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PRELIMINARY RESULTS ON THE SPATIO-TEMPORAL VARIABILITY OF *GLYCASPIS BRIMBLECOMBEI* (HEMIPTERA PSYLLIDAE) POPULATIONS FROM A THREE-YEAR MONITORING PROGRAM IN SARDINIA (ITALY) ⁽¹⁾

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Mannu R., Buffa F., Pinna C., Deiana V., Satta A., Floris I. – Preliminary results on the spatio-temporal variability of *Glycaspis brimblecombei* (Hemiptera Psyllidae) populations from a three-year monitoring program in Sardinia (Italy).

The red gum lerp psyllid *Glycaspis brimblecombei* is an invasive insect species worldwide. Prolonged attacks by this psyllid may cause both direct and indirect damages to *Eucalyptus* trees, such as plant weakening, developmental reductions and phylloptosis, resulting in death within 2-3 years. After the first report in Campania (Italy) in 2010 on *Eucalyptus camaldulensis* trees, it quickly spread to all surrounding central-southern regions of Italy. In Sardinia, *G. brimblecombei* was first recorded in 2011, and is currently found throughout the island. From 2013 to 2015 a monitoring program was carried out in 11 locations throughout Sardinia in order to estimate the density pattern of both its adults and preimaginal stages, as well as the general population trend of *G. brimblecombei* over the years. An analysis of *G. brimblecombei* population abundance showed an almost stable level of infestation over the years, and a seasonal pattern with a population peak in the summer. However, an earlier peak of population abundance was detected in 2015 compared to the previous years. A spatial heterogeneity of the level of infestation was observed throughout the island, highlighting the potential effects of environmental conditions in regulating the populations of both *G. brimblecombei* and its natural enemies.

KEY WORDS: *Eucalyptus*, psyllid populations, pests, monitoring.

INTRODUCTION

Glycaspis brimblecombei Moore (Hemiptera: Psyllidae), also known as red gum lerp psyllid, is a phloem-sucking insect native to Australia. The psyllid can infest several *Eucalyptus* species, particularly *E. camaldulensis* Dehn (BRENNAN *et al.*, 1999; 2001). The insect feeds on leaves, completing its development underneath white conical shelters secreted by the nymphs, commonly called lerps. *G. brimblecombei* is a multivoltine species able to complete from two to four generations per year in its native range (MORGAN, 1984), although up to six generations have been estimated under neotropical environmental conditions (FIRMINO-WINCKLER *et al.*, 2009; CUELLO *et al.*, 2018). Temperature and relative humidity have been shown to be the main factors affecting *G. brimblecombei* populations (CUELLO *et al.*, 2018; MARGIOTTA *et al.*, 2017). In neotropical areas, the combination of low temperatures and high relative humidity negatively influences psyllid abundance, whereas positive effects on population abundance have been observed in relation to high temperatures and low relative humidity (LIMA DA SILVA *et al.*, 2013; CUELLO *et al.*, 2018).

The parasitoid *Psyllaephagus bliteus* Riek (Hymenoptera: Encyrtidae) is considered the most important biotic control factor of the red gum lerp psyllid, reaching a parasitism rate of 30% under laboratory conditions (DAANE *et al.*, 2005). The parasitoid was voluntarily introduced and released in several psyllid-infested areas of California (DAHLSTEN *et al.*, 2005) and Mexico (PLASCENCIA-GONZÁLEZ *et al.*, 2005), to control *G. brimblecombei* infestations. Despite its host specificity, the parasitism rate of *P. bliteus* seemed to be different in areas with different environmental conditions, since the insect is less tolerant to high temperatures than the red gum lerp psyllid (DAANE *et al.*, 2012).

Severe *G. brimblecombei* infestations can cause premature defoliation, thus affecting tree growth (BRENNAN *et al.*, 2001), and potentially resulting in death within 2-3 years (DAANE *et al.*, 2005). The general weakening of the infested plants also results in a strong reduction in flowering and nectar production, consequently causing considerable production losses in unifloral eucalyptus honey (BUFFA, 2015). Such losses are particularly worrying, as eucalyptus honey represents about 50% of the total annual honey production of some Mediterranean regions, including Sardinia (FLORIS *et al.*, 2007).

G. brimblecombei was first recorded outside its native area in 1998 in California (USA) (BRENNAN *et al.*, 1999), whereas in Europe it was detected for the first time in Portugal and Spain in 2007 (VALENTE and HODKINSON, 2008). Currently, *G. brimblecombei* is also present in almost all Mediterranean countries, such as Italy (LAUDONIA

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and GARONNA, 2010; LAUDONIA *et al.*, 2014), France (COCQUEMPOT *et al.*, 2012), Morocco (MAATOUF and LUMARET, 2012), Algeria (REGUIA and PERIS-FELIPO, 2013), Montenegro (MALUMPHY *et al.*, 2013), Greece (BELLA and RAPISARDA, 2013), and Tunisia (BEN ATTIA and RAPISARDA, 2014).

In Italy, after having been first found in Lazio and Campania in 2010 (LAUDONIA and GARONNA, 2010), *G. brimblecombei* spread rapidly into regions where eucalyptus plantations have been historically established, such as Sicily (LO VERDE *et al.*, 2011), and Sardinia (BUFFA, 2015). However, during the following years the specific parasitoid *P. bliteus* was also recorded in some psyllid-infested areas of Italy, where it was probably introduced accidentally together with the psyllid (CALECA *et al.*, 2011; PANTALEONI *et al.*, 2012; LAUDONIA *et al.*, 2014; MARGIOTTA *et al.*, 2014).

Sardinia, where over 88% of the Italian *Eucalyptus* plantations are located (GASPARINI and TABACCHI, 2011), is the most damaged area in Italy by the psyllid infestations. In addition, as *G. brimblecombei* infestations are also associated with other parasites and diseases, the sanitary status of *Eucalyptus* plantations may be worsened, making control strategies more difficult to be managed (DEIDDA *et al.*, 2016; FLORIS *et al.*, 2018; DEIANA *et al.*, 2018).

Given the economic and social importance of *Eucalyptus* plantations in Sardinia and in other Mediterranean countries, a *G. brimblecombei* monitoring program was carried out from 2013 to 2015 covering several areas of the Island. In this work, we analyzed the data from the monitoring activity in order to evaluate (1) the general trend of *G. brimblecombei* populations both between and within the years of the monitoring period; (2) the seasonal pattern of the different development stages during the spring-summer period; (3) the regional variability of pest abundance.

MATERIALS AND METHODS

FIELD SAMPLING AND LABORATORY ANALYSIS

Field surveys were carried out from March 2013 to December 2015 in 11 locations selected throughout Sardinia (Table 1).

During these three years, both adults and preimaginal stages were monitored monthly in the winter, and every fifteen days in the spring, summer and autumn. The adult

populations of red gum lerp psyllid were monitored using four yellow sticky traps (20 cm × 20 cm) in each study area. Traps were spaced at least 20 m from each other and positioned on a branch of a tree crown at a height of approximately 2 m above the ground. All traps were collected and subsequently replaced at each sampling date. Traps were placed on the same *Eucalyptus* trees during the three-year monitoring period.

In addition, for each location and date, four *Eucalyptus* trees were randomly selected in the field and one branch approximately 40 cm long was randomly sampled from each tree canopy. In the laboratory, four leaves from each sampled branch were randomly selected, for a total of 16 leaves/location/date. In the laboratory, *G. brimblecombei* unhatched eggs, larvae and nymphs were counted on the upper side of the leaves using a stereomicroscope. For the larvae and nymphs, only the number of unparasitized juvenile stages of *G. brimblecombei* were counted.

DATA ANALYSIS

All statistical analysis were performed using R software (R CORE TEAM, 2016).

The temporal variability of the *G. brimblecombei* population in Sardinia was analyzed for all the monitored stages following the protocol suggested by ZUCCHINI and NEMADIĆ (2011). Firstly, the average monthly abundance was calculated for each stage to obtain time series data, and a non-parametric regression technique was applied. The trends (T_t) were estimated through a decomposition of the time series (X_t) using local polynomial regression, whereas the seasonal component (S_t) and residuals were estimated by calculating the differences ($X_t - T_t$).

In order to reduce misleading information resulting from an excess of zero counts typical of the winter period, spatial variation was examined on data from May to September, corresponding to the period of higher abundance of *G. brimblecombei* under Mediterranean field conditions (LAUDONIA *et al.*, 2014). The effects of location on the density of adults, eggs, larvae and nymphs were evaluated separately for each stage, fitting a zero-inflated negative binomial (ZINB) regression model estimated by maximum likelihood using the zeroinfl function of the “pscl” package in R (ZEILEIS *et al.*, 2008). ZINB regression models are commonly used to analyze insect count data as they generally account for over-dispersion and excess zero counts (SILESHI, 2006). In all fitted models, the factor “year”

Table 1 – General information about *Eucalyptus camaldulensis* monitored locations.

Location	Latitude	Longitude	Elevation	Type of plantation
Alghero	40.5939	8.2903	7	Ornamental
Arbatax	39.9284	9.7084	13	Ornamental
Arborea	39.8018	8.6298	7	Plantation
Olbia	40.8707	9.5155	15	Windbreak
Ottana	40.2325	9.0317	185	Windbreak
Ozieri	40.6134	8.9305	390	Windbreak
S. M. la Palma	40.6527	8.2905	30	Windbreak
San Vito	39.3344	9.5309	13	Windbreak
Serramanna	39.4134	8.8628	30	Windbreak
Siliqua	39.2712	8.8146	66	Plantation
Uta	39.2569	8.9307	6	Plantation

was included. To address variability due to time of sampling within each monitoring year, year $\times$ sampling time interaction were also considered. Analysis of deviance was performed to assess the statistical significance of factors, and χ^2 statistics were computed. Finally, a Tukey post-hoc test was conducted with a significance level of $p < 0.05$.

RESULTS

TEMPORAL VARIABILITY

Decomposition of the time series revealed a similar seasonal pattern (within-year pattern) for all different stages. However, differences in the between-years pattern were particularly evident between eggs and other stages (Fig. I). In particular, a moderate increase in the average population abundance was observed for all stages from

2013 to early 2014. However, while egg abundance revealed a strong decline and a subsequent stable period in 2014 and 2015, respectively, adults, larvae and nymphs showed a stationary period in 2014 preceding an insignificant population decrease in 2015.

SEASONAL PATTERN

Although the dynamics of the adults captured by traps had approximately the same pattern every year, a peak of abundance was observed in mid-July in 2013 compared to the beginning of July and the end of June in 2014 and 2015, respectively (Fig. II). After the peak, adult populations decreased in all the monitored years, reaching values below 100 individuals/traps in mid-September. Both the dynamics and the shift in peak of abundance among years were also similar for preimaginal stages (Fig. II).

The number of eggs regularly increased from May to

Fig. I – Seasonal decomposition of time series data for Adults, Eggs, Larvae, and Nymphs of *G. brimblecombe* from Sardinia (Italy) during 2013-2015. The original structure of time series data (Data), the within-year pattern (Seasonal), the between-year pattern (Trend), and the unexplained variance (Remainder) are reported for each stages.

Fig. II – Activity pattern of *G. brimblecombei* adults, eggs, larvae and nymphs observed in late spring-summer period of 2013, 2014 and 2015, respectively. Each line indicates the average number of individuals captured during monitoring period.

June in 2013, reaching a peak of abundance in mid-July with 19.4 eggs/leaf, after which they decreased to the lowest level. However, in the following years, the highest total number of eggs was observed earlier in the season, as already shown for adult populations. In particular, a peak of population abundance of eggs in 2014 and 2015 was observed in early and mid-June with 16.9 and 11.5 eggs/leaf, respectively.

The analysis of the seasonal pattern of larvae also showed an earlier population peak in both 2014 and 2015 compared to 2013. Unlike the adults and other preimaginal stages, the larval populations reached the highest abundance in 2014 and 2015 with 14.5 and 17.4 larvae/leaf, respectively. Finally, the population dynamics of nymphs followed a pattern already observed for larvae, showing average values of 4.4, 2.7 and 4.2 nymphs/leaf with population peaks in 2013, 2014 and 2015, respectively.

SPATIAL VARIABILITY AT REGIONAL SCALE

Significant effects of location, as well as of year and their interaction, on *G. brimblecombei* adults and preimaginal stages were found (Table 2). During the three-year monitoring period, the numbers of adults captured by traps

Table 2 – ANOVA table of ZINB regression results indicating the χ^2 , degrees of freedom (df) and significance of year, location and their interaction on the abundance of *G. brimblecombei* juvenile stages and adults from May to September, respectively.

Preimaginal stage	Factor	χ^2	df	p
Eggs	Year	108.09	2	<0.01
	Location	54.64	10	<0.01
	Year $\times$ Location	50.37	20	<0.01
Larvae	Year	1.17	2	0.55
	Location	53.72	10	<0.01
	Year $\times$ Location	33.89	20	0.06
Nymphs	Year	15.94	2	<0.01
	Location	23.94	10	<0.01
	Year $\times$ Location	30.13	20	0.07
Adults	Year	5.28	2	0.07
	Location	135.51	10	<0.01
	Year $\times$ Location	34.11	20	<0.01

were significantly higher at the locations in “Serramanna” and “Ottana” ($p < 0.01$), whereas “Arbatax”, “Siliqua” and “Uta” showed the lowest average values of 72, 78 and 81 individuals/trap, respectively (Table 3). However, different results at a regional level were observed for preimaginal stages. In fact, despite a low average values of adults captured by traps, “Arbatax” was more infested than the other monitored locations ($p < 0.01$), showing average egg, larval and nymph values of 3.9, 3.9, and 1.6 individuals per leaf, respectively. The location with significantly higher levels of infestation for almost all preimaginal stages was Ozieri, where mean values of 7.7, 4.9, and 2.1 were observed for eggs, larvae and nymphs, respectively. In general, a higher spatial heterogeneity of the infestation level was observed for eggs and nymphs, whereas the infestation level of larvae was relatively homogeneous across the different locations.

DISCUSSION

An examination of the time series revealed a similar within-year pattern among the various development stages. For each stage, the late-spring increase was followed by a peak in the summer and a subsequent decrease in the autumn-winter period. These results are in line with other studies carried out in the Mediterranean (LAUDONIA *et al.*, 2014). In particular, higher levels of infestation by *G. brimblecombei* eggs and juvenile stages have been observed in June and August in Campania and Lazio, respectively (LAUDONIA *et al.*, 2014). In addition, both adults and preimaginal stages of the red gum lerp psyllid were observed in winter. As reported for central Italy (LAUDONIA *et al.*, 2014), the presence of the different development stages in winter indicates that when favorable conditions occur *G. brimblecombei* can continue to develop even during the coldest period of the year, as recently observed in the Mediterranean environment (ISPRA, 2016).

A decreasing egg abundance over the monitoring years was particularly evident, whereas no reduction in the abundance of other stages was found. A reduction in the average egg abundance over the years could be related to

Table 3 – Mean $\pm$ standard error (SE) of adults, eggs, larvae and nymphs observed at 11 locations in Sardinia during May-September of 2013, 2014 and 2015, respectively. Different lowercase and capital letters indicate significant differences in abundance among years within same location and locations within same year, respectively (Tukey's test significance, $p < 0.05$).

	Location	2013	2014	2015	Total
Adults	Arbatax	30 $\pm$ 12 aA	54 $\pm$ 13 abA	131 $\pm$ 30 bAB	72 $\pm$ 12 A
	Siliqua	84 $\pm$ 29 aAB	61 $\pm$ 20 aAB	88 $\pm$ 29 aA	78 $\pm$ 15 AB
	Uta	108 $\pm$ 31 aAB	75 $\pm$ 27 aAB	58 $\pm$ 21 aA	80 $\pm$ 15 AB
	San Vito	120 $\pm$ 43 aAB	69 $\pm$ 20 aAB	80 $\pm$ 21 aA	90 $\pm$ 17 AB
	Alghero	60 $\pm$ 22 aAB	88 $\pm$ 50 abAB	216 $\pm$ 54 bABC	121 $\pm$ 26 ABC
	Olbia	95 $\pm$ 29 aAB	165 $\pm$ 65 aAB	180 $\pm$ 58 aABC	147 $\pm$ 30 ABCD
	Arborea	149 $\pm$ 43 aAB	180 $\pm$ 48 aAB	162 $\pm$ 46 aAB	164 $\pm$ 26 BCD
	S. M. la Palma	166 $\pm$ 56 aAB	305 $\pm$ 80 aB	256 $\pm$ 75 aABC	242 $\pm$ 41 CDE
	Ozieri	163 $\pm$ 46 aAB	231 $\pm$ 60 abAB	408 $\pm$ 106 bBC	268 $\pm$ 44 DE
	Ottana	381 $\pm$ 106 abAB	162 $\pm$ 40 aAB	486 $\pm$ 99 bC	343 $\pm$ 51 E
	Serramanna	513 $\pm$ 215 aB	294 $\pm$ 98 aAB	446 $\pm$ 133 aBC	418 $\pm$ 90 E
	Total	170 $\pm$ 24 ab	153 $\pm$ 16 a	228 $\pm$ 22 b	
Eggs	Alghero	6.3 $\pm$ 1.8 bA	3.0 $\pm$ 0.6 abAB	2.7 $\pm$ 0.9 aA	3.9 $\pm$ 0.7 A
	San Vito	6.0 $\pm$ 2.1 bA	4.1 $\pm$ 0.8 abABC	1.6 $\pm$ 0.5 aA	3.9 $\pm$ 0.8 AB
	Arbatax	5.2 $\pm$ 1.3 aA	4.3 $\pm$ 0.9 aABC	2.1 $\pm$ 0.5 aAB	3.9 $\pm$ 0.6 AB
	Olbia	7.7 $\pm$ 2.3 bA	2.5 $\pm$ 0.6 aA	3.6 $\pm$ 0.9 abAB	4.6 $\pm$ 0.9 AB
	Uta	4.8 $\pm$ 1.3 aA	5.5 $\pm$ 1.7 aABC	4.5 $\pm$ 1.7 aAB	4.9 $\pm$ 0.9 AB
	Siliqua	8.6 $\pm$ 1.8 bA	2.8 $\pm$ 0.7 aABC	4.1 $\pm$ 1.3 abAB	5.2 $\pm$ 0.8 ABC
	S. M. la Palma	7.7 $\pm$ 1.8 aA	5.0 $\pm$ 1.3 aABC	3.7 $\pm$ 0.8 aAB	5.5 $\pm$ 0.8 ABC
	Arborea	7.8 $\pm$ 2.3 bA	6.7 $\pm$ 2.0 abABC	4.1 $\pm$ 1.3 aAB	6.2 $\pm$ 1.1 ABC
	Serramanna	11.9 $\pm$ 2.3 bA	7.9 $\pm$ 2.5 bBC	3.5 $\pm$ 0.9 aAB	7.7 $\pm$ 1.2 BC
	Ozieri	9.6 $\pm$ 1.6 aA	6.8 $\pm$ 1.3 aC	6.7 $\pm$ 1.8 aAB	7.7 $\pm$ 0.9 C
	Ottana	11.6 $\pm$ 2.6 bA	3.9 $\pm$ 0.9 aABC	7.8 $\pm$ 1.6 abB	7.8 $\pm$ 1.1 C
	Total	7.9 $\pm$ 0.6 b	4.8 $\pm$ 0.4 a	4.0 $\pm$ 0.4 a	
Larvae	Siliqua	2.3 $\pm$ 0.7 aA	1.9 $\pm$ 0.5 aA	2.8 $\pm$ 0.7 aA	2.3 $\pm$ 0.3 A
	Alghero	3.0 $\pm$ 0.8 aA	2.6 $\pm$ 0.7 aA	2.2 $\pm$ 0.7 aA	2.6 $\pm$ 0.4 AB
	Ottana	3.2 $\pm$ 1.2 aA	1.6 $\pm$ 0.4 aA	4.1 $\pm$ 1.3 aA	3.0 $\pm$ 0.6 ABC
	S. M. la Palma	1.8 $\pm$ 0.4 aA	4.0 $\pm$ 0.9 aA	3.4 $\pm$ 1.0 aA	3.1 $\pm$ 0.5 ABC
	San Vito	4.3 $\pm$ 1.2 aA	2.6 $\pm$ 0.7 aA	2.8 $\pm$ 1.0 aA	3.2 $\pm$ 0.6 ABC
	Serramanna	3.7 $\pm$ 1.2 aA	2.9 $\pm$ 0.9 aA	3.2 $\pm$ 1.3 aA	3.3 $\pm$ 0.7 ABC
	Olbia	4.7 $\pm$ 1.5 aA	2.4 $\pm$ 0.5 aA	3.8 $\pm$ 1.2 aA	3.7 $\pm$ 0.7 ABC
	Arbatax	3.9 $\pm$ 0.8 aA	3.8 $\pm$ 0.8 aA	3.9 $\pm$ 0.9 aA	3.9 $\pm$ 0.5 ABC
	Uta	2.2 $\pm$ 0.6 aA	5.3 $\pm$ 1.8 aA	4.8 $\pm$ 1.8 aA	4.1 $\pm$ 0.9 ABC
	Ozieri	3.7 $\pm$ 0.8 aA	6.5 $\pm$ 1.2 aA	4.6 $\pm$ 1.2 aA	4.9 $\pm$ 0.6 ABC
	Arborea	6.4 $\pm$ 2.9 aA	8.2 $\pm$ 3.1 aA	4.1 $\pm$ 1.8 aA	6.2 $\pm$ 1.5 BC
	Total	3.6 $\pm$ 0.4 a	3.8 $\pm$ 0.4 a	3.6 $\pm$ 0.4 a	
Nymphs	Ottana	0.8 $\pm$ 0.2 aA	0.8 $\pm$ 0.1 aA	0.8 $\pm$ 0.2 aA	0.8 $\pm$ 0.1 A
	Siliqua	0.9 $\pm$ 0.3 aA	0.8 $\pm$ 0.2 aA	1.1 $\pm$ 0.2 aA	1.0 $\pm$ 0.1 A
	Olbia	0.9 $\pm$ 0.3 aA	1.0 $\pm$ 0.2 aA	1.0 $\pm$ 0.4 aA	1.0 $\pm$ 0.2 AB
	S. M. la Palma	0.8 $\pm$ 0.3 aA	1.6 $\pm$ 0.4 aA	0.8 $\pm$ 0.2 aA	1.1 $\pm$ 0.2 AB
	San Vito	1.3 $\pm$ 0.3 abA	1.5 $\pm$ 0.4 bA	0.5 $\pm$ 0.1 aA	1.1 $\pm$ 0.2 AB
	Alghero	1.6 $\pm$ 0.5 aA	1.0 $\pm$ 0.3 aA	1.0 $\pm$ 0.3 aA	1.2 $\pm$ 0.2 AB
	Arborea	1.6 $\pm$ 0.6 aA	1.4 $\pm$ 0.3 aA	0.7 $\pm$ 0.3 aA	1.2 $\pm$ 0.2 AB
	Uta	1.3 $\pm$ 0.5 aA	1.8 $\pm$ 0.4 aA	0.7 $\pm$ 0.2 aA	1.3 $\pm$ 0.2 AB
	Serramanna	1.9 $\pm$ 0.6 aA	0.7 $\pm$ 0.2 aA	1.3 $\pm$ 0.6 aA	1.3 $\pm$ 0.3 AB
	Arbatax	1.9 $\pm$ 0.5 aA	1.4 $\pm$ 0.3 aA	1.3 $\pm$ 0.3 aA	1.6 $\pm$ 0.2 AB
	Ozieri	2.5 $\pm$ 0.8 aA	1.7 $\pm$ 0.4 aA	2.1 $\pm$ 0.7 aA	2.1 $\pm$ 0.4 B
	Total	1.4 $\pm$ 0.1 b	1.2 $\pm$ 0.1 ab	1.0 $\pm$ 0.1 a	

the action of a generalist predatory complex during the whole egg-laying period. Observations carried out in Campania have highlighted the potential activity of ants, spiders, ladybugs and pirate bugs as general predators of different *G. brimblecombei* development stages (LAUDONIA *et al.*, 2014), also before the detection of the specific parasitoid *P. bliteus* in the field (LAUDONIA and GARONNA, 2010). An activity of the same predators was sporadically observed also in Sardinia during the monitoring period, though not quantified.

Contrary to our findings for eggs, there was no gradual downward trend over the years for larvae, nymphs and adults, apart from a slight decline from 2014 to 2015. These results could be related to the low effects of *P. bliteus* parasitoid activity on *G. brimblecombei* populations at a regional scale, especially during the first years of monitoring. Environmental conditions favoring *P. bliteus* parasitoid activity are different from those positively influencing *G. brimblecombei*, with a significant reduction in the parasitism rate at high temperatures (FIRMINO, 2004; DAANE *et al.* 2005; 2012; FERREIRA FILHO *et al.*, 2015; CUELLO *et al.*, 2017). Although environmental conditions are heterogeneous in space, we found a general increase in temperatures at regional scale throughout the monitoring years. In fact, despite the temperatures observed in Sardinia in 2013 being in line with those recorded during the previous years (ARPAS, 2014), 2014 and 2015 were characterized by an anomalous increase in average annual temperatures, which were approximately 1 °C higher than historical temperatures (ARPAS, 2015, 2016). This pattern of temperatures may have influenced *P. bliteus* activity within each monitoring year, thus affecting the development and survival on *G. brimblecombei* juvenile stages. Despite this, a positive effect of *P. bliteus* parasitism has been observed in Sardinia immediately after its accidental introduction, which caused a significant decrease in *G. brimblecombei* populations the following year (BUFFA, 2015).

Within each development stage, the seasonal pattern based on abundance was similar among years. However, earlier population peaks were observed in 2014 and 2015 compared to the first year of monitoring. This was particularly evident for eggs, resulting in a regular shift of the *G. brimblecombei* seasonal pattern from the first to the last monitoring year. Changes in the pattern of *G. brimblecombei* dynamics over time might be mainly due to the effects of a general increase in mean temperatures recorded in the Mediterranean area over the last few years (ISPRA, 2016). In particular, the increase in average monthly temperatures in Sardinia, which was significant from 2014 to 2015, was associated with a general decrease in the total annual rainfall (ARPAS, 2014, 2015, 2016). Temperatures and relative humidity are the variables that most affect the abundance of *G. brimblecombei* (FIRMINO, 2004; CUELLO *et al.*, 2018). The development time of the red gum lerp psyllid is strongly associated with temperature, influencing the first instars more than the last ones when in the laboratory they were exposed to temperatures higher than 26 °C (FIRMINO, 2004). Temperatures above 30 °C limit both development and reproduction in laboratory conditions (FIRMINO, 2004). In Mediterranean field conditions, where temperatures above 30 °C also frequently occur in the summer, the reproductive and development rate is more likely to be affected, thus influencing both the abundance and the dynamics of *G. brimblecombei* populations in the field. Hence, the increase in temperatures may accelerate development during spring, while it slows down or stops development in summer.

Differences in abundance of both adults and preimaginal stages were found among locations. Locations where higher

numbers of adults were collected did not necessarily show higher levels of egg infestation and juvenile stages in the same year.

Although the factors affecting *G. brimblecombei* infestations have not been accurately estimated, variability in space may be linked to the combination of both environment and local climatic conditions, such as water availability. In particular, ensuring optimal water conditions to *Eucalyptus* trees during summer and after a period of dryness can indirectly promote *G. brimblecombei* development, as a soft-tissue leaf favors sup-sucking insect feeding (LAUDONIA *et al.*, 2014). However, maintaining tree vigor by hydration can also limit psyllid infestation (PAINE and HANLON, 2010).

CONCLUSIONS

The results of monitoring did not show a significant reduction in psyllid populations, nor did it show a regular spatial pattern at the regional level. This is probably due to variations in environmental climatic conditions (e.g. temperatures) in space and time during the monitoring period, which either positively or negatively affected the pest and its parasitoid. Based on these preliminary results, there is a clear need to improve monitoring activities in order to assess the evolution of *G. brimblecombei* population dynamics. Further control strategies, such as rearing and mass release of *P. bliteus*, should be set up to contain the infestations of red gum lerp psyllid.

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