Biological Control

Table 1.

Insect species tested as potential biological control agents against *Chromolaena odorata* [pdf]

Figure 2. Neotropical insect species established on *Chromolaena odorata* in the Old World, on a country record basis. Map generated by Jimaima Le Grand (Queensland Department of Primary Industries and Fisheries). A version of this map was published in Zachariades et al. (2009) and is used here with permission from Cambridge University Press [pdf]

(Table 1 and Figure 2 indicate which agents are established in which countries.)

Established agents are as follows:

1. *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae)
2. *Cecidochares connexa* Macquart (Diptera: Tephritidae)
3. *Actinote thalia pyrrha* (Fabr.) and *Actinote anteas* (Doubleday & Hewitson) (Lepidoptera: Nymphalidae)
4. *Acalitus adoratus* Keifer (Acari: Eriophyidae)
5. *Calycomyza eupatorivora* Spencer (Diptera: Agromyzidae)
6. *Pareuchaetes insulata* (Walker)

1. Pareuchaetes pseudoinsulata Rego Barros (Lepidoptera: Arctiidae)

Adult *P. pseudoinsulata*.
Photo: Po-Yung Lai, NPUST

Action: Leaf feeder (defoliator)

Distribution:

- *Native:* Trinidad, eastern Venezuela (Cock & Holloway, 1982)
- *Origin of biocontrol agent culture:* Trinidad
- Introduced: This month is now widely established in the Old World (Table 1, Fig 2)

Biology:

Adults are nocturnal, living about a week. Females lay eggs in batches on the underside of leaves. The young larvae feed as a group, removing the surface of, and later skeletonising leaves. Older larvae are solitary, eating holes through the leaves, and the largest larvae can eat entire leaves, leaving only a mid-rib. Young larvae remain on the plants, feeding at night, whereas older larvae

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Mature *P. pseudoinsulata* larva.
Photo: Michael Day, QDPIF

Mature *P. pseudoinsulata* larvae,
one pupating, on a leaf with typical feeding damage.
Photo: Po-Yung Lai, NPUST

move down during the day, ultimately spending this time in the leaf litter below the plant. Heavy feeding on plants in the field results in the entire plant turning yellow. Pupation occurs in a flimsy cocoon within dead leaves lower on the plant or on the ground. The lifecycle takes about 6 weeks in the laboratory.

Safety: The moth shows a good degree of specificity, feeding only on chromolaena and, as a secondary host, the closely related *Ageratum conyzoides*, which is also an invasive alien species in the Old World.

Ease of rearing and release: Although *P. pseudoinsulata* is easily mass-reared in containers with cut foliage in the laboratory, it is highly susceptible to disease in this environment, a factor which has resulted in the failure of several release programs. A sophisticated, hygienic laboratory situation under the supervision of an entomologist is necessary to increase the chances of success. In general, it seems that releases of large numbers of larvae (e.g. >100,000) over an extended period of time (e.g. 2-3 years) increases the probability of establishment. This means that release sites should be within driving distance of the mass-rearing station and that personnel are required to conduct releases on a regular basis over an extended period.

Establishment and efficacy: Results, both in establishing *P. pseudoinsulata* and in its subsequent effectiveness, have been very variable. In some countries, it was easily established from the release of a few thousand individuals (adults/larvae), while in others, despite concerted efforts and releases of hundreds of thousands of individuals, it has still not established. Although little research has been conducted on the species, the possible reasons for non-establishment (vary from case to case) include poor climate matching, poor site selection, insufficient numbers released over an insufficient period (leading to loss of the population through Allee effects and predation) and release of diseased individuals. The insect spreads reasonably quickly once it has established. Although defoliation of large areas of chromolaena has been reported, this generally happened within a few years of the agent's establishment, and longer-term efficacy has generally not been very high. The only places where a high degree of efficacy (i.e. long-term reduction of chromolaena populations) has been reported are some Pacific islands. Waterhouse (1994) and Zachariades *et al*. (2009) have reviewed the history and success of *P. pseudoinsulata* releases around the world.

Recommendations: This insect is quite difficult to establish, and generally is not very effective in reducing chromolaena populations. It is lower on the recommended list than *C. connexa* (for the Asian/West African chromolaena biotype). As it is a leaf feeder and does not seem to have a strong diapause, it will probably not establish in areas which have a long, severe dry season.

Availability: Several countries in South-East Asia, Oceania and Ghana. Contact the IOBC working group convenor at ZachariadesC@arc.agric.za for more information.

2. Cecidochares connexa Macquart (Diptera: Tephritidae)

Adult *C. connexa*.
Photo: Colin Wilson

Larvae and pupae in a gall.
Photo: Po-Yung Lai, NPUST

Action: Stem galler

Distribution:

- Native: Continental South and Central America, where C. odorata is present
- Origin of biocontrol agent culture: Colombia (Caribbean coast)
- Introduced: First released in Sumatra (Indonesia) in 1995. It has since been released and easily established from small founder cultures in several other countries (Table 1, Fig. 2).

Biology:

Adult flies lived for less than 2 weeks in the laboratory. Females insert their eggs into the plant tissue in the tip of the shoot. In the field usually 2 eggs are laid in each tip. After about 2 weeks a swelling in the node becomes visible. The mature gall becomes woody and is 2–3 cm long and 0.8–1.5 cm wide. In the field, 2-4 larvae usually develop in separate chambers in each gall, and before pupating an exit tunnel is chewed, leaving a thin layer of epidermis (a 'window'). The lifecycle takes an average of 60 days (McFadyen *et al*., 2003).

Safety:

This fly is highly specific, only developing on the Asian/West African biotype of *C. odorata*.

Ease of rearing and release:

This fly is easy to rear on potted plants in cages in the shadehouse or nursery. Galls with 'windows' indicating the presence of pupae can be placed into the field; adults emerge from the galls and establish easily. Once a population has been established in the field, galls can be collected from there for redistribution.

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Mating *C. connexa*.
Photo: Warea Orapa, SPC

Ovipositing female *C. onnexa*.
Photo: Po-Yung Lai, NPUST

Young *C. connexa* galls.
Photo: Michael Day, QDPIF

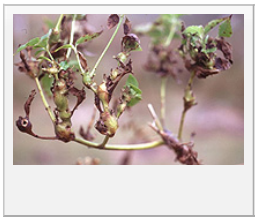
Establishment and efficacy:

The fly spreads and builds up the population size quickly. It locates isolated *C. odorata* plants efficiently, and is generally very damaging. Large numbers of galls are frequently found on individual plants, stressing and sometimes killing them. Significant reduction in the density of infestations has been recorded in several countries. The fly appears to be somewhat less effective in seasonally drier parts of the invasive range of chromolaena, where stems die back in the dry season and fires occur, and in cooler, higher altitude regions where fly development is slower. Some degree of parasitism and predation of larvae has been recorded in East Timor and Indonesia but does not significantly affect the impact of the agent. A number of papers on the establishment and efficacy of this fly in Indonesia and Papua New Guinea have been published in the proceedings of more recent chromolaena workshops, and reviewed in Zachariades *et al.* (2009).

Recommendations: *C. connexa* is the best biocontrol agent for chromolaena available at present, in terms of host range, efficacy and ease of establishment. Unfortunately, due to its narrow host range, it cannot develop on the SA biotype of chromolaena.

Availability: India, and several countries in South-East Asia and Oceania. Contact the IOBC working group convenor at for more information.

India, and several countries in South-East Asia and Oceania. Contact the IOBC working group convenor at ZachariadesC@arc.agric.za for more information.



Old *C. connexa* galls, some showing exit holes.
Photo: Colin Wilson

3. Actinote thalia pyrrha (Fabr.) and Actinote anteas (Doubleday & Hewitson) (Lepidoptera: Nymphalidae)

Adult male *A. thalia pyrrha*

Adult *A. anteas* (= *A. thalia thalia*)

Action: Leaf feeder (defoliator)
Distribution:

Native: Actinote anteas was recorded by Rachel Cruttwell in Trinidad, and appears to have a geographical range extending to Venezuela and Costa Rica. The taxonomy of Actinote spp. is rather complex and confused. http://www.funet.fi/pub/sci/bio/life/insecta/lepidoptera/ditrysia/papilionoidea/nymphalidae/heliconiinae/actinote/index.html#About%20maps lists *Actinote anteas* (=A. thalia anteas) as having a range Mexico, Costa Rica, Honduras, Guatemala, Panama, Venezuela and Colombia; and Actinote thalia pyrrha (=A. pyrrha pyrrha): Brazil (Espirito Santo, Minas Gerais, Paraná, Rio Grando do Sul, Rio de Janeiro, Santa Catarina, São Paulo) and Argentina (Entre Rios).

Origin of biocontrol agent cultures: A culture from Costa Rica was imported into quarantine in SA in the early 1990s and partially tested for host range, but the culture was lost (Caldwell & Kluge, 1993). It was imported into Indonesia (Sumatra) in 1996 from Colombia and tested for host specificity; however, the culture was again lost. At the same time Actinote thalia pyrrha was imported into SA from north-eastern Brazil and comprehensively tested. However, it was found to feed on the native Mikania capensis and M. natalensis as well as chromolaena. Actinote spp. are associated with Mikania species in the Americas and there are several other Mikania species native to the African continent. It was thus not released in South Africa (Zachariades et al., 2002), but a culture was sent to Indonesia, where Mikania micrantha is a major threat. A culture of a species from Venezuela, identified in SA as A. thalia thalia but which is probably A. anteas, was also sent to Indonesia. Both were released in Indonesia (Desmier de Chenon et al., 2002)

Introduced: A. thalia pyrrha spread quite quickly and is widespread through Sumatra. A. anteas proved less robust, and has not spread far from the release sites on Sumatra. A. thalia pyrrha has been forwarded to China as a biocontrol agent against M. micrantha, but did not establish due to low ambient temperatures (R. Desmier de Chenon, pers. comm.). cultures of both species were lost from quarantine in Fiji, while applications to import into PNG are pending (M. Day, pers. comm.).

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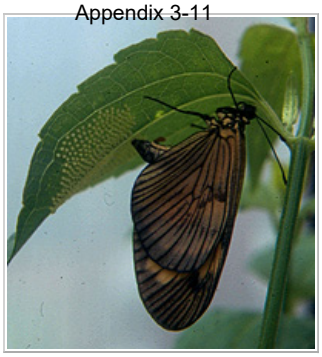


Ovipositing *A. thalia pyrrha*

Mature egg batch of *A. thalia pyrrha* on underside of *C. odorata* leaf

Young *A. thalia pyrrha* larvae feeding on *A. inulifolium*. Photo: Roch Desmier de Chenon

Biology:

The diurnally active butterfly adults lay eggs in large batches on the underside of leaves. The young larvae feed communally to skeletonize leaves, creating a characteristic silk webbing over the plant. Older larvae are solitary and consume entire leaves. Mature larvae pupate on stems and leaves, often on neighbouring plants, attached with a silk pad. The lifecycle takes about 2.5 to 3 months.

Safety:

The larvae of both these butterflies are oligophagous, feeding over more than one genus in the asteraceous tribe Eupatorieae (Chromolaena, Mikania, Austroeupatorium). Therefore in countries with native species of Eupatorieae, exhaustive host-range testing should be conducted on these species before release.

Ease of rearing and release:

Initial problems with mating of adults in cages appear to have been overcome by keeping cages with potted plants in a warm sunny position. Eggs cannot be removed from leaves attached to the plant, and it is best to allow development of younger instars on potted plants. If space or potted plants are constraining, older larvae can be reared in containers. Release of younger, gregarious larvae in large numbers over several generations is recommended (Desmier de Chenon et al., 2002).

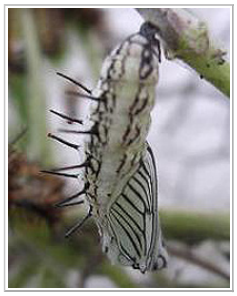
Establishment and efficacy:

A. thalia pyrrha is very damaging not only to chromolaena and mikania, but also to the related neotropical invasive, Austroeupatorium inulifolium (R. Desmier de Chenon, A. Simamora and Nirwanto, Indonesian Oil Palm Research Institute, personal information, 2006).

Recommendations:

A. thalia pyrrha is effective where it has been released. Both species can probably be used against chromolaena, mikania and austroeupatorium. However, Actinote species are not recommended for release where native Mikania species or other, untested Eupatorieae are present.

Availability: Indonesia [Photo right: *Actinote* pupa. Photo: Warea Orapa, SPC]



Young *Actinote* larvae, probably *A. thalia thalia*, skeletonizing *C. odorata* leaves in Venezuela

First and last larval instars, *A. thalia pyrrha*

Yellowing of *C. odorata* leaves after feeding by *A. thalia pyrrha*. Photo: Roch Desmier de Chenon

Mature *A. anteas* (= *A. thalia thalia*) larva

4. Acalitus adoratus Keifer (Acari: Eriophyidae)

Action: Leaf feeder

Distribution:

- *Native*: Widespread through continental South America, where *C. odorata* is present. May also be present in the Caribbean and Central America.
- *Origin of biocontrol agent culture*: Probably Trinidad
- *Introduced*: It was introduced accidentally into SE Asia (probably Malaysia, from Trinidad) and has since spread widely (Table 1, Fig. 2) (McFadyen, 1995).

Biology:

Feeding by the mite causes the development of hairy patches on leaves, and in severe infestations these can coalesce to cause leaf deformity.

Safety:

This mite was shown to be host specific by Cruttwell (1977b), and recommended as an agent.

C. odorata leaves in Venezuela with erinia, probably caused by *A. adoratus*. Note also the *C. reticulatus* oviposition sites

C. odorata leaves in Jamaica showing deformity associated with eriopyhid mite feeding

Ease of rearing and release:

This mite has never been intentionally reared and released.

Establishment and efficacy:

This mite has established throughout Southeast Asia from unintentional releases at probably only one site. No research has been conducted on the efficacy of the mite, but it is thought to be low.

Recommendations:

There are better agents available and in the pipeline. Lower priority.

Availability:

Most countries in Southeast Asia have this agent, as does PNG.

5. Calycomyza eupatorivora Spencer (Diptera: Agromyzidae)

C. odorata seedling in Jamaica with heavy *C. eupatorivora* mining

Mid-instar *C. eupatorivora* larva

C. eupatorivora pupa

C. eupatorivora adult. Photo: Rob Osborne

Action: leaf feeder (blotch mine)

Distribution:

- Native: It is widely distributed in the neotropics (Martinez et al., 1993), but at the time of Cruttwell's PhD study was not recognized as a species separate from C. flavinotum, which has a broader host range. It was later described (Spencer & Stegmaier, 1973).
- Origin of biocontrol agent culture: Jamaica
- Introduced: The first releases were made in 2003 in South Africa. The fly has since established along the coast of KwaZulu-Natal province, and is becoming more common. It is also present in Mpumalanga province and some unsuccessful releases were made in Papua New Guinea.

Biology: Adult flies live less than two weeks in the laboratory. Females insert eggs singly on the underside of the leaf, and the larvae form blotch mines which cover about 50% of the leaf surface. Larvae exit the mine and drop to the ground to pupate. The lifecycle takes about 4-5 weeks in the laboratory.

Safety: Host range testing in South Africa showed that the fly was highly specific to C. odorata (Zachariades et al., 2002). It has also been recorded from Brazil on Alomia fastigiata (Asteraceae: Eupatorieae) (Spencer & Stegmaier, 1973).

Ease of rearing and release:: The insect is best reared in a large walk-in cage with a large number of potted chromolaena plants. Adults can be released in the cage and leaves harvested just before larvae exit them to pupate. Pupae are placed in an emergence box and adults collected from the attached vial. Pupae are the easiest developmental stage to release (at the initial site of establishment in South Africa, ~500 were put out over 4 months). In order to minimize predation on the pupae they should be placed in a container with exit holes, suspended from a tree by cord coated with antbar.

Establishment and efficacy: In South Africa, the insect established fairly easily at a site where chromolaena remained in good condition throughout the year. It spreads quite quickly, but until now does not seem highly damaging, except possibly to young plants in shadier conditions.

Recommendations: May do best in island ecosystems with fewer predators (can be very abundant in Jamaica). Will probably not do well in areas experiencing a prolonged, severe dry season because it is a leaf feeder. May prefer relatively cooler subtropical rather than tropical areas.

Availability: ARC-PPRI, South Africa (C. Zachariades)

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Large mines with mature *C. eupatorivora* larvae

6. Pareuchaetes insulata (Walker)

P. insulata (upper) and *P. pseudoinsulata* (lower) adults are very similar

P. insulata egg batch on underside of *C. odorata* leaf

P. insulata eggs about to hatch. Larval head capsules and setae visible

Young *P. insulata* larva

Mature *P. insulata* larva

Action:

Leaf feeder (defoliator)

Distribution:

Native: From western Venezuela through Central America and the Caribbean to Florida (Cock & Holloway, 1982).

Origin of biocontrol agent cultures: USA (Florida), Jamaica, Cuba.

Introduced: Released in KwaZulu-Natal province, South Africa from 2001 until present. Out of the 18 sites at which the culture from Florida was released, only one has established (where the largest number of larvae, 380,000, were released over 21 months), with confirmation of establishment in late 2004. Populations from Jamaica and Cuba were also imported and released at four sites each but have probably not established. The Florida culture is spreading along the KZN South Coast (Zachariades & Strathie, 2006; Zachariades et al., 2009).

Biology: As for *P. pseudoinsulata*.

Safety: As for *P. pseudoinsulata*.

Ease of rearing and release: As for *P. pseudoinsulata*.

Establishment and efficacy:

Probably similar to *P. pseudoinsulata*. An outbreak during the 2005/6 summer in the vicinity of the established site in KZN, South Africa caused widespread defoliation and death of *C. odorata* plants, but has not been repeated as yet. By April 2008 the insect had spread about 100km along the coast and 10km inland.

Recommendations:

It proved very difficult and expensive to establish this agent in South Africa, and will probably not establish in areas with a prolonged and severe dry season. Possibly better adapted to cooler, less tropical conditions than *P. pseudoinsulata.*

Availability: ARC-PPRI, South Africa (C. Zachariades)

HISTORY

Research on the biocontrol of chromolaena was initiated in the 1960s, when a survey of the phytophagous arthropods on chromolaena was undertaken, mainly in Trinidad, by Rachel Cruttwell (McFadyen). Of the 225 species found feeding on chromolaena in the neotropics (Cruttwell, 1974), several were considered suitable for further study due to the damage they caused and their likely narrow host range. Host range tests were carried out on five species, of which four were found to be safe for release.

During the 1970s, two of these, the moth *Pareuchaetes pseudoinsulata* (Lepidoptera: Arctiidae) and the weevil *Apion brunneonigrum* (Coleoptera: Curculionidae) were released in various Old World countries, with an emphasis on *P. pseudoinsulata*. The moth, which has caterpillars which feed on the leaves of chromolaena, has been released in 15 countries, and established in 10. In most countries in which it established, the moth acted as an outbreak species, initially building up to high numbers and causing widespread defoliation of the weed. However,

Appendix 3-11

P. insulata pupa

Damage to *C. odorata* leaves in Florida caused by *P. insulata* larvae. Mid-instar larvae typically remove a triangular are between the larger veins on the leaf during one night's feeding. Larvae feed from underneath the leaf

Damage to *C. odorata* leaves in Florida caused by older *P. insulata* larvae, which typically leave only the mid-vein after a night's feeding

A *C. odorata* bush in South Africa largely defoliated by *P. insulata* larvae. The leaves have turned yellow in response to heavy feeding

C. odorata plants are visible as grey patches

except for on some Pacific islands, it subsequently fell to low densities and has not been a satisfactory agent in the long term. *A. brunneonigrum*, whose larvae feed in the flowers, did not establish in any of the six countries in which it was released.

A third neotropical arthropod, the leaf-galling mite *Acalitus adoratus* (Acari: Eriophyidae), became accidentally established in South East Asia, probably through infected plant material used in field releases of *A. brunneonigrum* in the 1980s. However, its impact has not been evaluated and is unlikely to be very high.

In the 1990s, a project in South East Asia funded by the Australian Centre for International Agricultural Research (ACIAR) imported the stem-galling tephritid, *Cecidochares connexa*, into Sumatra for host-range testing. The first releases were made in 1995, and since then, the fly has been widely redistributed throughout South-East Asia and also spread by itself. It has proved a great success, consistently damaging plants over time, resulting in die-back and thinning of plants. It has subsequently been released in 10 countries, establishing in all but one of these.

In South Africa, which has a different chromolaena biotype ('SA biotype') to that of South-East Asia ('AWA biotype'), the biocontrol programme started in the late 1980s. Problems were initially encountered because the origin of the SA biotype could not be ascertained, and some of the insects (including *C. connexa*), and all the pathogens, imported into quarantine in South Africa, did not develop on this form. Furthermore, field releases of two *Pareuchaetes* species did not result in establishment. However, recent studies suggest that the probable origin of the SA biotype is Jamaica, Cuba or another island in the northern Caribbean. In addition, *Pareuchaetes insulata* and the leaf-mining fly *Calycomyza eupatorivora* (Diptera: Agromyzidae) are now established.

Funding:
Several sources of funding have contributed towards research on the biocontrol of *C. odorata* over the years (McFadyen, 1996). Funding for the initial surveys in the 1960s was provided by the Nigerian Institute for Oil Palm Research. Sustained funding from national governments in Ghana (in the 1990s), South Africa and Micronesia allowed biocontrol programmes to be undertaken in those countries. International funding from ACIAR was provided for projects in Indonesia, the Philippines, Papua New Guinea (PNG) and East Timor during the 1990s and 2000s. The International Organization for Biological Control of Noxious Animals and Plants (IOBC) provided seeding money and institutional support for several international workshops and publications. However, not all international interventions have proved successful. A project funded by the European Economic Community from 1990-1992 produced limited results due to its short duration, and a UN Food and Agriculture Organization project in West Africa was blocked due to the controversy surrounding the usefulness of *C. odorata* as a fallow crop. Chromolaena remains a major weed in numerous countries so backing from national and international sources for control programmes is still necessary

Current research and other projects

Currently this is the only project world-wide that is investigating the host range and efficacy of new biocontrol agents. The project is conducted from Cedara, KZN (insects) and Stellenbosch, Western Cape (pathogens). The project concentrates on insects which will be compatible with the SA biotype of chromolaena and those which will tolerate prolonged dry periods and fire. All attack different parts of the stem. [read more]

Other Insects

Other insects have been considered over the years, and some of these were released but did not establish. [read more]

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