Flight Patterns of *Hedya dimidioalba*, *Spilonota ocellana* and *Pandemis heparana* (Lep.: Tortricidae) Based on Data from Pheromone Traps

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Abstract

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During 1992–1999 the flight activity of *Hedya dimidioalba*, *Spilonota ocellana* and *Pandemis heparana* was investigated by pheromone traps placed in six apple orchards and a plum orchard in Central and East Bohemia. The cumulative catches of each species were plotted against time of the catch expressed as the sum of degree-days above 10°C (*H. dimidioalba* and *S. ocellana*) and 8°C (*P. heparana*) and approximated by Richards' function. Common parameters of Richards' function could be found for *Hedya dimidioalba* and *Spilonota ocellana* from all localities. In *Pandemis heparana* the flight pattern was different for groups of localities with similar climatic conditions. It was found that the beginning, peak and end of the flight activity of these species in the Czech Republic can be reasonably predicted.

Keywords: *Spilonota ocellana; Hedya dimidioalba*; *Pandemis heparana*; apple orchards; flight activity; monitoring; pheromone traps; flight pattern; sum of degree-day

Green budworm, *Hedya dimidioalba* Retzius, eye-spotted bud moth, *Spilonota ocellana* Den. & Schiff., and dark fruit tree tortrix moth, *Pandemis heparana* Den. & Schiff., are polyphagous Palaearctic tortricids (Lep.: Tortricidae) and widely distributed in Europe. They were introduced also to North America (MUTUURA 1980; STRICKLER & WHALON 1985). The primary hosts are *Rosaceae*, but the species may feed also on trees and shrubs of other families (ALFORD 1991).

The overwintered larvae of *H. dimidioalba* and *S. ocellana* begin to feed on buds in early spring, and proceed to attack blossoms or leaves and often tie them together. Later in the season, larvae of *S. ocellana* feed on developing fruits and cause typical shallow pits on their surface. When abundant, the larvae may cause fruit drop. However, the damage is more important in spring when larvae attack the developing buds. The larvae of *H. dimidioalba* skeletonize leaves, but don't eat fruits and consequently cause less damage. Again, spring feeding on flower parts is more important (GEEST & EVENHUIS 1991). The overwintered larvae of *P. heparana* feed in spring on foliage and shoots, causing minimal damage, whereas that caused by summer larvae on the fruit surface is more important (GEEST & EVENHUIS 1991). *S. ocellana* is a univoltine species, *H. dimidioalba* and *P. heparana* are univoltine or partially bivoltine species in the Czech Republic.

In conventional plant protection in orchards the leafroller species were reduced by broad-spectrum insecticides used also for the control of *Cydia pomonella* and other pests. The importance and abundance of tortricids increased following the change of pest control strategy. *P. heparana* is now an important pest of apples in France (AUDEMARD 1981), the Netherlands (DE REEDE *et al.* 1985) and Germany (DICKLER 1982). *H. dimidioalba* became abundant in the United Kingdom (CROSS 1996) and Nova Scotia (RINGS 1992). *S. ocellana* became an important pest in western Canada (MCBRIEN & JUDD 1998), but it causes some damage also in other apple growing areas of the northern hemisphere (WEIRES & RIEDL 1991).

In this paper we present the results of 8 year monitoring of male flight activity of *H. dimidioalba, S. ocellana* and *P. heparana* by pheromone traps, which revealed the phenology and relative abundance of these species in apple orchards of the Czech Republic. We expressed the course of the flight activity of the species in relation to calendar dates and biological time (degree-days) and determined the effects of pest control strategies and weather on total catches.

MATERIALS AND METHODS

Adult male flight activity of *H. dimidioalba*, *S. ocellana* and *P. heparana* was monitored from 1993 to 1999 in apple orchards with different pest control strategies. From 1992 to 1995, *P. heparana* was monitored also in a plum orchard. The orchards were at six localities (Table 1); they used different technologies of fruit growing and plant protection: 1) Horoměřice – intensive apple orchard, for a long time treated by pyrethroids and organophosphorous insecticides, experimental area 2 ha, cultivar Idared; 2) Prague-Ruzyně – experimental orchard of the Research Institute of Crop Production, without chemical treatment, experimental area 1 ha, different cultivars; 3) Doksany – formerly intensive apple orchard, since 1992 without chemical treatment, experimental area 1 ha, cultivar Golden Delicious; 4) Roudnice – intensive apple and plum orchard with a long-term regime of integrated pest management (IPM), experimental area 1 ha, cultivar Champion; 5) Slaný – intensive apple orchard with IPM regime, experimental area 1 ha, cultivar Idared; 6) Holovousy – experimental orchard without chemical treatment, experimental area 1 ha, different cultivars. Cardboard delta traps with sticky inserts and pheromone dispensers were used for the monitoring of the flight of moths. The pheromone dispensers for *H. dimidioalba* contained (Z)-8–dodecen-1-yl acetate, for *S. ocellana* (Z)-8-tetradecen-1-yl acetate and for *P. heparana* (Z)-11-tetradecen-1-yl acetate. The traps were suspended 160 cm above the ground, at one-third distance from the crown periphery. In each orchard there was one trap. The traps were run from late April or early May until fruit harvest (September). The catches of moths were checked in weekly intervals, when the sticky inserts were replaced. The pheromone dispensers were replaced once a season.

Maximum (t_{max}) and minimum (t_{min}) temperatures were obtained from the meteorology stations at Prague-Ruzyně (data used for localities of Central and North Bohemia) and Holovousy (data used for localities of East Bohemia). A threshold temperature (T_b) of 10°C was used for calculating the sums of degree-days (DD; accumulation of daily active temperatures) for *H. dimidioalba* and *S. ocellana* because this base temperature was used in management programs (RIEDL *et al.* 1976). For *P. heparana* we used an 8°C threshold (DE REEDE & DE WILDE 1986). The daily active temperature was calculated as:

$$\frac{t_{min} - t_{max}}{2} - T_b$$

For calculating biological time the daily active temperatures were summed from January 1. For each species weekly trap catches of the overwintered generation were expressed as percents of total trap catches of the overwintered generation. Richards' function was fitted into a plot of cumulative percentage of catches and biological time

$$y = \frac{100}{\left(1 + c_3 \times e^{-c_1(x-c_2)}\right) \times 1/c_3}$$

where: c_1, c_2, c_3 – parameters of the Richards' function (FIRCKS & VERWIJST 1993)
y – cumulative percentage of captured moths
x – biological time

The parameter c_1 means the slope of the curve, c_2 the time of 50% catch and c_3 the upper limit of the curve. The plots of Richards function for particular species and years we further call "flight pattern". In *H. dimidioalba* and *P. heparana* it was impossible to construct the flight pattern of the second generation. The calculations were made using STATISTICA for Windows.

RESULTS

H. dimidioalba

The flight curves indicated that *H. dimidioalba* is univoltine or has a partial second generation in the Czech Republic. The flight activity had usually one large peak, particularly in years with high temperatures. In cold years (Table 1) there were several small peaks of the flight. Examples of typical flight curves of *H. dimidioalba* from Ruzyně 1997 and Slaný 1995 are shown in Fig. 1. The beginning and

Table 1. Geographical characteristics of the localities of the experiment and temperatures during the vegetative period (IV–X), 1992–1999

Locality	Geographical location	Altitude	Temperature								
			1992	1993	1994	1995	1996	1997	1998	1999	average
Ruzyně	50°06′N, 14°15′E	364	15.5	13.6	14.4	14.0	13.0	13.3	14.3	14.7	14.1
Horoměřice	50°08′N, 14°21′E	315	15.5	13.6	14.4	14.0	13.0	13.3	14.3	14.7	14.1
Roudnice	50°26′N, 14°15′E	175	15.3	14.4	14.7	14.7	13.5	13.9	15.0	15.3	14.6
Doksany	50°46′N, 14°17′E	158	15.3	14.4	14.7	14.7	13.5	13.9	15.0	15.3	14.6
Slaný	50°14′N, 14°05′E	160	15.4	14.5	14.9	14.9	13.6	13.9	15.0	15.4	14.7
Holovousy	50°37′N, 15°58′E	321	14.9	14.1	14.7	14.7	13.5	13.7	14.3	15.1	14.4

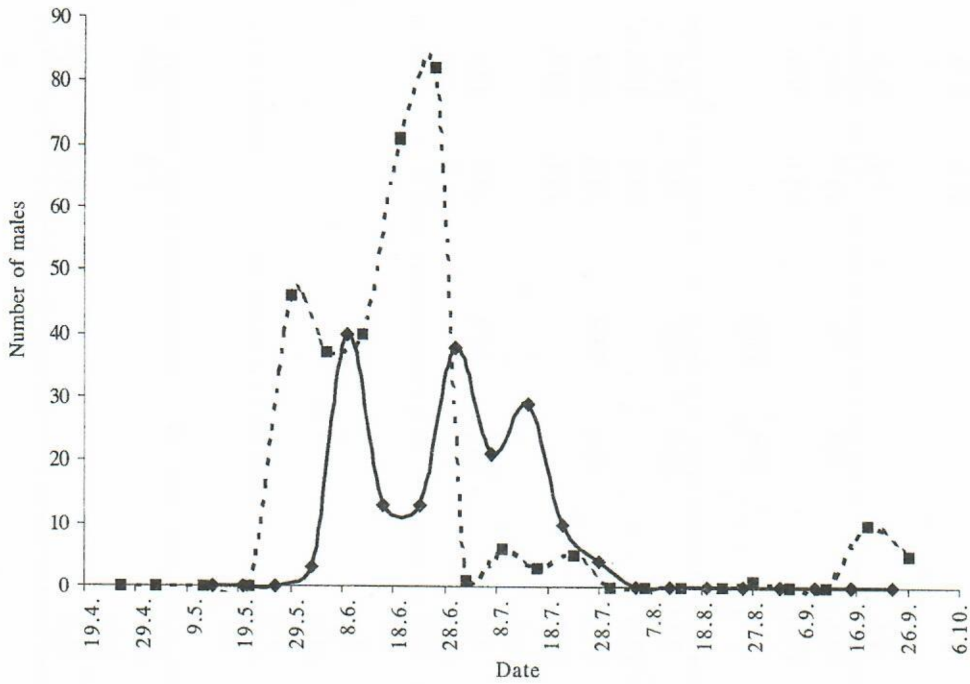


Fig. 1. Examples of the different course of flight curves of *Hedya dimidioalba*, Ruzyně 1997 (solid line) and Slaný 1995 (dotted line)

termination of the flight of the overwintered and second generation are presented in Table 2.

The flight activity of the overwintered generation began usually in late May and ended in late July. The flight peak occurred usually in the first half of June. During cold temperature, abundant flight was prolonged. The earliest beginning of the flight of the overwintered generation was recorded at Horoměřice in 1994 (May 3), the latest at Slaný in 1996 (June 5). Flight activity ceased between June 15 (Ruzyně 1993, Horoměřice 1993) and August 28 (Doksany 1995, Slaný 1995). The peak of flight activity was between May 19 (Roudnice 1993, Doksany 1993) and July 8 (Ruzyně 1996).

In warm years a partial second generation occurred at some localities (Table 1). The males of this generation appeared from late August to late September (Table 2). The catches of the second generation were usually up to 20% of the total catch; although at Doksany in 1994 the second generation amounted to 59% of the total catch (Table 3).

Total catches of the overwintered and second generation of *H. dimidioalba* varied between years and localities (Table 3). In the chemically treated orchard at Horoměřice the total catch was 13 males in 1994 and 193 in 1995. In the untreated orchard at Holovousy the catch was 65 males in 1995 and 143 in 1997.

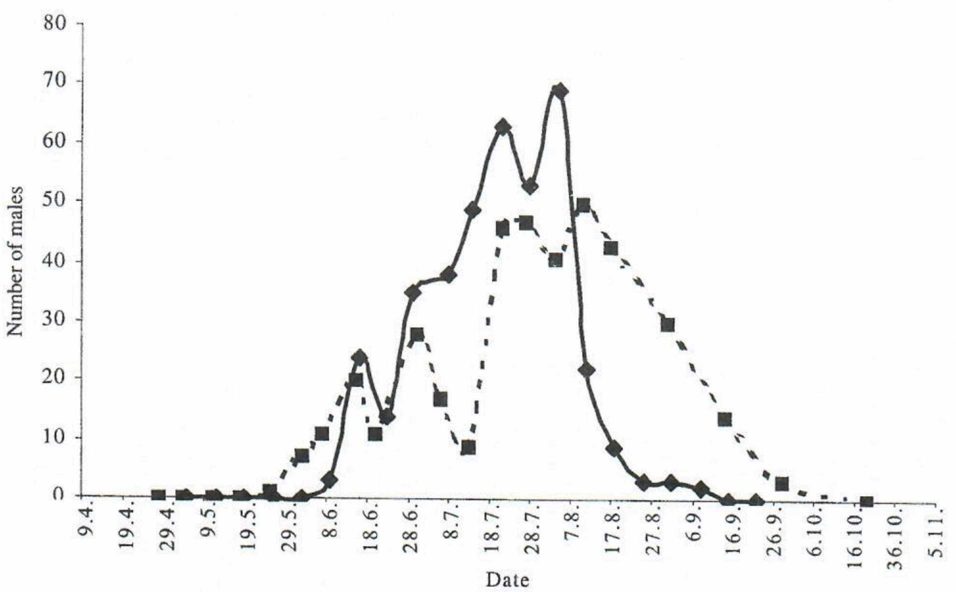


Fig. 2. Examples of the different course of flight curves of *Spilonota ocellana*, Ruzyně 1999 (solid line) and Doksany 1993 (dotted line)

Table 2. Dates of first and last occurrence of the overwintering generation of *H. dimidioalba*, *S. ocellana* and *P. heparana*, *H. dimidioalba* and *P. heparana* males in pheromone traps

Year	Location	*H. dimidioalba*		*S. ocellana*		*P. heparana*		*H. dimidioalba*		*P. heparana*	
		first	last	first	last	first	last	first	last	first	last
1992	Roudnice plums					19.5.	28.7.			25.8.	14.9.
1993	Horoměřice	4.5.	15.6.	1.6.	4.10.	18.5.	25.8.			8.9.	22.9.
	Ruzyně	13.5.	15.6.	4.5.	9.9.	4.5.	18.8.				
	Doksany	5.5.	22.7.	26.5.	29.9.	3.6.	4.8.			11.8.	15.9.
	Roudnice apples	12.5.	16.6.	19.5.	29.9.						
	Roudnice plums					26.5.	4.8.			1.9.	15.9.
1994	Horoměřice	3.5.	22.6.	22.6.	26.8.	3.5.	19.8.	2.9.	9.9.	26.8.	23.9.
	Ruzyně	28.5.	22.7.	9.6.	18.8.	3.6.	18.8.			25.8.	23.9.
	Doksany	12.5.	3.8.	8.6.	20.9.			25.8.	20.9.		
	Roudnice apples	2.6.	3.8.	12.5.	3.8.						
1995	Horoměřice	1.6.	3.8.	26.5.	26.9.	1.6.	3.8.	19.9.	26.9.	24.8.	26.9.
	Ruzyně	5.5.	4.8.	15.6.	13.9.	15.6.	10.8.			31.8.	13.9.
	Doksany	22.5.	28.8.	6.6.	19.9.	30.5.	14.8.	19.9.	27.9.	28.8.	27.9.
	Roudnice apples	30.5.	24.7.	13.6.	22.8.	13.6.	31.7.			22.8.	19.9.
	Roudnice plums					30.5.	31.7.				
	Slaný	30.5.	28.8.	6.6.	7.8.	30.5.	7.8.	19.9.	27.9.	11.9.	19.9.
	Holovousy	30.5.	4.7.	4.7.	19.9.	6.6.	15.8.			29.8.	26.9.
1996	Horoměřice	30.5.	21.8.	13.6.	5.10.	5.6.	5.9.				
	Ruzyně	27.5.	19.8.	17.6.	1.10.	3.6.	2.9.				
	Slaný	5.6.	14.8.	13.6.	26.9.	30.5.	21.8.				
	Holovousy			17.6.	23.9.	20.5.	9.9.				
1997	Ruzyně	3.6.	29.7.	17.6.	9.9.	1.7.	9.9.				
	Holovousy	2.6.	14.7.	16.6.	8.9.						
1998	Ruzyně	22.5.	6.8.	4.6.	9.9.	4.6.	27.8.			2.9.	17.9.
	Holovousy	25.5.	27.7.	8.6.	7.9.	1.6.	10.8.				
1999	Ruzyně	20.5.	22.7.	10.6.	9.9.	3.6.	19.8.			26.8.	16.9

Table 3. Total catches of first (I.g.) and second (II.g.) generations of males of *H. dimidioalba* in pheromone traps

Year	Horoměřice		Ruzyně		Doksany		Roudnice		Slaný		Holovousy	
	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.
1993	30		139	0	378	0	25					
1994	10	3	51	0	50	72	9					
1995	190	3	238	0	231	56	175		292	15	65	
1996	89	0	484	0				393				
1997			171	0							143	
1998			331	0							120	
1999			387	0								

In *H. dimidioalba*, the length of the flight activity was not significantly correlated with the magnitude of the catch ($R = 0.4905$, $P > 0.05$). E.g. in 1998, 331 males were caught over 12 weeks at Prague/Ruzyně, while at Holovousy 120 males were caught over 10 weeks. A relationship between insecticide treatment of the orchards and numbers of *H. dimidioalba* was not found.

S. ocellana

S. ocellana is a univoltine species in the Czech Republic. The curve of the flight activity of was usually prolonged, with one large and several small peaks (Fig. 2).

The flight activity started earlier and ended later at warm localities (Doksany, Roudnice, Slaný) than at cold ones (Ruzyně, Horoměřice, Holovousy). The flight activity began in most years and localities in the first week of June and ceased in mid-September (Table 2). The peak of flight occurred usually in early August, but the length of the period of high catches varied between years. The earliest beginning of flight was recorded at Ruzyně in 1993 (May 4) and the latest one at Holovousy in 1995 (July 4). The earliest end of flight activity was recorded at Roudnice in 1994 (August 3) and the latest one at Horoměřice in 1996 (October 5). The flight peak was between June 8 (Holovousy 1998) and August 27 (Prague-Ruzyně 1996).

The length of the flight activity was positively correlated with population density. Thus, in 1994 28 males of *S. ocellana* were caught at Roudnice and the length of the flight activity was 12 weeks. At Doksany, 183 males were caught during 15 weeks in the same year. In this study, *S. ocellana* was generally more numerous in untreated orchards at Ruzyně and Doksany (on average 230 males per year) than in chemically treated orchards at Horoměřice and Slaný (on average 110 males per year).

Total catches (Table 4) varied between years and localities. In the chemically treated orchard at Horoměřice 18 males were caught in 1994 and 177 in 1996. In the untreated orchard at Ruzyně total catches varied between 107 (1994) and 403 (1996). The correlation between number of moths and duration of the flight activity was not significant ($R = 0.3929$, $P > 0.05$).

P. heparana

According to flight curves, *P. heparana* is univoltine or has a partial second generation in the Czech Republic. The curve of the flight activity was prolonged with one large and several small peaks (Fig. 3). The flight of the overwintered generation began usually in early June and ceased in the third decade of August (Table 2). The catches were low for 3–4 weeks, the flight peak occurred usually during the third decade of July and was prolonged in some years.

The earliest beginning of the flight of the overwintered generation was recorded at Horoměřice in 1994 (May 3),

Table 4. Total catches of males of *S. ocellana* in pheromone traps

Year	Horoměřice	Ruzyně	Doksany	Roudnice	Slaný	Holovousy
1993	107	139	378	161		
1994	18	107	183	28		
1995	50	147	88	21	28	39
1996	177	403			259	215
1997		206				45
1998		363				150
1999		387				

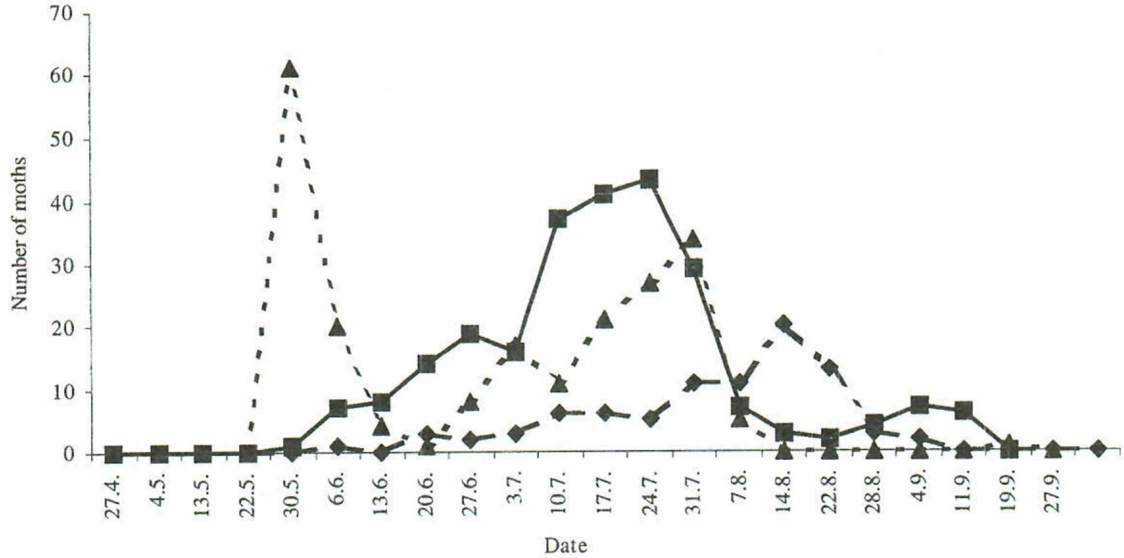


Fig. 3. Examples of the different course of flight curves of *Pandemis heparana*, Ruzyně 1999 (solid line), Slaný 1995 (dashed line) and Horoměřice 1996 (dotted line)

the latest one at Prague-Ruzyně in 1997 (July 1). The earliest end of the flight of the overwintered generation was observed in a plum orchard at Roudnice in 1992 (July 28), the latest one at Holovousy 1996 and Ruzyně 1997 (September 9). The flight peak was found between July 1 (Doksany 1993 and Ruzyně 1994) and August 19 (Holovousy 1996). The length of the flight activity varied with temperature of the locality and year. The partial second generation appears in the Czech Republic regularly in warm areas, while at cold localities it appears only exceptionally (Tables 1 and 5). The length of the flight activity wasn't correlated with the number of moths ($R = 0.0200$, $P > 0.05$). Thus, in 1996 only 86 males were caught at Horoměřice during 14 weeks, while at Ruzyně 551 males were caught during 13 weeks in the same year. The length of the period of flight activity varied mainly with the temperature conditions of a given locality and year. The beginning of the flight of the second generation was recorded between August 11 (Doksany 1993) and September 11 (Slaný 1995) and the end of the flight between September 13 (Ruzyně 1995) and September 27 (Doksany 1995) (Table 2). The second generation represented 8 ± 6% of the annual catches. Only exceptionally the moths of the second generation represented a significant part of the total catch, e.g. at Doksany 1993 where it represented 18% of the total annual catch.

The flight activity of *P. heparana* in a plum orchard differed slightly from the flight activity in a near apple orchard. The overwintered generation began 2 weeks earlier on plums than on apples (Table 2). A partial second generation on plums appeared from late August to mid-September (Table 2).

Table 5. Total catches of first (I.g.) and second (II.g.) generations of males of *P. heparana* in pheromone traps

Year	Horoměřice		Ruzyně		Doksany		Roudnice apples		Roudnice plums		Slaný		Holovousy	
	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.	I.g.	II.g.
1992									193	3				
1993	71	1	124	0	109	24			28	5				
1994	89	15	346	25										
1995	67	7	251	21	461	36	111	7	96	0	209	1	40	12
1996	86	0	551	0							133	0	150	0
1997			119	0										
1998			228	3									32	0
1999			225	19										

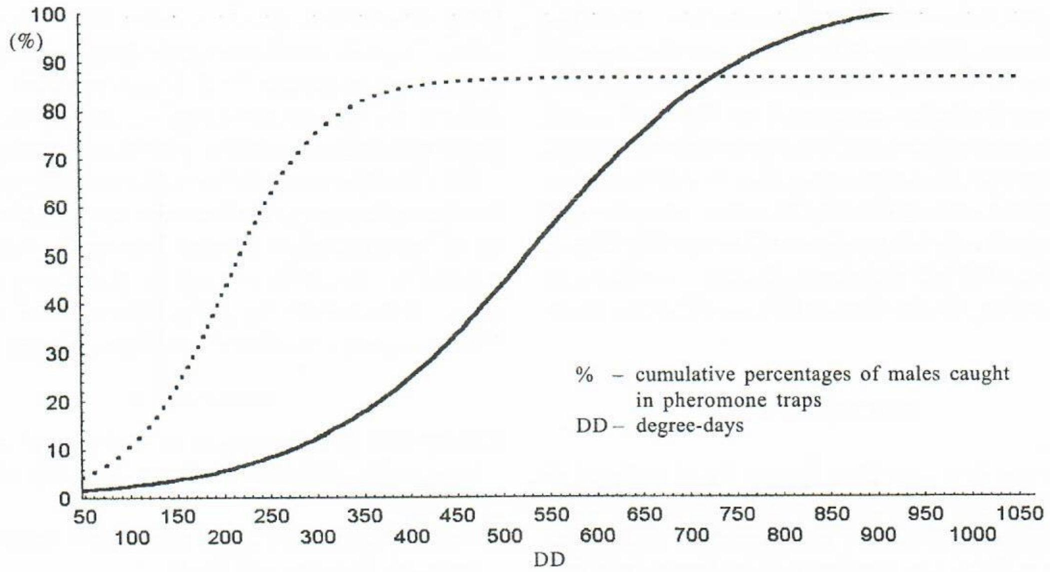
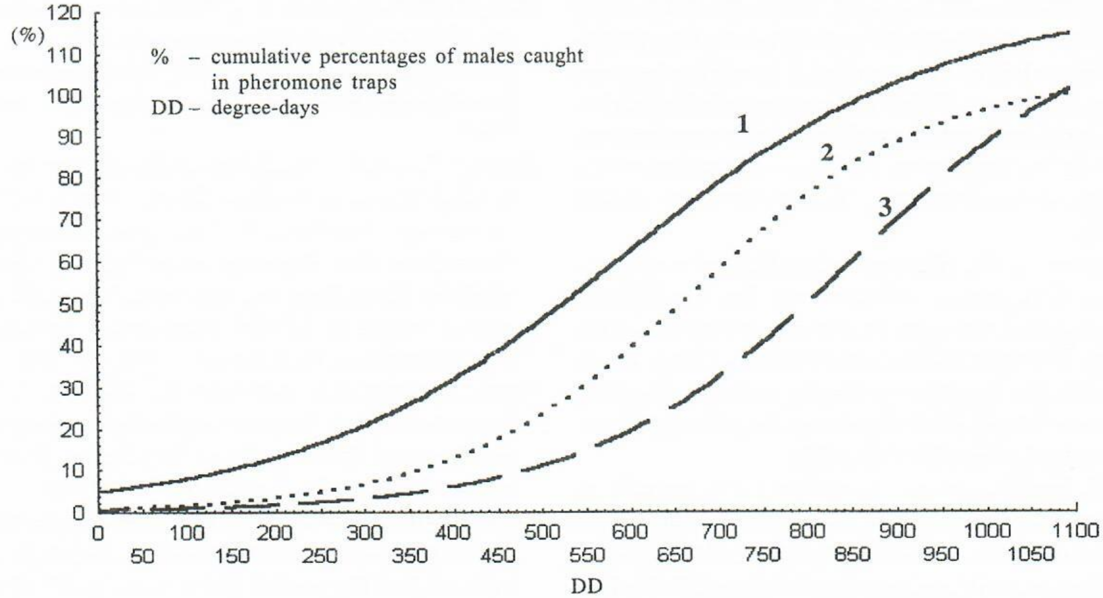


Fig. 4. Flight patterns of *Spilonota ocellana* (solid line) and *Hedya dimidioalba* (dotted line), constructed by using Richards' function, at Doksany, Roudnice, Slaný, Ruzyně, Horoměřice and Holovousy, 1993–1999

Total catches of *P. heparana* (Table 5) varied between localities and years. The range of variation was greater in the untreated orchard at Ruzyně (catches between 1993–1999 were 119 to 551 males) than in the chemically treated orchard at Horoměřice (catches between 1993–1996 were 72 to 104 males).

Cumulative catches

Cumulative catches of the overwintered generation of each species were plotted against the biological time scale. In *H. dimidioalba* and *S. ocellana* the results of different years and localities were similar after calculating the time scale. Consequently, a common curve for cumulative catches could be constructed (Fig. 4, Table 6). By contrast, in *P. heparana*, the time course of catches differed between localities and a universal pattern of cumulative catches for the overwintered generation was not constructed (Fig. 5, Table 6). Instead, separate curves were constructed for three groups of localities, (1) Doksany, Roudnice and Slaný, (2) Ruzyně and Horoměřice, and (3) Holovousy. A common biological time for cumulative catches of the



1 – Doksany, Roudnice, Slaný (solid line), 2 – Ruzyně, Horoměřice (dotted line), 3 – Holovousy (dashed line), 1992–1999

Fig. 5. Flight patterns of *P. heparana* constructed by using Richards' function

summer generation of *P. heparana* and *H. dimi-dioalba* was not formed. The flight activity of *H. dimidioalba* started (5% catch) at 50 DD, median catch (50% catch) was at 220 DD and the flight terminated at 400 DD (85% catch). The corresponding data for *S. ocellana* were at 150 DD, 530 DD and 810 DD, respectively (Fig. 4). In *P. heparana*, the biological time of the median catch increased with decreasing average temperatures of the locality (Fig. 1, Table 1) from 520 DD at Doksany, Roudnice and Slaný, to 660 DD at Ruzyně and Horoměřice, to 800 DD at Holovousy.

DISCUSSION

S. ocellana is a univoltine species in all areas of its distribution (GEEST & EVENHUIS 1991) and we also found only one generation in the Czech Republic. The start of the flight activity was similar to Canadian populations (MCBRIEN & JUDD 1998), where the flight began at 140–145 DD compared to 150 DD in the Czech Republic. We confirmed the results of STRICKLER and WHALON (1985) who found that *S. ocellana* was abundant in abandoned orchards. However, CROSS (1996) found no relationship between abundance of *S. ocellana* and history of insecticide treatment.

P. heparana is usually univoltine in the Czech Republic, but a partial second generation may occur at warm localities. This corrects the earlier opinion of GEEST and EVENHUIS (1991) who considered *P. heparana* bivoltine in Central Europe. Since the second generation of *P. heparana* causes more important damages than the overwintered one, the species is in the Czech Republic not so important a pest as in other areas of Europe, where two generations occur regularly. The length of the flight activity didn't depend on the population density. CROSS (1996) also observed the variability in catches between localities and years. While we found no relationship between total catch of males and insecticide management, CROSS (1996) found more numerous populations in the unsprayed and cider orchards than in chemically treated orchards.

The timing of the flight initiation differed widely between the three species of leaf-rollers. The variability in the beginning of the flight of *P. heparana* has also been found by DE REEDE and DE WILDE (1986). Like in *Cydia pomonella*, the apparent variability may be caused by using meteorological data that do not describe actual conditions of the orchard (BAKER 1991).

For *H. dimidioalba* and *S. ocellana* it is possible to construct universal curves of cumulative catches usable at several localities, while for *P. heparana* the flight patterns of the overwintered generation are specific for particular localities. Different selective pressure at particular localities might explain this variation. The variation of the flight activity can be influenced by differences in diapause incidence (LARGUIER 1992; BERÁNKOVÁ *et al.* 1986). In *Cydia funebrana* the flight of the overwintered generation was similar for different localities, while the flight of the second generation varied between populations from different localities (HRDÝ *et al.* 1996).

The simulation models of the flight activity are usually constructed for particular localities and the general validity of these models is limited. For species whose local populations have different flight patterns, the monitoring of the flight activity by pheromone traps is necessary. Thus, the control strategy should be modified every year.

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STARÁ J., KOCOUREK F. (2001): **Teplotní modely letové aktivity** *Hedya dimidioalba*, *Spilonota ocellana* **a** *Pandemis heparana* (Lep.: Tortricidae) **založené na datech z feromonových lapáků.** Plant Protect. Sci., **37**: 129–137.

Monitorování letové aktivity *Hedya dimidioalba*, *Spilonota ocellana* a *Pandemis heparana* pomocí feromonových lapáků probíhalo v letech 1992–1999 na šesti lokalitách ve Středních a Východních Čechách. Na základě analýzy letových křivek byly sestaveny teplotní modely letové aktivity pro jednotlivé druhy obalečů. Tyto modely byly sestrojeny za použití Richardsovy funkce a vyjadřují závislost mezi kumulativním procentem motýlů zachycených ve feromonových lapácích a termínem odchytu vyjádřeným v sumách efektivních teplot (SET) nad 10 °C (*H. dimidioalba* a *S. ocellana*) a nad 8 °C (*P. heparana*). Pro *Hedya dimidioalba* a *Spilonota ocellana* byly sestrojeny univerzální modely letové aktivity pro všechny sledované lokality. Pro *Pandemis heparana* byly sestrojeny modely letové aktivity pro jednotlivé populace z klimaticky podobných lokalit. Bylo zjištěno, že pro sledované druhy je možné přepovědět začátek, vrchol a konec letové aktivity v České republice.

Klíčová slova: *Hedya dimidioalba*; *Spilonota ocellana*; *Pandemis heparana*; jabloňové sady; letová aktivita; monitoring; feromonové lapáky; model letové aktivity; suma efektivních teplot

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