https://doi.org/10.17221/53/2019-PPS

Predicting aphid abundance on winter wheat using suction trap catches

Alois Honěk[1], Zdenka Martinková[1], Marek Brabec[2], Pavel Saska[1]*

[1]*Crop Research Institute, Prague-Ruzyně, Czech Republic*
[2]*Department of Statistical Modelling, Institute of Computer Science AS CR, Prague, Czech Republic*
**Corresponding author: honek@vurv.cz*

Citation: Honěk A., Martinková Z., Brabec M., Saska P. (2020): Predicting aphid abundance on winter wheat using suction trap catches. Plant Protect. Sci., 56: 35–45.

Abstract: The relationship between the number of cereal aphids in flight (recorded by a national grid of suction traps in the Czech Republic) and their occurrence on winter wheat (in Prague) was established between 1999–2015. The flight of all the species was bimodal. Except for *Rhopalosiphum padi*, whose flight activity peaked in autumn, > 80% of individuals were trapped during April to mid-August. The species frequency was different between the winter wheat and aerial populations. *R. padi*, the dominant species in the trap catches, formed a small proportion of the aphids on the winter wheat, while *Sitobion avenae* and *Metopolophium dirhodum*, which were underrepresented in the suction traps, alternately dominated the populations on the wheat. The aphid abundance in the wheat stands was correlated with the suction trap catches in the "spring" peak (April to mid-August), and the maximum flight activity occurred 4–10 days after the peak in the number of aphids on the wheat. In contrast, the prediction of the aphid abundance in the wheat stands using the total suction trap catches until the 15th of June (the final date for the application of crop protection actions) was reliable only for *M. dirhodum*. Its maximum abundance on the wheat exceeded 40 aphids per tiller if the total suction trap catch until the 15th of June was ≥ 60 individuals per trap. The prediction of *R. padi* and *S. avenae* abundance using the suction trap catches was not reliable.

Keywords: *Triticum aestivum*; *Metopolophium dirhodum*; *Rhopalosiphum padi*; *Sitobion avenae*; flight

In central Europe, cereal crop stands are colonised by three abundant aphid (Hemiptera: Aphididae) species, *Rhopalosiphum padi* (L. Linnaeus, 1758), *Metopolophium dirhodum* (Walker, 1849) and *Sitobion avenae* (Fabricius, 1775). As important pests, they deserve extensive research attention (Vickerman & Wratten 1979; Dixon 1987; Dedryver *et al.* 2010). These species are native in the Holarctic and have been introduced to South America, South Africa and Australia, which are regions where cereals and maize are intensively cultivated (Blackman & Eastop 1984). In central Europe, these species are holocyclic and dioecious when overwintering on Rosaceae (*R. padi*, *M. dirhodum*) (Dixon 1971; Hand & Williams 1981) or monoecious overwintering on Poaceae (*S. avenae*) (Müller 1977). The fundatrices hatch in March–April, and the next few generations then live on the primary hosts. In May, alate migrants move to stands of small-grain cereals and maize (Bode 1980; Leather & Walters 1984), where several generations of their offspring grow in number until late June – early July, when their populations collapse because of alate emigration (Howard & Dixon 1992) and mortality (Honěk

Supported by the Ministry of Agriculture of the Czech Republic, project No. QK1910281.

https://doi.org/10.17221/53/2019-PPS

1991; Honěk *et al.* 1998; Honěk & Martinková 2004) caused by the worsening host plant quality, the onset of diseases and the actions of natural enemies. The migrants then populate alternative hostplants (e.g., grasses, bulrushes, and cereal volunteers), where they survive until the autumn migration to the primary hosts, which takes place in September to October (Blackman & Eastop 1984).

Dispersal and migration by flight, thus, constitutes a regular and important part of the cereal aphid life cycle. The factors involved in the flight activity have been extensively studied in different aphid species (Johnson 1969; Kring 1972). The alate individuals may begin flying after the teneral period. A portion of the individuals then take flight, aiming to move to new hostplant stands. Other than these long-distance fliers, most alate individuals make short flights among neighbour hostplants within stands (Moericke 1955). The amount of take-off activity depends on the light intensity, temperature and wind speed. Active flying can last for a few hours, but aphids may be captured in moving aerial masses and be passively transported over long distances (Johnson 1969).

In cereal aphids, the migration from and to primary hosts is carried out by individuals called alate "migrants", and movements within and among stands of secondary hosts are carried out by alate "exules" A proportion of the individuals that are capable of sustained flight may become a component of the "aerial plankton", which is the assemblage of airborne organisms that are unable to maintain their flight independently of the movement of air masses. The fliers captured in aerial plankton assemblages can be transported for a long distance and colonise hostplant stands not yet occupied by aphids. The number of aphids in the aerial plankton is, thus, a proxy for the ability of aphids to colonise new habitats and, thus, is useful for predicting the development of the aphid abundance. The process of sampling aerial plankton aphid populations was standardised by using Johnson-Taylor suction traps (Johnson 1969; Taylor 1972). The trap is a chimney-shaped suction device with an opening at a height of 12.2 m. The trap attracts aphid migrants flying above the approximately 9 m high boundary layer of air where aphids are behaviourally conditioned to move (Taylor 1960; Carter 1961) and samples the aerial plankton at the height where its composition is not determined by the local conditions, but reveals the mean aphid abundance and temporal fluctuation over a large area (Davis *et al.* 2014). This trapping makes it possible to monitor population changes and anticipate the pest potential of aphids at a regional level (Taylor 1977).

The relationship between the aphid abundance in the cereal stands and the catches in the suction traps has been extensively investigated. The suction trap catches reflect the emigration of the alate aphids following the build-up of the aphid populations in particular areas (Cochrane 1980; Clark *et al.* 1992; Elberson & Johnson 1995; Davis *et al.* 2014). The annual and seasonal variation in the catches was recorded and analysed in western (Hullé *et al.* 1994), southern (Coceano *et al.* 2009), central (Ruszkowska & Zlotkowski 1977; Węgorek & Stacherska 1977) and northern Europe (Kirchner *et al.* 2013). The geographic differences in the timing of the aphid migration reveals the variation in the aphid performance among the regions with different climatic conditions (Dewar *et al.* 1980; Zhou *et al.* 1995; Basky & Harrington 2000).

In this paper, we used the 15-year data on the flight activity of cereal aphid species collected by the national grid of suction traps run in the Czech Republic and maintained by the Central Institute for Supervising and Testing in Agriculture and the data of aphid abundance in the plots of winter wheat grown at the Crop Research Institute at Prague-Ruzyně (CRI). We addressed four issues: (*i*) the seasonal patterns of the flight activity in the particular species as revealed by the suction trap catches, (*ii*) comparing the species composition of the aphid populations in the suction trap catches and in the winter wheat stands, (*iii*) establishing the relationship between the aphid abundance on the winter wheat stands on the ensuing size of the suction trap catches and (*iv*) predicting the abundance in the winter wheat stands from the suction trap catches.

MATERIAL AND METHODS

Aphids in the suction traps. The flight of the aphids was monitored by a national grid of suction traps operated by the Central Institute for Supervising and Testing of the Czech Republic. The grid consists of five standard Johnson-Taylor suction traps (12.2 m high), which were placed at Čáslav (49.902N, 15.409E, 260 m a.s.l.), Chrlice (49.121N, 16.634E, 190 m a.s.l.), Lípa (49.552N, 15.535E, 505 m a.s.l.), Věrovany (49.470N, 17.671E, 207 m a.s.l.) and Žatec (50.302N, 13.519E, 285 m a.s.l.). The map of the trap positions and more geographic details are available

https://doi.org/10.17221/53/2019-PPS

at http://eagri.cz/public/web/ukzuz/portal/skodlive-organismy/aphid-bulletin/. The suction traps are placed in different agricultural production areas in the country. They are operated in March–November, and weekly catches of the particular aphid species are published in the "Aphid Bulletin" (Anonymous 2018). This periodical publishes weekly catches of 16 aphid species of economic importance and of a mixed sample of aphids not identified to the species level. The aphid catches are summed over the civil calendar weeks starting from Monday to Sunday. In this paper, the weeks are marked by the median Julian day of the weekly sampling interval. To compare data from the particular periods among years (the numbers of aphids trapped over a particular sampling period), the aphid numbers were summed starting from the week whose median Julian day immediately exceeded the lower limit of the selected sampling interval until the week whose median Julian day fell just short of the upper limit of the sampling interval.

For each week, the mean values of the aphid numbers were calculated. We used (*i*) the data from all the suction traps. These data were used to study the seasonal patterns of the flight activity. (*ii*) The data from the suction traps nearest to the experimental wheat plots at CRI in Prague-Ruzyně, i.e., the suction traps at Žatec (65 km in distance from the experimental winter wheat plots) and Čáslav (80 km in distance), which are also placed in similar landscape conditions and crop growing regions. These data were used to compare the average species abundance in the suction trap catches and the aphid numbers on the winter wheat.

Aphids in the wheat stands. The aphid abundance on the winter wheat crops was established using the counts conducted in the production stands at Prague-Ruzyně in the western part of the Czech Republic (50.086N 14.294E, at 320–360 m a.s.l.). The wheat stands were cultivated in accordance with the recommended agriculture practices (Špaldon 1982). No insecticides were applied during the study, and the fungicides and liquid fertilisers were sprayed early in the season before the aphids arrived. Every year, several 5 × 10 m plots were placed on a line transect across a wheat field, 30–50 m apart, with a 30 m minimum distance from the field margin. The number of plots varied, but in most years, there were three replicates. The plots were split into 5 × 5 m sub-plots where the wheat was cleared in mid-April (the crop density at the time of the maximum aphid abundance was 40–45 tillers/m^2) and 5 × 5 m sub-plots where the crop stand production was left intact (a crop density of 270–290/m^2). Since the aphid numbers in the cleared stands were greater than those in the dense stands (Honěk & Martinková 1999; 2002), this design increased the spatial diversity of the aphid abundance and contributed to estimating the range that was likely to occur in the production stands. Each year, the weekly aphid counts were conducted on 30–300 tillers per plot during the 6–10 weeks that the aphids were present in the wheat, and the maximum abundance (the cumulative number of the individuals on the leaves and ears) of the particular aphid species in the particular plots was ascertained.

Data analysis. The flight season was divided into three periods: period 1 (P1) from the initiation of the flight activity to the 31st of May, period 2 (P2) from the 1st of June to the 15th of August, and period 3 (P3) from the 16th of August to the termination of the flight activity. The periods P1 and P2 together were further called the "spring flight season", and P3 was called the "autumn flight season". P1 was the season for the migration from the winter hosts to the crop stands (cereals and maize) limited by the extinction of the populations on the winter host plants (Leather & Walters 1984; Leather 1993). P2 was the season for the migration among crop stands and from the crop stands to the alternative summer host stands, and P3 was the season for the migration among the alternative host stands and from the alternative host stands to the winter crops and the primary hosts. The transition between P1 and P2 was characterised by a swift change in the size of the suction trap catches at the beginning of June, and P2 and P3 were distinguished by the temporal reduction in the suction trap catches around mid-August. The justification for the periods is further examined in the first part of the Discussion.

To calculate the regression of the maximum species abundance in the winter wheat stands on the spring flight activity, we used the catch data from the start of the flight activity until the 15th of June. This deadline was used because this is the latest time period when the crop development still enables protection measures (Špaldon 1982) because it precedes the term of the maximum aphid abundance by 2–3 weeks (Honěk *et al*. 2017; 2018).

The problems addressed in this study were solved by several methods. (*i*) The seasonal pattern of the flight activity of the particular species was established by plotting the weekly catch data in the particular years over a time scale (Julian days). (*ii*) The annual variation in the species abundance in the suction

https://doi.org/10.17221/53/2019-PPS

trap catches (the percentage of each species in the total catch) was calculated using the data from the spring period from the traps at Žatec and Čáslav. The annual variation in the species abundance was calculated using the average maximum abundances of this species in the winter wheat plots at Prague-Ruzyně. (*iii*) To compare the aphid catch data in the subsequent periods, we calculated the regression of the catch in P2 on the catch in P1 (indicating the effect of the aphid abundance on the winter hosts on the abundance on the crops) and the catch in P3 against the catch in P2 (indicating the effect of the abundance on the crops on the abundance of the autumn population). (*iv*) To establish the relationship between the aphid abundance in the wheat stands and in the suction trap catches during the spring season, we regressed the average catches of Čáslav and Žatec on the maximum aphid abundance in the wheat plots at Prague-Ruzyně. (*v*) To detect the relationship between the spring suction trap catches and the maximum abundances on the winter wheat, we regressed the average maximum abundances of the particular species at the plots in Praha-Ruzyně against the average catches over the spring period before the 15th of June for the traps at Čáslav and Žatec. The statistical analyses were performed using SigmaStat 3.5 software (version 2006).

RESULTS

Seasonal pattern of the flight activity. The annual catches in the suction traps and maximum abundances in the wheat stands differed among the aphid species and varied among the years by one order of magnitude (Table 1). The seasonal distributions of the flight activity of a particular species, as revealed by the suction trap catches, was consistent over the 17-year period of observation (Figure 1). In all the species, the pattern of the flight activity was bimodal. The spring flight season started in April, the flight activity peaked in early July and declined before mid-August. In the autumn flight season, the flight activity began to increase in late August, peaked in late September–early October and terminated in November. The magnitude of the catches in the particular flight P1 to P3 varied (Figure 2). For all the aphid species, the catches in P1 represented only 1–3% of the total annual catch. The catch in period P2 represented a dominant proportion of the annual catch for *M. dirhodum* (86%) and *S. avenae* (87%), while for *R. padi,* it represented only 36% of the total annual catch. In the autumn flight period, the P3 catch of *R. padi* represented 63% of the total, while the catches of *M. dirhodum* (12%) and *S. avenae* (11%) were smaller. The regressions of the catches in P2 on those in P1 and the catches in period P3 on those in period P2 were not significant, except for a positive regression of the catch in period P2 on the catch in period P1 for *R. padi* (Table 2).

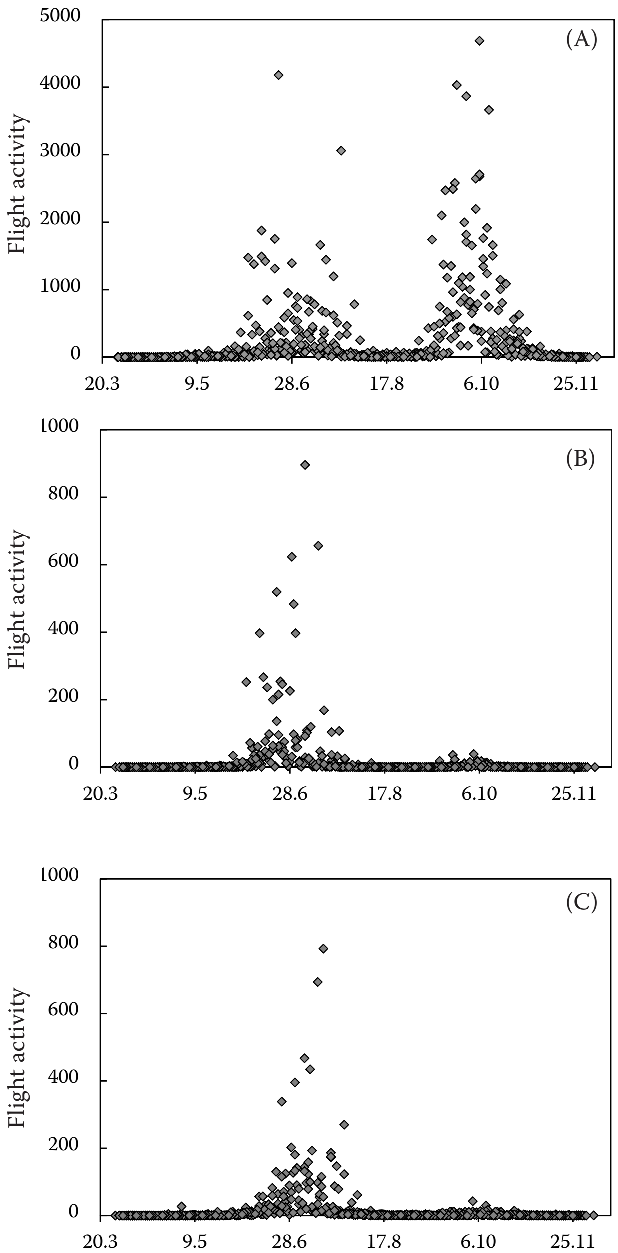

Figure 1. The seasonal distribution of the average weekly catches in the national grid of suction traps of the Czech Republic in 1999–2015: (A) *Rhopalosiphum padi*, (B) *Metopolophium dirhodum* and (C) *Sitobion avenae*

https://doi.org/10.17221/53/2019-PPS

Table 1. The average (± SE) maximum abundance of the aphids in the experimental plots of the winter wheat in Prague-Ruzyně (MAXAB) and the average annual catches per trap in the national grid of suction traps of the Czech Republic (CATCH), in 1999–2015

Year	*Rhopalosiphum padi*		*Metopolophium dirhodum*		*Sitobion avenae*	
	MAXAB	CATCH	MAX AB	CATCH	MAXAB	CATCH
	n per tiller	n per year	n per tiller	n per year	n per tiller	n per year
1999	1.9 ± 1.04	8 810	22.3 ± 7.67	1 239	7.5 ± 2.74	425
2000	0.0 ± 0.01	15 211	0.3 ± 0.13	379	1.1 ± 0.27	973
2001	0.00	8 957	0.4 ± 0.12	64	0.8 ± 0.25	225
2002	5.3 ± 3.42	8 313	21.1 ± 6.19	936	5.5 ± 1.22	401
2003	0.6 ± 0.34	5 137	2.2 ± 1.05	605	5.0 ± 1.34	1 592
2004	7.2 ± 4.72	6 937	1.8 ± 0.67	219	10.0 ± 4.12	735
2005	9.9 ± 4.37	13 208	48.7 ± 6.56	2 632	19.3 ± 5.20	1 773
2006	0.1 ± 0.08	3 764	4.1 ± 1.49	225	0.3 ± 0.09	150
2007	0.4 ± 0.20	6 294	2.2 ± 0.98	71	1.1 ± 0.37	192
2008	12.1 ± 6.14	12 230	12.9 ± 5.24	189	0.7 ± 0.22	212
2009	3.5 ± 1.94	11 246	34.1 ± 1.54	856	55.5 ± 11.60	979
2010	1.0 ± 0.44	3 810	5.0 ± 1.89	381	1.0 ± 0.18	157
2011	4.4 ± 2.43	12 028	10.5 ± 4.97	316	11.3 ± 4.12	311
2012	5.5 ± 3.05	12 988	32.7 ± 12.98	1 131	2.5 ± 0.94	360
2013	0.0 ± 0.02	10 950	0.5 ± 0.34	276	0.6 ± 0.35	721
2014	0.2 ± 0.13	11 685	2.1 ± 0.74	208	0.2 ± 0.07	506
2015	0.0 ± 0.00	5 528	1.1 ± 0.45	262	0.4 ± 0.15	378

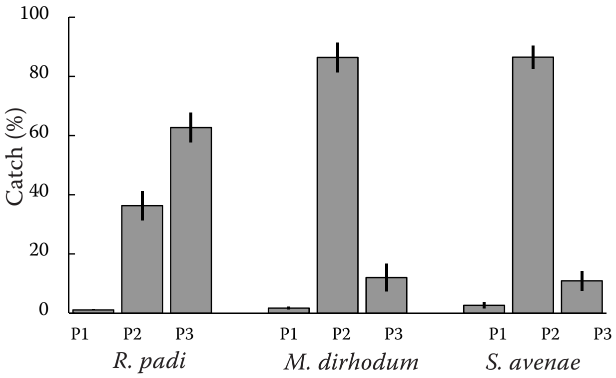

Figure 2. The percentage of the annual suction trap catches (± SE) trapped in the particular periods of the aphid flight activity

P1 – Period 1 (April–31 May); P2 – Period 2 (1 June–15 August); P3 – Period 3(16 August–30 November)

The species composition of the aerial populations and the populations on the winter wheat. The percentages of the individual aphid species in the total aphid population on the winter wheat and in the populations caught by the suction traps were different (Figure 3). In the winter wheat, the aphid populations at the time of peak aphid abundance were dominated by *M. dirhodum,* which, in certain years, represented 10–91% (on average 54 ± 9.8%) of the total aphid population. *S. avenae* represented 3–76% (34 ± 8.9%), while *R. padi* was a minority species that represented only 0–47% (12 ± 5.9%) of the total. In the suction trap catches summed over the spring flight season, the dominant species was *R. padi,* which represented 45–92% of the total catch of the cereal aphids (on average 73 ± 5.7%). *M. dirho-*

Table 2. The correlation between the average annual suction trap catches in period P1 (April–31 May) and period P2 (1 June–15 August), and the catches in period P2 and period P3 (16 August–30 November), in 1999–2015

Flight period	*Rhopalosiphum padi*			*Metopolophium dirhodum*			*Sitobion avenae*		
	Rsqr	*F*	*P*	Rsqr	*F*	*P*	Rsqr	*F*	*P*
P1 × P2	0.3180	6.983	0.018	0.0227	0.349	0.564	0.1090	1.837	0.195
P2 × P3	0.0101	0.153	0.701	0.1140	1.926	0.186	0.0674	1.083	0.314

Rsqr – coefficient of determination; *F* – *F* criterion of ANOVA; *P* – probability

https://doi.org/10.17221/53/2019-PPS

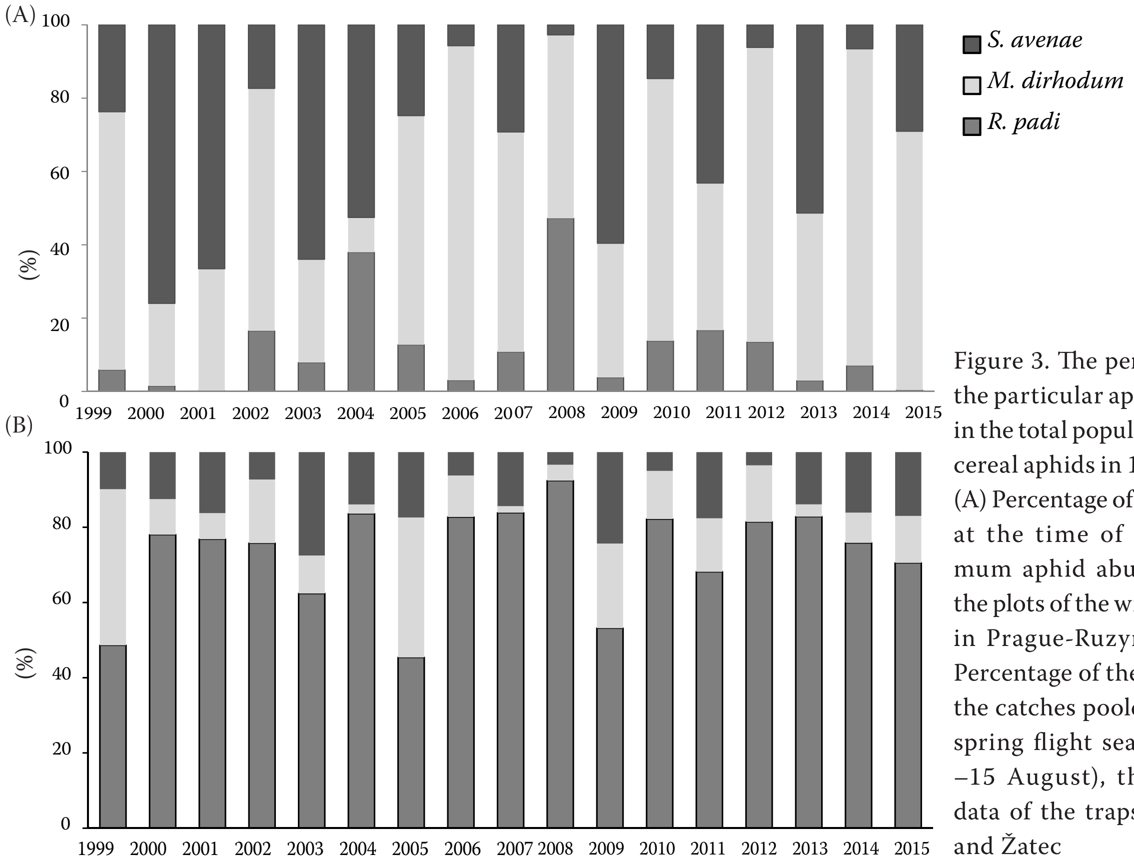

Figure 3. The percentage of the particular aphid species in the total population of the cereal aphids in 1999–2015: (A) Percentage of the species at the time of the maximum aphid abundance in the plots of the winter wheat in Prague-Ruzyně and (B) Percentage of the species in the catches pooled over the spring flight season (April –15 August), the average data of the traps of Čáslav and Žatec

dum represented 2–42% (14 *Sitobion* ± 5.0%) and *S. avenae* represented 3–28% (13 ± 3.0%) of the total catch of the cereal aphids.

The aphid abundance in the winter wheat stands and the suction trap catches. In all the aphid species, we found a positive regression of the total suction trap catches in the spring flight season on the maximum abundance in the winter wheat stands (Figure 4). The regression was significant for *R. padi* (r^2 = 0.301, ANOVA: $F_{1,16}$ = 6.457, P = 0.023) and *M. dirhodum*

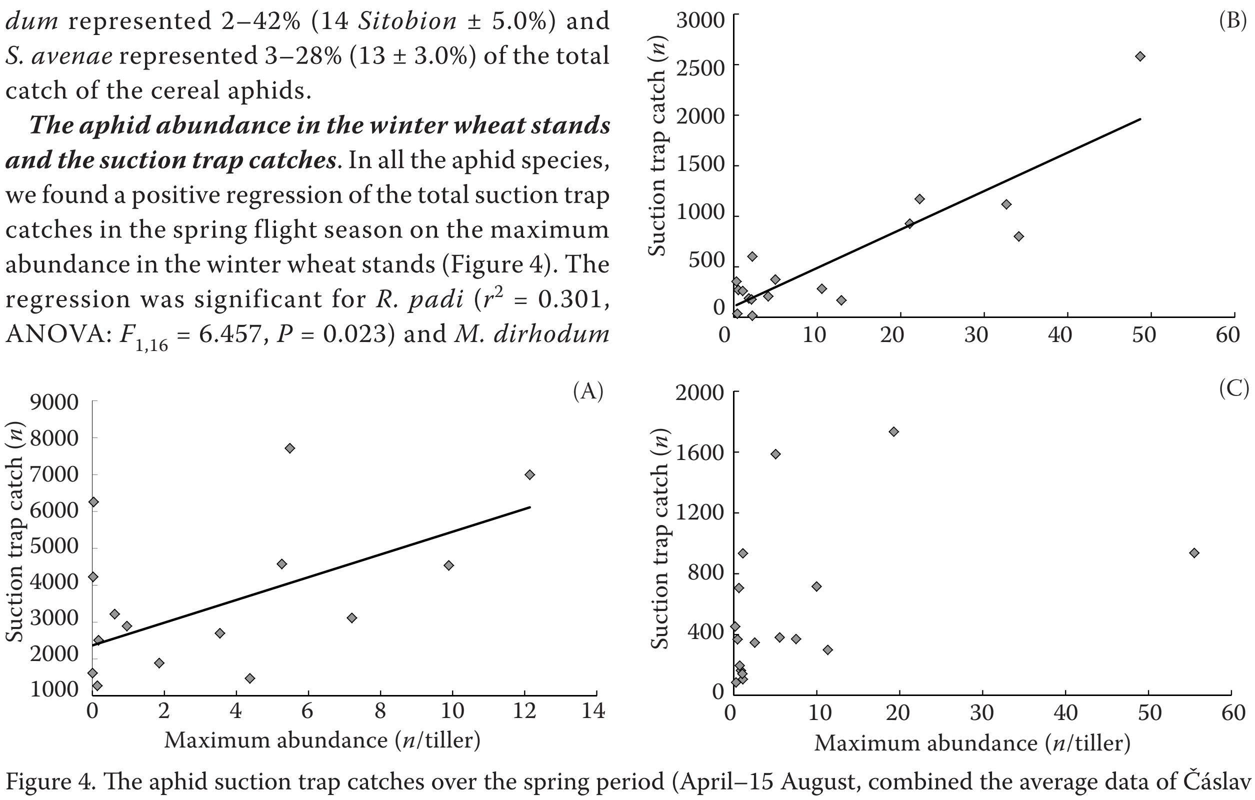

Figure 4. The aphid suction trap catches over the spring period (April–15 August, combined the average data of Čáslav and Žatec) plotted against the average maximum abundances of the species (*n*/tiller) in the experimental plots in Prague-Ruzyně: (A) *Rhopalosiphum padi*, (B) *Metopolophium dirhodum* and (C) *Sitobion avenae*

https://doi.org/10.17221/53/2019-PPS

(r^2 = 0.783, ANOVA: $F_{1,16}$ = 54.102, P < 0.001) but not significant for *S. avenae* (r^2 = 0.164, ANOVA: $F_{1,16}$ = 2.943, P = 0.107).

Predicting the maximum abundance in the winter wheat stands from the suction trap catches. The maximum abundance of the specific species in the winter wheat was regressed on the total average catch before June 15th in the suction traps in Čáslav and Žatec. In *M. dirhodum* (Figure 5A), the maximum abundances exceeded the damage thresholds of 40/tiller if the suction trap catch was greater than 60 aphids. However, the aphid numbers on the winter wheat exceeded this damage threshold even in the years when the average suction trap catches were low. This occurred in four out of the thirteen years with a low flight activity (catch < 60 individuals) of *M. dirhodum* in 2005 (3.5 aphids trapped, an average maximum abundance of 62 ± 3.5 aphids/tiller), in 2006 (18 aphids, 92 ± 1.2 aphids/tiller), in 2014 (27 aphids, 91 ± 2.6 aphids/tiller) and in 2015 (35 aphids, 67.6 ± 5.1 aphids/tiller). For *S. avenae* (Figure B) and *R. padi* (Figure 5C), there was no reliable relationship between the size of the suction trap catch and the abundance in the winter wheat plots. The threshold size for the suction trap catch that was followed by an economically important maximum abundance was, thus, determined in *M. dirhodum* only.

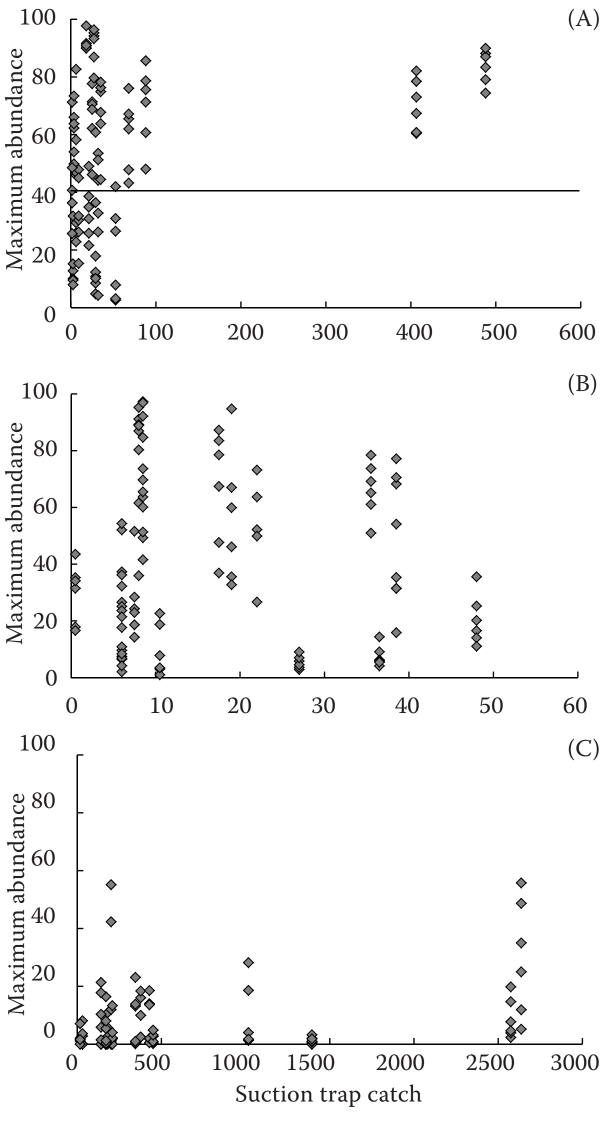

Figure 5. The maximum abundance (n/tiller) in the experimental plots in Prague-Ruzyně (each plot is indicated by a particular symbol) plotted against the average suction trap catch before the 15th of June in the combined data from Čáslav and Žatec (n aphids): (A) *Metopolophium dirhodum*, (B) *Sitobion avenae* and (C) *Rhopalosiphum padi*; Horizontal line – damage threshold of 40 aphids per tiller

DISCUSSION

Seasonal pattern of the flight activity. The flight activity of the cereal aphid species was bimodal. This seasonal distribution pattern of the suction trap catches is typical for these species and is similar to that in other areas of Europe (Stacherska 1977; Karl 1991; Hullé *et al*. 1994; Coceano *et al*. 2009). Furthermore, we only discuss the activity during the spring flight season, which is relevant in predicting the aphid abundance in cereal crops.

Distinguishing the flight of migrants from the winter hosts (period P1) from the flight of the aphids born in the cereal stands (period P2) would require determining the presence of the migrants (moving from the primary to the secondary hosts) and the exules (moving among the secondary hostplants) in the suction trap catches. The identification of the morphs is possible (Simon *et al*. 1991; Taylor *et al*. 1994), but difficult, and is apparently impracticable during the routine aphid identification because of the necessity of using time-consuming measurements of aphid morphological characteristics and multivariate computation methods. The division of both periods, thus, can only be based on the indirect evidence of the existence of a sharp increase in the flight activity. Overwintering of anholocyclic aphid populations in winter cereal stands seems impossible due to the winter frosts that limit aphid survival in the cereal crop stands. For instance, in 1999–2015 at Prague-Ruzyně, the minimum temperatures at 5 cm in height ranged between 12.0 and 25.4°C

https://doi.org/10.17221/53/2019-PPS

(mean –17.5 ± 0.98°C). The spring catches (period P1), therefore, consisted of emigrants flying from the winter hosts. The likely start of the flight activity of the exules developed on the cereal stands is not earlier than after the first larvae deposited on the crop terminates their development. The thermal constants for the pre-adult development of the aphid species in this study were similar (Honěk & Kocourek 1990; Honěk 1996). Using the average values for the three species, a lower development threshold of 2.7°C and the sum of the effective temperatures 131 day degrees (sum of daily temperatures above the lower development threshold), and the average May temperature at Prague-Ruzyně, 12.7°C, gives a development duration of ~13 days. The median day of the first discovery of *M. dirhodum* and *S. avenae* at Prague-Ruzyně was 15–20 May, and aphids were not observed in the winter wheat stands before ~10 May during the 40-year period of monitoring the cereal stands by sweeping or direct counts (Authors unpublished). The individuals born in the cereal stands, thus, cannot substantially contribute to the aerial aphid populations earlier than at the beginning of June. In fact, a sharp increase in the suction trap catches, probably due to the flight activity of the individuals recruited from the cereal stands, starts in the first week of June (Figure 1). This justifies setting the limit of period P1 (flight from the primary hosts) and period P2 (flight of the alate exules born at the cereal stands) at the turn of May and June, which is the term adopted in this paper. Since the total catch of period P1 was only 2–3% of the annual total in all the species, distinguishing the limit with greater precision has little practical value.

Species representation in the aerial populations and in wheat stands. The differences in the percentage representation of the aphid species in the aerial catches and the cereal stands were enormous. The most prominent example was *R. padi,* which was the dominant species in the suction trap catches, but only represented a minority in the winter wheat stands. This difference might have had several causes. First, the flying aphids may originate from the populations on grasses (Wiktelius 1987a) and there are more than 250 other Poaceae hostplant species (Holman 2009). The grass species are colonised more frequently by *R. padi* than the other cereal aphid species. Abundant populations also develop on maize (Honěk & Martinková 1991). Second, *R. padi* may lead a hidden life on the subterranean and low plant parts or inside leaf sheaths (Wiktelius 1987b). Establishing this segment of the population requires destructive methods of hostplant sampling that were not performed in our sampling of the winter wheat plants. This may have resulted in an underestimation of the *R. padi* numbers in this study, but could hardly explain the lack of correlation between the suction trap catches and the censuses on the winter wheat. Third, the agrotechnical and soil conditions could make some cereal stands more convenient for the development of *R. padi* populations than our conventionally maintained experimental crops. In the earlier experiments, the *R. padi* abundance was positively affected by the unbalanced fertilisation with high N (Authors unpublished). Fourth, the difference may have reflected a divergence in the flight behaviour of the aphid species because *R. padi*, compared to *M. dirhodum* and *S. avenae*, produces a greater proportion of alate individuals that tend to fly at higher air levels. The existence of such differences remains to be investigated.

The different effects of predators on the individual aphid species are unclear and require further research. In an important predator group of ladybugs (Coccinellidae), there is a large spatiotemporal variability in their abundance (Honěk *et al*. 2017). During our experiment, the abundance of ladybugs had been low in recent years (Honěk *et al*. 2019); therefore, their assumed varying impact on the populations of the individual aphid species has not been studied.

The suction trap catches in the spring and the maximum aphid abundance in the winter wheat stands. Why do suction trap catches poorly correlate with the cereal aphid abundance on the winter wheat? One reason may be that aphid flight is dependent on the weather to such an extent that the catches do not provide reliable information about the aphid abundances on the primary and secondary hostplants. In fact, weather factors affect the suction trap catches in different ways depending on the area, season and weather conditions (Harrington *et al.* 1990; Howard & Dixon 1990; Klueken *et al.* 2009; Davis *et al.* 2014), and the effects of these factors should be further studied to better interpret the data about the suction trap catches in the Czech Republic.

The accuracy of the predictions further depends on the length of the interval between the termination of the aerial sampling and the time of the maximum aphid abundance. This is because of the effect of the weather on the aphid reproduction rate, the effects of the natural enemies (Taylor 1977; Honěk 1991; Honěk & Martinková 2004) or the effects of the

https://doi.org/10.17221/53/2019-PPS

control measures targeted against the weeds (SASKA *et al.* 2016) on the aphid population.

The difference may be further caused by annual variations in the production of alate exules. The development of alate morphs is determined by a number of factors, including the hostplant quality. This may vary due to the variations in the winter and spring weather conditions that influence the rates of crop development (BRABEC *et al.* 2014). The portion of the alate population that was born before the population peak is predicted to vary between the years. The accuracy of the prediction is then decreased because of the annual variation in the seasonal dynamics of the alate exules.

Aphid polyphagy may also confound the relationship between the aphid catches in the suction traps and their abundance on the winter wheat. Cereal aphid species colonise other small grain cereals (barley, rye, oats and small grain cereals less commonly) and maize. Although winter wheat is the dominant crop in the Czech Republic, its acreage is only approximately 50% of the cropland that is convenient for cereal aphid species breeding (ANONYMOUS 2016). In particular, cropping maize is important because, in this crop, the numbers of aphids may become enormous, far exceeding their abundance on the cereals (HONĚK *et al.* 1998). The exules from other crops contribute to the suction trap catches, and the differences in the aphid seasonal dynamics on the particular crops may confound the correlation between the suction trap data and the data from the winter wheat.

To summarise, our results revealed the good correspondence between the aphid numbers in the winter wheat and the successive catches in the suction traps. This alignment suggests that the aphid populations on the winter wheat significantly contribute to the aphid aerial populations. Even so, the possibility of using spring suction trap catches (consisting of migrants plus early-born exules) for predicting the maximum aphid abundances on the wheat was limited. Except for *M. dirhodum*, where the abundant suction trap catches signalled a high abundance on the winter wheat, the predictions for *S. avenae* and *R. padi* were not reliable. The species composition of the aerial populations and the populations on the winter wheat were different. The differences point to the importance of further studies of the relationship between the aerial aphid populations and their abundance on the crops that can draw conclusions useful for agricultural practice.

Acknowledgement. We thank Mrs. J. Kohoutová, and Mrs. H. Uhlířová for their excellent technical assistance

References

Anonymous (2016): Statistická ročenka České republiky.

Anonymous (2018): Aphid Bulletin. Available at http://eagri.cz/public/web/ukzuz/portal/skodlive-organismy/aphid-bulletin/aphid-bulletin-2018 (Acessed Oct 4, 2018).

Basky Z, Harrington R. (2000): Cereal aphid flight activity in Hungary and England compared by suction traps. Anzeiger für Schädlingskunde Pflanzenschutz Umweltschutz, 73: 70–74.

Blackman R.L., Eastop V.F. (1984): Aphids on the World's crops. Chichester, John Wiley and Sons: 466.

Bode E. (1980): Aphids in winter wheat: abundance and limiting factors from 1976 to 1979. Bulletin SROP WPRS Bulletin, 3: 49–57.

Brabec M., Honěk A., Pekár S., Martinkova Z. (2014): Population dynamics of aphids on cereals: digging in the time-series data to reveal population regulation caused by temperature. PLoS ONE 9:e106228, doi: 10.1371/journal.pone.0162139.

Carter W. (1961): Ecological aspects of plant virus transmissions. Annual Review of Entomology, 6: 347–370.

Clark S.J., Tatchell G.M., Perry J.N., Woiwod I.P. (1992): Comparative phenologies of two migrant cereal aphid species. Journal of Applied Ecology, 29: 571–580.

Coceano P.G., Peressini S., Bianchi G.L., Caciagli P. (2009): Long-term changes of aphid vectors of Barley yellow dwarf viruses in north-eastern Italy (Friuli-Venezia Giulia). Annals of Applied Biology, 155: 37–50.

Cochrane J. (1980): Meteorological aspects of the numbers and distribution of the rose-grain aphid, *Metopolophium dirhodum* (Wlk.), over south-east England in July 1979. Plant Pathology, 29: 1–8.

Davis T.S., Abatzoglou J.T., Bosque-Perez N.A., Halbert S.E., Pike K., Eigenbrode S.D. (2014): Differing contributions of density dependence and climate to the population dynamics of three eruptive herbivores. Ecological Entomology, 39: 566–577.

Dedryver C.A., LeRalec A., Fabre F. (2010): The conflicting relationships between aphids and men: a review of aphid damage and control strategies. Comptes Rendus Biologies, 333: 539–553.

Dewar A.M., Woiwod I., Choppin de Janvry E. (1980): Aerial migrations of the rose-grain aphid, *Metopolophium dirhodum* (Wlk.), over Europe in 1979. Plant Pathology, 29: 101–109.

Dixon A.F.G. (1971): The life cycle and host preferences of the bird-cherry-oat aphid, *Rhopalosiphum padi* L., and their bearing on theories of host alternation in aphids. Annals of Applied Biology, 68: 135–147.

https://doi.org/10.17221/53/2019-PPS

Dixon A.F.G. (1987): Cereal aphids as an applied problem. Agricultural Zoology Review, 2: 1–57.

Elberson L.R., Johnson J.B. (1995): Population trenda and comparison of sampling methods for *Diuraphis noxia* and other cereal aphids (Homoptera, Aphididae) in northern Idaho. Environmental Entomology, 24: 538–549.

Hand S.C., Williams C.T. (1981): The overwintering of the rose-grain aphid *Metopolophium dirhodum* on wild roses. In: Thresh J. (ed.): Pests, Pathogens and Vegetation: the Role of Weeds and Wild Plants in the Ecology of Crop Pests and Diseases. London, Pitman: 285–298.

Harrington .R, Tatchell G.M., Bale J.S. (1990): Weather, life-cycle strategy and spring populations of aphids. Acta Phytopathologica et Entomologica Hungarica, 25: 423–432.

Holman J. (2009): Host Plant Catalog of Aphids. Springer, Dordrecht: 1140.

Honěk A. (1991): Factors determining the peak abundance of *Metopolophium dirhodum* (Homoptera, Aphididae) on cereals. Bulletin of Entomological Research, 81: 57–64.

Honěk A. (1996): The relationship between thermal constants for insect development: a verification. Acta Zoologica Bohemica, 60: 115–152.

Honěk A., Kocourek F. (1990): Temperature and development time in insects: a general relationship between thermal constants. Zoologische Jahrbücher Abteilung für Systematik Ökologie und Geographie der Tiere, 117: 401–439.

Honěk A., Martinková Z. (1991): Competition between maize and barnyard grass *Echinochloa crus-galli*, and its effect on aphids and their predators. Acta Oecologica, 12:741–751.

Honěk A., Martinkova Z. (1999): Host-plant mediated influences on population development of *Sitobion avenae* (Sternorrhyncha: Aphididae). European Journal of Entomology, 96: 135–141.

Honěk A., Martinkova Z. (2002): Factors of between- and within-plant distribution of *Metopolophium dirhodum* (Hom., Aphididae) on small grain cereals. Journal of Applied Entomology, 126: 378–383.

Honěk A., Martinkova Z. (2004): Host plant age and population development of a cereal aphid, *Metopolophium dirhodum* (Hemiptera: Aphididae). Bulletin of Entomological Research, 94: 19–26.

Honěk A., Martinkova Z., Lipavská H. (1998): Distribution of *Metopolophium dirhodum* in maize and cereals. In: Nieto-Nafria J.M., Dixon A.F.G. (eds): Aphids in Natural and Managed Ecosystems. León, Universidad de León: 569–578.

Honěk A., Martínkova Z., Dixon A.F.G., Saska P. (2017): Annual predictions of the peak numbers of *Sitobion avenae* infesting winter wheat. Journal of Applied Entomology, 141: 352–362.

Honěk A., Martinkova Z., Saska P., Dixon A.F.G. (2018): Aphids (Homoptera: Aphididae) on winter wheat: predicting maximum abundance of *Metopolophium dirhodum*. Journal of Economic Entomology, 111: 1751–1759.

Honěk A., Dixon A.F.G., Soares A.O., Skuhrovec J. (2017): Spatial and temporal changes in the abundance and compostion of ladybird (Coleoptera: Coccinellidae) communities. Current Opinion in Insect Science, 14:61–67

Honěk A, Martinkova Z., Roy H.E., Dixon A.F.G., Skuhrovec J., Pekár S., Brabec M. (2019): Differences in the phenology of *Harmonia axyridis* (Coleoptera: Coccinellidae) and native coccinellids in Central Europe. Environmental Entomology 48: 80–87.

Howard M.T., Dixon A.F.G. (1990): Forecasting of peak population density of the rose grain aphid *Metopolophium dirhodum* on wheat. Annals of Applied. Biology, 117: 9–19.

Howard M.T., Dixon A.F.G. (1992): The effect of plant phenology on the induction of alatae and the development of populations of *Metopolophium dirhodum* (Walker), the rose-grain aphid, on winter wheat. Annals of Applied. Biology, 120: 203–213.

Hullé M., Coquio S., Laperche V. (1994): Patterns in flight phenology of a migrant cereal aphid species. Journal of Applied Entomology, 31: 49–58.

Johnson C.G. (1969): Migration and dispersal of insects by flight. London, Methue: 592.

Karl E. (1991): Suction trap used for monitoring the flight activity of cereal aphids (Homoptera, Aphidinea, Aphididae). Entomologia Generalis, 16: 161–166.

Kirchner S.M., Hiltunen L., Doering T.F., Virtanen E., Palohuhta J.P., Valkonen J.P.T. (2013): Seasonal phenology and species composition of the aphid fauna in a northern crop production area. PLoS ONE 8(8):e71030. doi: 10.1371/journal.pone.0071030

Klueken A.M., Hau B., Freier B., Friesland H., Kleinhenz B., Poehling H.M. (2009): Comparison and validation of population models for cereal aphids. Journal of Plant Diseases and Protection, 116: 129–140.

Kring JB (1972): Flight behavior of aphids. Annual Review of Entomology, 17: 461–492.

Leather S.R. (1993): Overwintering in six arable aphid pests: a review with particular relevance to pest management. Journal of Applied Entomology, 116: 217–233.

Leather S.R., Walters K.F.A. (1984): Spring migration of cereal aphids. Zeitschrift für Angewandte Entomologie, 97: 431–437.

Moericke V. (1955): Über die Lebensgewohnheiten der geflügelten Blattläuse (unter besonderer Berücksichtigung des Verhaltens beim Landed). Zeitschrift für Angewandte Entomologie, 37: 29–91.

https://doi.org/10.17221/53/2019-PPS

Müller F.P. (1977): Überwinterung und Fundatrix der Getreideblattlaus *Macrosiphum* (*Sitobion*) *avenae* F. Archiv für Phytopathologie und Pflanzenschutz, 13: 347–353.

Ruszkowska M., Zlotkowski J. (1977): Badania populacyjne nad ważnymi gospodarczo gatunkami mszyc na podstawie polówow z powietrza Część II. Dynamika sezonowa lotów mszycz (Studies on aphid of economic importance species populations on the basis of aerial sampling. II. Seasonal dynamics of the aphids flying). Prace Naukowe Instytutu Ochrony Roslin, 19: 125–144.

Saska P., Skuhrovec J., Lukáš J., Chi H., Tuan S.J., Honěk A. (2016): Treatment by glyphosate-based herbicide alters life history parameters of the rose-grain aphid *Metopolophium dirhodum.* Scientific Reports, 6: 1–10.

Simon J.C., Dedryver C.A., Pierre J.S. (1991): Identifying bird cherry-oat aphid *Rhopalosiphum padi* emigrants, alate exules and gynoparae – application of multivariate methods to morphometric and anatomical features. Entomologia Experimentalis et Applicata, 59: 267–277.

Špaldon E. (1982): Rastlinná výroba (Plant Production). Bratislava, Priroda: 628.

Stacherska B. (1977): Badania nad lotami mszyc zbożowych i trawowych w Poznaniu w latach 1970–1973 (Studies on flights of cereal and grass aphids in Poznan in 1970–1973). Prace Naukowe Instytutu Ochrony Roslin, 19: 57–110.

Taylor M.S., Tatchell L.M., Clark S.J. (1994): Morph identification in natural populations of alate female bird cherry aphids, *Rhopalosiphum padi* L., by multivariate methods. Annals of Applied Biology, 125: 1–11.

Taylor L.R. (1960): The distribution of insects at low levels in the air. Jounal of Animal Ecology, 29: 45–63.

Taylor L.R. (1972): Insect migration, flight periodicity and the boundary layer. Jounal of Animal Ecology, 43: 225–238.

Taylor L.R. (1977): Aphid forecasting and the Rothamsted Insect Survey. Journal of the Royal Agricultural Society of England, 138: 75–97.

Vickerman G.P., Wratten S.D. (1979): The biology and pest status of cereal aphids in Europe: a review. Bulletin of Entomological Research, 69: 1–32.

Węgorek W., Stacherska B. (1977): Badania populacyjne nad ważnymi gospodarczo gatunkami mszyc na podstawie polowów z powietrza Część I. Dynamika wieloletnia (Studies on aphid of economic importance species populations on the basis of aerial sampling I. many years populations' dynamic). Prace Naukowe Instytutu Ochrony Roslin, 19: 111–124.

Wiktelius S. (1987a): The role of grasslands in the yearly life-cycle of *Rhopalosiphum padi* (Homoptera: Aphididae) in Sweden. Annals of Applied Biology, 110: 9–15.

Wiktelius S. (1987b): Distribution of *Rhopalosiphum padi* (Homoptera: Aphididae) on spring barley plants. Annals of Applied Biology, 110: 1–7.

Zhou X.L., Harrington R., Woiwod I.P., Perry J.N., Bale J.S., Clark S.J. (1995): Effects of temperature on aphid phenology. Global Change Biology, 1: 303–313.

Received: April 18, 2019
Accepted: October 10, 2019
Published Online: December 9, 2019