habits and to eliminate the fear of any threat to economic plants (Braimah and Timbilla, 1991).

**Mass Rearing and Field Releases**

Large numbers of *P. pseudoinsulata* were reared by following the methods described above. Several adult females were allowed to lay eggs in 45 x 45 x 75 cm cages in a laboratory where temperatures were held between 25 and 29°C. Except for the placement of jars of water in the cages to increase the local humidity, no effort was made to regulate the general atmospheric humidity.

Larvae were fed *ad libitum* on fresh *C. odorata* leaves. Each cage held an average of between 200 and 500 first and second instar larvae.

Field releases were preceded by surveys of potential sites during the day to identify suitable fields. At night (18h00 – 22h00), cages with the required ages of larvae were taken to the field and all their contents were placed on the fresh *C. odorata*. Cages were also opened and placed on the leaves and left overnight to allow the larvae to crawl out onto the plants. The releases were done at night to maximise the chances of establishment by reducing the effects of predators such as ants (Cock and Holloway, 1982), birds and lizards that are active during the day. It was also to exploit the behaviour of the insect, which is active at night.

Field releases were made with third, fourth and fifth instar larvae and adults. To overcome the predatory pressure, at least 500 larvae were released at any site at a time. For adults a minimum of 100 was released at a place each time (Table 1).

Between September 1991 and October 1993, over 119 000 larvae and 6 000 adults (Table 1) were released at the Fumesua experimental fields of the Crops Research Institute (22 km east of Kumasi). In 1996 some 50 000 larvae and 1 500 adult *P. pseudoinsulata* were released at Nfensi, Kwadaso and Bekwai which are to the west, north and south of Kumasi respectively. Again in 1997, 45 000 larvae were released in Assin Dadieso about 112 km south of Kumasi.

<table>
<thead>
<tr>
<th>Year</th>
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<th>Distance from rearing facility</th>
<th>Larvae</th>
<th>Adults</th>
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<tr>
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<td>22</td>
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<td>1 489</td>
</tr>
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<tr>
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<td>2 623</td>
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<td></td>
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<td>1997</td>
<td>Assin-Dadieso</td>
<td>112</td>
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of Kumasi, while 340 adults were released at Potrikkrom and 210 at Abesewa which are 45km and 85km to the north of Kumasi respectively (Table 1).

### Field Monitoring Surveys
Monitoring was done at the release sites at weekly intervals after the first release. This was later extended to fortnightly intervals. After some time, monitoring was undertaken monthly. Thereafter monitoring was done close to the site and areas around it on a monthly basis. As establishment and spread of the insect was confirmed, monitoring was done further away from the site, increasing the distance from the site with time. A light trap consisting of a high-powered halogen incandescent bulb and a white cotton cloth screen were used to monitor adult populations in the field.

### Indices of Establishment of Pareuchaetes pseudoinsulata in the Field
The establishment of *P. pseudoinsulata* in the field was confirmed by the use of indices such as:
- The presence of feeding holes in leaves and damage to some buds of *C. odorata*.
- Frass of *P. pseudoinsulata* on the leaves.
- Larvae on the lower surfaces of *C. odorata* leaves.
- Eggs of *P. pseudoinsulata* on the leaves.
- Presence of adult *P. pseudoinsulata*.

Repeated and severe damage of *C. odorata* caused by *P. pseudoinsulata* was manifested in a yellowing of the leaves. Yellow leaves of *C. odorata* in a field were also used as an indication of the establishment of the insect from a distance.

### RESULTS AND DISCUSSION
The survey of the distribution of the weed in the country indicated that it occurred in all ecological areas of the country below latitude 08.15 N (Timbilla and Braimah, 1996). Its spread further north appears to have been halted by the low and unimodal rainfall pattern.

### Host Specificity, Mass Rearing and Field Releases
All plants tested were rejected as food by the larvae, and this led to their death by starvation within a week (Brainmah and Timbilla, 1991). This indicated that *P. pseudoinsulata* is very host specific. Similar results were recorded by Kluge and Caldwell (1993) when they studied another species of *Pareuchaetes*, *P. aurata aurata* (Butler), in South Africa. Cultures of the insect could only be maintained on *C. odorata*. Bennett and Cruttwell (1973) also demonstrated that *Pareuchaetes* species are restricted in their host-plant range to the genus *Chromolaena*. The moth was therefore seen as an excellent candidate for the control of the weed. Field observations of the feeding habits of the insect confirmed its host specificity.

### Establishment and Effectiveness of Pareuchaetes pseudoinsulata
Almost all the batches of insects that were released in Fumesua established and caused considerable foliar damage to *C. odorata* within the first year. However, as the dry season set in from the middle of November onwards, no insects could be found in the field. In May 1992, damage symptoms, particularly leaf punctures and frass, were found in and around most of the sites, and by June, larvae and other indices of establishment of the insect could be found at the sites and up to some 50m away. In subsequent months increased populations of *P. pseudoinsulata* and damage to *C. odorata* was visible. Most *C. odorata* plants at the original release sites had been completely defoliated and had either died, were withering or had turned yellow. Again in November, as the dry season set in, populations of the insect in the field declined and by mid-January and up to the end of March 1993 neither the insects nor damage to the plants could be found in the field. *Pareuchaetes pseudoinsulata* seemed to have developed a perfect synchrony with the Ghanaian seasonal changes and was once more found causing damage to the plant with the first early rains in April – May 1994. The insects continued to be found in the field all through that year, although populations were lower, and insects were more difficult to locate, in the dry season.

The seasonal pattern of activity of the moth suggests that it is susceptible to moisture stress and goes into a period of quiescence, probably a diapausing pupal stage, during the dry season, when environmental humidity is low. *Pareuchaetes aurata aurata* was found to be prevalent in shaded areas near surface water in its native Argentina (Kluge and Caldwell, 1993), and Cock and Holloway (1982) were of the view that *Pareuchaetes* species may be adapted to riverine microclimates. In both of these environments the relative humidities will be quite high. The adaptation to high relative humidity may account for the life pattern of *P. pseudoinsulata* observed in Ghana. This pattern has continued to be observed and the association with high humidity is supported by the observation in the field that the first signs of resurgence of the insects after each dry season are often seen in valleys and the more humid low-lying areas.

By 1994, appreciable damage had been caused to *C. odorata* in three of the four release sites at Fumesua. For the first time since 1991, the opening up of the canopy of *C. odorata* by *P. pseudoinsulata* had allowed other weeds to grow through. The insect had also spread to a village 2km away.
Figure 1. Establishment and efficacy status of Pareuchaetes pseudoinsulata in Ghana since 1993: (a) 1995-1996, (b) 1997-1998
Spread of Pareuchaetes pseudoinsulata in Ghana

Following the credible indication of establishment of *P. pseudoinsulata* at the release sites and in areas around them, monitoring surveys were conducted some distance away in June 1995 (Fig. 1a). *Pareuchaetes pseudoinsulata* was found in Ejisu-Besease, Mampong and Effiduase, which are 14, 16 and 25km respectively from Fumesua. They had caused defoliation to the weed in large patches in all these places. Indices of establishment such as frass and chewed perforations on leaves were widespread. A few larvae were also found. Further monitoring indicated that the insect had now spread to areas up to within a 45km radius of the original release sites in Fumesua. At Dumanafio, for example, which is 32km away, larvae of all stages of development and adults were found on the weed. Spectacular damage had also been caused to *C. odorata* in Wadie-Ejumakase (38km). Here, death of the weed as a result of persistent defoliation by *P. pseudoinsulata* led to the widespread growth of *Centrosema* spp. (Fabaceae). In this village farmers had already noticed the effects of the insects on the weed and one praised it for helping him weed his farm.

By 1996, *P. pseudoinsulata* had spread to New Edubiase, Teacherkrom and Konongo, which are 85km south, 80km south-east and 51km east of Kumasi respectively (Fig. 1a). Its spread to the west appeared to be impeded by physical structures of the city of Kumasi. However, release of *P. pseudoinsulata* in this area in 1996 resulted in establishment. The vegetation along roadsides that had hitherto been a monotonous of mats of *C. odorata* had begun to open up and give way to one of more diversified flora. Between June and July 1997 the population of *P. pseudoinsulata* was so high that larvae could be found on *C. odorata* even in obscure places within the city of Kumasi. Adults, on the other hand, could be seen attracted to bright lights at night. This high population of the insect may have peaked from a gradual build-up from 1996 and probably accounted for its rapid spread between 1996 and 1998 (Fig. 2).

*Pareuchaetes pseudoinsulata* demonstrated its monophagous feeding habits in the field. Only *C. odorata* was attacked and damaged from among all plants in association. Yellowing of the leaves of *C. odorata* had become a common observation, and the spread of the insect into new areas continued. Although the insects could not be located along the roadside in some areas, farmers who were interviewed in a rapid-rural-appraisal manner indicated that the insect had either been seen in earlier years, earlier in the same year or in certain places around the village at the time of the survey. Invariably, the establishment of the insects in the area was confirmed during a later visit.

The culture of *P. pseudoinsulata* released at Assin-Dadieso in May 1997 established, and by October had caused extensive damage to *C. odorata* in the young oil palm plantation in which it had been released. Larvae of all stages of development were found in the field, but light traps that were set at night did not catch any adults. This was thought to be due to a lack of overlap of generations of the insects at the time. The farmer, who was hesitant at the time of release of the insect, was happy to cooperate with us after witnessing the results.

As the areas to survey increased with increasing spread of the insect, monitoring costs also increased. As a result, only occasional monitoring surveys have been carried out since 1998. This notwithstanding, these few trips have shown that the insect has spread from Ashanti into the Central, Eastern, Western and Brong Ahafo regions of Ghana (Fig. 1b). It is found as far as Begoro, Amankwatanwo, Akim-Oda, Nkawkaw and Kade in the eastern Region. In the Western region it has been located at Bibiani while in Brong Ahafo it has been reported from Sunyani and Duayaw Nkwanta. *Parechaetes pseudoinsulata* has also been located in Assin Fosu, Cape Coast and Twifo Praso in the...
Central region (Fig. 1b). All these towns have benefited from the migration of *P. pseudoinsulata*, since no releases of the insects had been made there previously. The insect can be found in almost all towns in Ashanti region (Timbilla, 1996) even though it appears to be more effective in some areas than others. *Pareuchaetes pseudoinsulata* even crossed the river Volta and has reached the remote Afram plains (Fig. 1b). This is one of the furthest places from the Kumasi release site, and means that the insect is now found in about 66% of the land area covered by *C. odorata* in Ghana (Figs 1b, 2).

**Local Fauna Associated with *Pareuchaetes pseudoinsulata***

Several local organisms have been found to be associated with *P. pseudoinsulata*. Lizards, ants and birds were partly blamed for the failure of the earlier efforts at the biological control of the weed using *P. pseudoinsulata* (Cock and Holloway, 1982; Greathed, 1989). During the current programme, generalist predators and parasitoids such as assassin bugs, tachinid flies, braconid wasps, predatory mites and spiders have been found attacking the insect in the field. The death of several larvae in culture was attributed to infection by unidentified fungi and bacteria (R.T. Awuah, pers. comm.).

**Lessons from Ghana**

From the work in Ghana, *P. pseudoinsulata* has demonstrated its effectiveness as a biological control agent for suppressing *C. odorata*. However, it only defoliates the weed and thus repeated attacks are required to achieve the desired level of suppression. The work reported here and by others elsewhere indicates that the efficacy of *P. pseudoinsulata* is affected by the moisture regime of the environment (Cock and Holloway, 1982; Lyla et al., 1998). Unfortunately, in Ghana, *C. odorata* tends to flower during periods of moisture stress, when the populations and efficacy of *P. pseudoinsulata* are reduced. As a result, the insect has little effect on the rather prolific flower-and seed-set stage of the weed. This near-unimpeded ability of *C. odorata* to set seed, and the likelihood of it re-colonising fields, suggest that it will be difficult to suppress by use of a defoliator alone.

The greatest danger to the insect appears to be an ignorant public, probably because of its close resemblance to crop pests. There have been a few cases of scared farmers and extension agents reporting plagues of insects only for them to turn out to be *P. pseudoinsulata*.

The biological control of Siam weed in Ghana is probably the cheapest ever obtained anywhere in the world. This has been the reason that our government was able to finance it. Other governments in West Africa do not seem to have similar interests. Meanwhile, experiences with the spread of the insect indicate that even ecological barriers can impede it only temporarily. It establishes and spreads easily if large numbers are released at a time.

**Future Plans**

*Pareuchaetes pseudoinsulata* is not expected to adequately suppress *C. odorata* on its own, because of the shortcomings cited above. In the future other natural enemies that attack the stems and roots (Zachariades et al., 1998) of the weed and may be destructive both during the wet and dry seasons will be introduced to supplement the efforts of *P. pseudoinsulata*. The use of more virulent pathogenic fungi would also be investigated. Agronomic and land management practices that the farmers already use will be evaluated scientifically, in order to understand their role and integrate them into the biological control approach.

Studies on the inter-relationships between *P. pseudoinsulata* and the local fauna, especially predators, are planned. The contribution of the local herbivore fauna to suppression of *C. odorata* will also be quantified. Through such studies we shall generate information on the ecological interactions within the ‘new’ *C. odorata* ecosystem. Armed with such information we can then devise technologies for ameliorating the effects of suppressive factors, particularly predation, on the efficacy of *P. pseudoinsulata*.

There is an urgent need to educate the general public, especially farmers, on the establishment of *P. pseudoinsulata* on *C. odorata*, its effectiveness, and the indiscriminate use of insecticides (Singh, 1998) pose to it. This will be achieved through radio and television programmes and talk shows, public lectures and forums, posters and billboards as well as extension leaflets and hand-outs.

The programme discussed above will require substantial funding to execute effectively, which the government of Ghana alone may not be able to finance. Sustainable financing of the project could be achieved through the pooling of resources on a regional front. In this case, governments within the West African sub-region that share the problem would collaborate to support a centrally placed group to execute the project. Alternatively, each government could strengthen a national group so that it works effectively to complement the efforts of others. A regional programme may also be more attractive to international donors than a number of projects from individual countries.
ACKNOWLEDGEMENTS

The authors are greatly indebted to all the staff of the Biological Control Unit of the Crops Research Institute, Kumasi for technical and other assistance since the inception of this project. We are grateful to the Director of the Crops Research Institute for permission to publish the information. We are similarly thankful to the Director General of the CSIR Ghana for permission to attend the workshop. Many thanks are due to the organisers of the workshop for accommodating the late responses of the first author and financing his hotel accommodation, meals and local travel, thus making it possible for him to participate. The first author is similarly greatly indebted to the Valco Trust Fund Ghana who paid for his air tickets and participation fees. We are thankful to Dr J.V.K. Afun for constructive criticisms on the original manuscript. Last but not least, thanks go to the staff of the Cartography section of the Soil Research Institute, Ghana for drawing the maps.

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PROCEEDINGS
OF THE FIFTH INTERNATIONAL
WORKSHOP ON
BIOLOGICAL CONTROL AND
MANAGEMENT
OF CHROMOLAENA ODORATA

DURBAN, SOUTH AFRICA, 23-25 OCTOBER 2000

EDITED BY
COSTAS ZACHARIADES
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**INTRODUCTION**

Chromolaena odorata (L.) R.M. King and H. Robinson belongs to the family Asteraceae (tribe Eupatorieae), the largest angiosperm family, comprising 1,528 genera and 22,750 species worldwide (Mabberley, 1997). This represents about 10% of all vascular plants. In southern Africa, the family Asteraceae is also the largest in genera (246) and species (2,305) (Herman et al., 2000). The Eupatorieae comprises 169 genera and 2,400 species worldwide (Mabberley, 1997). Seven genera of Eupatorieae occur in southern Africa, represented by 13 species. Members of Chromolaena, Ageratina, Ageratum and Campuloclinium are all alien invaders in the region. Mikania, Adenostemma and Stomatanthes have six indigenous species that are of importance in host-specificity trials of potential biological control agents. These species occur mainly in the eastern part of the region. Members of the Eupatorieae are herbs or shrubs, sometimes twining or scrambling, characterized by discoid capitula with florets bisexual, corollas with five relatively short, broad apical lobes, style arms with conspicuous papillose appendages and black achenes. Features of the anthers, pappus and involucral bracts are used to distinguish the different genera. Adenostemma is characterised by anthers without apical appendages and a pappus of three or five gland-tipped processes, whereas the other genera have anthers with apical appendages and eglandular pappi of bristles or scales. Scales occur on the achenes of Ageratum, whereas Chromolaena and the other genera are characterized by achenes with pappi of many capillary bristles and involucral bracts with coloured tips.

**KEY WORDS:** Adenostemma, Ageratina, Ageratum, alien invasive, Campuloclinium, Chromolaena odorata, distribution, Mikania, morphology, Stomatanthes

**THE TRIBE EUPATORIEAE (ASTERACEAE) IN SOUTHERN AFRICA**

Elizabeth Retief

The tribe Eupatorieae (Asteraceae) comprises about 170 genera, occurring mostly in South, Central and North America and the West Indies, with several pantropical species. Seven genera of the tribe occur in southern Africa, represented by 13 species. Members of Chromolaena, Ageratina, Ageratum and Campuloclinium are all alien invaders in the region. Mikania, Adenostemma and Stomatanthes have six indigenous species that are of importance in host-specificity trials of potential biological control agents. These species occur mainly in the eastern part of the region. Members of the Eupatorieae are herbs or shrubs, sometimes twining or scrambling, characterized by discoid capitula with florets bisexual, corollas with five relatively short, broad apical lobes, style arms with conspicuous papillose appendages and black achenes. Features of the anthers, pappus and involucral bracts are used to distinguish the different genera. Adenostemma is characterised by anthers without apical appendages and a pappus of three or five gland-tipped processes, whereas the other genera have anthers with apical appendages and eglandular pappi of bristles or scales. Scales occur on the achenes of Ageratum, whereas Chromolaena and the other genera are characterized by achenes with pappi of many capillary bristles and involucral bracts with coloured tips.

**INTRODUCTION**

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**DISTRIBUTION**

The tribe Eupatorieae occurs mostly in South, Central and North America and the West Indies. Species of the different genera concerned are found mainly in the eastern parts of southern Africa (Fig. 1A–H). The distribution map of C. odorata is based on the holdings of the National Herbarium, National Botanical Institute, Pretoria, and does not reflect its true distribution as indicated on a map by Zachariades et al. (1999). This is a typical example of a weed that is under-collected and misrepresented in a herbarium collection, the resultant data thus not revealing its true range.

**DISTINGUISHING CHARACTERS OF THE TRIBE EUPATORIEAE**

Seventeen tribes are recognised within the Asteraceae by Herman et al. (2000). The genus Eupatorium is regarded as Eupatorium sensu stricto, following the treatment of the tribe by King and Robinson (1987) with E. odoratum L. placed in the genus Chromolaena. The tribe Eupatorieae is distinguished from all other tribes by the following characteristics (Fig. 2):

- Style branches with conspicuous papillose appendages
- Capitula discoid
- Florets bisexual
- Florets white, blue, mauve, purplish pink or purple
- Corolla with five (four) relatively short, broad apical lobes
- Mature achenes (cypsellas) black

**KEY WORDS:** Adenostemma, Ageratina, Ageratum, alien invasive, Campuloclinium, Chromolaena odorata, distribution, Mikania, morphology, Stomatanthes
Figure 1. Distribution maps of the Eupatorieae in southern Africa: Eupatorieae (A), Mikania (B), Stomatanthes (C), Adenostemma (D), Chromolaena (E), Ageratina (F), Campuloclinium (G), Ageratum (H).
MORPHOLOGICAL CHARACTERS OF TAXONOMIC SIGNIFICANCE

Habit
Members of the Eupatorieae are herbs or shrubs, erect, twining or scrambling. Species of the relevant genera in southern Africa are: (i) annual or biennial herbs (Ageratum); (ii) perennial herbs, usually suffrutescent (Adenostemma, Ageratina, Campuloclinium and Stomatanthes); (iii) twining or scrambling (Chromolaena, Mikania).

Leaf
Different characteristics of the usually trinerved leaf are of taxonomic significance. In species of Adenostemma, Campuloclinium and Stomatanthes the leaves are sessile or with short petioles and the blades are more or less ovate (Fig. 3A–C). In Ageratina, Ageratum, C. odorata and Mikania the leaves are prominently petiolate and ovate in outline (Fig. 3D–F). These genera differ in morphology of the blade base, serration of margin and in the indumentum. The form of C. odorata invasive in southern Africa is distinct in its morphology from forms that have invaded other areas of the world. Determination of the exact identity and origin of the southern African C. odorata is important in order to ensure complete compatibility of candidates for biological control with the weed (Zachariades et al., 1999). Various attempts to solve the problem are currently in progress (e.g. von Senger et al., this Proceedings).

Florets
The capitula of C. odorata and species of Mikania are oblong in outline, differing from the other genera in which the capitula are more or less campanulate in outline. Chromolaena and Mikania differ in the apex of the bracts. Bracts of C. odorata are obtuse at the apex, whereas those of Mikania species are acute.
to acuminate (Fig. 4A, B). In C. odorata the bract has simple, multicellular hairs along the margin, some scattered, simple, multicellular hairs as well as sessile, glandular trichomes on the blade, and is furthermore characterized by a prominent dark spot at the apex. In Campuloclinium macrocephalum (Less.) DC. the bract is covered with sessile glands and simple, multicellular hairs (Fig. 4C). The indumentum of the corollas also differs. The corolla of C. odorata, for example, is glabrous on the outside, as opposed to the corolla of Ageratum, which is hairy (Figs 2C, 4D). The anthers of the Eupatorieae usually have flat appendages (Fig. 4E), but anthers of Adenostemma are without apical appendages or are minutely apiculate. Receptacles of the genera vary in shape. In Chromolaena, for example, the receptacle is flat to convex, but in Campuloclinium it is hemispherical to conical (Fig. 4F).

**Pappus**

Pappi of the Eupatorieae display various features that can be used to distinguish the species. Adenostemma, with a pappus of three to five short, rigid, gland-tipped processes, differs from the rest of the genera in southern Africa (Fig. 5A). Pappi of Ageratum are coroniform with five or six free scales or awns, or pappi are absent (Fig. 5B). Ageratina, Campuloclinium, Chromolaena, Mikania and Stomatanthes are characterized by capillary, scabrid, barbellate bristles (Fig. 5C).

**Achene**

Almost all achenes are black, having a carbonized layer in the achene wall as in the Heliantheae and many Helenieae tribes that are regarded as tribes related to the Eupatorieae (Bremer, 1994). The achenes are three- to five-angled, differing in surface indumentum as follows:

- **Ageratina**: glabrous
- **Adenostemma**: glandular trichomes and/or protuberances
- **Chromolaena**: simple hairs, single or twins
- **Campuloclinium, Mikania**: glandular trichomes
- **Stomatanthes**: glandular trichomes, simple hairs
- **Ageratum**: simple hairs and/or glandular trichomes

Fig. 5D–E displays some of the characteristics listed above.
Figure 4. Some characters of the florets: (A) involucral bracts, *Chromolaena odorata*, Strey 8780; (B) involucral bracts, *Mikania sagittifera*, Bethune 80; (C) indumentum of a bract, *Campuloclinium macrocephalum*, Pienaar 1201; (D) upper part of a floret, *Ageratum houstonianum*, Killian 12; (E) anther appendage, *Chromolaena odorata*, Hitchins & Ward 16; (F) receptacle, *Campuloclinium macrocephalum*, Pienaar 1201. 10mm scale bars: (A, B) 249µm; (C) 50µm; (D) 71µm; (E) 75µm; (F) 277µm.
Figure 5. Some characters of the fruit: (A) glandular style arms, *Adenostemma perottetii*, Vahrmeijer 511; (B) pappus of scales, *Ageratum houstonianum*, Killian 12; (C) barbellate bristles, *Chromolaena odorata*, Hitchins & Ward 16; (D) glabrous achene, *Ageratina adenophora*, MacDonald A13; (E) achene with hairs, *Chromolaena odorata*, Hitchins & Ward 16; (F) achene with sessile, glandular trichomes, *Campuloclinium macrocephalum*, Pienaar 1201. 10mm scale bars: (A) 119µm; (B) 217µm; (C, E) 38µm; (D) 55µm; (F) 92µm.
DISCUSSION

Although the genera of the Eupatorieae display a range of characteristics, the tribe is well circumscribed. Comparing different features of the Eupatorieae occurring in southern Africa, the genus *Mikania* shows strong similarity to *C. odorata* in its distribution, habit, leaf blade outline, floret colour (both have white corollas), capitulum outline and structure of the achene. *Chromolaena odorata* was first recorded in 1947 near Ndwedwe, KwaZulu-Natal. *Ageratum conyzoides* L., first recorded in KwaZulu-Natal by Krauss in 1839 and most probably introduced by Africans before the advent of white settlers (Hilliard, 1977), has more or less the same distribution pattern as *C. odorata* (Fig. 1E, H). Both species have been declared as dangerous alien invaders by the National Department of Agriculture of South Africa, and need urgent attention as subjects for biological control. However, members of *Mikania*, *Adenostemma* and *Stomatanthes*, with members indigenous to southern Africa, also occur in the known distribution areas of these two aliens and could be affected by biological control agents as reported by Zachariades et al. (1999). Eradication of *C. odorata* by means of biological control is therefore by no means an easy task.

ACKNOWLEDGEMENTS

The author wishes to thank the Plant Protection Research Institute, Agricultural Research Council, for the invitation to participate; the National Botanical Institute for the opportunity to do so and for financial support to attend the workshop. Special thanks to Emsie du Plessis, Lesley Henderson, Gill Condy, Noluthando Netnou, Julie Ready, Adéla Romanowski and Sandra Turck for their valuable help in preparing the manuscript.

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Appendix 1. Members of the tribe Eupatorieae (Asteraceae) in southern Africa. * = alien. Key to
distributions: B = Botswana; N = Namibia; South Africa: EC = Eastern Cape, G = Gauteng, KZN = KwaZulu-
Natal, M = Mpumalanga, NP = Northern Province, NW = North West, WC = Western Cape; S = Swaziland.

1. **ADENOSTEMMA** J.R.Forst & G.Forst.
   **caffrum** DC.
   Distr.: N, B, NW, NP, G, M, S, KZN, EC
   *dregei* DC. = **A. viscosum**
   *natalense* DC. = **A. viscosum**
   *perrottetii* DC. = **A. viscosum**
   **viscosum** J.R.Forst. & G.Forst.
   A. *dregei* DC.
   A. *natalense* DC.
   A. *perrottetii* DC.
   Distr.: M, KZN

2. *AGERATINA* Spach
   *adenophora* (Spreng.) R.M.King & H.Rob.
   *Eupatorium adenophorum* Spreng.
   Distr.: G, KZN, WC
   *altissima* (L.) R.M.King & H.Rob.
   *Eupatorium rugosum* Houtt.
   Distr.: NP
   *riparia* (Regel) R.M.King & H.Rob.
   *Eupatorium riparium* Regel
   Distr.: KZN

3. *AGERATUM* L.
   *conyzoides* L.
   Distr.: B, NP, M, S, KZN, EC
   *houstonianum* Mill.
   A. *mexicanum* Sims
   Distr.: NP, NW, M, S, KZN, EC
   *mexicanum* Sims = **A. houstonianum**

4. **CAMPULOCLINIUM** DC.
   **macrocephalum** (Less.) DC.
   *Eupatorium macrocephalum* Less.
   Distr.: NP, G, KZN

5. **CHROMOLAENA** DC.
   *odorata* (L.) R.M.King & H.Rob.
   *Eupatorium conyzoides* Vahl (1)
   *Eupatorium odoratum* L. (1)
   Distr.: NP, M, S, KZN, EC
6. **MIKANIA** Willd.

   *angustifolia* (O.Hoffm.) R.E.Fr. = **M. sagittifera**
   *asparagoides* Licht. ex Less. = **Euryops asparagoides**
   *auriculata* Willd. = **Senecio deltoideus**

   **capensis** DC.
   *M. oxyota* DC.
   Distr.: NP, M, S, KZN, EC

   *cordata sensu* Hilliard non (Burm.f.) B.L.Rob. = misapplied name

   **natalensis** DC.
   Distr.: KZN

   *oxyota* DC. = **M. capensis**

   **sagittifera** B.L.Rob.
   *M. angustifolia* (O.Hoffm.) R.E.Fr.
   Distr.: N, B

7. **STOMATANTHES** R.M.King & H.Rob.

   **africanus** (Oliv. & Hiern) R.M.King & H.Rob.
   *Eupatorium africanum* Oliv. & Hiern
   Distr.: NP, M, S