INTRODUCTION

The bronze bug Thaumastocoris peregrinus Carpintero et Dellapé (Hemiptera: Thaumastocoridae) is a sap-feeding insect native to Australia, which infests plant species belonging to Myrtaceae (Noack et al., 2011). Its common name is due to the symptoms associated with infestation: adults and nymphs feeding on leaves lead to a decrease in the photosynthetic area and leaf discoloration, followed by leaf silverying and tanning (Dias et al., 2014).

Bronze bug infestations cause tree defoliation, branch dieback, and reduction in tree growth, as well as tree death when attacks are particularly severe and prolonged (Jacobs and Neser, 2005; Nadel et al., 2015). T. peregrinus thus represents a potential key pest of different plant species, especially in areas where the insect has been newly introduced.

The bronze bug has been recently found in several areas outside its native range, such as South Africa (Jacobs and Neser, 2005), Argentina (Noack and Coviella, 2006), Uruguay (Martinez and Bianchi, 2010), Brazil (Wilkens et al., 2010), Italy (Laudonia and Sasso, 2012), Portugal (Garcia et al., 2013), and Mexico (Jimenez-Quiroz et al., 2016). Mediterranean and subtropical areas are considered to be the most suitable for T. peregrinus worldwide, as already observed by the analysis of its potential global distribution (Montemayor et al., 2015; Saavedra et al., 2015). Among all potential hosts, T. peregrinus has been generally associated with several Eucalyptus species (Laudonia and Sasso, 2012; Soliman et al., 2012; Garcia et al., 2013), and different development rates and levels of infestation have been observed among the plant species on which it develops (Jacobs and Neser, 2005; Noack and Coviella, 2006; Ide et al., 2011; Soliman et al., 2012; Barbosa et al., 2014; Santadino et al., 2017).

Soliman et al. (2012) showed that the longevity of bronze bug adults varies from 4 to 78 days, and males generally live longer than females. On average, E. urophylla and E. grandis were found to be the most suitable species for the development and reproduction of T. peregrinus under laboratory conditions (Soliman et al., 2012). However, T. peregrinus develops well on other Eucalyptus species, such as E. camaldulensis (Laudonia and Sasso, 2012; Soliman et al., 2012; Garcia et al., 2013), thus leading to severe infestations and serious damages (Jacobs and Neser, 2005; Garcia et al., 2013).

E. camaldulensis is the most important Eucalyptus species cultivated in Italy, and is used as a windbreak and as ornamental plants in parks and gardens, as well as being cultivated for biomass fuel. In Italy, Eucalyptus plantations are located above all in central-southern regions, including Sardinia and Sicily (Dudda et al., 2016).

In Sardinia, E. camaldulensis was introduced at the beginning of the last century and primarily in land
reclamation areas. Today, *Eucalyptus* plantations are predominantly at less than 400 m above sea level (DEIDDA et al., 2016), covering approximately 23,000 hectares and representing one of the main regions for *Eucalyptus* plantations in Italy (GASPARINI and TABACCHI, 2011). *Eucalyptus* trees are commonly found in several agricultural and forest landscapes in Sardinia and their flowers are valuable sources of nectar and pollen (FLORIS et al., 2007). The presence of *T. peregrinus* in such areas has a negative impact on the phytosanitary status of *Eucalyptus*, which has already been affected by several phytophagous species such as psyllids, particularly the red gum lerp psyllid *Glycaspis brimblecombei* Moore (Hemiptera Aphalaridae) (DEIDDA et al., 2016; MANNU et al., 2018).

A monitoring network in Sardinia covering different *Eucalyptus* distribution areas was carried out to: 1) obtain information on the distribution of *T. peregrinus* in Sardinia; 2) evaluate the seasonal abundance and main periods of infestation of bronze bug under Mediterranean conditions. We had already conducted similar study for *G. brimblecombei* (FLORIS et al., 2018; MANNU et al., 2018).

**MATERIALS AND METHODS**

**FIELD SURVEYS AND SAMPLING PROCEDURE**

Field surveys were carried out in 2015 and 2016, and stations were selected to cover the northern, central and southern parts of Sardinia. In 2015, four stations for each macroarea for a total of 12 were monitored, and three stations (one for each macroarea) were surveyed in 2016 (Fig. 1): “Santa Maria La Palma” (Northern), “Ottana” (Central) and “Uta” (Southern). In both years we monitored the “Uta” location as it was the nearest to the first observation site of *T. peregrinus* in Sardinia (DI LASCIO and NANNINI, 2016).

Adults of *T. peregrinus* were monitored in 2015 and 2016 using yellow sticky traps, which are considered to be one of the most effective methods for capturing adults (NADEL et al., 2015). Four yellow sticky traps (20 x 20 cm) were placed in four different *Eucalyptus* trees randomly selected at each location. Traps were positioned on branches located in the middle of the canopy, which is the best position to capture *T. peregrinus* adults (MARTINEZ et al., 2010; NADEL and NOACK, 2012; NADEL et al., 2015).

![Fig. 1 – Distribution of locations constituting the monitoring network of *T. peregrinus* adults and eggs in Sardinia (Italy). Numbers from 1 to 12 indicating each location are sorted according to a North-South gradient (1=”Olbia”; 2=”Santa Maria La Palma”; 3=”Ozieri”; 4=”Alghero”; 5=”Ottana”; 6=“Siniscola”; 7=”Arbatax”; 8=”Arborea”; 9=“Serramanna”; 10=”San Vito”; 11=”Siliqua”; 12=”Uta”). Different colors in the map indicate different geographical areas (Orange=North Sardinia; Green=Central Sardinia; Grey=South Sardinia).](image-url)
The traps were collected and replaced biweekly in the summer and monthly in other seasons. The traps collected in the field were then taken to the laboratory where the T. peregrinus adults were counted.

Observations of eggs were conducted only in 2016. At each location and sampling date, four branchlets of approximately 40 cm in length were collected from the canopy of the four trees. Again, samplings were carried out from the middle of the canopy, as it is also recommended for assessing the density of bronze bug eggs (Martínez et al., 2010; Nadel et al., 2015; Jiménez-Quiroz et al., 2016). Each branchlet was collected separately in a plastic bag and transferred to the laboratory, where the numbers of unhatched eggs were counted under a stereoscopic microscope on both sides of four mature leaves per branch.

**Statistical analysis**

All statistical analysis were performed using R software (R Core Team, 2016). Firstly, abundance data were log(x+1)-transformed to satisfy the normality assumption. In order to explore the effects of location on the abundance of T. peregrinus adults and eggs, a Linear Mixed Model (LMM) was considered for each year using the lmer function of the "lme4" package in R (Bates et al., 2015). Location was considered as the fixed factor, whereas sampling dates and traps were the random factors. Analysis of variance (ANOVA) considering Type II Wald F tests with Kenward-Roger correction of degrees of freedom was used to test the significance of factors, followed by Tukey’s post-hoc test at a significance level of p<0.05 for mean separation.

Finally, a linear regression model approach was used to evaluate the relationship between the average number of eggs and adults captured either at the same or different sampling times. The average monthly numbers of eggs observed in 2016 in all locations were thus compared to those of adults captured either in the same (t), or previous (t-1), or following (t+1) month, by linear regression models. ANOVA was performed to test the significance of the regression models and Pearson’s correlation coefficient was calculated to evaluate the relationship between the variables.

**RESULTS**

Adults of T. peregrinus were captured in all monitored locations in 2015, and statistical differences among locations were found (F_{11,40,257}=20.30; p<0.001). “Serramanna”, “Uta”, “Olbia” and “Arbatax” were the most infested locations, which showed an average monthly number of adults greater than 10 individuals per trap (Table 1). However, five locations showed average values lower than one adult per month compared to all the monitored areas. Statistical differences in adult abundance were also found between geographical areas (F_{2,73.158}=7.37; p<0.001). The highest and the lowest average monthly number of adults captured by traps was observed in south (16.3 ± 3.1) and north (4.2 ± 1.7) Sardinia, respectively.

The seasonal abundance of T. peregrinus in 2015 was similar in all the geographical areas (Fig. II). The population dynamics of adults was comparable in the three geographical areas, showing an increase in the average number of adults in August and a peak in population abundance from September to October in southern and central Sardinia. Although population abundance increased simultaneously in all areas, in northern Sardinia, the number of adults decreased immediately after September.

Significant differences between the three areas were also found in 2016 both for adults (F_{2,9}=14.96; p<0.001) and eggs (F_{2,9}=14.60; p<0.001). The “Ottana” (i.e. central Sardinia) location showed the highest average monthly

### Table 1 – Average monthly number of adults per traps and eggs per branch of T. peregrinus captured at 12 and 3 locations distributed throughout Sardinia (Italy) during 2015 and 2016, respectively. Labels identify each location according to North-South gradient. Values are reported as mean ± standard error. Different letters in a column indicate significant differences in abundance among locations within same year (Tukey’s post hoc test, p<0.05).

<table>
<thead>
<tr>
<th>Label</th>
<th>Geographical area</th>
<th>Location</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Adults</td>
<td>Adults</td>
</tr>
<tr>
<td>1</td>
<td>North Sardinia</td>
<td>Olbia</td>
<td>12.45 ± 3.90 b</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>North Sardinia</td>
<td>S. M. La Palma</td>
<td>0.02 ± 0.02 a</td>
<td>8.36 ± 2.58 ab</td>
</tr>
<tr>
<td>3</td>
<td>North Sardinia</td>
<td>Ozieri</td>
<td>0.09 ± 0.09 a</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>North Sardinia</td>
<td>Alghero</td>
<td>0.02 ± 0.02 a</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Central Sardinia</td>
<td>Ottana</td>
<td>0.03 ± 0.02 a</td>
<td>20.54 ± 5.03 b</td>
</tr>
<tr>
<td>6</td>
<td>Central Sardinia</td>
<td>Siniscola</td>
<td>6.38 ± 1.97 b</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Central Sardinia</td>
<td>Arbatax</td>
<td>11.11 ± 4.00 b</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Central Sardinia</td>
<td>Arborea</td>
<td>0.03 ± 0.02 a</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>South Sardinia</td>
<td>Serramanna</td>
<td>16.67 ± 5.51 b</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>South Sardinia</td>
<td>San Vito</td>
<td>8.72 ± 3.08 b</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>South Sardinia</td>
<td>Siliqua</td>
<td>7.16 ± 2.61 b</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>South Sardinia</td>
<td>Uta</td>
<td>16.48 ± 4.74 b</td>
<td>4.82 ± 1.28 a</td>
</tr>
</tbody>
</table>
values of both adults and eggs compared to the other areas (Table 1). The seasonal abundance of eggs over time was comparable to that of adults in each location (Fig. III). Despite this, adults and egg abundance in “Ottana” reached their peak in August, whereas in other locations an increase in the population of both adults and eggs was observed only after the middle of September. In general, the seasonal abundance of eggs was comparable to that of adults in the same location, with an earlier abundance peak of eggs than of adults.

Finally, the average monthly number of eggs was significantly related to the average number of adults captured in the same month ($F_{1,2e}=29.73; p<0.001$; Pearson’s $R=0.72$) and in the following month ($F_{1,2e}=59.49; p<0.001$; Pearson’s $R=0.84$). On the other hand, no significant relationship was found between eggs and the average number of adults captured in the previous month ($F_{1,2e}=0.62; p=0.43$; Pearson’s $R=0.16$) (Fig. IV).

**DISCUSSION**

*T. peregrinus* is a serious pest of *Eucalyptus* species worldwide (Laudonia and SassO, 2012; Soliman et al., 2012). The presence of the pest in all monitored locations throughout Sardinia ten months after its first recording confirms that the Mediterranean basin is one of the most suitable areas for its settlement (Laudonia and SassO, 2012; Montemayor et al., 2015; Saavedra et al., 2015). The rapid diffusion of *T. peregrinus* in Sardinia after its introduction may be due to both its high passive dispersal ability through wind and human transport (Wylie and Speight 2012; SassO et al., 2014), and its capacity to remain active in the field during all seasons (SassO et al., 2014; Nadel et al., 2015). In Sardinia, the highest population abundance of bronze bug was also observed during the seasonal period characterized by the highest presence of tourists (from August to September), which probably represents one of the most important phoretic means for its spread. However, the insect may also spread during other seasons, as no diapause period has been observed for *T. peregrinus* (Nadel et al., 2015). The spread of *T. peregrinus* adults in the field on a local scale during all seasons, is also probably positively affected by the emission of different volatile compounds from uninfested trees, which are presumed to act as kairomones on mated females (Camila et al., 2013).

The adult population dynamics observed during the first monitoring year in Sardinia was comparable to that reported for other infested regions in Italy (SassO et al., 2014). In 2015, the adult dynamics followed the same pattern in all three areas in Sardinia, despite the different environmental conditions of the monitored locations (Deidda et al., 2016; Mannu et al., 2018). However, a few differences in population dynamics, as well as seasonal abundances, were found from area to area in the second year. Although in southern Sardinia seasonal abundances decreased from the first to the second year, the adult population dynamics did not show a different pattern compared to 2015. In contrast to this, an increase in seasonal abundance was observed both in central and northern Sardinia, likely indicating the spatial expansion of *T. peregrinus* population throughout the Island, in line with the typical pattern of an invasive alien (non native) species (Andow et al., 1990). In fact, biological invasions are always characterized by three time-steps (1) introduction of the invasive species, (2) its establishment, and (3) spatial expansion into new areas (Elton, 1958).

In addition, the adult dynamics recorded in 2016 in central Sardinia was different to those of northern and southern Sardinia observed in the same and previous years. Population dynamics and seasonal abundance are generally affected by different factors, including management and environmental conditions, which both directly and indirectly influence other *Eucalyptus* pest species (Laudonia et al., 2014; Mannu et al., 2018). Of these, water availability, especially during the summer, is considered one of the most influencing factors as it allows a good foliage development which might influence su- sucking insect feeding (Laudonia et al., 2014).

Finally, the high correlations obtained between the average number of eggs and the average number of adults...
could be particularly useful for improving monitoring activities. They could enable adult population abundance of the bronze bug to be predicted in the short-term, particularly from the perspective of biological control, e.g. using the specific egg parasitoid *Cleruchoides noackae* Lin and Huber (Hymenoptera: Mymaridae) (Barbosa et al., 2017).

**CONCLUSIONS**

In Sardinia *T. peregrinus* is now well established throughout the island just two years after its introduction. The presence of bronze bug complicates the health of Eucalyptus plantations, which are already being affected by the presence of various phytophagous and several phytopathogens (Deidda et al., 2016). This highlights the need to take phytosanitary measures to contain and limit the entry of other new species which could lead to irreversible ecological changes and economic losses. In accordance with Italian legislation, we are now evaluating the possibility of introducing the specific egg parasitoid *C. noackae*, due to its promising potential for the biological control of *T. peregrinus* (Barbosa et al., 2017).

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