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ORIGINAL PAPER

Overwintering mortality of the oak lace bug (*Corythucha arcuata*) in Hungary – a field survey

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Abstract

The North American oak lace bug (*Corythucha arcuata*) was first discovered in Europe (Norhern Italy) in 2000. It started a rapid area expansion in the last decade and has been reported in 20 countries so far. Almost all European oaks are suitable hosts. On top of the host availability, abiotic factors like weather/climate may also have a decisive impact on its further spread and future outbreaks. We conducted a simple field survey within three years, at five locations to estimate the overwintering mortality of the species. Our results suggest that not even a relatively harsh winter (as 2016/2017) caused severe mortality in the overwintering populations. The average mortality of the nine year/location combinations was 30.6% (range 9.1–58.5%). Based on this, the low winter temperature is unlikely to restrict its further spread, therefore continuing area expansion can be predicted.

Key words: invasive insects; area expansion; climate change; abiotic limitation; overwintering success

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1. Introduction

Alien species are appearing at an accelerated rate worldwide, including European countries (Roques 2010; Csóka et al. 2010; 2012; Tuba et al. 2012; Smith et al. 2018). While some of them do not have any evident impact in the newly colonized areas, others may become invasive, rapidly expanding their area and imposing severe pressure on the invaded area's ecosystems both from an economic and an ecological point of view. The chance of a non-native species becoming invasive strongly depends on the suitability of the environmental conditions including availability of host plants (Csóka et al. 2019; Paulin et al. 2020), effects of native natural enemies (Csóka et al. 2009; Panzavolta et al. 2018; Kos et al. 2020). The weather and climate may also be decisive factors from the point of the establishment and the future of the established populations. Different weather parameters may have different impacts on the different life stages of insects (Neuvonen & Virtanen 2015). Among many others, overwintering success is an extremely important issue (Leather et al. 1993; Marshall et al. 2020; Vétek et al. 2020). Cold winter temperatures have both lethal and sub-lethal impacts on overwintering insects (Turnock & Fields 2005; Scaccini et al. 2020). Any information on the overwintering success of a new non-native insect is vital to make predictions on its further spread and expected importance.

Insects can be classified as either freeze-tolerant or freeze-intolerant (or freeze-avoidant). The extracellular freezing is not lethal for the freeze-tolerant, they regularly freeze between −5 to −10 °C, or at even lower temperature. After this they can be cooled to far lower temperatures (some species even as low as −50 °C). With temperature increase they thaw and recover showing normal functions and development (Bale 1993). The freeze intolerant (freeze-avoidant) insect may avoid freezing by lowering their super cooling point (SCP). SCP is the lower lethal temperature for the freeze-avoidant, since the ice formation is intracellular (Sinclair et al. 2015). On top of the extreme low temperature many other factors may have significant effect on the insects' survival (Sinclair et al. 2003).

The North American oak lace bug (*Corythucha arcuata* (Say 1832) – Heteroptera: Tingidae) is a recent invader in Europe, first discovered in Italy in 2000 (Bernardinelli et al. 2000). In the last decade, it showed an explosive area expansion and has been reported from 20 European countries (Paulin et al. 2020). As almost all native deciduous oaks are suitable hosts for the oak lace bug (OLB), at least 30 million hectares of oak for-

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ests provide acceptable hosts for it in Europe (Csóka et al. 2019). Although there are major gaps in knowledge concerning the further spread and damage of the OLB, it seems potentially very dangerous both from an economic and an ecological point of view (Nikolic et al. 2019; Csóka et al. 2019; Paulin et al. 2020).

OLB adults stop feeding in late autumn (October/November) and migrate to their overwintering microhabitats. These are under raised bark, bark crevices, branch forks covered by leaf litter, etc. Overwintering adults are rarely found on the soil surface under the leaf litter, but the vast majority of the overwintering bugs use tree trunks, branches and dead logs on the ground. No overwintering larvae have been found in Hungary so far. They finish overwintering and climb up on the trees starting from early/mid-April. It is assumed that the mild winters and early spring might help the further area expansion and outbreaks. However this is not yet supported by scientific results and no published information are known on temperature demands of OLB either.

In order to obtain information on its overwintering success, we conducted a simple field survey within three years at five Hungarian locations already invaded by the OLB. The finding of the first year's survey was already published (Csepelényi et al. 2017), but its results have also been incorporated in this study.

2. Methods

Adult oak lace bugs were collected from their overwintering microhabitats in the second half of March prior to their emergence (early/mid-April). In all three years, at all locations samples were taken from at least ten trees, normally providing different overwintering microhabitats (raised bark, bark crevices, branch forks covered by leaf litter, etc.). Sampling dates differed between years and locations mainly due to different spring weather conditions. The main aspect was to sample before the bugs leave the overwintering microhabitats, since the late sampling would have overestimated the mortality. Locations, dates of samplings and sample sizes are provided in Table 1. After keeping the bugs at room temperature (20–22 °C) for 24–36 hours, living and dead bugs were counted. Temperature dates were obtained either from local meteorological stations or from the daily reports of the Hungarian Meteorological Service. Based on these data, the following temperature variables were calculated/considered:

- Average temperature of the period (average of the daily average temperatures).
- Average of the daily minimum temperature of the period.
- The lowest temperature measured in period.
- Lowest 10-day running average of the daily minimum temperatures in the period.

The "period" always means the time window from December 1st until the last day prior the sampling date. For example, December 1st 2016 – March 15th 2017 at Gyula. Measured and calculated temperature variables are provided in Table 2.

Mortality rates were correlated with the meteorological variables listed above.

3. Results

Mortality rates of the 9 year/location combinations (presented in Table 3) ranging from 9.1% to 58.5% show considerable variation. The average of all combinations merged is 30.6%.

None of the four meteorological variables gave any significant correlation with the mortality rates at 95% significance level.

Table 1. Sample sizes (number of adult *C. arcuata*) and sampling dates (in bracket) in three years at five locations.

Winter/Location	Békéscsaba 46.6728°N 21.1431°E 85 m a.s.l.	Gyula 46.6940°N 21.3350°E 86 m a.s.l.	Mátrafüred 47.8308°N 19.9658°E 355 m a.s.l.	Szarvas 46.8759°N 20.5314°E 87 m a.s.l.	Szolnok 47.2042°N 20.1814°E 86 m a.s.l.
2016/2017	3,187 (03.20–24)	201 (03.16)	—	683 (03.30)	
2018/2019	—	1,329 (03.20)	386 (03.29)	—	4,929 (03.21)
2019/2020	—	2,582 (03.19)	1,816 (03.19)	—	2,519 (03.20)

Table 2. Temperature variables within three years at five locations.

Temperature variables	Winter/Location	Békéscsaba	Gyula	Mátrafüred	Szarvas	Szolnok
Average of daily average temperatures	2016/2017	0.7	0.1	—	0.9	—
	2018/2019	—	2.4	2.0	—	2.8
	2019/2020	—	3.1	2.4	—	4.3
Average of the daily minimum temperatures	2016/2017	−2.8	−3.3		−2.8	
	2018/2019	—	−1.2	−1.3	—	−0.9
	2019/2020	—	−0.8	−0.7	—	1.1
The lowest temperature measured	2016/2017	−19.0	−18.0	—	−19.0	
	2018/2019	—	−7.7	−9.3	—	−13.0
	2019/2020	—	−9.5	−10.1	—	−8.0
Lowest 10 days running average of the daily minimum temperatures	2016/2017	−8.1	−7.5		−7.5	
	2018/2019	—	−3.1	−6.6	—	−3.9
	2019/2020	—	−3.1	−2.5	—	−1.2

Table 3. Percentage of dead *C. arcuata* in samples collected in three years at five locations.

Winter/Location	Békéscsaba	Gyula	Mátrafüred	Szarvas	Szolnok	Average
2016/2017	21.4%	51.7%	—	44.1%	—	39.1%
2018/2019	—	58.5%	18.7%	—	44.6%	40.6%
2019/2020	—	13.0%	9.1%	—	14.4%	12.2%
Average	—	41.7%	13.9%	—	29.5%	30.6%

4. Discussion

Bernardinelli (2006) compared the climatic conditions of the OLB's native range (Eastern USA and Canada) and Europe and concluded that most of Europe's climate may allow the further spread of the species. Zielinska & Lis (2020) concluded that the climate in Southern Poland is suitable for the OLB, and the presence/abundance of oak forests may also increase the chance of its establishment. Our results seem to support their conclusions.

The mortality rates did not show significant correlation with our four meteorological variables. The 9 data points is likely not enough to reveal correlations if they are any. But it is already evident that the mortality rates are rather low, even during a relatively harsh winter (2016/2017).

It is clear that the overwintering mortality rates are influenced by many factors other than the extremely low winter air temperature. The state of the overwintering microhabitats (tree exposure, thickness of bark, etc.), number of thaw-freeze transitions, rate of temperature change, cumulative chill injury might be very different, resulting in different chances of survival (Sinclair et al. 2003).

The availability and quality of the pre-overwintering food quality also have important roles, both in the success of overwintering and the post-overwintering performance, as demonstrated by Zvereva (2002) for the leaf beetle, *Chrysomela lapponica* and by Trudeau et al. (2010) for *Malacosoma disstria*.

In warm periods during overwintering, insects may use their energy sources and this can have negative impacts on them on the longer term (Hahn & Denlinger 2011; Sinclair 2015). It can be particularly important for insects starting overwintering with low energy reserve. In other words, insects starving before overwintering will have a lower chance to survive and even if they survive, they will have less resource to use for post-wintering activities (dispersal, mating, etc.). The relative importance of this aspect is likely becoming more important as warmer periods during winters are becoming more frequent.

In case of the OLB, the pre-overwintering starvation seems likely for location/year combinations we studied (except Mátrafüred 2018/2019). The abundance of the OLB was always high enough for overexploitation of food sources by late summer or early autumn, resulting in a uniform discoloration and desiccation of foliage on large contiguous territories. In this situation, the majority of the population either starved or had to feed on other secondary hosts (*Rubus*, *Acer*, etc.). But even so, the mortality rates remained relatively low. This may mean that winter low winter temperature itself is unlikely to restrict the further spread to the East, North and West.

Jun et al. (2010) studied the supercooling point (SCP) and the cold hardiness of the closely related *Corythuca ciliata* in China, where this species is an invasive pest of *Platanus* trees. The average SCP was −11.49 °C for males and −9.54 °C for females. They found *C. ciliata* freeze-intolerant, but chill-tolerant, tolerating subzero temperatures by supercooling. It worth mentioning that supercooling points of a given species' individuals may show considerable variation geographically, monthly and inter annually as it was demonstrated by Vétek el al. (2020) for the invasive *Aproceros leucopoda* (Hymenoptera: Argidae). No similar information is known yet for the OLB, although our related cooperative experiments are already in progress.

5. Conclusions

Based on the results, the low winter temperatures themselves do not seem to restrict the further area expansion of the oak lace bug towards North, West or East. However, many factors other than winter temperature can influence the overwintering mortality of the oak lace bug. Additional studies (both in field and laboratory) are needed to clarify the potential climatic limitation of the further spread.

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