Biological control of the native shrubs *Cassinia* spp. using the native scale insects *Austrotachardia* sp. and *Paratachardina* sp. (Hemiptera: Kerriidae) in New South Wales

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Summary
Naturally occurring populations of the native scale insects *Austrotachardia* sp. and *Paratachardina* sp. killed large areas of native *Cassinia* spp. in, respectively, central and north-western New South Wales, from 1988 to 1993. These scales, which are specific to *Cassinia* spp., have been widely spread through New South Wales by the transfer of infested cuttings by humans. Observations on one property near Orange revealed that deliberate transfer of *Austrotachardia* sp. assisted in killing 70% (255 ha) of *C. arcuata* on the property between 1988 and 1993. *Cassinia* spp. are usually replaced by native grasses; however, poor management can lead to re-infestation by woody weeds. Both scales have an annual life cycle and are spread by transferring infected cuttings to new plants 10 to 30 days before first-instar nymphs emerge. A complex of parasitoids and predators, mainly small wasps, may limit the effectiveness of the scales in controlling *Cassinia* spp. Parasitoids can be partially controlled by destroying cuttings immediately after crawler emergence because they continue to emerge for up to seven months after the crawlers. This study indicates that if humans assist by spreading scale insects and controlling parasitoids and predators the scales could be useful biological agents for the control of *Cassinia* spp.

Introduction
Cassinia spp. (Asteraceae), native shrubs widespread in New South Wales, Victoria and Queensland (Campbell 1977, 1990), generally grow on infertile acid soils. They invade pastures in response to soil or plant disturbance and become weeds because they are unpalatable, competitive, unproductive and difficult and costly to control (Campbell *et al.* 1990). They also provide harbour for noxious animals and make stock mustering difficult. The four main species are *Cassinia arcuata* R.Br., *C. longifolia* R.Br., *C. laevis* R.Br. and *C. quinquefaria* R.Br. *C. arcuata* has invaded 616 000 hectares in central and southern New South Wales and is a declared noxious weed in 10 shires (Campbell 1990, Campbell *et al.* 1990). Preliminary estimates indicate *C. laevis* and *C. quinquefaria* are present on 250 000 hectares in north-western New South Wales. On arable land *Cassinia* spp. can be controlled by ploughing, sowing improved pastures and applying fertilizers to overcome nutrient deficiencies and soil acidity (McGowen *et al.* 1990). On non-arable land conventional methods of control e.g., spraying and aerial distribution of pasture seed and fertilizers, are impractical because herbicide treatments are uneconomic and pasture establishment difficult on the unploughed acid soils (Campbell 1990).

Native scale insects have killed small areas of *C. arcuata* and *C. longifolia* in central New South Wales since 1979 (J.J. Dellow, NSW Agriculture, Orange, personal communication) and patches of *C. laevis* and *C. quinquefaria* in north-western New South Wales since 1988. However, between 1988 and 1993 relatively large areas of *Cassinia* spp. were killed by *Austrotachardia* sp (Hemiptera: Kerriidae) in central New South Wales (Campbell and Wykes 1991, 1992) and by *Paratachardina* sp. (Hemiptera: Kerriidae) in north-western New South Wales (Holtkamp and Campbell 1992). Although similar scales were described by Froggatt (1903), no data on their biology were available. Thus observations began on *Austrotachardia* sp. in 1988 and *Paratachardina* sp. in 1991 to record their biology and to ascertain whether they could be used for the biological control of *Cassinia* spp.

Life cycle of *Austrotachardia* sp. and *Paratachardina* sp.
Austrotachardia sp. was studied at "Daydawn", Kerrs Creek and at the Agricultural Research and Veterinary Centre, Orange. *Paratachardina* sp. was studied in the Tamworth and Manilla districts.

First-instar nymphs (crawlers) of *Austrotachardia* sp. (Figure 1) (orange in colour and 0.5 mm long) emerged in December 1990 and established on stems of *C. arcuata*. Initially, all second-instar nymphs appeared identical. However, by February 1991, the red, oblong (1.5 × 0.6 mm) male tests were distinguishable from the red, oval (1 mm diameter) female tests (Figure 2). The red-coloured male flies emerged in March 1991, but it is not known whether fertilization occurred at this time because mating was not observed. Scale insects reproduce by a variety of means including hermaphroditism, parthenogenesis and normal fertilization (O'Brien *et al.* 1991).

Females of *Austrotachardia* sp. grew slowly during winter 1991, increasing from 1.5 mm to 2.0 mm in diameter. As the females matured, embryos appeared

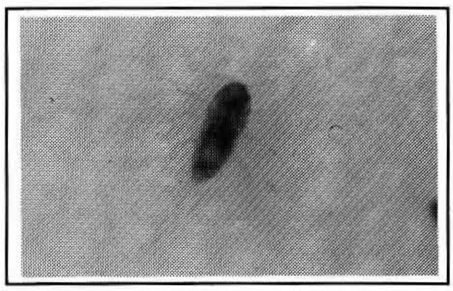

Figure 1. First-instar nymphs (crawlers, 0.5 mm long) of *Austrotachardia* sp. emerge in summer or autumn ; transfer of infected cuttings should take place 10 to 30 days before crawler emergence.

Figure 2. An oblong male nymph (centre) surrounded by six oval females of *Austrotachardia* sp.

Figure 3. A fully developed *Austrotachardia* sp. female one year old.

inside and developed into crawlers that emerged in December 1991. Thus the life cycle of the population that began at Kerrs Creek in December 1990 was approximately one year (Figure 3). Another population, that began with crawlers in February 1991, had males emerging and females 1 mm in diameter in December 1991, and crawlers emerging in February 1992. These two populations repeated their respective life cycles in 1992/93 and 1993/94; crawlers from the first population emerged in January 1993 and December 1993 and those from the second, in March 1993 and March 1994. The two latter emergences were later than in 1991/92. Buckley (1987) recorded that climatic and habitat factors may affect ant-plant-homopteran interactions and regulate population dynamics. Thus, lower than normal temperatures and higher rainfall in 1992 (average daily mean 11.2°C and total rainfall 1322 mm in 1992 compared with the 100 year average of 12.1°C and 901 mm) may have increased the length of the life cycle of *Austrotachardia* sp. It was also observed that female *Austrotachardia* sp. grew more slowly, with a corresponding increase in length of life cycle, on retarded *C. arcuata* plants or on plants growing in the shade.

Two years of observations in north-west New South Wales indicate that *Paratachardina* sp. produces crawlers in November and has an annual life cycle. *Paratachardina* sp. closely resembles *Austrotachardia* sp., the main external difference being that *Paratachardina* sp. are brown and *Austrotachardia* sp. are red.

Insects and fungi associated with *Austrotachardia* sp. and *Paratachardina* sp.

Predators and parasitoids

The major parasitoids of *Austrotachardia* sp. and *Paratachardina* sp. are small wasps: *Dolichogenidea* sp. (Hymenoptera: Braconidae: Macrogastrinae) black wasp with long antennae; *Encarsia* sp. (Aphelinidae: Hymenoptera) small black wasp; and undetermined Encyrtidae (Hymenoptera) brown backed and yellow wasps. These wasps lay eggs either in or under an establishing nymph; the larvae feed on female scales, pupate under the test and the adults emerge by cutting a round hole in the test. Often female scale insects produce crawlers despite the presence of a wasp larva. Wasps continue to emerge after crawler emergence has ceased; for example, in the early autumn 1993 *Austrotachardia* sp. population, 61% of wasps emerged in the two months after crawler emergence had ceased and continued to emerge for a further seven months. This indicates that cuttings attached to new plants to spread *Austrotachardia* sp. should be destroyed after crawler emergence (Campbell and Wykes 1991, Campbell 1992) to reduce wasp numbers.

The larvae of an undetermined moth (Lepidoptera: Coleophidae) predate on *Austrotachardia* sp., spinning a protective web under which they feed. A dark brown beetle, *Trogoderma* sp., (Coleoptera: Dermestidae), a black and white moth, *Macrobathra* sp. (Lepidoptera: Cosmopterigidae) and an unidentified case moth (Lepidoptera: Psychidae), are often present; their larvae are suspected of feeding on crawlers, females, dead scales or detritus.

Despite these predators and parasites, populations of *Austrotachardia* sp. and *Paratachardina* sp. increased markedly from 1988 to 1993 and the transfer of scales from infected plants to new plants was successful.

Ants

Ants observed tending *Austrotachardia* sp. included *Iridomyrmex rufoniger* (Lowne), *I. purpureus* (F. Smith), *Anonychomyra itinerans* (Lowne) and *Camponotus* sp. (Hymenoptera: Formicidae); the first three in daylight and the latter at night. A healthy infestation of scale insects is often covered by a mass of ants feeding on honeydew. The repetitive procedure for collecting honeydew was for the ant to shake a small bulb-shaped mass produced by the female scale; in response a large bubble was produced which the ant duly consumed.

It is possible that large numbers of ants could assist *Austrotachardia* sp. and *Paratachardina* sp. by discouraging predators and parasitoid, by preventing oviposition, eating eggs or attacking larvae or adults of predators and parasitoids (Buckley 1987). For example, attendance by ants raised the survival rate of tuliptree scales in Pennsylvania from 8% to 47% (Burns 1973) and defence of the scale *Toumeyella numismaticum* by *Formica obscuripes* was necessary for its survival (Bradley 1973). On the other hand, ants did not reduce the mortality of *Pulvinarius mesembryanthemi* or *Pseudococcus macrozamiae* in Western Australia despite the presence of significant numbers of predators and parasitoids (Majer 1982, Collins and Scott 1982, Dolva and Scott 1982). Although ants assist homopterans by carrying them (e.g., *Pseudococcus* spp.) to new habitats (Strickland 1958, Way 1963) we have not observed such assistance for *Austrotachardia* sp. and *Paratachardina* sp.

Other insects and animals

Honeydew from *Austrotachardia* sp. and *Paratachardina* sp. attracted honeybees, ladybird beetles, hoverflies, wasps and blowflies which did not harm the scale insects. However, rabbits, hares, sheep and goats often ate the scale insects which was most detrimental when a new colony was establishing.

Fungi

Austrotachardia sp. and *Paratachardina* sp. are commonly covered by the black sooty mould, *Capnodium walteri* (Ascomycotina), which does not seem to harm them because large numbers of crawlers are produced from completely covered females.

Distribution of the scale insects

No detailed survey has been carried out on the distribution of *Austrotachardia* sp. and *Paratachardina* sp. in New South Wales. However *Austrotachardia* sp. has been observed on *Cassinia* spp. between Gulgong and Uarbry, north of Coolah, throughout the Pilliga scrub, Bathurst, Hill End and in a 40 kilometre arc north of Orange. *Paratachardina* sp. has been observed in the Tamworth, Armidale, Inverell, Tenterfield, Glen Innes, Bingara, Barraba, Bundarra, Manilla and Merriwa districts.

Natural dispersion of the scale insects

Natural dispersal of *Austrotachardia* sp. and *Paratachardina* sp. relies on crawlers walking or being transported by wind, water, insects or animals. Observations in the laboratory showed that crawlers walk at 2 m h^{-1} across a flat surface. They exhibit negative geotaxis, phototaxis, or a combination of both, crawling upwards on plants in the field and to the top of cuttings standing upright in the laboratory; if the cutting is horizontal the crawlers walk across the area in front, spreading out to cover the full width of the area presented to them. As each 2 mm diameter female produces about 300 crawlers, and with 30 females per cm on a heavily infested stem 2 cm in diameter, the maximum reproduction rate is about 9000 crawlers per cm. In the field, crawlers establish most successfully in cracks in the bark on new stems.

Natural dispersal of *Austrotachardia* sp. was studied by deliberately infecting 12 previously uninfected plants at Orange in December 1990. The resultant females produced crawlers in December 1991 which further infected the 12 plants but also moved to adjacent plants. By November 1992, 43 of the 96 adjacent plants were infected with *Austrotachardia* sp., 91% on the main stem or on branches within 20 cm of the ground, indicating that crawlers walked across the ground and to the new plants. Seventy-six percent of the newly infected plants were within 2 m of a previously infected plant; the greatest distance crawlers spread was 6 m. No *Austrotachardia* sp. were found more than 20 cm above ground level on new plants indicating that wind was not responsible for their spread. Scale insects are often spread by wind, for example, in 11 years *E. orariensis* was carried 140 km north, 46 km east and 53 km south of a large infestation in New Zealand by prevailing winds (Hoy 1961). The failure of wind to spread *Austrotachardia* sp. in the above observations may have been due to the small infestation supplying limited numbers of crawlers and the short time over which spread was measured.

Deliberate transfer of the scale insects by humans

If we are to rely on nature to spread native scale insects, then the possibility of controlling *Cassinia* spp. is low because of the deleterious effects of native predators and parasitoids. But, if humans aid the spread of scales and enemies are controlled, the chances of success could be improved. Scale insects have been spread by humans in India (Froggatt 1899), New Zealand (Hoy 1961) and Australia (Hosking *et al.* 1988, Campbell and Wykes 1992). In the latter case P.J. Wykes spread cuttings infected with *Austrotachardia* sp. through his property "Daydawn", Kerrs Creek from 1985 to 1992 which resulted in the control of 70% of the *C. arcuata* on the property (Table 1). The role of natural dispersal in this example is not known but it is thought to have been important particularly in population increases of *Austrotachardia* sp. before deliberate transfer began in 1985.

To determine the best time to transfer *Austrotachardia* sp. to new plants, cuttings were taken weekly from Kerrs Creek between October and December 1991, stored dry in a laboratory at room temperature and observed. Crawlers emerged from late November to late December. There was no external indication of impending emergence; it was best ascertained through dissecting females and tracing embryo development. Cuttings that produced the most crawlers were those taken 10 to 30 days before emergence. Taking cuttings 30 days before emergence appeared to hasten emergence in response to desiccation of the cutting. In eight days at Orange, large cuttings (12 cm long × 1.2 cm diameter) of *C. arcuata* stems lost 70% and small cuttings (3 cm long × 0.3 cm diameter) lost 89% of their moisture in a laboratory at room temperature. It would thus appear that female scales survive on cuttings for up to 30 days, mainly on moisture stored in their bodies.

In summers from 1990/91 to 1993/94 deliberate transfer of scale insects took place in New South Wales by supplying *Austrotachardia* sp. infected cuttings from Kerrs Creek to 400 landholders; cuttings were taken approximately 10 days before estimated crawler emergence. *Paratachardina* sp. infected cuttings were dispersed to landholders in north-western New South Wales from infestations in the Manilla and Barraba districts. Many landholders transferred the cuttings more than 300 km in one day, thus greatly accelerating the rate of spread over that of natural dispersion. Transfer of cuttings is best done in a dry, cool box as moisture and high temperature adversely affect the scale insects. Crawlers in the laboratory at Orange existed without food for up to 16 days at 2 – 5°C, but died within two days at 32°C.

Austrotachardia sp. were transferred by tying 10 cm long infected cuttings to uninfected plants 0.5 to 1 m above the ground (Campbell 1992). By taking cuttings 10 to 30 days before crawler emergence at Kerrs Creek, 50% of new plants were infected at Orange. To facilitate control of *Cassinia* spp. on their properties, landholders need to transfer cuttings annually until most plants are infected. The insects could be obtained from introduced cuttings or from recently established colonies on their own properties. Some landholders who received cuttings in 1990 and 1991 recognized that the scale was already present on *Cassinia* spp. on their properties and subsequent transfers were made from within their properties. Using cuttings to spread scale insects restricts the time of transfer to the 30 days before emergence. One way to extend the transfer period is to transplant infected plants which allows the scale insects to be spread at any time of the year. Transfer of cuttings in large infestations of *Cassinia* spp. could be facilitated by aerial application; in New Zealand cuttings infected with *E. orariensis* were distributed by aircraft with successful results (Hoy 1961).

Table 1. Cumulative amount of *Cassinia* spp. killed annually by *Austrotachardia* sp. on "Daydawn", Kerrs Creek, New South Wales.

Year	Hectares of dead *Cassinia* spp.	% of property with dead *Cassinia* spp.
1985-87	0	0
1988	3	1
1989	18	5
1990	172	47
1991	255	70
1992	255	70

Effectiveness of scales in killing *Cassinia* spp.

Although *Austrotachardia* sp. had killed small areas of *Cassinia* spp. on the central tablelands since 1979, it was not until 1988 that large areas were killed. Even then the insect failed to spread in some situations after killing small patches. Thus the effectiveness of *Austrotachardia* sp. at Kerrs Creek (Table 1) could be due to a particularly lethal strain. As scale insects kill plants by sucking out nutrients, transmitting viruses, rickettsia, bacteria or mycoplasma, or injecting toxins (O'Brien *et al.* 1991), it is possible that successful strains may transmit toxic substances that unsuccessful strains do not.

It is also possible that the habitat at Kerrs Creek may provide the nutrient status in *C. arcuata* that increases its susceptibility to scale insects (McClure 1985) or that the ecotype of *C. arcuata* is preferred by the scales to other ecotypes in the central tablelands. Not only can ecotypes affect homopteran preference but individual plants, within the one ecotype, can differ in their susceptibility to scale insects (Edmunds and Alstad 1978).

Host specificity of *Austrotachardia* sp.

Although *Austrotachardia* spp. have a wide host range, the *Austrotachardia* sp. referred to in this paper has only been found on *C. arcuata, C. quinquefaria* and *C. longifolia*, despite access to a varied plant community over thousands of hectares in the Kerrs Creek district.

In a laboratory experiment conducted over seven days at Orange, *Austrotachardia* sp. crawlers were allowed a choice of 10 cm cuttings from eight plant species spaced at random in four replications 10 cm apart. This resulted in means of 24 and 16 nymphs per cutting on *C. arcuata* and *C. longifolia* respectively, but none on *Acacia concurrens* Pedley (Fabaceae), *Eucalyptus albens* Benth. (Myrtaceae), *Hypericum perforatum* L. (Clusiaceae), *Pinus radiata* D. Don (Pinaceae), *Rosa rubiginosa* L. (Rosaceae) and *Rubus fruticosus* L. (Rosaceae). The plant species used were chosen because they are trees or shrubs that commonly

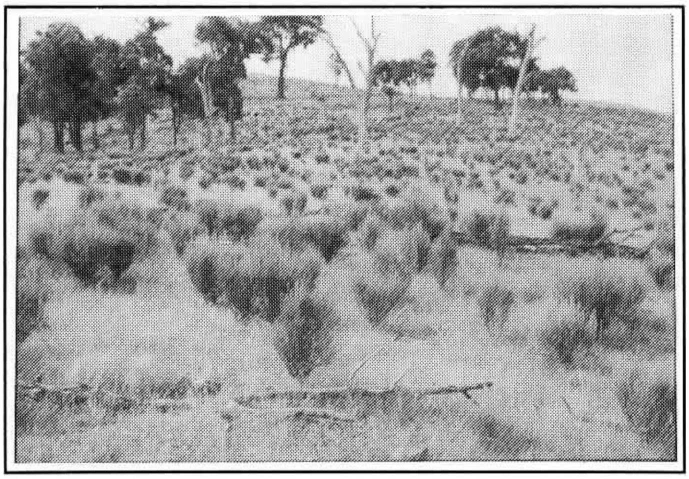

Figure 4. *Cassinia arcuata* infesting land near Boorowa.

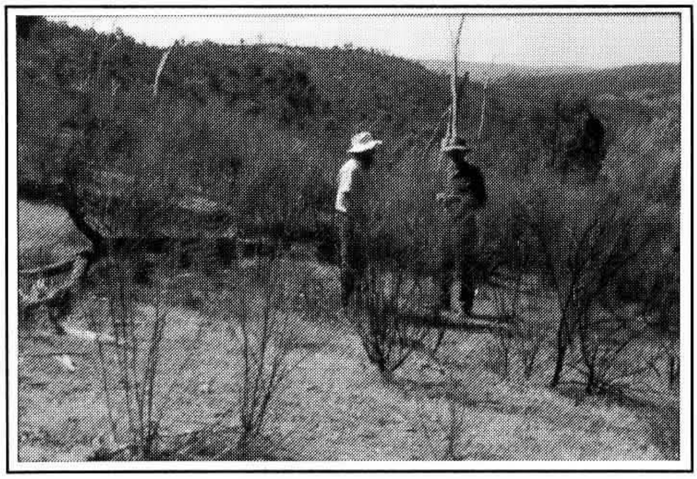

Figure 5. A dense stand of *Cassinia arcuata* killed by *Austrotachardia* sp. near Kerrs Creek.

occur in areas infested by *Cassinia* spp.

Paratachardina sp. has only been observed on *C. laevis* and *C. quinquefaria* in northern New South Wales, despite access to many other plant species.

Other insects that attack *Cassinia* spp.

In the central tablelands of New South Wales the scale *Chionaspis* sp. (Hemiptera: Diaspididae) occurs on *C. arcuata* with or without *Austrotachardia* sp. At Kerrs Creek crawlers observed in October and January develop into brown nymphs and reside in cracks in the bark. Later, the females produce a soft white cover under which she lays her eggs. The male is a small red fly similar to the male of *Austrotachardia* sp. The time taken for the life cycle has not been determined. *Chionaspis* sp. does not appear to kill *C. arcuata*.

A dark brown scale, *Coccus* sp. (Hemiptera: Coccidae), has killed a few plants of *C. arcuata* near Orange and *C. longifolia* near Crookwell.

A native pine looper *Chlenias* sp. (Lepidoptera: Geometridae) defoliated 100 ha of *C. arcuata* near Boorowa in the southern tablelands (Figure 4) in 1989 and killed a few plants, but is not considered a possible bio-control agent because it also attacks *Pinus radiata*.

Larvae of a jewel beetle (Coleoptera: Buprestidae) have killed small areas of *C. arcuata* on the central tablelands but its effectiveness as a bio-control agent has not been studied.

Replacement of *Cassinia* spp. killed by scale

At Kerrs Creek, native perennial grasses and *Acacia dealbata* replaced large areas of *C. arcuata* killed by *Austrotachardia* sp. (Figure 5). An 800 m^2 experimental area completely infested with *C. arcuata* in 1988, was partly replaced by *Danthonia* spp., and some other useful species in 1991 and 1992 (Table 2). Few *C. arcuata* seedlings (0.01 m^{-2}) reinfested after the death of the mature plants because the seedlings were killed by *Austrotachardia* sp. This contrasts with other control methods where heavy reinfestations of seedlings occur (Campbell *et al.* 1990). For example, after slashing a dense infestation of *C. arcuata* in autumn 1989 at Mullion Creek, New South Wales, 170 seedlings per square metre reinfested by September 1989. Most of these seedlings, and those of subsequent reinfestations in 1990 and 1991, died due to competition for moisture and nutrients, but sufficient survived to ensure complete reinfestation (Table 3).

In north-western New South Wales, observations on two properties where *Paratachardina* sp. had killed *C. laevis* revealed that red grass (*Bothriochloa macra*) replaced the weed at Bingara, but sticky daisy bush (*Olearia elliptica*) became dominant at Barraba, due to a large rabbit

Table 3. Regeneration of *C. arcuata* from seed in the soil, in winters 1989, 1990 and 1991 and subsequent decline in plant numbers, after mature plants were killed by slashing in April 1989 at Mullion Creek, New South Wales.

Observation date	Plants[A] (m^{-2}) establishing in					
	1989	(s.d.[B])	1990	(s.d.)	1991	(s.d.)
September 1989	170	(1.8)				
May 1990	23	(1.5)	62	(1.6)		
October 1990	19	(1.4)	24	(1.5)		
June 1991	8	(1.3)	2	(1.2)	47	(1.5)
January 1992	8	(1.3)	1	(1.1)	35	(1.5)
June 1992	7	(1.3)	1	(1.1)	22	(1.5)
June 1993	6	(1.3)	1	(1.1)	10	(1.4)

[A] measured in a 5 ha paddock on 48 × 0.25 m^2 randomly selected permanent quadrats.
[B] standard deviation.

Table 2. Botanical composition before and after *C. arcuata* was killed by *Austrotachardia* sp. in 1988–90 at Kerrs Creek, New South Wales.

Spring	Ground cover (%)						
	Danthonia spp.	*Microlaema stipoides* and other perennial grasses	Annual legumes and grasses	Broadleaved plants	*Cassinia arcuata*	Moss and litter	Bare ground
1987	9	2	7	8	53	2	19
1991	34	3	10	7	<1	23	23
1992	42	6	3	8	<1	30	11

population. On both properties *C. laevis* did not reinfest.

These investigations indicate that *Austrotachardia* sp. and *Paratachardina* sp. are capable of controlling infestations of *Cassinia* spp. However, this control must be augmented by a program to re-establish and maintain a pasture of perennial grasses and annual legumes to prevent reinfestation by *Cassinia* spp in case all the scale insects die as a result of killing all the host *Cassinia* spp.

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