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Parasitisation of *Yponomeuta malinellus* feeding on *Crataegus monogyna* in the allotment gardens in the city of Poznań, Poland

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Abstract: The apple ermine moth (*Yponomeuta malinellus* Zeller) is an economically important pest of apple trees and apple orchards. It is also a pest of ornamental trees and shrubs in urban habitats. The aim of our study was to determine the degree of parasitisation of the apple ermine moth pupae collected from the common hawthorn (*Crataegus monogyna* Jacquin) in the allotment gardens in Poznań, Poland, by parasitoids from the Ichneumonidae family, to determine parasitoid species and the dates when they start flying. Judged from the parasitisation of pupae, the parasitoids reduced the apple ermine moth population by 9.1% over the period 2014–2016. The apple ermine moth pupae were parasitised by the following six parasitoid species: *Gelis areator* (Panzer), *Herpestomus brunnicornis* (Gravenhorst), *Itoplectis alternans* (Gravenhorst), *I. maculator* (Fabricius), *I. tunetana* (Schmiedeknecht), and *Pimpla turionushtana* (Linnaeus). The most effective entomophages *H. brunnicornis* and *I. tunetana* reduced the apple ermine moth population by 3.2% and 2.7%, respectively. Our results suggest that the apple ermine population in urban allotment gardens exposed to heavy anthropogenic pressure can be reduced by parasitoids of the Ichneumonidae family. The degree of parasitisation of the moth in this particular urban habitat may be comparable to the degree of its parasitisation in orchards.

Keywords: Ichneumonidae; parasitoids; pupae; greenery areas

The apple ermine moth (*Yponomeuta malinellus* Zeller) (Lepidoptera: Yponomeutidae) is an economically important pest of apple trees and apple orchards within Europe and Asia (Unruh et al. 1993; Kuhlmann et al. 1998). In North America the moth is reported as an invasive species (Parker & Schmidt 1985; Antonelli 1991). The larvae of the apple ermine moth eat the leaves of their hosts, entwine tree branches with yarn and reduce the yield of crops (Kot 1964; Parker & Schmidt 1985). This species mostly feeds on apple trees (*Mallus* Miller) in orchards and less frequently on pear trees (*Pyrus*

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Linnaeus) and cherry trees (*Prunus avium* Linnaeus) (Menken et al. 1992; Kuhlmann et al. 1998; Lee & Pemberton 2005; Narmanlioğlu & Çoruh 2017). In urban habitats it can also cause damage to ornamental trees and shrubs such as willows (*Salix* Linnaeus), poplars (*Populus* Linnaeus), blackthorns (*Prunus spinosa* Linnaeus), rowans (*Sorbus aucuparia* Linnaeus), and hawthorns (*Crataegus* Linnaeus). Various hawthorn species, especially the common hawthorn (*Crataegus monogyna* Jacquin), are utilized as ornamental hedges in allotment gardens in urban areas. City dwellers value the common hawthorn for its decorative, white and cream flowers gathered in subumbellates. The larvae of the apple ermine moth, gnawing leaves and flowers completely, inhibit the growth of their hosts and reduce their decorative value. The population of this pest in orchards needs to be controlled chemically with the crop protection products. It is very difficult or impossible to control the apple ermine moth in urban areas by using pesticides due to the presence of people and animals. However, the apple ermine moth feeding in this environment can be reduced by its natural enemies such as parasitoids. They parasitise the eggs, larvae, and pupae of the apple ermine moth (Kot 1964; Hérard & Prévost 1977; Kuhlmann 1996; Kuhlmann et al. 1998; Cossentine & Kuhlmann 2000; Lee & Pemberton 2005; 2007; 2010; Yu et al. 2012; Žikić et al. 2018).

No study investigated comprehensively the parasitisation of preimaginal (developmental) stages of the apple ermine moth feeding in orchards and urban green spaces in Poland. The only research on the matter was conducted in the apple orchards near Warsaw (Kot 1964). Our study carried out in the allotment gardens in the city of Poznań, exposed to heavy anthropogenic pressure, was aimed to determine the degree of parasitisation of the apple ermine moth pupae on the common hawthorn by parasitoids from the Ichneumonidae family, to determine parasitoid species and the dates when they start flying.

MATERIAL AND METHODS

Locality. The study was conducted in the allotment garden complex located in Piątkowska Street in the city of Poznań (52°42'93''N, 16°91'59''E) between 2014 and 2016. The garden complex is approximately 4.85 ha in area. It is located 2.57 km from the geographical centre of the city of Poznań in the immediate vicinity of high-density development with a low proportion of green space (30.5%). The whole area is exposed to heavy anthropogenic pressure. The average annual concentrations of PM10 (a mixture of particulate matter with a diameter of 10 μm or less) range from 25.0 to 29.9 μg/m^3. In total 159 species of vascular plants were recorded in the allotment garden complex. During the study no chemical crop protection products were applied in the allotment gardens.

Method. In late June and early July 2014, 2015 and 2016 branches of the common hawthorn with the apple ermine moth pupae on them were cut out. A total of 1 000 pupae were collected from the branches at random every year. The branches were then placed in isolators and the pupae were bred in the insectarium of the Department of Entomology and Environmental Protection, Poznan University of Life Sciences, Poland. Containers with water were placed in the isolators to increase the air humidity. The pupae were monitored every day to record flight activity of parasitoids. The species of parasitoids were identified according to the key by Kasparyan (1981).

There were similar weather conditions in individual years of the study, specifically in 2014 and 2015. The years 2014 and 2015 were warmer than the year 2016. In July 2014 and August 2015 the highest air temperatures were recorded. In each year the spring and summer months were warm. There were similar air temperatures in the spring and summer of particular years, but in May and June 2016 they were higher (Figure 1).

Data analysis. The chi-squared test of independence (Agresti 2007) was employed (analysis of count data) to find out whether or not the variables parasitisation of the apple ermine moth pupae and time were independent. The nonparametric Kruskal-Wallis test (Hollander & Wolfe 1973) was used to compare the parasitisation of the apple ermine pupae by species of the Ichneumonidae family between individual years of the study (compared groups – Table 1). The Dunn multiple comparison test with the Holm-Šidák correction (Holm 1979) was used to compare individual pairs of the parasitoid species according to their share in the parasitisation of the host throughout the study period. The principal component analysis of raw abundances of parasitoid species

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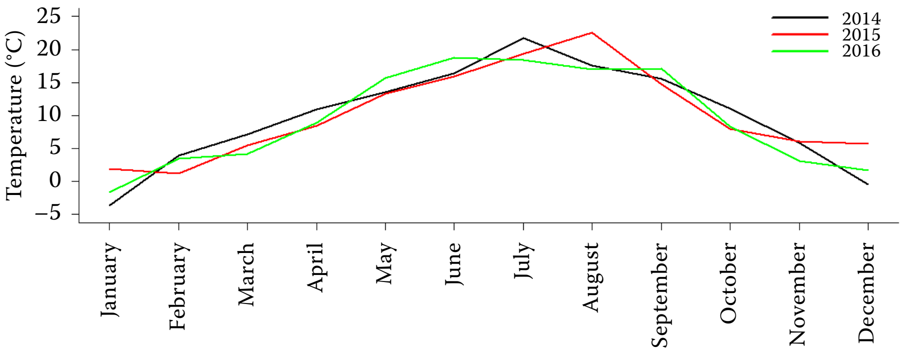

Figure 1. Average monthly air temperatures in particular year of the study

was used to illustrate the qualitative and quantitative structure of the parasitoid species in individual years of the study. The principal component analysis results were presented as a biplot (Jolliffe & Cadima 2016). The R software (version 4.0.3) was used for statistical calculations (R Core Team 2020).

RESULTS

Between 2014 and 2016 a total of 3 000 the apple ermine moth pupae were collected from the allotment gardens in Poznań. Of them, 2 648 (88.3%) pupae developed into butterflies, 78 (2.6%) pupae dried out, and 274 (9.1%) pupae were parasitised by species of the Ichneumonidae family (Table 1). The parasitisation level was low. In 2014 and 2015 the parasitisation was very similar – 6.3% and 7.2%, but in 2016 it was higher – 13.9%. The parasitisation rate over the period 2014–2016 was 9.1%. The variables parasitisation of the apple ermine moth pupae and time were not independent (χ^2 = 41.554, df = 2, P < 0.000 1). Statistically significant differences were detected in the degree of parasitisation of the apple ermine moth pupae between individual years of the study (Kruskal-Wallis χ^2 = 44.399, df = 5, P < 0.000 1).

The apple ermine moth pupae were parasitised by six species of parasitoids (Table 1). In each year of the study the following four species of parasitoids decreased the apple ermine moth population: *Herpestomus brunnicornis* (Ichneumoninae), *Itoplectis maculator, I. tunetana*, and *Pimpla turionellae* (Pimplinae). *Herpestomus brunnicornis* and *I. tunetana* parasitised the apple ermine moth pupae most effectively, reducing the pest population by 3.2% and 2.7%, respectively. The other parasitoids were less effective, decreasing the apple ermine moth population by 0.1–1.9% (Table 1).

The results of the Dunn multiple comparison test with the Holm-Šidák correction showed that the majority of the compared species differed from each other in their share in the parasitisation of the

Table 1. The parasitisation of *Yponomeuta malinellus* pupae by parasitoids of the Ichneumonidae family in the allotment gardens in Poznań, 2014–2016

Species	Years			
	2014	2015	2016	2014–2016
Cryptinae				
Gelis areator (Panzer)		2 (0.2%)		2 (0.1%)
Ichneumoninae				
Herpestomus brunnicornis (Gravenhorst)	30 (3.0%)	15 (1.5%)	50 (5.0%)	95 (3.2%)
Pimplinae				
Itoplectis alternans (Gravenhorst)	2 (0.2%)		8 (0.8%)	10 (0.3%)
Itoplectis maculator (Fabricius)	6 (0.6%)	8 (0.8%)	12 (1.2%)	26 (0.9%)
Itoplectis tunetana (Schmiedeknecht)	11 (1.1%)	19 (1.9%)	53 (5.3%)	83 (2.7%)
Pimpla turionellae (Linnaeus)	14 (1.4%)	28 (2.8%)	16 (1.6%)	58 (1.9%)
Total parasitisation	63 (6.3%)	72 (7.2%)	139 (13.9%)	274 (9.1%)

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Table 2. The Dunn multiple comparison test showing the parasitisation of *Yponomeuta malinellus* pupae by parasitoids of the Ichneumonidae family in the allotment gardens in Poznań, 2014–2016

Species 1	Species 2	Dunn *z*-test statistics	Method Holm-Šidák
Gelis aerator	*Herpestomus brunnicornis*	–4.094	*
Gelis aerator	*Itoplectis alternans*	–0.465	ns
Gelis aerator	*Itoplectis maculator*	–1.321	ns
Gelis aerator	*Itoplectis tunetana*	–3.798	*
Gelis aerator	*Pimpla turionellae*	–3.302	*
Herpestomus brunnicornis	*Itoplectis alternans*	4.619	*
Herpestomus brunnicornis	*Itoplectis maculator*	3.892	*
Herpestomus brunnicornis	*Itoplectis tunetana*	0.428	ns
Herpestomus brunnicornis	*Pimpla turionellae*	1.106	ns
Itoplectis alternans	*Itoplectis maculator*	–1.067	ns
Itoplectis alternans	*Itoplectis tunetana*	–4.244	*
Itoplectis alternans	*Pimpla turionellae*	–3.604	*
Itoplectis maculator	*Itoplectis tunetana*	–3.480	*
Itoplectis maculator	*Pimpla turionellae*	–2.781	*
Itoplectis tunetana	*Pimpla turionellae*	0.683	ns

Method – adjusts the *P*-value for multiple comparisons using the Holm-Šidák (Holm 1979) adjustment; ns – not significant
*Significant at $P \leq 0.05$

host throughout the study period (Table 2). These were the following pairs of species:

- *Gelis areator* compared with *H. brunnicornis*, *I. tunetana*, and *P. turionellae*;
- *H. brunnicornis* compared with *I. alternans* and *I. maculator*;
- *I. alternans* compared with *I. tunetana* and *P. turionellae*;
- *I. maculator* compared with *I. tunetana* and *P. turionellae*;
- *I. tunetana* compared with *P. turionellae.*

The principal component analysis showed that *H. brunnicornis* dominated the apple ermine moth parasitoid complex in 2014 and 2016. This means that occurrence of this entomophage was strongly

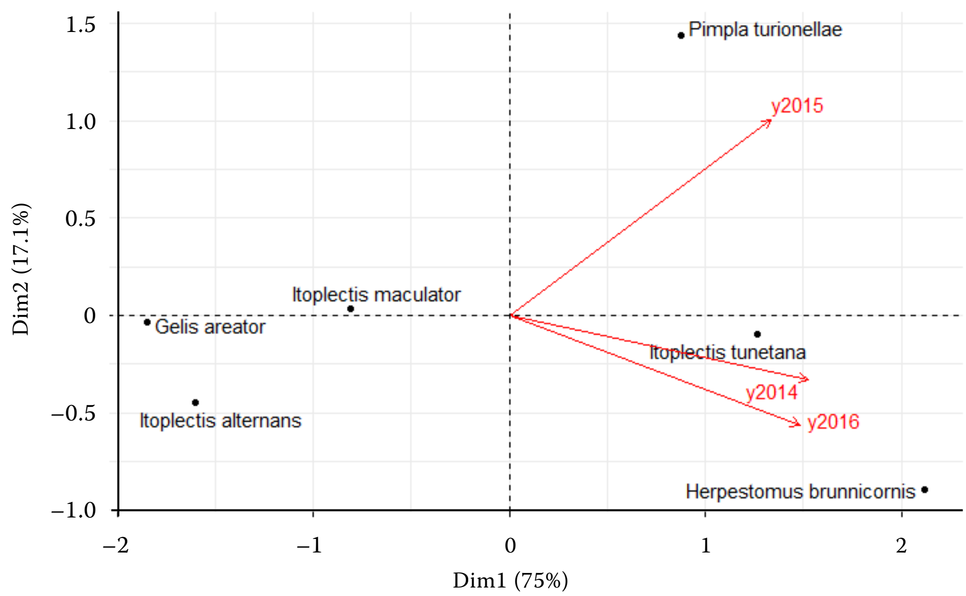

Figure 2. A principal component analysis biplot showing the distribution of parasitoids of the Ichneumonidae family in 2014, 2015 and 2016

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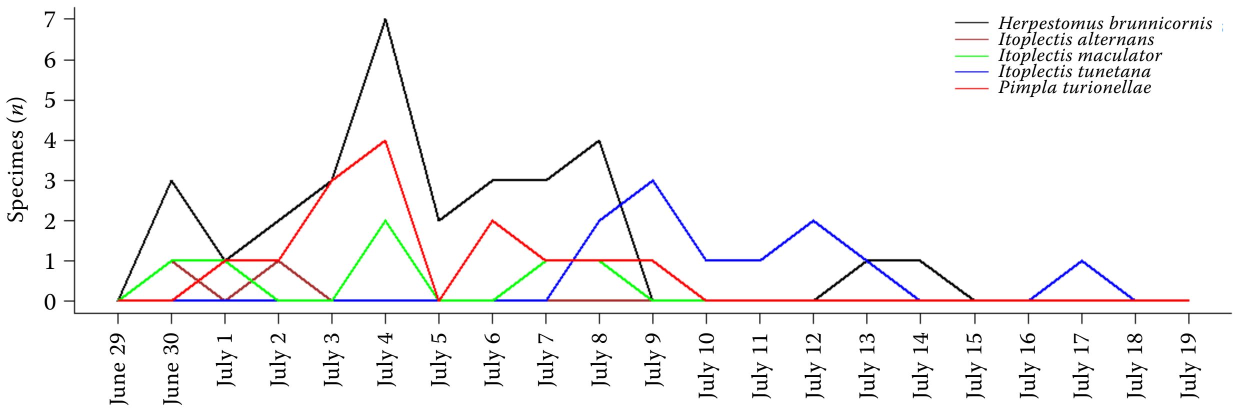

Figure 3. The emergence of parasitoids from *Yponomeuta malinellus* pupae in 2014

associated with that of the host. In 2015 *P. turionellae* was the most abundant parasitoid species, whereas in 2016 *I. tunetana* was predominant (Figure 2).

In 2014 the parasitoids started flying in late June and their flight activity ended in mid-July (Figure 3). The first species to appear were as follows: *H. brunnicornis*, *I. alternans* and *I. maculator*. The last specimens emerging from the apple ermine moth pupae were those of *H. brunnicornis*. The parasitoids' flights peaked in early July.

In 2015 the parasitoids' flights began and ended in the same period as in 2014 (Figure 4). The representatives of *H. brunnicornis* were flying first. The last flying specimens were represented by *H. brunnicornis* and *P. turionellae*. The parasitoids' flights peaked in mid-July.

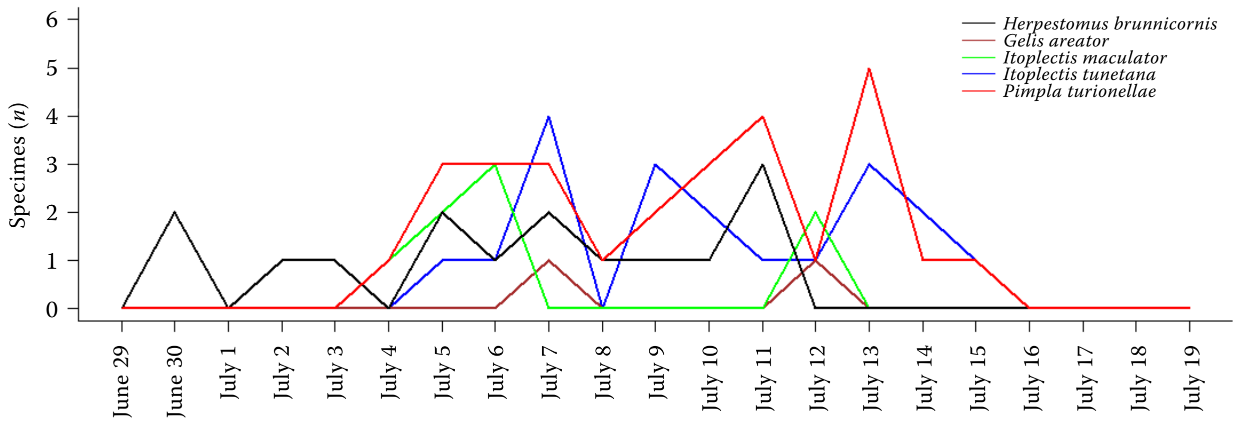

Figure 4. The emergence of parasitoids from *Yponomeuta malinellus* pupae in 2015

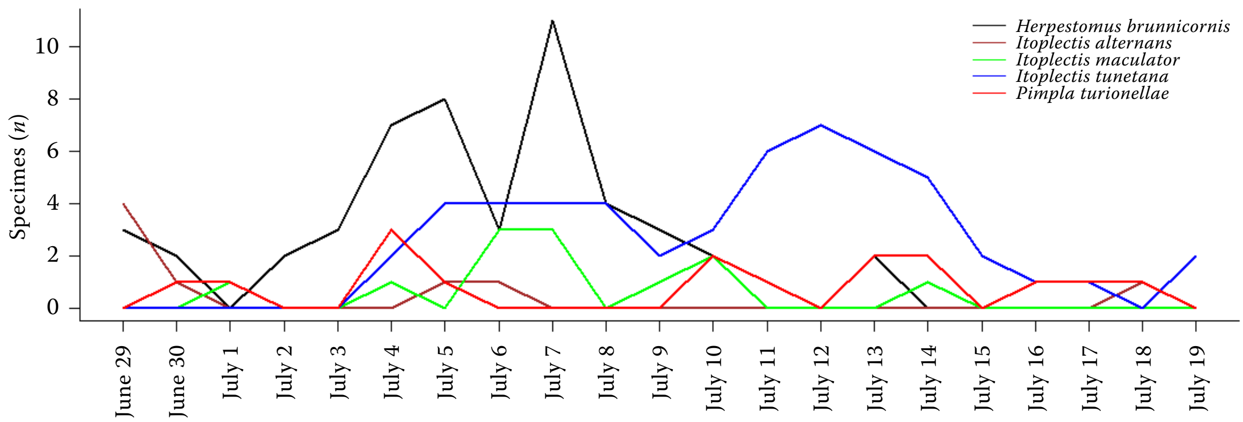

Figure 5. The emergence of parasitoids from *Yponomeuta malinellus* pupae in 2016

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In 2016 the parasitoids' flights began and ended as in the previous years (Figure 5). The first species to appear were *H. brunnicornis* and *I. alternans*. The representatives of *H. brunnicornis* were the last ones to fly. The peak of the parasitoids' flights was in early July.

DISCUSSION

Our study showed that between 2014 and 2016 there was a low parasitisation rate of the apple ermine moth pupae collected from the common hawthorn in the allotment gardens in Poznań, which were exposed to heavy anthropogenic pressure. Parasitoids from the Ichneumonidae family reduced the apple ermine moth population only by 9.1% over the study period. In 2016 the reduction was higher than in the previous years – 13.9%. The degree of parasitisation may have been influenced by the weather conditions in the spring months of 2016. Lee and Pemberton (2010) conducted a study on apple orchards in northeastern Asia and observed that the rate of parasitisation of the apple ermine moth pupae was highly diversified. The highest parasitisation rate (38.5%) was noted in Korea. The parasitisation rates in apple orchards in Japan amounted to 17.2% and 10.1%, which was similar to the results of our study. The lowest parasitisation rate (2.1%) was recorded in China. Kuhlmann (1996) observed that the apple ermine moth population in orchards in Germany was reduced by 19.0% and 13.1%. The further study by Kuhlmann et al. (1998) showed a similar parasitisation rate in that region – the apple ermine moth population was reduced by 11–14%.

The study by Narmanlioğlu and Çoruh (2017) on the total parasitisation of the apple ermine moth population in apple orchards in the Çoruh valley, Turkey, showed that parasitoids reduced it by 25.5%. The study conducted by Kot (1964) in apple orchards near Warsaw showed that the total parasitisation rate of the apple ermine moth population usually ranged from 3.7% to 43.5%.

Lee and Pemberton (2005) studied the parasitisation of the apple ermine moth larvae in northeastern Asia where various parasitoid species decreased the apple ermine moth population by 9.3–22.7%. Another study by Lee and Pemberton (2007) in that region showed that parasitoids reduced the population of the apple ermine moth larvae by 20.1–24.0%. Kot (1964) studied the parasitisation of younger larval stages in apple orchards near Warsaw and found that the parasitisation rate ranged from 2.4% to 33.1%.

Three of the recorded species, *I. alternans*, *I. maculator* and *P. turionellae*, are polyphagous pupal endoparasitoids. *Itoplectis tunetana* is a pupal endoparasitoid of the Lepidoptera. *Herpestomus brunnicornis* is a larval and pupal endoparasitoid of species of the Plutellidae, Yponomeutidae, and Tortricidae (Lepidoptera) families. *Gelis areator* is a larval and pupal endoparasitoid of the representatives of Lepidoptera, Hymenoptera and Diptera. It is also classified as a hyperparasitoid which parasitises the representatives of Braconidae and Ichneumonidae (Hymenoptera) families (Yu et al. 2012).

Our research showed that six species of parasitoids from the Ichneumonidae family reduced the population of the apple ermine moth pupae. The *H. brunnicornis* and *P. turionellae* species were also found in this host in Poland by Kot (1964). The other species were bred from the apple ermine moth in Poland for the first time. All the parasitoid species were found in this host by Yu et al. (2012).

Our research clearly showed that the apple ermine moth population was most effectively reduced by the *H. brunnicornis* and *I. tunetana* parasitoid species, i.e. by 3.2% and 2.7%, respectively. There were similar results of the study by Gençer (2003) who found that *H. brunnicornis* and *I. tunetana* parasitised and reduced the apple ermine moth population in apple orchards in Sivas, Turkey, by 3.4% and 3.6%, respectively. Kuhlmann (1996) conducted a study in apple orchards in Germany and found that the parasitisation rate of the apple ermine moth pupae by *H. brunnicornis* ranged from 3.0% to 9.0%. Kot (1964) observed that *H. brunnicornis* reduced the number of the apple ermine moth pupae in apple orchards near Warsaw by up to 49.7%. Narmanlioğlu and Çoruh (2017) conducted a study in apple orchards in the Çoruh valley, Turkey, and found that *I. tunetana* was one of the dominant species in the apple ermine moth parasitoid complex. Its share amounted to 11%.

Our study confirmed the presence of *I. maculator* and *P. turionellae* in the apple ermine moth parasitoid complex. Narmanlioğlu and Çoruh (2017) found that *I. maculator* was the dominant species (16%) among the apple ermine moth parasitoids in apple orchards in the Çoruh valley, Turkey. The study conducted by Kot (1964) in orchards near Warsaw showed that *P. turionellae* was one of the two species parasitising the apple ermine moth pupae. This species reduced the pest population by 3.7%.

Our study showed that *H. brunnicornis* was the most numerous species among apple ermine moth entomophages and that it was the most strongly associated with this host and the environment of allotment gardens in the city of Poznań despite the heavy anthropogenic pressure. The effectiveness of *H. brunnicornis* in reducing the apple ermine moth population was comparable to the rate of parasitisation of this pest in apple orchards in Germany and Turkey (Kuhlmann 1996; Gençer 2003). There was an attempt to use this species for the biological control of apple orchards in the northwest of Washington State, USA (Unruh et al. 2003).

The results also showed that *H. brunnicornis*, *P. turrionellae* and *I. tunetana* were dominant species in the consecutive years of the research. The dominance of these species proves their stability in this biocoenosis.

In our study the peak of flights of the parasitoids developing from the apple ermine moth pupae was in early and mid-July. Specimens of the *H. brunnicornis* species were the first and last to appear in all years of the research.

It may be concluded that the population of the apple ermine moth feeding on the common hawthorn in allotment gardens in an urban agglomeration affected by heavy anthropogenic pressure can be limited by parasitoids from the Ichneumonidae family. The effectiveness of these parasitoids in reducing the apple ermine moth population is comparable to the effectiveness of these entomophages in an orchard environment.

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