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SPECIAL FEATURE: REVIEW

Alien pests threatening biodiversity of forest ecosystems

Introduced *Eucalyptus* psyllids in Brazil

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Abstract In the last 10 years, four species of psyllid were detected in Brazil on eucalypts: *Ctenarytaina spatulata* in 1994, *Blastopsylla occidentalis* in 1997, *Ctenarytaina eucalypti* in 1998 and *Glycaspis brimblecombei* in 2003. The latter two are serious pests in several countries. In Brazil, *G. brimblecombei* caused significant damage to the eucalypt plantations in the first years of its introduction. Now this pest is under control due to the programmes of integrated pest management, where the parasitoid is the principal control agent. The four eucalypt psyllid species introduced into Brazil are presented with information on distribution, hosts, biology and control.

Keywords *Blastopsylla occidentalis* · *Ctenarytaina eucalypti* · *Ctenarytaina spatulata* · Eucalypt pests · *Glycaspis brimblecombei*

Introduction

Many eucalypt species find suitable weather and environmental conditions to develop in Brazil. Today eucalypts are commercially grown on a large scale, covering an estimated surface of over 3 million hectares. The native myrtaceous trees of Brazil host an abundant fauna of phytophages, some of which attack eucalypts. There is also an increasing number of exotic pests such as the Australian eucalypt psyllids.

Psyllids or jumping plant-lice (Hemiptera: Psylloidea) are tiny sap-sucking insects of 1–10 mm body length resembling minute cicadas (Hodkinson 1988; Burckhardt 1994). World-wide some 3,500 species have been described, most of which develop on woody dicotyledons. Larvae of many species, such as *Ctenarytaina eucalypti*, are free-living, sometimes covered in waxy secretions or sitting in the buds of leaves or flowers. Some psyllid species induce galls on their host plants (Hodkinson 1984; Burckhardt 2005) or build waxy coverings called lerps (Hollis 2004). Depending on the climatic conditions, psyllid species of the temperate regions tend to be univoltine or bivoltine, and those of the tropics, as in Brazil, polyvoltine, with several overlapping generations per year (Burckhardt 1994; Hollis 2004).

The tribe Spondyliaspidini (Psyllidae) is almost exclusively restricted to Australia, and most of the constituent species develop on *Eucalyptus* and other Myrtaceae (Burckhardt 1991). Unsurprisingly, several species of Australian Spondyliaspidini have been introduced into other continents where eucalypts are planted on a large scale (Taylor 1997; Hollis 2004).

In Brazil, the first spondyliaspidine, a *Ctenarytaina* species, was observed in 1994 in *Eucalyptus grandis* plantations in Paraná State (Iede et al. 1997). These insects were identified and described by Taylor (1997) as *Ctenarytaina spatulata* Taylor (Burckhardt et al. 1999). *C. spatulata* develops on several eucalypt species. In Brazil it prefers the most widely planted eucalypt species, *E. grandis*.

In Brazil another three species infesting eucalypts have been discovered in the last 10 years: *Blastopsylla occidentalis* in 1997, *C. eucalypti* in 1998 and *Glycapis brimblecombei* in 1998 (Maschio et al. 1997; Burckhardt et al. 1999).

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Ctenarytaina eucalypti can cause up to 30% of production loss, as observed by Dahlsten et al. (1998b) in California's commercial plantations of *Eucalyptus pulverulenta*.

Due to a large, almost continuous surface planted with eucalypts, the psyllids could easily spread and are found today in nearly every eucalypt plantation.

The eucalypt psyllids in Brazil

Ctenarytaina spatulata Taylor

Ctenarytaina spatulata Taylor, 1997, originates from southeast Australia, and has been introduced into New Zealand, the United States of America (California), Uruguay, Brazil, Portugal and Spain (Burckhardt et al. 1999; Santana et al. 1999; Hollis 2004; Valente et al. 2004). It was observed for the first time in Brazil in Arapoti–Paraná in 1994, in an *E. grandis* plantation (Burckhardt et al. 1999). It is found now commonly in São Paulo, Paraná, Santa Catarina and Rio Grande do Sul.

The adults of *C. spatulata* (Fig. 1a) are yellowish or orange with dark spots or dark brown stripes. The forewings are transparent and yellowish with slightly darker veins.

The adults of *C. spatulata* remain most of the time on the leaves and new apical shoots, where they feed and reproduce. The females lay their eggs (Fig. 1b, c) on the newly growing leaf axils (Santana and Zanol 2006).

All five larval instars have a dorso-ventrally flattened body. They live in colonies and feed on young plants or shoots. They secrete large amounts of honeydew, which is secreted as small wax-covered globules, together with a large amount of flocculent waxy secretions along the sides of the abdomen spread out all over the colony (Santana and Zanol 2005). Honeydew and waxy secretions harm the development of the young plants, particularly in the first 2 years of planting (Collet 2001). In the first larval instar the body is entirely yellow, except for the small red eyes (Fig. 1d). In the final instar larva, the length of the body is 1.40–1.43 mm. The body is brown to yellowish with brown patches (Fig. 1e). The caudal plate bears five lanceolate setae on each side of the anus. The wing buds are well-developed; forewing buds lack a humeral lobe; their fore margin lies posterior to the posterior eye margin (Taylor 1997; Santana and Zanol 2005).

Ctenarytaina spatulata is associated with several *Eucalyptus* spp., in particular *E. grandis*, *E. saligna*, *E. robusta*, *E. pellita*, *E. resinifera* and *E. urophylla* (Santana 2003). It has also been observed in lower numbers on *E. deani*, *E. saligna*, *E. tereticornis*, *E. microcorys*, *E. viminalis*, *E. camadulsensis*, *E. alba* and *E. nitens* (Santana 2003). Among the species of *Corymbia*, only eggs of *C. spatulata* have been observed on adult leaves of *C. citriodora*. Neither eggs nor larvae of *C. spatulata* were observed on native Myrtaceae (Santana 2003).

Valente et al. (2004) found *C. spatulata* mostly on *E. globulus*, the main eucalypt species planted in the Iberian Peninsula. It is also a major host of *C. spatulata* in California (Brennan et al. 2001). They also observed large populations of the psyllid on *E. nitens*, *E. dalrympleana* and *E. maidenii*.

Other species mentioned in the literature as hosts are *E. leucoxylon*, *E. mannifera maculosa*, *E. pauciflora*, *E. longifolia*, *E. rodwayi*, *E. ovata*, *E. nitida* (Taylor 1997), *E. amplifolia*, *E. dunnii*, *E. robusta*, *E. rostrata* and *E. tereticornis* (Burckhardt et al. 1999).

In Brazil, this species has many generations per year, showing a higher number of individuals during the cold and dry months.

The damage of this pest was observed on *E. grandis* in Paraná State and hybrids of *E. grandis* × *E. urophylla* in São Paulo, with symptoms like sooty moulds on the leaves and tips, dieback, loss of apical dominance, super sprout and decrease of growth (Santana et al. 2005). *C. spatulata* completes its life cycle at temperatures of about 20°C, from egg to adult in approximately 45 days (Santana and Zanol 2006). In São Paulo and Paraná, all life stages of the species can be observed during the entire year (Santana 2003).

The first damage by *C. spatulata* to *E. grandis* is caused by oviposition (Santana et al. 2005). A small black spot appears where the egg is inserted (Fig. 1f), which may increase and lead to withering of the terminal buds. The larvae secrete large amounts of honeydew, i.e. excrements rich in sugar, that accumulates on leaves and buds, allowing the growth of sooty moulds (Fig. 1g) and phytopathogenic fungi.

The successive piercing of the substrate and the extraction of plant sap cause deformations and curling of the leaf, reducing the leaf surface. High populations weaken the plant further by the extraction of plant sap, causing the death of the terminal buds, the loss of apical dominance and the super sprout of the lateral buds (similar to formation of witches' brooms by excessive growth of lateral buds) (Cadahia 1980; Zondag 1982; Meza and Baldini 2001; Santana et al. 2005).

Furthermore, the sucking of *C. spatulata* can reduce the growth of the stem diameter and of the internodes, resulting in more branches on the stem and thus rendering the wood of the stem more fragile (Santana et al. 2005).

The damage caused by *C. spatulata* in Brazil was estimated in a greenhouse (Santana et al. 1999). By studying the nutritional stress, the authors observed that there is an interaction between the insects and Mg deficit. Both factors together may stop growth and production of biomass, in addition to affecting root development.

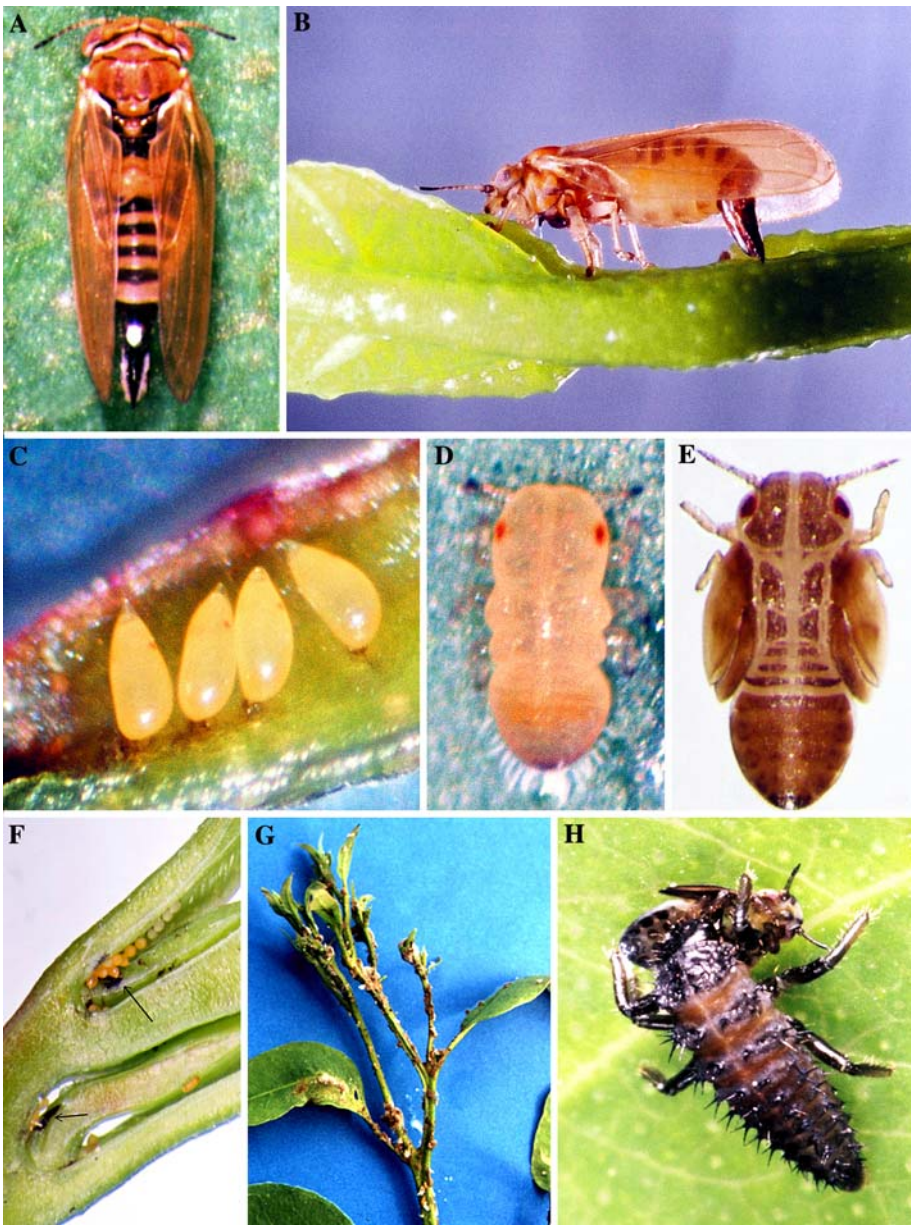

Fig. 1 *Ctenarytaina spatulata*. **a** Adult. **b** Female laying eggs. **c** Eggs. **d** First instar larva. **e** Fifth instar larva. **f** Damage of egg laying. **g** Damage on eucalypt shoot. **h** Coccinellidae larva feeding on *C. spatulata* larva

The research done in the greenhouse and the field shows that *C. spatulata* appeared in all samples, with 100% occurrence of larvae and eggs. Its presence was observed during all months of the year, in every stage, typical for a polyvoltine life cycle. It also shows a population peak in the colder months with low rainfall (Santana et al. 2005).

Water stress is one of the ambiental factors that may improve the development of the psyllid population (White 1969) because the nitrogen concentration in the plants is higher. Santana et al. (2003a) simulated water stress in *E. grandis* plants, with and without the presence of *C. spatulata*, and noticed that the insects may cause a 20% loss of height growth in *E. grandis*. The combination of water stress and presence of the insects may cause large damage.

The overlapping generations of the psyllids make chemical control even harder, because this requires successive spraying of insecticides. This increases production costs and requires additional work, which makes the definition of a management strategy recommendable. Usually, their control is carried out through an integrated pest management programme (IPM), mainly biological control using predators (Fig. 1h) or parasitoids.

The following potential natural enemies of *C. spatulata* were observed: *Coccinella ocelligera* Crolch, *Curinus coeruleus* Mulsant, *Cycloneda pulchella* (Klug), *Cycloneda sanguinea* Linnaeus, *Eriopsis connexa* (Germar), *Harmonia axyridis* (Pallas), *Hyppodamia convergens* (Guérin), *Hyperaspis* sp., *Scymnus* (*Pullus*) sp. and *Olla v-nigrum*

(Mulsant) (Coleoptera: Coccinellidae) (Fig. 1g), *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae); *Allograpta exotica* (Wiedemann), *Pseudodorus clavatus* (Fabricius) and *Syrphus phaeostigma* Wiedemann (Diptera: Syrphidae), as well as spiders and the fungus *Verticilium lecanii* (Santana 2003).

Ctenarytaina eucalypti (Maskell) (blue-gum psyllid)

This is a species from southeast Australia that has been introduced into many countries all over the world. The first mention of *C. eucalypti* from Brazil is by Burckhardt et al. (1999) who reported it from Colombo to Paraná on seedlings of *E. dunnii*. Later it has also been detected in São Paulo, Santa Catarina and Rio Grande do Sul. Its geographical distribution, apart from its origin in Australia, includes Bolivia, Brazil, Chile, Colombia, Eire, France, Germany, Italy, New Zealand, Papua New Guinea, Portugal, South Africa, Spain, Sri Lanka, Switzerland, UK, Uruguay and USA (Burckhardt 1998; Hodkinson 1999; Durán and Urrutia 2001; Burckhardt and Mühlethaler 2003).

The adults of *C. eucalypti* (Fig. 2a) measure from 1.5 to 2.0 mm and have dirty whitish fore-wings with contrasting brown veins and clear membrane that are normally folded over the body (Burckhardt et al. 1999). The body colour is usually dark brown to black (Burckhardt et al. 1999), with darker transverse stripes on the abdomen dorsally and ventrally. The antennae are yellow, with dark apices of the individual segments. The compound eyes are dark brown and prominent. The legs are dark yellow. The female proctiger is longer and more slender in comparison with *E. spatulata*, with relatively acute apico-lateral peg setae and strongly curved valvula ventralis (Burckhardt et al. 1999).

The first instar larvae are light yellow with red eyes and thick legs. There are thick setae along the margin of the caudal plate (Zondag 1982). The last instar larvae are yellow with dark patches. The eyes, antennae and wing buds are reddish-brown.

The female lays 20–100 eggs, normally in groups, on the leaf buds and in the axils of young leaves in nurseries or on young trees. Eggs are also laid in small fissures between the bud and the leaf pedicel. Several females may contribute to one egg mass. In summer, the incubation lasts about 1 week, whereas it is longer in the cold periods (Cadahia 1980).

In Brazil, the development is continuous throughout the year, with several overlapping generations. All developmental stages have been observed to occur together at any particular time in the same population. All five larval instars feed on plant sap. They excrete large amounts of honeydew and white waxy secretions (Fig. 2b).

The damage caused by the psyllid on its host can be direct by sucking the sap, or indirect by injecting toxic substances in its saliva or transmitting viruses. Hodkinson (1999) described the damage of *C. eucalypti* that included direct effects of psyllid feeding including severe shoot dieback, leaf curl and leaf discolouration. A further factor damaging the plants is growth of sooty moulds growing on the honeydew, which is secreted in large amounts.

Ctenarytaina eucalypti is considered a pest with economical importance in some countries where it has been introduced. In Brazil it has been observed on many species of *Eucalyptus* such as *E. globulus*, *E. maidenii*, *E. bicostata*, *E. dunnii* and *E. nitens*. Of particular importance is *E. dunnii*, covering large surfaces in the South of Brazil, where a high psyllid attack was observed (Santana et al. 1999).

Azevedo and Figo (1979) list the following natural enemies of *C. eucalypti* in Portugal: *Syrphocotonus abdominator* (Bridgeman) (Hymenoptera: Ichneumonidae); *Haematopota ocelligera* Kröber (Diptera: Tabanidae); *Sphaerophoria scripta* (Linnaeus), *Meliscaeva cinctellus* (Zetterstedt), *Pipizella* sp., *Eumerus* sp. (Diptera: Syrphidae); and *Bradysia* sp. (Diptera: Sciaridae). The predator complex feeding on *C. eucalypti* includes hoverfly larvae, ladybirds, lacewings, anthocorids and spiders (Hodkinson 1999).

According to Zondag (1982), *C. eucalypti* is frequently attacked by a small black wasp in New Zealand. In Tasmania, a small ladybird (*Cleobora mellyi* Mulsant), used to control a beetle, has been observed feeding on larvae and eggs of psyllids, showing a high potential to control *C. eucalypti*.

In Brazil, in the end of 2000/beginning of 2001, a sudden population decrease was observed, because of the hymenopterous parasitoids which attacked *C. eucalypti*. The parasitoid was identified as *Psyllaephagus* sp. (Hymenoptera: Encyrtidae), the same genus which was introduced into many European and American countries for the biological control of *C. eucalypti* (Santana et al. 2002).

The overlapping generations make chemical control difficult as the psyllids always return to the plants in the treated areas, which necessitates repeated applications.

Blastopsylla occidentalis Taylor

Blastopsylla occidentalis Taylor originates from West and South Australia. Its geographical distribution is: Argentina, Brazil, Chile, Hong Kong, Kenia, Mexico, New Zealand, Paraguay and USA (Hodkinson 1991; Burckhardt et al. 1999; Burckhardt and Elgueta 2000; Hollis 2004; Bouvet et al. 2005).

Fig. 2 Eucalypt psyllids. **a** *Ctenarytaina eucalypti* adult. **b** Colony of *C. eucalypti*. **c** *Blastopsylla occidentalis* adult. **d** Larvae of *B. occidentalis*. **e** Syrphidae larva feeding on *B. occidentalis* larva. **f** *Glycaspis brimblecombei* adult. **g** Eggs of *G. brimblecombei*. **h** Larvae of *G. brimblecombei*. **i** Colony of *G. brimblecombei*. **j** *Eucalyptus* clones resistant (*left*) and susceptible (*right*) to *G. brimblecombei* in Minas Gerais state. **k** and **l** Chrysopidae larvae feeding on *G. brimblecombei* larvae

The adults are small insects, measuring 1.5–2.0 mm. They have a yellow head and thorax with dark pattern; the head is as large as the thorax, and strongly inclined relative to the longitudinal body axis, with short antennae (Fig. 2c). The fore-wings have brown veins and a grey membrane. The male terminalia are yellow, those of the females are dark brown with yellow base of the subgenital plate. The males are usually yellow, the females are darker coloured. The last instar larvae (Fig. 2d) are yellow with dark brown antennal tip, lacking humeral lobe on fore wing buds or specialized setae, and with nine-segmented antennae (Burckhardt and Elgueta 2000; Meza and Baldini 2001; Durán and Urrutia 2001).

Blastopsylla differs from other Spondyliaspidini by the very long posterior lobes on the basal segment of the male proctiger and often in the presence of a single spur on the metabasitarsus (Burckhardt and Elgueta 2000). *B. occidentalis* can be easily separated from *Ctenarytaina* species by the lack of an outer apical comb of bristles on the mesotibia, and the apically curved vein Rs in the fore-wings (Taylor 1990; Burckhardt et al. 1999; Burckhardt and Elgueta 2000). Within *Blastopsylla*, *B. occidentalis* is similar to *B. moorei*, from which it differs in the shape of the apical portion of the aedeagus—which is spherical rather than elongate and weakly curved as in *B. moorei*—and the fewer black setae on the apical portion on the inner surface of the paramere and the 4–6 dark sclerotised setae

which form a line along the hind margin, rather than a group of 5–7 as in *B. moorei* (Taylor 1985).

The females of *B. occidentalis* lay the eggs on the shoots, the leaf axils, on small branches and young leaves. The larvae secrete large amounts of small wax-covered globules containing honeydew and copious white flocculence, which enhances growth of soothy mould (Taylor 1985; Meza and Baldini 2001). The wax often sticks to the end of the larval abdomen.

Blastopsylla occidentalis was observed for the first time in Brazil in Goiás in 1997, on hybrids of *E. urophylla* and *E. grandis* (Burckhardt et al. 1999). Other hosts are *E. microtheca*, *E. rudis*, *E. gomphocephala*, *E. camaldulensis*, *E. microneura*, *E. nicholsii*, *E. spathulata*, *E. forrestiana*, *E. oleosa*, *E. rudis*, *E. tereticornis*, *E. saligna*, *E. globulus* and *E. nicholii* (Meza and Baldini 2001; Hollis 2004).

Contrary to the two *Ctenarytaina* spp., *B. occidentalis* occurs in Central Brazil where the dry season is longer than in Southern Brazil, with over 4 months without rain.

In Brazil, the natural enemies of *B. occidentalis* are the same as those of *C. spatulata*, including Syrphidae (Fig. 2e), Dolichopodidae (both Diptera), Chrysopidae (Neuroptera) and Coccinellidae (Coleoptera) (unpublished data).

Glycaspis brimblecombei Moore

Glycaspis brimblecombei (Fig. 2f), the red gum lerp psyllid, has an Australian origin and was introduced into USA in June 1998 (Brennan et al. 1999). In 2000 it was observed in Mexico, in Chile in 2002 (Dahlsten 2003), in Brazil in 2003 and in Argentina in 2004 (Bouvet et al. 2005).

In Brazil, *G. brimblecombei* was detected for the first time in São Paulo in June 2003. Now it is wide-spread in Brazil where its host is planted.

The eggs are laid in groups, usually in rows or circles (Fig. 2g). The larvae of *G. brimblecombei* (Fig. 2h) differ from those of the other three species discussed above, as they are not free-living. They live under a shield of wax called lerp (Fig. 2i).

Glycaspis brimblecombei develops on various *Eucalyptus* spp., especially *E. camaldulensis* and *E. tereticornis* but also on *E. blakelyi*, *E. brassiana*, *E. bridgesiana*, *E. camphora*, *E. dealbata*, *E. diversicolor*, *E. globulus*, *E. mannifera*, *E. mannifera maculosa*, *E. nitens* and *E. sideroxylon* (Brennan et al. 2001; Hollis 2004).

The damage created by this species is similar to that made by the other species discussed above, but *G. brimblecombei* is more aggressive. There are reports of outbreaks in many American countries where the species caused the death of the trees, resulting in large production losses (Fig. 2j).

Considering the fast dispersal and establishment of this psyllid, eradication methods are not effective, and chemical control is expensive and not very efficient. The easy adaptation to the Brazilian climatic conditions, the fast dispersal and the large areas planted with eucalypts suggest that this psyllid should be controlled by a programme of integrated pest management, based on the management of the pests and their interaction with the ambient and other organisms.

The decrease of the *G. brimblecombei* population observed in São Paulo at the end of spring/beginning of summer in 2003 was attributed to the rainfall, and certainly also occurred because of the presence of parasitoids and predators (Fig. 2k, l). The parasitoid *Psyllaephagus bliteus* Riek (Hymenoptera: Encyrtidae) was detected in the year of introduction of *G. brimblecombei* into São Paulo State, Paraná and Minas Gerais. With the detection of this parasitoid it is expected that the population of the psyllid will also stabilize (Santana et al. 2003b). Now the management of the pest and its natural enemies is established.

Management and control

The monitoring of the psyllids can be done by installing sticky traps, or by manual collections. These should be done continuously and in regular intervals. Yellow sticky traps are the best way to monitor psyllids infesting eucalypts. Adult psyllids and psyllid parasites are attracted by the yellow colour and get stuck to the surface. The traps should be inspected once a week, and the number of adult psyllids and their parasites should be counted and recorded (Paine et al. 2007).

Adult psyllids can also be monitored by shaking or beating plants over a collecting sheet to knock them onto the collecting surface, where they can be easily seen and counted. The sample should be taken about once a week during the season with new plant growth when adult psyllids are expected (Dreistadt and Dahlsten 2007).

Through the monitoring it is possible to determine the moment of population peak, the occurrence of natural enemies and other factors that affect the insect population.

In the IPM, the sampling for monitoring the development of the pests is one of the main components, which uses different techniques to quantify the population and predict outbreaks of the pest. In addition, it can be also used to determine the geographic distribution of the pest, to detect a risk on the area before any damage actually occurs, and to determine the effectiveness of the control treatment.

A biological control programme of *C. eucalypti* was supported by the UC IPM project in California. The parasitoid *Psyllaephagus pilosus* was collected in Australia, reared at UC Berkeley and released in California. The

parasitoids quickly established in the release sites, and sampling in 1994 revealed parasitism rates of 50–100%. By 1995, the parasitoids had become broadly distributed throughout many parts of the state. An economic analysis of the benefit to the cut-foliage industry alone indicated that the biological control programme generated a benefit cost ratio ranging from a minimum of 9:1 to a maximum of 24:1, based solely on elimination of pesticide treatments (Dahlsten et al. 1998a).

A similar IPM programme was adopted to manage the populations of the lerp psyllid *G. brimblecombei* in California (Paine et al. 2007).

In Brazil, the eucalypt psyllids are attacked by many predators including the ladybird beetles (*C. sanguinea* (Linnaeus), *O. v-nigrum* Casey, *Hippodamia convergens* Guérin-Méneville, *E. connexa* Germar and *H. axyridis* (Pallas), the green lacewings (*Chrysoperla* spp.), syrphid flies, pirate bugs (*Anthocoris* sp.) and spiders (Santana 2003; Santana et al. 2004). Although predators do not provide complete biological control, they can reduce psyllid abundance. Whenever possible, management efforts should be selected that have less adverse effects on these beneficial species (Paine et al. 2007).

Except for the red gum lerp psyllid, the eucalypt psyllids in Brazil require no management; even when populations are abundant, plants can tolerate substantial feeding, and psyllid populations will decline naturally. The blue gum psyllid is under effective biological control, and requires no management except to conserve natural enemies. If control is necessary, an integrated programme should be used incorporating appropriate plant care, conservation of natural enemies, and where feasible the use of least-toxic insecticides.

Tolerance varies among eucalypt species and location of plants. Prevention of planting susceptible species is the best way to avoid damage. Adult psyllids should be monitored before damage becomes evident, and the numbers of adults present should be recorded on a weekly basis. During subsequent seasons control action should be taken, if necessary, when populations or damage approach the levels that were previously identified to be intolerable. The foliar damage is primarily caused by larvae, but sprays are aimed at killing eggs or newly hatched larvae before the damage occurs, which is why the adults should be monitored. Therefore, a decision to spray should be based on the numbers of adults infesting the plants several weeks before larval damage becomes intolerable (Dreistadt et al. 2007).

In Brazil, the parasitoids of *C. eucalypti* (*P. pilosus*) and *G. brimblecombei* (*P. bliteus*) were introduced accidentally together with their hosts (Santana et al. 2002; Berti Filho et al. 2003). These parasitoids adapted and they dispersed over the whole Brazilian territory. Now they can be found in practically all the areas where the pest is present. The control of these psyllids has been done successfully using the specific parasitoids. Chemical control is not recommended because it is expensive, less efficient and may cause environmental damages (unpublished data).

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