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Artículos de investigación / Research paper

Influence of temperature and rainfall on the population dynamics of *Glycaspis brimblecombei* and *Psyllaephagus bliteus* in *Eucalyptus camaldulensis* plantations

Influencia de la temperatura y la precipitación sobre la dinámica poblacional de *Glycaspis brimblecombei* y *Psyllaephagus bliteus* en plantaciones de *Eucalyptus camaldulensis*

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Abstract: The work analyzes the effect of temperature and rainfall on the population dynamics of *Glycaspis brimblecombei* (Hemiptera: Aphalaridae) and its parasitoid *Psyllaephagus bliteus* (Hymenoptera: Encyrtidae) in a *Eucalyptus camaldulensis* (Myrtaceae) plantation in São Paulo State, Brazil. During the study 53 yellow sticky traps were installed and 53 branches were collected from a 19 ha plot of *E. camaldulensis* plantation per evaluation. A total of 42 evaluations was made from January 2006 to 2008. The number of adults of *G. brimblecombei* and *P. bliteus* caught in the yellow sticky traps as well as the immature and mummies of the parasitized psyllids on *E. camaldulensis* leaves varied with seasons. The population also varies according to the season, with a peak in the winter and decreases in the summer when temperature and rainfall increase. The *G. brimblecombei* and *P. bliteus* populations were inversely correlated with temperature and rainfall. These results are discussed as potential limitations to the establishment of the pest and its parasitoid.

Key words: Biological control. Forest Pest. Monitoring. Myrtaceae.

Resumen: El trabajo analiza el efecto de la temperatura y las precipitaciones sobre la dinámica poblacional de *Glycaspis brimblecombei* (Hemiptera: Aphalaridae) y su parasitoide *Psyllaephagus bliteus* (Hymenoptera: Encyrtidae) en una plantación de *Eucalyptus camaldulensis* (Myrtaceae) en el estado de São Paulo, Brasil. Durante el estudio fueron instaladas 53 trampas pegajosas amarillas y 53 ramas de una parcela de 19 ha de *E. camaldulensis,* fueron colectadas para evaluación. Se realizó un total de 42 evaluaciones entre enero de 2006 y de 2008. El número de adultos de *G. brimblecombei* y *P. bliteus* capturados en las trampas amarillas pegajosas así como el de inmaduros y momias de los psílidos parasitados en las hojas de *E. camaldulensis* varió con las estaciones. La población también varía según la estación, con un pico en el invierno, sin embargo, disminuye en el verano cuando la temperatura y las precipitaciones aumentan. Las poblaciones de *G. brimblecombei* y *P. bliteus* se correlacionaron inversamente con la temperatura y las precipitaciones. Estos resultados se discuten como posibles limitaciones para el establecimiento de esta plaga y su parasitoide.

Palabras clave: Control biológico. Plaga forestal. Monitoreo. Myrtaceae.

Introduction

Plantations of *Eucalyptus* spp. (Myrtaceae) and *Pinus* spp. (Pinaceae) are very important in Brazil with more than 7 million ha of land, 78.1 % and 21.9 %, respectively (Indústria Brasileira de Árvores 2016). This high extension causes the presence of a high number of native insect pests in *Eucalyptus* spp. such as leaf cutter ants (Hymenoptera: Formicidae) (Ferreira-Filho *et al*. 2015a), termites (Isoptera: Termitidae) (Wilcken *et al*. 2002) and defoliating caterpillars (Lepidoptera) (Zanuncio *et al*. 1994). However, the exotic pests such as the red gum lerp psyllid *Glycaspis brimblecombei* Moore, 1964 (Hemiptera: Aphalaridae) are which more damage on the productivity of *Eucalyptus* spp. plantations (Wilcken *et al*. 2003), mainly in water-deficit areas (Paine and Hanlon 2010).

The red gum lerp psyllid *G. brimblecombei*, native to Australia, was detected in June 1998 in California, United States, in *Eucalyptus camaldulensis* Dehnh (Garrison 1998). Later it was recorded in New Zealand (Withers 2001), Mexico (Ramirez *et al*. 2002), Argentina (Bouvet *et al*. 2005), Venezuela (Rosales *et al*. 2008), Ecuador, Peru (Burckhardt *et al*. 2008), Portugal, Spain (Valente and Hodkinson 2009), Canary Islands (Malumphy 2010), Italy (Laudonia and Garonna 2010), Uruguay (Bentancourt and Scatoni 2010), Chile (Huerta *et al*. 2011), France (Cocquempot *et al*. 2012), Morocco (Maatouf and Lumaret 2012), South Africa (Hurley 2012), Algeria (Reguia and Peris-Felipo 2013), Colombia (Taylor *et al*. 2013), Greece (Bella and Rapisarda 2013), Tunisia (Ben Attia and Rapisarda 2014), Israel (Spodek *et al*. 2015), and Turkey (Karaca *et al*. 2015). In Brazil was detected for the first time in Mogi-Guaçu, São Paulo State

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in June 2003 in *E. camaldulensis*, *Eucalyptus tereticornis* Sm. and *Eucalyptus urograndis* (*Eucalyptus grandis* W. Hill ex Maiden × *Eucalyptus urophylla* S. T. Blake) plantations where trees had 100 % defoliation with any possibility of recovery (Wilcken *et al*. 2003).

The numbers of *G. brimblecombei* and its parasitoid *Psyllaephagus bliteus* Riek, 1962 (Hymenoptera: Encyrtidae) were high during periods of low temperature, and rainfall did not affect the population dynamic of these insects in Brazil (Ferreira-Filho *et al*. 2008). The parasitism rates of *G. brimblecombei* in 2006 and 2007 were 0.21–5.92 % and 0.28–7.03 % in areas without parasitoid releases; these values rose to 28.28–78.57 % and 30.32–79.34 %, respectively, in areas involved in parasitoid release in Brazil (Ferreira-Filho *et al*. 2015b). Low to moderate mortality of *G. brimblecombei* by parasitism from *P. bliteus*, ranging of 0 to 48 %, was observed in field samples in Portugal (Boavida *et al*. 2016).

The ecological modeling based on environmental variables can estimate the world-wide dispersal potential of *G. brimblecombei* (Laudonia *et al*. 2014). For example, in Brazil this species is very abundant in the southern Atlantic forest, pampas, and in the savanna region because of the temperate climatic conditions (Queiroz *et al*. 2013). Immature stages and adults of *G. brimblecombei* feed on the sap of the leaves and secrete a sugary substance consisting of amylase, amylopectin and dextrin that hardens to form crystals. These secretions are used to build a protective lerp or a white and quite visible conical conch (Dreistadt and Gill 1999). The red gum lerp psyllid *G. brimblecombei* can cause 15 % plant mortality in the first year and 40 % in the second due to the direct impact of feeding by continuous sucking the sap and fall leaves (Gill 1998).

The study evaluated the effect of climatic conditions (temperature and rainfall) on the population dynamics of *G. brimblecombei* and *P. bliteus* in a *E. camaldulensis* plantation.

Materials and methods

Study area. This study was conducted in Luiz Antônio, São Paulo State, Brazil (22°87'S × 76°13'E, 729 m) in an approximately nine years old plantation of *E. camaldulensis*. The plantation has an extension of 19 ha with 2.5 × 3 m spacing between tress where the presence of the red gum lerp psyllid was abundant. The regional climate is classified as Köppen's Cwa – mesothermal humid subtropical, with a dry winter and a hot and wet summer. The mean annual rainfall is 1,400 mm yr^{-1}, and the mean annual temperature is 27 °C (Cianciaruso *et al*. 2006).

Sampling methods. *Glycaspis brimblecombei* and *P. bliteus* were sampled using yellow sticky traps and leaves for 25 months, from January 23, 2006 to January 23, 2008. A total of 53 yellow sticky traps (10 × 12 cm) with spaced 50 × 36 m at 1.8 m plants of height, forming a sampling grid in the field, was sampled. Each trap was attached with a plasticized wire strung between two trees. Forty-two samples were collected from each point at, approximately, 15 days intervals.

The traps were labeled and packaged with transparent plastic film to avoid damage to the captured insects and facilitating their identification. After the collection, the traps were taken into laboratory for sorting and counting the insects. The number of adults of *G. brimblecombei* and *P. bliteus* was counted on both sides of the yellow sticky traps using a stereoscopic microscope under 10X magnification.

On the other hand, leaves were sampled by the branches collection. A total of 53 trees (three branches from each) were selected using a 6 m long pole pruner. Branches were collected randomly in the middle-third of each tree and placed in paper bags during the period when the yellow sticky traps were replaced. *Glycaspis brimblecombei* and *P. bliteus* specimens were counted in a 7.5 m^2 area occupied by each tree (a spacing of 2.5 × 3 m/tree) around the yellow sticky trap. The branches were taken into laboratory and placed in Biochemical Oxygen Demand (BOD) chamber at 18 °C to keep the foliage turgid until the evaluation. Ten leaves were randomly selected from three branches per tree per sampling point to assess the number of *G. brimblecombei* lerp and immature stages on their abaxial and adaxial parts. Lerp was removed from the leaves, and immature stages were counted and classified according to its size. The first and second stages were mostly small immature; third and fourth were average and the fifth was the biggest. The number of mummies (parasitized immature) and empty mummies (after emergence of *P. bliteus* adults) were obtained by observation using stereoscopic microscope.

Data analysis. Weather conditions (temperature and rainfall) were obtained every day from the weather station of the Brazilian Agricultural Research Corporation - Embrapa Cattle Southeast in São Paulo State, Brazil (20°65'E × 05°68'S, 840 m) placed in the studied area.

The number of *G. brimblecombei* and *P. bliteus* adults captured in the 53 yellow sticky traps and those of immature and mummies of *P. bliteus* per leaf sampled at 53 points as well as temperature and rainfall were analyzed by Pearson's correlation. A t test was applied to determine the significance of the linear correlation between variables (SAS INSTITUTE INC. 2002-2003). The correlation coefficient is generally suitable for analysis of two variables without dependency of functional relationships, but with correlation between them (Snedecor and Cochran 1967).

Results

The number of *G. brimblecombei* and *P. bliteus* adults caught in the yellow sticky traps and those of immature and mummies parasitized by *P. bliteus* varied with the seasons of the year, with 134,723 psyllid and 10,753 parasitoid individuals collected. Furthermore, 287,314 *G. brimblecombei* immature and 7,545 mummies parasitized by *P. bliteus* were sampled from *E. camaldulensis* leaves. The average numbers of *G. brimblecombei* and *P. bliteus* during summer 2006, when the rainfall was better distributed (452 mm), were low (6.53 psyllids per trap and 0.06 immature per leaf, and 0.64 parasitoids per trap and 0.08 mummies per leaf, respectively), and the average minimum and maximum temperatures remained around 17 and 28 °C, respectively. They increased after 106 days of evaluation (May 9th, 2006), in the fall, when the rain was less intensive (135 mm), and minimum and maximum temperature averages were 11 and 24 °C, respectively. Peak population of *G. brimblecombei* (430.66 psyllids per trap and 38.2 immature per leaf) and *P. bliteus* (33.7 parasitoids per trap and 1.3 mummies per leaf) at the 169th day of evaluation (July 11th, 2006) in the winter coincided with the year low rainfall period (79 mm) and low temperature (12 °C).

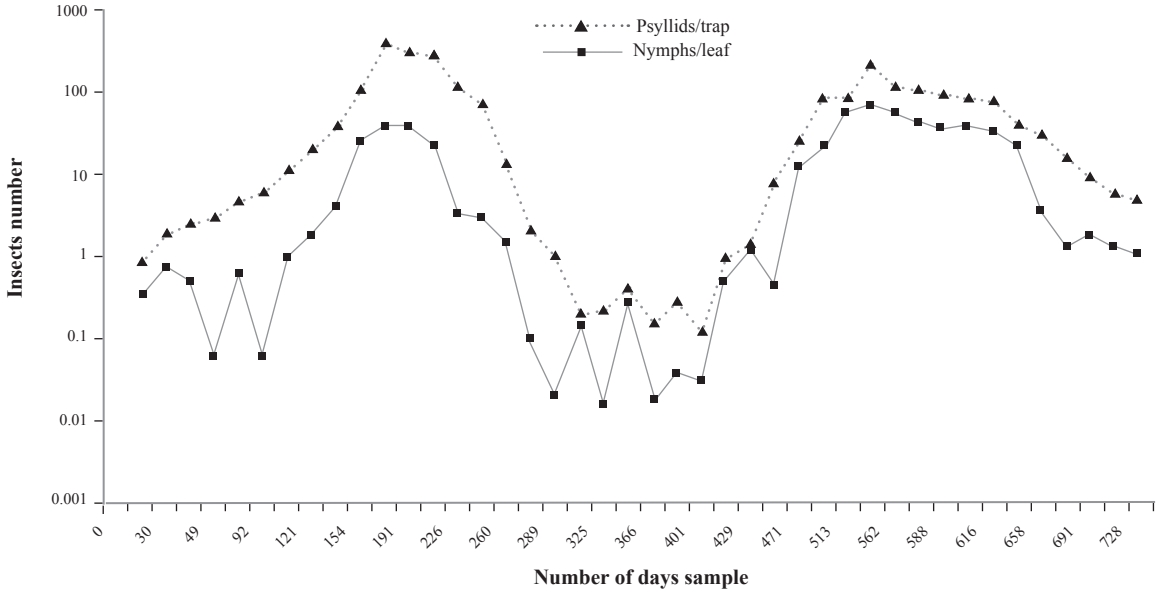

Figure 1. Number of *Glycaspis brimblecombei* (Hemiptera: Aphalaridae) adults per yellow sticky trap and immature per leaf in a *Eucalyptus camaldulensis* (Myrtaceae) plantation. Luiz Antônio, São Paulo State, Brazil. January 23, 2006 to January 23, 2008.

Populations of both species decreased again, in the spring, at the 260th day of evaluation (October 10th, 2006) when the rain started again and became evenly distributed (349 mm) with higher average minimum and maximum temperatures (18 and 29 °C), respectively (Figs. 1, 2, and 3).

Glycaspis brimblecombei and *P. bliteus* populations in the summer 2007 were lower, similar to the fall of the previous year, with 8.25 psyllids and 7.02 parasitoids per yellow sticky trap and 0.42 immature and 0.12 mummies per leaf, respectively. From the 352th day of evaluation (January 10th, 2007) the rainfall (799 mm) with was more frequent and distributed and average minimum and maximum temperatures were around 19 and 30 °C, respectively. The population of these insects increased again when the rain became irregular (255 mm) at the 429th day of evaluation (March 28th, 2007). In early winter, at the 542th day of evaluation (July 19th, 2007), in the dry period (11 mm) and low average minimum and maximum temperatures (13 and 26.5 °C) coincided with *G. brimblecombei* and *P. bliteus* populations peaks (233.13 psyllids per yellow sticky trap and 66.71 immature per leaf and 12.91 parasitoids per yellow sticky trap and 2.1 mummies per leaf, respectively). The populations of both species de-

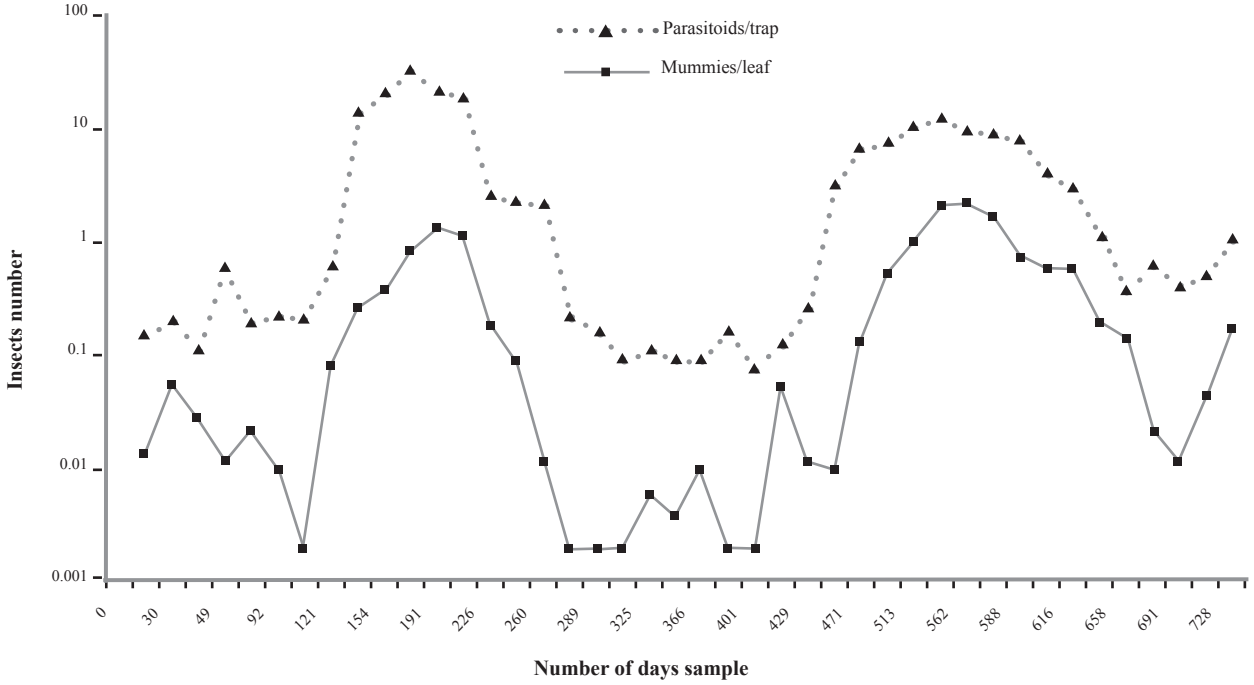

Figure 2. Number of *Psyllaephagus bliteus* (Hymenoptera: Encyrtidae) adults per yellow sticky trap and mummies per leaf in a *Eucalyptus camaldulensis* (Myrtaceae) plantation. Luiz Antônio, São Paulo State, Brazil. January 23, 2006 to January 23, 2008.

Table 1. Values of Pearson correlation and significance (*P*-value) between the number of *Glycaspis brimblecombei* (Hemiptera: Aphalaridae) adults, immature and mummies parasitized and *Psyllaephagus bliteus* (Hymenoptera: Encyrtidae) adults with maximum, minimum and average temperatures, and rainfall in *Eucalyptus camaldulensis* (Myrtaceae) plantation. Luiz Antônio, São Paulo State, Brazil. January 23, 2006 to January 23, 2008.

Insects number		T max	T min	T aver	Rainfall
Glycaspis brimblecombei adults on traps	r	-0.39	-0.70	-0.61	-0.41
	P	0.0100	< 0.0001	< 0.0001	0.0100
Glycaspis brimblecombei immature on leaves	r	-0.39	-0.66	-0.59	-0.42
	P	0.0120	< 0.0001	< 0.0001	0.0060
Psyllaephagus bliteus adults on traps	r	-0.69	-0.70	-0.64	-0.41
	P	< 0.0001	< 0.0001	< 0.0001	0.0090
Psyllaephagus bliteus mummies on leaves	r	-0.71	-0.67	-0.62	-0.40
	P	< 0.0001	< 0.0001	< 0.0001	0.0100

creased again in late winter and early spring at the 616th day of evaluation (October 3rd, 2007) when the rain was better distributed and abundant (285 mm) with high average minimum and maximum temperatures (19 and 29 °C) (Figs. 1, 2, and 3, and Table 1).

Discussion

The variations in the population of *G. brimblecombei* and *P. bliteus* adults captured using yellow sticky traps and of psyllid immature and mummies parasitized by the parasitoid in dry and rainy season in the *E. camaldulensis* plantation agree with that reported for these insects in United States (Garrison 1998; Halbert *et al*. 2001), Mexico (Ramirez *et al*. 2002), Chile (Huerta *et al*. 2011), Algeria, Spain (Reguia and Peris-Felipo 2013), Cuiabá, Mato Grosso State, Brazil (Silva *et al*. 2013), and Italy (Laudonia *et al*. 2014). These results show that *G. brimblecombei* has lower population growth with the onset of summer and higher rainfall, which may be due to mechanical control performed by the contact of the water with its protective lerp or because most insects are susceptible to heat stress between 28 and 32 °C (Kiritani 2013). In Italy, *G. brimblecombei* showed a seasonal population dynamic, suggesting that many generations occur during the year and the species overwinters in all stages without diapause. The population size in the new area of colonization was negatively affected by low winter temperatures, but also by high temperatures in the absence of rainfall (Laudonia *et al*. 2014).

The lowest numbers of *G. brimblecombei* and *P. bliteus* captured during summer 2006 and 2007 coincided with periods of better distributed rainfall and it increased after 106 days of evaluation (May 9th, 2006), in the fall, with less intense rain, as reported for the beginning of this psyllid with heavy rain in Mauritius (Sookar *et al*. 2003). The number of *G. brimblecombei* lerp per *E. camaldulensis* seedling was reduced by more than 50 %, and then, by 100 % after two and five days of simulated rain, respectively (Oliveira *et al*. 2012). This finding indicates, again, that the mechanical removal of the *G. brimblecombei* lerp by rain explains its population decrease under these conditions. Population peak

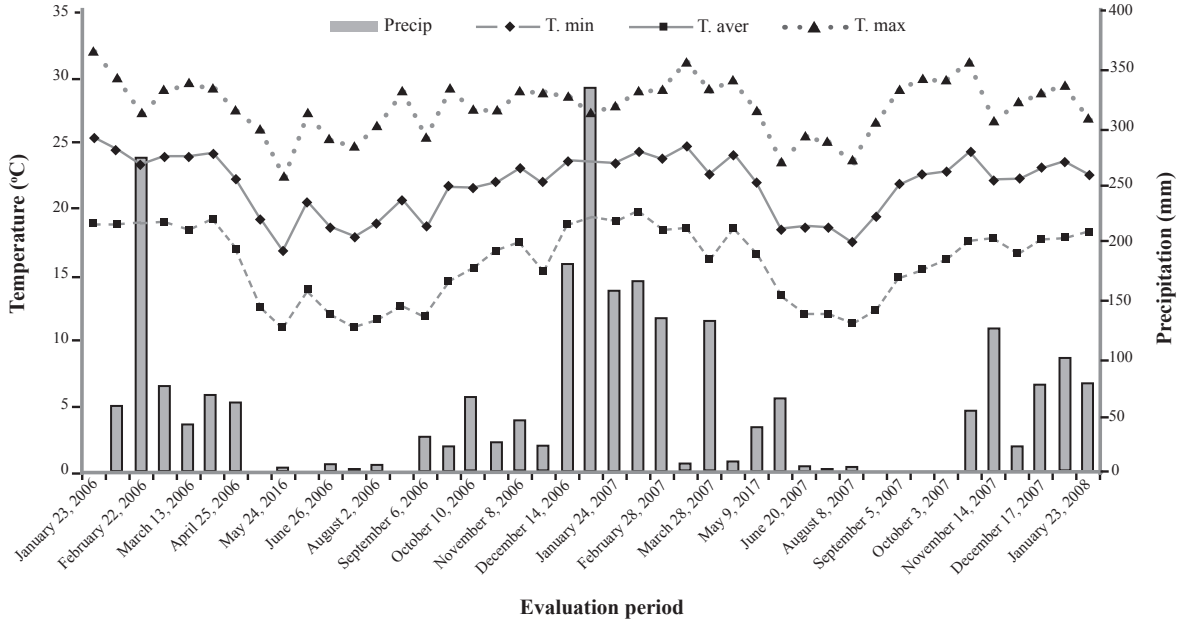

Figure 3. Maximum, minimum and average temperatures and fortnightly rainfall, Brazilian Agricultural Research Corporation - Embrapa Cattle Southeast. São Paulo State, Brazil. January 23, 2006 to January 23, 2008.

of *Cardiaspina*, *Creiis* (Hemiptera: Psyllidae) and *Glycaspis* was in the winter season (10 mm of rain) from June to August than in the summer (505 mm rainfall) from December to February in *Eucalyptus dunnii* Maiden in Brisbane and Bundaberg, Australia (Whyte *et al*. 2011). *Ctenarytaina eucalypti* Maskell, 1890 (Hemiptera: Psyllidae) and its natural enemy *Psyllaephagus pilosus* Noyes, 1988 (Hymenoptera: Encyrtidae) had higher population at early spring on *Eucalyptus globulus* Labill. in Rio Grande do Sul State, Brazil (Kurylo *et al*. 2010). During the autumn (April) in Wilpena Creek, high numbers of *Glycaspis eremica* Moore, 1970 were detected on *E. camaldulensis* and *Glycaspis hadlingtoni* Moore, 1970 and *Glycaspis froggatti* Moore, 1970 in May on *Eucalyptus intertexta* R. T. Baker in the Alice Springs, Australia (Moore 1978). The populations of *Diaphorina citri* Kuwayama, 1908 (Hemiptera: Psyllidae) were lower in the southern Baluchistan, Iran, during periods of higher relative humidity and rain (January to April) and it was lowest from May to August, with an increase in temperature and humidity (Rakhshani and Saeedifar 2013), which confirms the effects of rainfall on the population density of *G. brimblecombei*.

The reduction in the individual number of the parasitoid *P. bliteus* was similar for *Diclidophlebia smithi* Burckhardt, Morais and Picanço, 2006 (Hemiptera: Psyllidae) with lower populations density during the rainy season in Guaraciaba, Dionisio and Viçosa located in Minas Gerais State, Brazil, from November to March (Morais *et al*. 2013). The rainfall correlated significantly with the population densities of two *Greenidea* (Hemiptera: Aphididae) species in *Psidium guajava* L. (Myrtaceae) plants but no correlation was found between temperature and population densities of these aphids in Central Mexico (Salas-Araiza *et al*. 2011). This shows that the mechanical impact of a large rain droplet can control these insects by removing the individuals from the host plant. High *Glycaspis baileyi* Moore, 1961 populations were reported in southeastern Australia, New South Wales, on *Eucalyptus blakelyi* Maiden during the winter season (Moore 1961).

To conclude, dry and wet periods determinate the population dynamics of *G. brimblecombei* and *P. bliteus*. The population of these species peaked in the winter and reduced in the summer when temperature increased and rains were more frequent. These results are important for further integrated pest management and biological control programs. The parasitoid could be produced and released during periods of high pest population.

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