Bulletin of Insectology ***61*** *(1): 67-71, 2008*
ISSN 1721-8861

Overwintering of common green lacewings in hibernation shelters in the Hallertau hop growing area

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Abstract

During three winters from autumn 2002 to 2005, hibernation shelters for green lacewings (*Chrysoperla* spp.) were deployed at various sites in the Hallertau hop-growing area in Bavaria, Germany. Exposure sites were the wooden trellis support poles of two hop gardens and, nearby, a hill ridge, a sheltered topographic depression, a forest margin, a small forest clearing and a fallow boundary strip. A total of 39 shelters were examined in January during the three years, and the total of 5162 hibernating lacewings present were identified, sexed and counted. More *Chrysoperla* spp. overwintered each winter in the shelters on hop poles than at any other position. The mean numbers ranged from 238 to 336 lacewings per shelter. *Chrysoperla carnea* was the dominant species, *Chrysoperla pallida* was also common, and only few specimens of *Chrysoperla lucasina* were identified. The sex ratio of *C. carnea* in the shelters was significantly female biased, whereas significantly fewer females than males of *C. pallida* were found, and in *C. lucasina* the sex ratio was not significantly different. Overall mortality was 0.9%.

Key words: Neuroptera, Chrysopidae, *Chrysoperla*, green lacewings, hibernation, hops, Hallertau.

Introduction

Cultivated hop plants (*Humulus lupulus* L.) are regularly attacked by several arthropod pests. In Europe, the most prevalent are damson-hop aphid *Phorodon humuli* (Schrank) and two-spotted spider mite *Tetranychus urticae* Koch. Historically, hop farmers have had no alternative other than to apply insecticides and acaricides at regular intervals against these pests. The vertical structure of hop cultivation with plant heights of from two to seven meters, depending on the region and the cropping system, creates a difficult target for good pesticide coverage so frequent applications are often necessary. This reliance on pesticides for decades has stimulated the development and selection of pest resistance to those compounds (Neve, 1991). Furthermore, environmentally more compatible methods of plant protection are demanded by the public and are needed to break the cycle of selection for pesticide-resistant aphid and spider mite strains.

As in any other crop, a keystone for following an integrated pest management strategy in hop culture is the utilization and the promotion of naturally occurring antagonists. In the Hallertau hop growing region 85 insect taxa have been identified as natural predators or parasitoids of hop pests. Among those beneficials are 10 species of brown lacewings (Hemerobiidae) and 15 species of green lacewings (Chrysopidae) that are of special importance as predators of both *P. humuli* and *T. urticae*. High numbers of *Chrysoperla* spp. are found regularly in hop fields (Weihrauch, 2006). Preliminary data regarding the overwintering of green lacewings where reported by Weihrauch (2005).

At harvest, hop plants are cut down and transported away to be picked, a procedure that disrupts opportunities for overwintering in hop fields by many insect and other arthropod groups. The aim of the present study was to evaluate the suitability in hop culture of a proven successful design of lacewing hibernation shelter from the neuropterological literature (e.g. Şengonca and Frings, 1987; 1989; Frings and Şengonca, 1988; Şengonca and Henze, 1992; McEwen, 1998; McEwen and Şengonca, 2001), so as to promote overwintering by these beneficials. The key questions addressed were: which lacewing species will use hibernation shelters, and to what extent? How severe is natural mortality in the shelters during winter? What is the sex ratio of hibernating lacewings? Are sites for shelters in hop gardens preferred to those in surrounding habitats by lacewings?

Materials and methods

Study area and study sites

The study was conducted in the Hallertau, Bavaria, Germany. The Hallertau is the world's largest coherent hop-growing region, where hops in 2006 were cultivated on 14,280 ha or 29% of the world's area of this crop (Hopsteiner, 2006). The Hallertau is situated south of the River Danube in the central part of Bavaria and has an area totalling approximately 1,500 km².

Two hop gardens of two farms and their surroundings were chosen as study sites:

- Ursbach, Kelheim district, 48°46'36''N, 11°55'55''E, 426 m above sea level (a.s.l.), was a 1.0 ha organically managed garden, bordered by hops, hilly grassland, and dry mixed woodland on a hill (site used during all three winters).
- Buch, Kelheim district, 48°40'52''N, 11°42'55''E, 450 m a.s.l., was a 2.3 ha conventionally managed garden, bordered by hops, grassland, coniferous woodland, and fallow land (site used in the second and third winters only).

Hibernation shelters

Design and construction of the shelters followed the detailed instructions given by Şengonca and Frings (1987; 1989), Frings and Şengonca (1988), McEwen (1998), McEwen and Şengonca (2001) and Ç. Şengonca (personal communication). The shelters were constructed using 10 mm thick plywood boards as cubiform, ventilated boxes with 30 cm side lengths. The front and lower surfaces remained partially open, and were made from five slats (width 4 cm) on the front, and six on the bottom, in order to allow unhindered access by insects. The top cover overhung the front side by 4 cm to provide some protection from precipitation. An angle bracket was attached to the back side for the fixing of the shelters in the field. Finally the shelters were painted with matt-finished red-brown dispersion varnish for wood, and packed loosely with oat straw prior to placement in the field.

Experimental design

Thirty-two hibernation shelters were exposed during each of the three winters 2002/2003, 2003/2004 and 2004/2005.

In the first winter, 16 shelters were fixed approximately 160 cm above ground to 16 adjacent wooden poles of the trellis system of the hop garden at Ursbach on August 30, 2002, i.e., one day before harvest began in this field. Eight shelters were exposed at the same altitude above ground in a row on wooden fence poles driven into ground and separated by approximately 2 m from each other on an open hill ridge, and a corresponding set of eight shelters in a topographic depression protected from wind. Both rows were situated at a distance of 200 to 250 m from the hop field and set up on September 4, 2002. According to the recommendations of Şengonca and Henze (1992), McEwen (1998) and McEwen and Şengonca (2001), all 32 shelters were oriented northeast, i.e., opposite the prevalent wind direction at these sites. On December 17, 2002 all shelters were removed from the field and stored in an open, cool, dark barn.

In the second winter, 10 shelters were exposed as before in the hop gardens at Ursbach and Buch, respectively, four in a forest margin (Ursbach), four in a small forest clearing (Ursbach) and four in a fallow boundary strip (Buch). All chosen sites were at a maximum distance of 100 m from the hop gardens. All shelters were deployed before harvest on August 26, 2003, and removed for storage in the cool, dark barn on December 15, 2003. In the third winter the setting of shelters was similar, except that the forest margin was omitted, and the numbers of shelters in each hop field was increased to 12 instead. Shelters were deployed before harvest on August 24, 2004, and removed for storage in the barn on December 14, 2004.

Laboratory analysis of contents

During January of each of the three winters, four (only 2002/2003) or three shelters from each sampling position were taken to the laboratory for inspection of the contents. The contents of the remaining shelters were released during May in hop fields, and the oat straw was renewed for the following exposure period during August. A total of 39 shelters were inspected in the three years' study: twelve in the first, 15 in the second and 12 in the third winter.

Shelters for inspection were chosen without bias and transported from the barn, where they were stored under January temperatures, i.e., usually below 0 °C, to the laboratory. There the top cover was removed and the packed straw was emptied into a 70x70x90 cm insect rearing cage with Plexiglas windows that could be opened on the front side. The contents of the cage were searched straw by straw for hibernating lacewings. The specimens were then stored in 70% ethanol. The inner sides of the opened shelters were also searched for any lacewings that remained in hibernation rigour. Dead lacewings and other arthropods found in the straw were also recorded.

Finally, all ethanol-stored lacewing specimens were identified, sexed and counted. Species identification within the *Chrysoperla carnea* complex was performed by morphological characters, according to details given by Thierry *et al.* (1992; 1998), Duelli (1995) and Henry *et al*. (2001; 2002): *Chrysoperla lucasina* was identified by the presence of a lateral, brownish-black dash in the pleural fold of abdominal segment 2. *C. carnea* differs from *Chrysoperla pallida* by having black setae on the posterior abdominal segments, and a black bar on the stipes of the maxillae, whereas *C. pallida* has hyaline setae on the abdomen and stipes either without black mark or with a mark not exceeding 25% of the stipe length.

Taxonomy

There is an ongoing debate, yet to be resolved, among neuropterists on the correct identity of the European taxa that had formerly been ascribed to *Chrysoperla carnea* sensu lato, especially the taxa that are associated with the courtship song patterns "Cc2" ("slow motorboat") and "Cc4" ("motorboat") (Duelli, 1995). Henry *et al.* (2002) assigned "Cc4" to *Chrysoperla carnea* (Stephens) sensu stricto, whereas Canard and Thierry (2007) assigned "Cc4" to *Chrysoperla affinis* (Stephens). Concurrently, Henry *et al.* (2002) described "Cc2" as a new species under the name of *Chrysoperla pallida* Henry, Brooks, Duelli et Johnson, whereas Canard and Thierry (2007) assigned the same taxon to *Chrysoperla carnea* (Stephens) sensu stricto. Hence, the latter name is attributed either to the "Cc2" or "Cc4" courtship song pattern, depending on the point of view. Only the identities of "Cc1" as *Chrysoperla lucasina* (Lacroix) and "Cc3" as *Chrysoperla agilis* Henry, Brooks, Duelli et Johnson seem unambiguous. Hopefully this confusing situation in terminology will be resolved eventually by the International Commission of Zoological Nomenclature. In the meantime, I have used the nomenclature proposed by Henry *et al.* (2002), because it currently seems to have the widest acceptance. From a personal point of view, this decision is supported by the fact that the most common taxon in *Chrysoperla carnea* sensu lato found on hops thus will keep the name that I had been using previously for this sibling species complex for almost two decades.

Results

A total of 5162 *Chrysoperla* individuals were found in the 39 hibernation shelters examined in winters in the three years, 1323 from 12 shelters in 2002/2003, 2251 from 15 shelters in 2003/2004 and 1588 individuals from 12 shelters in 2004/2005. No lacewings other than *Chrysoperla* spp. were found in the shelters.

Influence of exposure site on the colonisation of shelters

Shelters on poles of the hop trellis system were chosen for hibernation significantly more frequently than those in neighbouring habitats by *Chrysoperla* spp. (table 1) at both sites every year. The mean numbers of lacewings from hop garden shelters ranged from 238 to 336 with much lower numbers elsewhere. With the exception of the low numbers in the forest margin in 2003/4, there were no significant differences between numbers in shelters situated outside of the hop gardens.

Species composition and sex ratio

C. carnea was the dominant species during all three winters with a total 4491 individuals (87.0%); *C. pallida* was represented by 651 individuals (12.6%) and *C. lucasina* was by far the rarest species in the shelters with only 20 individuals (0.4%) (table 2). A higher proportion of female than male *C. carnea* overwintered (2693 vs 1798) ($\chi^2 = 198.4$; $P < 0.001$) unlike *C. pallida* which had fewer females than males in the shelters (243 vs 408) ($\chi^2 = 41.8$; $P < 0.001$).The sex ratio of *C. lucasina* in hibernation shelters (13 females vs 7 males) was not significantly different from a ratio of 1:1 ($\chi^2 = 1.8$).

Mortality

A total of 11 dead lacewings were found in five of the 12 shelters examined in January 2003 (0.8%); 22 from 12 of 15 shelters opened in January 2004 (1.0%) and 14 from 12 of 15 shelters in January 2005 (0.9%), making the overall average mortality in the three winters 0.9%.

Accompanying fauna in the shelters

The lacewings in the 39 shelters examined were regularly accompanied by flies (Brachycera), with an average of 21.4 (0 to 87) individuals per shelter, and spiders (Arachnida), with an average of 4.3 (0 to 11) individuals. In addition, the shelters yielded nine ladybird beetles *Adalia bipunctata* (L.) and 13 other undetermined beetles (Coleoptera), 10 anthocorid and two mirid bugs (Heteroptera: Anthocoridae, Miridae), eight imagines of tortricid moths (Lepidoptera Tortricidae), one tiger moth caterpillar (Lepidoptera Arctiidae), one barklouse (Psocoptera) and 10 ichneumonid wasps including one individual of the giant sabre wasp *Rhyssa persuasoria* (L.) (Hymenoptera Ichneumonidae) as co-hibernating taxa.

Discussion

The separation of alcohol-stored specimens of *C. carnea* from those of *C. pallida* was not always straightforward. Although reportedly good morphological characters separate the two species according to the neuropterological literature (Duelli, 1995; Thierry *et al.*, 1992; 1998; Çaldumbide *et al.*, 2001; Henry *et al.*, 2001; 2002; Gruppe, 2002), approximately 3% of identifications here were uncertain. Hence, in table 2 only definite *C. pallida* (with almost exclusively hyaline setae on the abdomen) are listed under this taxon, whereas almost 150 specimens showed an overlap of the assumed distinguishing characters. Those with a black bar on the stipes not more than 25% of their length, but the majority of abdominal setae black were assigned to *C. carnea*. Gruppe (2002) encountered similar problems in a series of alcohol-stored specimens from the same region, and in 3.8% of cases was not able to identify an individual conclusively to species. However, characters separating *C. lucasina* from the two other species were consistent and reliable.

The percentage of the three *Chrysoperla* spp. in the shelters during hibernation seems to mirror the actual proportion that can be found during summer: Gruppe

Table 1. Mean (± standard error) numbers of *Chrysoperla* spp. per hibernation shelter (n = number of shelters examined per site), at exposure sites in the Hallertau region during three winters. Means within a column followed by the same letter are not significantly different by ANOVA, at p<0.001.

locality/winter	2002/2003 (n = 4)	2003/2004 (n = 3)	2004/2005 (n = 3)
Ursbach, hill ridge	45.8 ± 32.43 a		
Ursbach, depression	31.0 ± 17.98 a		
Ursbach, forest margin		21.0 ± 3.61 a	
Ursbach, clearing		53.3 ± 12.50 b	22.0 ± 10.60 a
Buch, fallow boundary strip		86.7 ± 18.01 b	28.0 ± 4.60 a
Ursbach, hop trellis poles	254.0 ± 17.17 b	253.0 ± 38.22 c	238.0 ± 29.80 b
Buch, hop trellis poles		336.3 ± 113.01 c	241.3 ± 119.60 b

Table 2. Species composition of *Chrysoperla* spp. in hibernation shelters exposed at various sites in the Hallertau region during three winters (% in parentheses).

species/winter	2002/2003 (n = 1323)	2003/2004 (n = 2251)	2004/2005 (n = 1588)	summarized (n = 5162)
C. carnea	1297 (98.0 %)	1899 (84.4 %)	1295 (81.5 %)	4491 (87.0 %)
C. lucasina	3 (0.2 %)	10 (0.4 %)	7 (0.4 %)	20 (0.4 %)
C. pallida	23 (1.7 %)	342 (15.2 %)	286 (18.0 %)	651 (12.6 %)

(2002) examined 1279 *Chrysoperla* specimens from southern Bavaria and found 84.7% were *C. carnea*, 9.5% *C. pallida* and 2.0% *C. lucasina*. In Hungary, Bozsik (2006) examined 2010 specimens of the assessed natural *Chrysoperla* spp. population and found almost identical proportions of 83.0% *C. carnea* (listed as *C. affinis*), 12.1% *C. pallida* (listed as *C. carnea*) and 2.5% *C. lucasina*. In the French Loire valley, Thierry *et al*. (2002) using hibernation shelters of a different design found 111 overwintering individuals of *C. carnea* [listed as *Chrysoperla kolthoffi* (Navas)], five *C. pallida* (listed as *C. carnea*), and one *C. lucasina*, a similar proportion of species to that found here in hops. These proportions are also supported by Trouvé *et al*. (1999) who found that *C. carnea* (listed as *C. kolthoffi*) was by far the dominant chrysopid species of agroecosystems in Pas-de-Calais, northern France, constituting 75.0% of all green lacewings in summer, whereas *C. pallida* (listed as *C. carnea*) comprised 3.1%. On the other hand, under examination of natural hibernation sites of lacewings (e.g. limp and convoluted chestnut leaves, brushwood, ivy) in the Loire valley, Thierry *et al*. (1994) found that 41.1% were *C. carnea*, 55.7% *C. pallida*, and 3.3% *C. lucasina*. Hence, *C. carnea* is much more ready than the other two species, to accept man-made structures for hibernation, as it was formerly assumed for *C. carnea* s.l. in general (Gepp, 1967). According to Thierry *et al*. (1994), *C. pallida* in the Loire valley prefers limp, convoluted leaves and tussocks of ivy for hibernation and *C. lucasina* is found almost exclusively under ivy in winter, whereas *C. carnea* prefers anthropogenic shelters such as barns or attics. This may be an additional factor for the dominance of the synanthropic *C. carnea* in my man-made shelters. As a predominantly arboreal species (Duelli *et al*., 2002; Canard, 2005), a different specific overwintering strategy can be assumed for *C. pallida*.

The significantly female biased sex ratio of *C. carnea* in the shelters either indicates that more females than males distinctly choose these sites for hibernation, or - probably more likely - that in a population of *C. carnea* during winter the proportion of females is generally higher, because females have a lesser pre-hibernation mortality than males. On the other hand, there is no reasonable explanation for the opposite, significantly male biased proportion of *C. pallida* in the shelters. Under consideration of the above-mentioned almost 150 critical specimens it cannot be excluded that this result was influenced by a sex biased error concerning *C. pallida* during the discrimination of species.

The accompanying fauna found to hibernate in the shelters gives evidence that these structures are not utilised by many other beneficials. An exception is probably the ladybird *A. bipunctata*, which to my personal experience also has an affinity for overwintering in and around houses.

The numbers of *Chrysoperla* spp. found in the shelters from the hop poles were generally higher than in earlier studies of other habitats. Annual averages between 238 and 336 hibernating lacewings, with a maximum of 407 individuals per shelter, were recorded here whereas Thierry *et al*. (2002) recorded a maximum of 30 individuals in their shelters, McEwen *et al*. (1998) recorded 58 individuals per shelter, Bozsik (2006) recorded a maximum of 63 individuals per shelter, and Şengonca and Henze (1992) found averages of 117 to 224 individuals, with a maximum of 289 per shelter. Only Frings and Şengonca (1988) recorded partly higher numbers of overwintering lacewings in their "green lacewing chambers", with average numbers of up to 447 individuals.

The lacewing winter mortality in the shelters of 0.9% is low, but in line with previous studies. Frings and Şengonca (1988) found a mortality of 1.9% at the beginning of winter, and Şengonca and Henze (1992) recorded mortality rates of 0.7 to 4.0% in their chambers. However, it has to be taken into account that the mortality in the shelters does not represent the actual winter mortality, because the actual survival rate appears only when overwintering females will oviposit in spring. In conclusion, the *Chrysoperla* hibernation shelters investigated here may enhance successful overwintering of lacewings in regions where natural shelters are scarce. This may be the case in large areas of predominantly monocultures, including regions where hop growing is concentrated. Pest control in a hop garden equipped with hibernation shelters may not necessarily benefit directly from the lacewings that overwinter within it as female *Chrysoperla* adults perform obligate preovipository migration flights (Duelli, 1984). Although it is not known whether this is in effect for females after diapause, most will have probably dispersed before aphid migration to hop starts, normally in the latter half of May. However, the provision of hibernation shelters for lacewings is likely to prove beneficial to any region that is characterised by large-scale agricultural areas or monocultures by enhanced natural control of pest arthropods, particularly aphids.

Acknowledgements

This study was part of a research project funded by the Bavarian State Ministry for Agriculture and Forests, Munich. My sincere thanks go to Professor Dr Çetin Şengonca, Bonn, for his advice in the design of the hibernation shelters; to Dr Axel Gruppe, Freising, for his advice in the discrimination of the three species in the *C. carnea* complex; to Dr Colin A. M. Campbell, Ditton, for polishing my English and commenting the manuscript; and to the hop growers Bartholomäus Obster, Buch, and Georg Prantl, Ursbach, for letting me use their hop gardens for this study. Earlier versions of the manuscript of this – according to my own categorisation – modest little entomological study benefited during review processes from comments of several anonymous peers, obviously renowned members of the neuropterists' community. Accordingly, the revision was a highly challenging experience for the author.

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Received October 8, 2007. Accepted March 14, 2008.