Sida acuta Burm.f - spinyhead sida, *Sida rhombifolia* L. - paddy's lucerne and *Sida cordifolia* L. - flannel weed

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ABSTRACT

Sida acuta, *Sida rhombifolia* and *Sida cordifolia* are invasive weeds in northern Australian rangelands. A survey for biocontrol agents of *S. acuta* and *S. rhombifolia* was conducted in Mexico from 1984 to 1986. Sixty-two species of phytophagous arthropods were found and 12 were considered to have potential as biocontrol agents. Six were imported into an Australian quarantine and three were approved for release in Australia. The first agent *Calligrapha pantherina* was released in 1989 and was widely established by 1997. This beetle defoliates *S. acuta* plants and reduces seed production. After several years of defoliation, populations of *S. acuta* were replaced by desirable native and exotic pasture species. *Calligrapha pantherina* has its greatest impact on *S. acuta* in coastal and sub-coastal areas. The fate of the other two agents released, two species of *Eutinobothrus* has not been investigated, although they are known to have survived the first dry season.

Key words: *Calligrapha pantherina*, *Eutinobothrus*, Malvaceae,

INTRODUCTION

Sida acuta Burm.f, *Sida rhombifolia* L. and *Sida cordifolia* L. (Malvaceae) are weeds in many parts of the world, including Australia. They are native to the Americas, although *S. rhombifolia* and *S. cordifolia* may be native to all tropical regions of the

world, including Australia. They can tolerate drought as well as high rainfall conditions. All species are erect perennial shrubs up to 1.5 m in height, occurring on a wide range of soil types. All have yellow flowers and reproduce by seed. They are weeds in disturbed and cultivated areas (Holm *et al.* 1991; Parsons and Cuthbertson 1992).

Sida acuta is common from the north-east corner of Western Australia through the Northern Territory, and south, particularly along the coastal areas of Queensland to Gladstone. *Sida rhombifolia* occurs in tropical to warm-temperate areas, extending further south than *S. acuta* to southern NSW. *Sida cordifolia* is also found throughout the tropical and subtropical north of the continent (Parsons and Cuthbertson 1992) (Figure 1).

BIOLOGICAL CONTROL HISTORY

Biocontrol of *Sida* spp. began in 1984 when the NT Government provided funds for exploratory studies on *S. acuta* and *S. rhombifolia* in their native range. Some work was also conducted opportunistically on *S. cordifolia*. Surveys were conducted out of the CSIRO's Mexican Field Station at Acapulco and later Veracruz and continued until 1991. The highest priority agents were imported into the quarantine facility at CSIRO's Long Pocket Laboratories, Brisbane where host specificity testing was conducted. Three agents *Calligrapha pantherina* Stål (Coleoptera: Chrysomelidae), *Eutinobothrus* sp. (Coleoptera: Curculionidae) and *E. pilosellus* Faust were approved for field release in 1989, 1994 and 1997 respectively. The majority of releases were conducted in the Northern Territory, where the most severe infestations were found. Some field releases of all three species were also conducted in north Queensland. Mass rearing and release of *Eutinobothrus* spp. continued until 1999, but it is not known if establishment occurred. Several other agents were also imported, but were not released as they were not specific to the target plants. *Calligrapha pantherina* established quickly and offers good control of *Sida* spp. in the Northern Territory. It was subsequently released in Papua New Guinea (Kuniata and Korowi 2004), Fiji and Vanuatu where it is offering some level of control against *Sida* spp. (W. Orapa *pers. comm*. 2009).

PLANT TAXONOMY

The genus *Sida* L. is a large, poorly-circumscribed group of species of pantropical distribution belonging to the tribe Malveae in the family Malvaceae (Fuertes Aguilar *et al*. 2003). The three *Sida* species considered in this chapter can be distinguished in the following ways. *Sida cordifolia* is a taller plant than *S. acuta* and *S. rhombifolia*. Its stems and leaves have a felt-like appearance due to the dense stellate hairs. The flowers are produced in clusters and the seed capsules divide into 10 segments. The two sharp points or awns on the end of each seed segment are longer than those of *S. acuta*. *S. rhombifolia* has leaves in which the under surface is paler in colour than the upper surface, whereas the leaves of *S. acuta* are dark green on both sides (Figure 2). *S. rhombifolia* produces pale yellow flowers which grow singly on stalks 10 to 35 mm long. The flowers of *S. acuta* are on stalks 3 to 8 mm long. The seed capsules of *S. rhombifolia* divide into 10 segments, each segment having two blunt points. The seed capsules of *S. acuta* divide into 5-8 segments, each segment having two sharp points (Pitt 1992; Parsons and Cuthbertson, 1992).

EXPLORATION

Native range

The Acapulco area of Mexico was chosen as the base for exploration due to a close climate match with Darwin. In particular, the dry season on the south Pacific coast of Mexico is long, potentially providing a source of agents capable of surviving the severe northern Australian dry season (Gillett *et al.* 1991). From 1984-86, 90 collections were made by John Gillett at 19 locations, all in Mexico. Preliminary host specificity testing was conducted in the native range (Gillett *et al.* 1991).

Exotic range

The phytophagous insect fauna of *S. acuta* and *S. cordifolia* was investigated in the Northern Territory of Australia (Wilson and Flanagan 1990). This study attempted to reveal any vacant niches which might be exploited by introduced biocontrol agents. Most of the 20 species on *S. acuta* and 23 species on *S. cordifolia* were rarely encountered. *S. cordifolia* was more heavily utilized and supported six species that damaged the plant heavily. The only species found in large numbers on *S. acuta* was the seed-sucking bug *Oxycarenus luctuosus* Montrouzier and Signoret. It was

concluded that vacant plant niches occurred on both plant species for introduced biocontrol agents (Wilson and Flanagan 1990).

CANDIDATES

Natural enemies (native range)

A total of 62 phytophagous arthropod species were collected from Mexico; 35 only on *S. acuta*, 11 only on *S. rhombifolia*, and 16 on both plant species. Data was obtained on the host specificity of 38 herbivorous species, which indicated that five of these were restricted to *Sida* spp. (Gillett *et al.* 1991). Species were ranked according to their perceived potential for control. Twelve species were selected for further consideration. Six species were imported into Australian quarantine and are treated in detail below.

Organisms tested but not released

Meskea horor Dyar (Lepidoptera: Thyrididae)

This species was imported into Australian quarantine for study between 1988 and 1990. Females lay eggs on the underside of leaves and the emerging active larvae enter the stem between the nodes. The larvae feed in stems, inducing plants to form galls. Pupation occurs in the galls and adults emerge through a clear window on the side of the gall. Development from egg to adult is about 190 days. During the testing stage, females preferred to oviposit on *S. rhombifolia* rather than *S. acuta* and there was a higher development rate on *S. rhombifolia*. In host specificity trials, oviposition occurred and development was completed on several other species, including *Abutilon oxycarpum* (F. Muell.) F. Muell. ex Benth. var. *acutatum*, *Gossypium hirsutum* L., *Hibiscus tiliaceus* L. and *Sida subspicata* F. Mueller ex Bentham (all in the family Malvaceae). Consequently, its field release was not sought and the colony was destroyed (Day *et al*. 1997).

Zygogramma nr *bigenera* (Coleoptera: Chrysomelidae)

A colony of the leaf-feeding chrysomelid, *Zygogramma* nr. *bigenera* was studied in Australia during 1994. Its life-cycle and damage to *S. acuta* and *S. rhombifolia* are similar to that of *Calligrapha pantherina*. However, attack on some native species of *Sida* was substantial and it was judged unsuitable as a biocontrol agent in Australia. The colony was destroyed.

***Acanthoscelides brevipes* (Sharp) (Coleoptera: Bruchidae)**

This species was imported into Australian quarantine for study between 1988 and 1990. This small black beetle feeds on mature seeds of *Sida* spp. Adults drink nectar from the flowers or water. The pre-oviposition period is about 2 weeks and females lay eggs between the seed and the calyx. Eggs can also be laid between two seeds within the infructescence. Upon emerging, larvae tunnel into the seed and feed for about 6-7 weeks. Pupation occurs within the seed (M Day unpublished).

During host specificity testing, adults emerged from ten species, of which seven were *Sida* spp., including *S. acuta*. Apart from *S. acuta*, the main species supporting *A. brevipes* were *S. cunninghamii* White and *S. fibulifera* Lindley. Of the non-*Sida* spp., nine adults emerged from *Abutilon oxycarpum* var *acutatum* and one adult each from *A. oxycarpum* var *subsagittatum* and *Triumfetta rhomboidea* Jacquin (M Day unpublished). In no-choice trials, adults emerged from eight species, of which six were *Sida* spp., including *S. acuta*. The main species supporting development were *S. brachypoda* F. Mueller ex Holland and Reynier, *S. fibulifera* and *S. spinosa* L. A total of 16 adults emerged from *A. oxycarpum* var *acutatum* while one adult emerged from *A. oxycarpum* var *subsagittatum* (M Day unpublished). Due to the number of species that supported development, including several native species, the agent was not considered for release and the colony was destroyed.

***Brachycoryna pumila* Guerin or near (Coleoptera: Chrysomelidae)**

Adults of the chrysomelid *Brachycoryna pumila* were screened against several *Sida* species in Mexico and close relatives in the Malvaceae. Adults damaged and reproduced on a number of non-target *Sida* species and so this insect was considered unsuitable to import and further testing in quarantine in Australia (W Forno *pers. comm*. 1995).

Agents released

Calligrapha pantherina Stal (Coleoptera: Chrysomelidae)

Calligrapha pantherina feeds on leaves of *S. acuta* and *S. rhombifolia* in Mexico. It is only known to occur in the states of Guerrero, Oaxaca, Veracruz and Chiapas. Adults and larvae both feed on leaves of their host plants (Gillett *et al.* 1991). Eggs are laid on the underside of mature leaves. Larvae feed gregariously for the first three instars (Figure 3), and singly during the fourth (final) instar. Older instar larvae may also feed on the flowers and fruits. Pupation occurs in the leaf litter or in fine soil and lasts for 6-12 days. The total time from egg to adult is about 24 days, with a pre-oviposition period of about 18 days. Newly emerged adults are dull brown but change to iridescent green with black markings, and become receptive to mating after about 7 days. The adults live for an average of 18 weeks and lay two batches of about 50 eggs each per week (Forno *et al*. 1992).

Host specificity studies showed that only *S. acuta, S. rhombifolia* and *S. spinosa* (another exotic weed) were good hosts for *C. pantherina.* The feeding, survival and oviposition on other native hosts was sufficiently poor for this agent to be acceptable for release in Australia (Forno *et al.* 1992).

Following release in 1989, *C. pantherina* quickly established and caused severe defoliation of *S. acuta* near Darwin in the Northern Territory (Wilson and Lonsdale 1992). Figure 4 shows an infestation before the release of *C. pantherina* and Figure 5 shows a similar infestation after damage by this insect. Populations of *C. pantherina* move as a front through stands of *S. acuta* and provide good control with maximum impact on coastal and sub-coastal stands of *S. acuta* in the Northern Territory (Flanagan *et al.* 2000). *Calligrapha pantherina* reduced annual seed production by an order of magnitude and reduces plant density (Lonsdale *et al*. 1995). Beetle survival during the severe dry season in northern Australia can be poor, as it often needs to be reintroduced to areas where high densities were present the previous dry season (Lonsdale *et al*. 1995). Many landowners value the insect and take measures to ensure its survival over the dry season (Grace *et al*. 2006).

Following its success in Australia, *C. pantherina* was sent to PNG in 1999 and soon provided effective control of *Sida* spp. (Kuniata and Korowi 2004). It has also

been released in Fiji and Vanuatu where it is offering some level of control against *S. acuta*, *S. rhombifolia* and *S. retusa* (W Orapa *pers. comm*. 2009).

Calligrapha pantherina failed to establish on *S. rhombifolia* near Brisbane in southeast Queensland and only limited establishment has occurred on *S. rhombifolia* near Townsville in north Queensland. Both *S. acuta* and *S. rhombifolia* are nutritionally similar hosts for *C. pantherina* (Heard and Gardner 1994). Climate matching shows that the location where the insect has established (near Darwin) is very similar to Acapulco (close to the epicentre of the native range). The location near Brisbane where the insect did not establish is not climatically similar to Acapulco, while the location near Townsville where limited establishment has occurred has an intermediate level of similarity (Heard and Gardner 1994). Hence, it appears likely that climatic factors influence the observed distribution of *C. pantherina* in Australia.

Eutinobothrus sp. (Coleoptera: Curculionidae)

Eutinobothrus sp. was first introduced into Australia in 1989. Following host specificity testing, it was released in May 1994. Adults graze on the thicker stems and eggs are laid in feeding scars or in nodes on the stems. Eggs hatch in about nine days and larvae tunnel into the stem, at the site of oviposition. Larvae feed for 34-56 days. Pupation occurs in the stems and adults emerge after 13 days and can live for about nine months (Day *et al*. 1995). *Eutinobothrus* sp. survived the first dry season in the NT at sites not too distant from Darwin. A total of 40,670 adults were reared at the CSIRO Long Pocket Laboratories, sent to the NT, WA and north Queensland and released at many widely dispersed sites from May 1994 to April 1999. Early surveys revealed establishment, continued survival and spread at most release sites that had not been disturbed by spraying or slashing (G Fichera *pers. comm*. 2010).

Eutinobothrus pilosellus Faust (Coleoptera: Curculionidae)

Adults of this beetle were imported accidentally with shipments of *Eutinobothrus* sp. These beetles differ from *Eutinobothrus* sp., being slightly smaller and more elongate. Adults of *E. pilosellus* tend to feed on leaves whereas those of *Eutinobothrus* sp. tend to feed on the stems. A separate colony of *E. pilosellus* was established and host specificity testing was conducted once numbers were adequate. Approval for release

of *E. pilosellus* was gained in March 1997 and from then until March 1999, 20 690 adults were reared at the CSIRO Long Pocket Laboratories and released in the NT. Approximately 4 000 were also released at sites in coastal Queensland, from Bowen to Gordonvale in 1998 (G Fichera *pers. comm*. 2010).

Other promising agents

Calligrapha polyspila heavily defoliates and even kills plants of *S. rhombifolia* in pine plantations in Argentina (Lopez *et al*. 2009). It is used to control *Sida* in Brazil (Garcia 1991). Hugo Cordo (USDA ARS South American Biological Control Laboratory) studied the host range of *Calligrapha polyspila* for the control of *Sida spinosa* in USA and concluded that it was specific to *S. rhombifolia*. It completed one generation on *S. spinosa*, but not a second and hence, was not released in the USA (H Cordo *pers. comm*. 2010). This insect may be a useful agent for *S. rhombifolia* in cooler areas of Australia where *C. pantherina* does not thrive.

In addition to the six agents imported into Australia for testing, Gillett *et al.* (1991) ranked the following species as having potential: *Calligrapha felina* Stal (Chrysomelidae), *Calycomyza* sp. poss. *C. sidae* Spencer or *C. ipomaeae* (Frost) (Agromyzidae), *Asphondylia* sp. poss. *sidae* Mohn (Cecidomyiidae), *Neolasioptera* sp. prob. *sidae* Mohn (Cecidomyiidae), *Neoptilia biramosa* (Klug) (Argidae), *Stegasta albocapitella* (F.) (Gellechiidae), *Pyrgus adepta* Ploetz (Hesperiidae) and *Bucculatrix* sp. (Lyonetiidae). Further work is needed to assess the potential of these agents.

DISCUSSION

Of the 62 species of phytophagous arthropods collected in three years of surveying in Mexico, 12 were considered to have potential as biocontrol agents (Gillett *et al*. 1991). Six were imported into Australian quarantine and three were approved for release in Australia. One of these, *C. pantherina* is severely impacting on the weed (Flanagan *et al.* 2000; Lonsdale *et al*. 1995). The other released agents, two species of *Eutinobothrus,* are known to have survived the first dry season following their release, but their current status is unknown.

On the basis of the number of phytophagous species reared on *S. acuta* and *S. rhombifolia* in Mexico, Gillett *et al.* (1991) concluded that Mexico is part of the native range of both these species. However, the presence of *Calligrapha polyspila*, a specific insect to *S. rhombifolia* in Argentina (H Cordo *pers.comm*. 2010), indicates that the native range of *S. rhombifolia* may be very broad through the American continents. Indeed, it has been suggested that both *S. rhombifolia* and *S. cordifolia* are pantropical species (Parsons and Cuthbertson 1992).

Page and Lacey (2006) estimated the present value costs of the biocontrol program against *S. acuta* and *S. rhombifolia* to outweigh the benefits, resulting in a negative net present value, and a benefit/cost ratio of 0.5:1. This implies that for every dollar invested, a benefit of only $0.50 was generated. However, this was with a high discount rate of 8% and the analysis was considered to underestimate the benefits, as it only included benefits received in the Darwin area.

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Figure 1. The distribution of *Sida acuta, Sida rhombifolia* and *Sida cordifolia* in Australia (Source: the Australian Virtual Herbarium).

Figure 2. A flowering and fruiting tip of *Sida acuta*. (Photo CSIRO).

Figure 3. Larvae and leaf damage of *Calligrapha pantherina*. (Photo CSIRO).

Figure 4. An undamaged stand of *Sida acuta* at Katherine Rural College in December 1987 before the release of *Calligrapha pantherina*. (Photo Colin Wilson).

Figure 5. A stand of *Sida acuta* at Marlow Lagoon, NT, in January 1991 defoliated by *Calligrapha pantherina.* (Photo Colin Wilson).