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# *Ageratina adenophora* (Sprengel) King and Robinson (Asteraceae)

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### 4.1 Introduction

*Ageratina adenophora* (Sprengel) King and Robinson (= *Eupatorium adenophorum*, *E. glandulosum*, *E. pasadense*) (Asterales: Asteraceae) is popularly known as the Crofton weed; other common names are eupatory, sticky snakeroot, cat weed, hemp agrimony, sticky agrimony, Mexican devil, and sticky eupatorium in different parts of the world (Hoshovsky and Lichti, 2007). In Hawaii it is known as *Maui pāmakani* and *pāmakani haole* and in Nepal as *banmara* (killer of the forests). Usually, it grows into an erect herb (occasionally into a subshrub) of one to three meters in height, with trailing purplish to chocolate-brown branches that strike roots upon contact with soil, resulting in dense thickets (Bess and Haramoto, 1958). The base of the plant is woody and densely clothed with stalked glandular hairs. Leaves are dark green, opposite, deltoid-ovate, serrate, and purple underneath, and each grows to about 10 cm in length. Flowers are white and borne terminally in compound clusters in spring and summer. The seed is an achene, varying from elliptic to oblanceolate, often gibbous, 1.5–2 mm long, 0.3–0.5 mm wide; with five prominent ribs and five to 40 pappi with slender scabrous bristles (Hickman, 1993). Dispersal occurs by wind-borne seeds and each plant produces about 100 000 seeds per season. Seeds are also spread by water, as contaminants of agricultural produce, via sand and gravel used in road preparation, via soil sticking to animals, machinery, and vehicles, and by adhering to footwear or clothing of farm workers (Parsons, 1992). Seeds are set without either pollination or fertilization, and 15–30% of seeds are usually not viable. Dense stands can contribute up to 60 000 viable seeds per square meter to the seed bank. Light is essential for seed germination, so unshaded contexts, such as vacant soil, are essential for the establishment of seedlings of *A. adenophora*. Once germinated, seedlings withstand considerable levels of shading, by increasing leaf area to compensate for reduced light intensity. The weed grows rapidly, forming dense thickets (Parsons, 1992).

*Ageratina adenophora* is a native of Mexico, but has naturalized in many countries. It was introduced into several parts of the world as an ornamental in the nineteenth century

and is now an established invasive weed in many subtropical regions of Asia (India, Nepal, China, the Philippines, Thailand, and Brunei), Oceania (Hawaiian Islands, Tahiti, New Zealand, Australia, and Papua New Guinea), Africa (Nigeria, Zimbabwe, and South Africa), and Europe (France, Greece, Portugal, and Spain) (Morris, 1989; Kluge, 1991; Parsons, 1992; Waterhouse, 1993; Wagner *et al.*, 1999). *Ageratina adenophora* was brought to the island of Maui (Hawaii) as an ornamental by Captain James Makee in 1860, and subsequently became a weed occupying rangelands and roadsides. It was introduced into California around 1849 and the first field collection was made in 1878. By 1920, it had spread throughout the mountains on the northern side of the Los Angeles Basin. It has flourished in areas which receive year-round rainfall, edging out native vegetation (Fuller, 1981). Robbins (1940) has reported the spread of *A. adenophora* as a “rare escape” in the San Francisco Bay area and along the southern coast of California. It was introduced to Australia as an ornamental under the name of “*E. riparium*,” probably as early as 1875 (Shephard, 1875, cited in Auld and Martin, 1975). In 1943, it was proclaimed as a noxious plant in New South Wales, while in southeastern Queensland the population exploded in 1949. It took complete possession of large tracts of pasture and horticultural land along the border of New South Wales and Queensland and the spread was so fast that in some areas farmers had to abandon their holdings (Everist, 1959; Dodd, 1961; Auld and Martin, 1975). Its occurrence in tropical countries such as India, Nepal, the Philippines, and Thailand is limited to elevations between 1000 and 2000 m in the hills (Borthakur, 1977; Sharma and Chhetri, 1977).

*Ageratina adenophora* is considered to be a serious weed in agriculture, especially in rangelands where it often replaces either the more-desirable vegetation or native species (Bess and Haramoto, 1958), but also in forests (Sharma and Chhetri, 1977). It is generally unpalatable to grazing animals, but goats graze on this plant infrequently (Wilson *et al.*, 1985). It is fatally toxic to horses and causes the “blowing disease” in Hawaii and “Numinbah disease” or “Tollebudgera horse disease” in Australia. The disease may take several years to become evident in horses (O’Sullivan, 1979). Symptoms such as coughing, difficulty in breathing, and violent blowing after exertion are the result of acute lung edema leading to hemorrhage (O’Sullivan, 1985). This plant reduces growth of nearby vegetation by releasing allelopathic compounds (Kaul and Bansal, 2002) and altering the soil microbial communities (Niu *et al.*, 2007). It is a problem weed in forest plantations as it infests disturbed areas and prevents self-seeding of cultivated trees, and hence it is known as *banmara* in Nepal (Sharma and Chhetri, 1977; Morris, 1989). Moreover, it reduces biodiversity by suppressing native vegetation, interfering with the movement of wildlife, depleting soil nutrients and clogging irrigation channels (Sharma and Chhetri, 1977, Wilson *et al.*, 1985).

Although *A. adenophora* replaces native vegetation such as grasses that protect soil from erosion, because of its dense canopy it protects soil from splash and rill erosion. In Nepal, the leafy stems are harvested and used as cattle bedding and the dry brittle stems are used as fuel (Wilson *et al.*, 1985). It is capable of replacing other invasive weeds such as *Imperata cylindrica* (L.) Beauv. (Poaceae) (Falvey, 1982) and *Lantana camara* L.

(Verbenaceae) (Dhyani, 1978). However, none of these benefits is sufficient to detract from the plant's status as an invasive weed.

## 4.2 Biological control initiatives

Mechanical control is difficult to practice as this plant grows on slopes (Hoshovsky and Lichti, 2007). Between 1920 and 1945, hundreds of acres of grazing land in Hawaii were reclaimed from *A. adenophora* by mechanical removal, which proved expensive. In Australia slashing followed by plowing is carried out (Parsons, 1992). Chemicals such as 2,4-D (Borthakur, 1977), glyphosate, 'dicamba+MCPA' and 'picloram+triclopyr' (Parsons, 1992) were recommended. These methods are expensive and temporary, and most countries where this weed is a problem have adopted classical biological control. When Crofton weed became a serious pest in agriculture and forestry in Hawaii, the gall-inducing fly, *Procecidochares utilis* Stone (Diptera: Tephritidae) was imported from Mexico in 1945 by the then Territorial Board of Agriculture and Forestry, Hawaii. The fly has since established in Maui and within three years, farmers had stopped managing this plant (Bess and Haramoto, 1958). The fly was imported into Queensland (Australia) from Hawaii in 1952 and it established easily. Populations of *P. utilis* increased substantially and suppressed the weed at sites closer to the release area (Dodd, 1961). It was later introduced into New Zealand from Queensland in 1958 and the first release was made on the Coromandel Peninsula, from where the fly spread naturally throughout the peninsula. In 1963, it was released and established over the rest of New Zealand (Hill, 1989). *Procecidochares utilis* was introduced from New Zealand into India and released in the states of Tamil Nadu, Assam, West Bengal, and Uttar Pradesh. By 1971, it had spread widely in the hill ranges of Nilgris and Darjeeling and provided localized control (Rao *et al.*, 1971). The fly reached Nepal from India and established in the Ilam, Terhathum, and Dhankuta districts by 1973 (Sharma and Chhetri, 1977). It then crossed the Himalaya and reached China in 1984 (Wan and Wang, 1991). It was introduced into South Africa from Australia and released at seven sites around Pietermaritzburg and one around Muden between October 1984 and March 1986 (Bennett, 1986). After three generations, galls induced by *P. utilis* on *A. adenophora* were spotted up to one kilometer radius from the release sites and after 20 months up to six kilometers further. It also established around Stellenbosch in 1986 (Kluge, 1991). Several releases have since been undertaken in other areas that have recently become invaded by the weed in South Africa and the agent is now widespread.

### 4.2.1 Biology of *Procecidochares utilis*

The female flies are capable of laying up to 160 eggs (mean number of eggs = 74). Eggs are laid in batches of 2–23 in the terminal vegetative buds. The female usually inserts the ovipositor through one of the second pair of leaves from the top and lays eggs in between

the first pair of young leaves. Eggs are creamy-white, elongate, 0.6 mm in length and coated with a mucoid secretion that adheres the eggs together when laid, thus offering a clumped appearance (Bess and Haramoto, 1958; Sharma and Chhetri, 1977; Bennett and Van Staden, 1986). As many as 20 eggs are laid at the tip of a plant, although the average is seven. The egg stage lasts three to four days during summer and six to eight days in winter in Honolulu, Hawaii (Bess and Haramoto, 1958), three to five days in Yunnan province in China (Zhang *et al.*, 1988) and five to eight days in Nepal (Sharma and Chhetri, 1977). Upon hatching from the eggs, the maggots migrate downward to the base of the leaves, mine into the apical meristem, feed on plant tissue and induce a gall. Occasionally galls develop on leaf petioles and/or leaf midribs. Three larval instars develop; the mature maggot (four mm long) usually excavates a tunnel from the larval chamber to the exterior of the gall before pupation, leaving the epidermis intact to form a "window." The larval stages last for about 20 days in the summer months in Hawaii (Bess and Haramoto, 1958) and 25–30 days in Yunnan (Zhang *et al.*, 1988). The puparia are blackish and are formed within the gall chamber, and the pupal stage lasts 14–21 days in Hawaii (Bess and Haramoto, 1958) and 20–25 days in Yunnan (Zhang *et al.*, 1988). Flies emerge from the galls by breaking the epidermis at the "window." In Nepal, the average time for development from egg to adult is 56 and 60 days for males and females, respectively. Dodd (1961) reported 41 days for males and 43 days for females to complete their life cycles, although Bennett and Van Staden (1986) found considerable variation under identical climatic conditions. The sex ratio of flies emerging from the galls was 1:1 irrespective of the number of larvae per gall. Mating occurs on the same day of emergence and oviposition may also commence on the same day; oviposition continues for up to three weeks, but the majority of the eggs are laid in the first week. The average number of eggs laid per female was 171. On average, adults live for two weeks, rarely extending to three weeks (Bess and Haramoto, 1958).

#### 4.2.2 Gall development

The first sign of gall development is evident a week after oviposition when the young leaves at the oviposition site turn crinkled and chlorotic. Three or four days later the stem bends to about 45° at the point where oviposition occurred (Bennett and Van Staden, 1986). In two weeks from the time of egg laying, gall initiation becomes evident with a red and pink pigmentation. Gall size depends on (1) the number of larvae and (2) the vigor of the plant. With one larva in the gall, the gall size is usually 15 × 10 mm, whereas, when multiple larvae occur, the gall may reach a size of 35 × 17 mm. The average number of larvae found in a gall was three, even though a maximum of 11 flies emerged from a gall (Bess and Haramoto, 1958). During favorable seasons and environmental conditions, oviposition continues and individual stems are attacked repeatedly, resulting in compound galls which are caused by smaller galls (those induced later in time) coalescing with previously induced ones. Larvae remain confined to individual chambers, but in larger galls the larval chambers may coalesce.

### 4.2.3 Effect of gall induction on the plant

In a favorable environment such as the Ulupalakua area in Maui, Hawaiian Islands, *P. utilis* is abundant throughout the year and all shoots are attacked during plant growth. In some instances, the shoot tips died because of intense oviposition (Bess and Haramoto, 1958). Galls function as nutrient sinks and the nutritive tissue establishes when the gall becomes visible. The larva that induces the gall derives its nourishment from the specialized tissue in this gall chamber, which is composed of proliferating parenchyma cells along the walls of the chamber (Meyer and Maresquelle, 1983; Bronner, 1992). Such specialized nutritive tissue becomes a metabolic sink for energy nutrients and accumulates minerals (Ca, Cu, Fe, Mg, Mn, Ni, and Zn) from adjacent plant tissues or other parts of the plant (Abrahamson and Weis, 1987; Raman, 1994; Raman and Abrahamson, 1995; Cruz *et al.*, 2006; Raman *et al.*, 2006). Gall induction also reduces several vital metabolic and transpiration efficiencies, stomatal conductance and water potential (Florentine *et al.*, 2001, 2005). In addition, galls reduce shoot height, and production of leaves, flowers, and seeds (Raman and Abrahamson, 1995; Cruz *et al.*, 2006). The exit holes cut by the inhabiting larvae enable access by microorganisms that induce decay. High galling intensity results in plant mortality.

### 4.2.4 Effect of parasitism on *P. utilis*

In its native range in Mexico, *P. utilis* is attacked by the parasitoids *Eurytoma obtusiventris* Gahan (Hymenoptera: Eurytomidae), *Eupelmus cyaniceps* (Ashm.) (Hymenoptera: Eupelmidae), *E. allynii* (French) (Hymenoptera: Eupelmidae), *Torymus umbilicatus* (Gahan) (Hymenoptera: Torymidae), *Galeopsomopsis* sp. (Hymenoptera: Eulophidae), and *Zatropis* sp. (Hymenoptera: Pteromalidae). Five species of parasitoids, *Opius tryoni* Cameron (Hymenoptera: Braconidae), *Opius longicaudatus* (Ashmead) (Hymenoptera: Braconidae), *Bracon terryi* (Bridwell) (Hymenoptera: Braconidae), *Eupelmus cushmani* (Crawford) (Hymenoptera: Eupelmidae), and *Eurytoma tephritidis* Fullaway (Hymenoptera: Eurytomidae) were reared from *P. utilis* in Hawaii. The two *Opius* spp. were imported into Hawaii to control tephritid pests but became casual parasitoids of *P. utilis*. Parasitism was higher in warmer months, increasing up to 93% in some localities and averaging 50% and 60% in 1950–1957 and 1966–1971 surveys, respectively. Despite high parasitism, *P. utilis* could still eliminate *A. adenophora* over large areas in Maui; the lack of success in other areas was attributed to heavy rainfall and wet conditions and not to recruited parasitoids (Bess and Haramoto, 1959, 1972).

In the high-altitude regions of Tamil Nadu (India) (2000–2300 m asl), four hymenopteran parasitoids, *Diameromicrus kiesenwetteri* (Meyr) (Hymenoptera: Torymidae), *Syntomopus* sp. (Hymenoptera: Pteromalidae), *Bracon* sp. (Hymenoptera: Braconidae) and *Eurytoma* sp. (Hymenoptera: Eurytomidae) have been recorded on *P. utilis* (Swaminathan and Raman, 1981). Parasitism by *Bracon* sp. was as high as 80% and was

considered to be the primary cause for the failure of the gall fly to control Crofton weed in India. In Nepal, the parasitoids *Eurytoma* sp. (Hymenoptera: Eurytomidae) and *Dimeromicrus vibidia* (Walker) (Hymenoptera: Torymidae) have been reported to parasitize up to 17.5% and 30%, respectively, of *P. utilis* populations (Sharma and Chhetri, 1977; Kapoor and Malla, 1979).

Nearly two years after the release and establishment of *P. utilis* in Australia, eight species of indigenous hymenopteran parasitoids were found attacking it. Of these, *Megastigmus* sp. (Hymenoptera: Torymidae), *Macrodontomerus australiensis* Gir. (Hymenoptera: Torymidae) and *Campyloneurus* sp. (Hymenoptera: Braconidae) were significant. In particular, *Megastigmus* sp. caused 90% parasitism (Dodd, 1961). Species of minor importance included one species each of *Campyloneurus* and Pteromalidae, and three species of Eupelmidae (Dodd, 1961). The reported population decline of the fly in Australia was due to parasitism by these diverse parasitoids; however, the fly still provided partial control of the weed. As a result, the rapid spread of the weed was halted and its vigor, growth and density have been reduced. The gall fly was introduced to New Zealand in 1958, and for many years no parasitoids were recorded on it. In 1964, some parasitism was recorded but was regarded as insignificant. However, in 1972, *Megastigmus* sp., the same parasitoid reported in Queensland, Australia, was found parasitizing up to 71% of the fly's population in New Zealand (Hill, 1989). In South Africa, *P. utilis* is attacked by *Dimeromicrus* sp. (Hymenoptera: Torymidae), *Eupelmus* sp. (Hymenoptera: Eupelmidae) and an unidentified species of Pteromalidae, and rate of parasitism varied from 26% to 52% (Bennett, 1986).

Other organisms that have been reported to feed on the galls include: larvae of *Heliothis* spp. (Lepidoptera: Noctuidae) in Australia (Dodd, 1961); larvae of *Spodoptera litura* (Lepidoptera: Noctuidae) and slugs in Nepal (Sharma and Chhetri, 1977); and mice in Oahu, Hawaii (Bess and Haramoto, 1958).

#### 4.2.5 Other natural enemies recorded on *A. adenophora*

*Oidaematophorus beneficus* Yano and Heppner (Lepidoptera: Pterophoridae)

This insect was introduced to Hawaii from Mexico for the control of *Ageratina riparia* (Regal) R. M. King and H. Robinson (Asteraceae) (Nakao *et al.*, 1975). The larva is a leaf feeder and causes smooth edged holes. In 1991, Conant (1998) reported finding a few specimens feeding on *A. adenophora* in Hawaii. It is possibly a spillover feeding incidence than a true association (T. Olckers, personal communication).

*Dihammus argentatus* Auriv. (Coleoptera: Cerambycidae)

*Dihammus argentatus* is an indigenous Australian cerambycid that has been recorded on *A. adenophora* since 1950 (Dodd, 1961). Stem-boring larvae are found in the rootstock and base of the stems of larger plants, while smaller plants are not favored. During the rainy season, the infested plants are not seriously weakened but in the dry season they

suffer damage and mortality in extreme cases. This insect has been observed damaging cultivated dahlias (Dodd, 1961) and thus cannot be considered for introduction into other countries as a “new association” biological control agent.

*Phaeoramularia* sp. (*Fungi: Ascomycota*)

A leaf-spot fungus, isolated at gall-fly release sites in Queensland, Australia, in 1954 suggested that the spores were passively transmitted by *P. utilis* adults from Hawaii. By 1957, the leaf-spot disease occurred in all Crofton weed areas in Australia. Originally this fungus was determined to be *Cercospora eupatorii* Peck (Dodd, 1961), but has since been assigned to *Phaeoramularia* and is probably a new species (Morris, 1991). This leaf-spot fungus could have originated from tropical Central America (Julien and Griffiths, 1998) and appears to have been introduced accidentally into Hawaii, Australia, New Zealand, India, and Nepal, wherever gall-fly releases took place.

For introduction into South Africa, a single-spore isolate of the pathogen was obtained from infected leaf material from Queensland in 1984 and used for host-specificity studies and subsequent releases (Morris, 1991). Several species of Asteraceae were tested and all, except *A. adenophora*, were found resistant to the fungus. It was originally released at Stellenbosch and Pietermaritzburg (South Africa) between 1987 and 1989, but has since been redistributed to other areas. The fungus has established well and has caused partial defoliation of plants at Pietermaritzburg, but not at Stellenbosch, as the fungus is not adapted to the Mediterranean climate of the southwestern Cape (Morris, 1991).

#### 4.2.6 Other candidate agents

The recent expansion of *A. adenophora* in South Africa has raised concerns that the weed is emerging as a more serious problem and that the two established agents are having little impact. Consequently, funds have been secured for the importation of additional biocontrol agents. In 2007, a trip was undertaken to Mexico to survey for promising insect and pathogen agents. Some of the more promising agents included stem-boring and defoliating insect species as well as a range of pathogens (S. Nesar, personal communication). More collecting trips have been planned and introductions of new agents are imminent.

### 4.3 Biological control and the status of the weed

In Hawaii, prior to the introduction of *P. utilis*, the weed had developed into dense thickets and grown up to three meters tall on commercially important grazing land; infested rangeland was reclaimed by expending labor and funds for mechanical removal of the weed. Within a few years after the introduction of the fly, the plant was effectively controlled in several thousand acres of rangeland. In some areas, the fly eliminated the weed completely. Even though parasitism of the fly was 50% or more in some areas, this did not diminish its efficacy in Hawaii. Although the fly did not prove effective in the wet,

steep slopes of east Maui, it was generally considered to be an outstanding success (Bess and Haramoto, 1958, 1959, 1972). The critical returns on the introduction of *P. utilis* into Hawaii included savings due to the reduced need for mechanical equipment and labor for removal of the weed, improvement in biodiversity, reduction in animal toxicity and prevention of further spread of the weed.

In Australia, partial control of the weed was achieved due to the introduction of the fly and was aided by the inadvertently introduced leaf-spot fungus and an indigenous cerambycid stem borer, *D. argentatus* (Dodds, 1961). Since 1952, the spread of this weed has not increased (Page and Lacey, 2006). In New Zealand, the fly inflicted significant damage on the weed for five years after its introduction. The abundance and importance of the weed have declined in the last 25 years and it is no longer considered to be economically important (Hill, 1989). Introduction of the gall fly into India and its eventual movement into Nepal has resulted in some reduction in vigor, growth, and density of the plant; however, the heavy incidence of parasitism has reduced the efficiency of *P. utilis* (Sankaran, 1973). The gall fly dispersed from Nepal and has established in an area near Tibet in 1984. The flies were also collected and released in Yunnan and neighboring provinces in southern China for control of the weed (Zhang *et al.*, 1988). In South Africa, recent studies have suggested the fly is having a limited impact and has not curtailed the spread of the weed, making the introduction of new agents a priority (S. Naser and A. B. R. Witt, personal communication).

The cost of introduction of *P. utilis* to various countries has been minimal. When the fly was collected on *A. adenophora* in Mexico in 1944, an immediate decision was made to import it into Hawaii by the Territorial Board of Agriculture and Forestry, and by 1945, it was released and established. Although some expenditure was incurred for initial host-specificity studies in Hawaii (including tests for Australia), no costs have accrued to other countries except for minor transportation expenses. In many countries, *P. utilis* has suppressed the weed and contained its spread, despite heavy parasitism by local parasitoids in some countries. Besides South Africa, none of the countries affected by *A. adenophora* has considered further introductions of additional natural enemies.

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