Migration Flight of Carrot Psyllid (*Trioza apicalis*) at Various Latitudes is Independent of Local Phenology

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Abstract

Láska P. (2013): **Migration flight of carrot psyllid** (*Trioza apicalis*) **at various latitudes is independent of local phenology**. Plant Protect. Sci., **49**: 187–192.

A particularly advantageous method of monitoring the flight and calculating the median was used. An example is given in order to understand better the calculation. The medians show that the timing is similar at different latitudes despite local phenological differences. The difference in median flight times between Finland and the Czech Republic was five days on average, but phenological differences are about a month, shown by a comparison of temperatures, the monitoring of buds on spruce, and by the stage of the carrot plants. During the attack by *T. apicalis* the carrot plants are younger towards north what is unusual in Psyllidae. In extreme north locations as Finland the genetic triggering for flight could not be realised by the strong declining of temperatures. Flight occurs here substantially later as to local photoperiodicity but is the earliest as to phenology, including carrot plants. The very small plants during flight are much more damaged here than the well-developed plants in central Europe.

Keywords: *Daucus carota;* median; monitoring of psyllids; photoperiod; Finland; Czech Republic

The carrot psyllid (*Trioza apicalis* Förster, 1848) is an important pest of carrot in northern Europe and occasionally in central Europe including the Czech Republic. Several earlier studies concerning carrot psyllid biology and pest status are from Baltic and Scandinavian countries: Denmark (Rostrup 1921), Latvia (Ozols 1925), Sweden (Lundblad 1929), Norway (Husas 1940), and Finland (Tiilikkala *et al.* 1996). A description of the immature stages, how to distinguish new and old generations and the biology were given in detail by Láska (1964, 1968, 1974) followed by Rygg (1977). Nissinen *et al.* (2007) showed that damage to small carrot seedlings exposed to just one individual of *T. apicalis* for only three days led to a significant yield reduction. Later Nissinen *et al.* (2012) found changes in the quality of the roots by attacked plants. The possible participation of *Liberibacter* on this reduction was discussed by Munyaneza *et al*. (2010). Nissinen *et al.* (2008) performed laboratory studies on plants preferences in connection with phototaxis. Luczak (2007) compared the occurrence of carrot psyllid on various cultivars of carrot and other plants in the field. Luczak and Gaborska (2010) found that carrot cultivars had different tolerances against larvae in pot experiments.

Carrot psyllids overwinter as adults on conifers, especially Norway spruce according to all northern authors (Ozols 1925; Lunblad 1929; Husas 1940; Rygg 1977; Valterová *et al.* 1997; Kristoffersen & Anderbrant 2007). However, the first damage to carrot by this pest occurred in Denmark (Rostrup 1921) where conifers and especially spruces are rather rare. In the Czech Republic, Baudyš (1936) recommended the winter spraying of neighbouring trees and shrubs (also non conifers). In Olomouc, carrot plots were about 5 km away from the nearest spruce stands (Láska 1968, 1974). The migration flight from winter shelters to carrot starts in late May or early June and lasts for several weeks (Krumrey & Wendland 1973; Láska 1974; Rygg 1977; Tiilikkala *et al.* 1996; Burckhardt & Freuler 2000).

The factors triggering the carrot psyllid migration from conifers to carrots are not known.

Valterová *et al.* (1997) suggested that photoperiod would play a role in controlling the shift between winter and summer host. Schönwitz *et al.* (1990) observed an inducement of some terpenes, including limonene, in spruce needles three weeks after bud opening. In addition, out of single terpenes, limonene was the most effective repellent in carrot fields in June (Nehlin *et al.* 1996). It was therefore suggested that changes in concentration of secondary metabolites in the winter host plant (i.e. Norway spruce) could affect the timing of the migration of carrot psyllids (Nissinen 2008).

In the present work, in order to compare across localities, it was necessary first to calculate characteristic dates from published graphs in the literature and make an attempt to find the triggering factors for migration. Some unpublished data are also used.

MATERIAL AND METHODS

The time-course of the flight of carrot psyllids to carrot were taken from graphs (Krumrey & Wendland 1973; Rygg 1977; Tiilikkala *et al.* 1996) or tables (Fischer pers. com.). For comparing the results from different latitudes, it is not possible to use the raw data, since one representative datum is needed from each location. This could be, for example, the date of the first psyllid caught. However, the beginning of the flight is very variable because the first specimens are singletons. When comparing a year with strong attack and one with weak attack, it is more likely to find the first specimen earlier in the former situation. In 1966 the first specimen in Olomouc was collected on May 16, but the second not until May 27 (Láska 1968, 1974). Thus one specimen exhibited an 11-day difference.

A better characteristic is provided by the median calendar date, i.e. the day on which 50% of the total number of migrating psyllids are reached. To calculate a precise date, we need to know also the end of the flight of the hibernating generation. Up to now, only Láska (1968, 1974) has distinguished the hibernated and new generations which usually occur together in August. However, the end of flight must be estimated for most of the literature used.

In monitoring, after each collection of psyllids the plot was sprayed using the very toxic but short-acting insecticide Phosdrin (mevinphos). On the day of spraying and the following day, the plants were assumed to be toxic for psyllids. For this reason we divided the weekly result by 6 days instead of 7 days (Láska 1974). The calculation is complicated so we give an example for one year (Table 2) in which also the calculation of the median is included. The graphs of Krumrey and Wendland (1973), Rygg (1977), and Tiilikkala *et al.* (1996) were transformed first to tables.

Plant phenology was compared in Finland (Kokemäki) and the Czech Republic (Olomouc). For this, we compared average temperatures, and the phenological phases of spruce and carrot.

RESULTS

Day lengths on June 17 (the average median date of migration of psyllids in Olomouc) at different locations are given in Table 2, as well as the median dates of migration.

Finland: The flight peak was roughly estimated from the graphs. The locality of Kokemäki (Finland) lies about 1000 km north of Olomouc, and therefore daylength on June 17 is longer. In Olomouc this day length is 16 h 17 minutes. The same daylength was reached at Kokemäki on May 13.

Norway: The data are relatively precise for estimating the median date in Landvik, which lies about 200 km further to the south than Kokemäki. Yellow water-traps were placed on the ground and at a height of 70 cm. Where the flight ended earlier, only the high traps were used since surface traps catch also psyllids making short flights from carrot to carrot (Table 2).

Latvia: Riga is about 200 km further to the south than Landvik. Ozols (1925) in his English summary gives only the beginning of the flight in three years (1920–1922; May 24–31), but wrote in Lettish about the main flight period between June 5–20. We used June 12 as the median date.

Germany (south): München is about 200 km further to the south than Olomouc (the precise localities are Ludwigmoos and Donaumoos). On June 17 the day in Olomouc is by 15 min longer than in München. A daylength of e.g. 16 h is achieved on June 1 in Olomouc, but not until June 13 in München. We have three dates from München and four from Olomouc. All Olomouc dates are earlier than dates from München. According to U-test of Mann and Whitney, the probability that the flight is earlier in Olomouc is by chance 0.028 (i.e. $P < 0.05$).

Table 1. Time-course of *T. apicalis* alighting on carrot in Olomouc in 1966 (calculation of median date of flight)

Date	Daily sample	Sum				
		plot 1	plot 2	plot 1 + 2	for 12 m	cumulative
June						
1	–	0	1.3	1.3	0.6	4.6
2	–	0	1.3	1.3	0.6	5.2
3	0	–	1.3	1.3	1.3	6.5
4	–	14.3	1.3	15.6	7.8	14.3
5	–	14.3	1.3	15.6	7.8	22.1
6	8(2)	14.3	1.3	15.6	7.8	29.9
7	–	14.3	–	14.3	14.3	44.2
8	–	14.3	73	87.3	43.6	87.8
9	86(1)	14.3	73	87.3	43.6	131.4
10	–	–	73	73	73	204.4
11	–	157	73	230	115	319.4
12	–	157	73	230	115	434.4
13	440(2)	157	73	230	115	549.4 median
14	–	157	–	157	157	706.4
15	–	157	29.6	186	93	799.4
16	945 (1)	157	29.6	186	93	892.4
17	–	–	29.6	29.6	29.6	922
18	–.	14.6	29.6	44.2	22	944
19	–	14.6	29.6	44.2	22	960
20	178 (2)	14.6	29.6	44.2	22	988
21	–	14.6	–	44.2	4.6	1002.6
22	–	14.6	4.3	18.9	7.5	1010.1
23	88 (1)	14.6	4.3	18.9	7.5	1017.6
24	–	–	4.3	4.3	4.3	1021.9
25	–	7	4.3	11.2	5.6	1027.5
26	–	7	4.3	11.3	5.6	1033.1
27	26 (2)	7	4.3	11.3	5.6	1038.7
28	–	7	–	7	7	1045.7
29	–	7	2	9	4.5	1050.2
30	–	7	2	9	4.5	1054.7
July						
1	49 (1)	7	2	9	4.5	1059.2
2	–	–	2	2	2	1061.2
3	–	5	2	7	3.5	1064.7
4	12 (2)	5	2	7	3.5	1068.2
5	–	5	–	5	5	1073.2
6	–	5	0	5	2.5	1075.7
7	–	5	0	5	2.5	1078.2
8	30 (1)	5	0	5	2.5	1080.7

Total 1080.7 1080:2 = 540 = median
The median of flight was reached on June 13

Table 2. The median flight in different locations and years

Location	Day length at June 17	Year	Median of flight	Average median	Latitude
Riga	17h 34 min	1920–1922	12.6.	12.6.	57°
Olomouc	16 h 17 min	1963	17.6.		
	16 h 17 min	1965	21.6.	17.6.	49°36
	16 h 17 min	1966	13.6.		
	16 h 17 min	1967	19.6.		
Ludvigmoos	16 h 2 min	1971	29.6.		
Donaumoos	16 h 2 min	1971	24.6.	24.6.	48°
	16 h 2 min	1972	20.6.		
Landvik	18 h 8 min	1970	21.6.		
	18 h 8 min	1971	8.7.	29.6.	59°
	18 h 8 min	1972	28.6.		
Kokemäki	19 h 8 min	1993	15.6.		
	19 h 8 min	1994	28.6.	22.6.	61°16
	19 h 8 min	1995	22.6.		

Switzerland (Geneva): The data are very variable, but the average of 18 medians from 1998–2009 was June 22, and thus later than in Olomouc where the average was on June 17.

Differences in phenology between Olomouc and Kokemäki make almost exactly one month, as is clear from following the shift in average monthly temperatures (over 50 years).

	Kokemäki	Olomouc
March		3.8°C
April	2.5°C	9.1°C
May	9.5°C	14.2°C
June	14.4°C	

The development of buds was observed on sprouts near Kokemäki in Finland and in Olomouc in 2009. The first “longer shoot” was observed on April 23 in Olomouc, whereas in Finland the buds were largely quiescent up to May 23, with the elongate new shoots really starting only during the last week of May. The delay is approximately one month.

The carrot stage was compared on June 16, 2008 (about the maximum of the average flight in Olomouc). The carrot in Finland had 2–3 true leaves and was 2–3 cm high, whereas in Olomouc the plants had 6–8 leaves and measured about 25 cm. This also indicated about a one-month delay in the development of the plants.

DISCUSSION

In the literature, sticky traps are mostly used for monitoring carrot psyllids. However, the leaf surface is small in very young plants compared with the greater surface of the traps, which may increase the attractiveness of the traps at the beginning of the vegetative season. Rygg (1977) considered water traps adequate to catch the early immigrants, but not suitable for measuring field populations and suggested utilizing direct counting methods, such as those used by Láska (1974), for developing threshold values. There is a need to make further trials with traps of various sizes and hues of yellow, and compare them with the actual presence of psyllids on plants.

Láska (1968, 1974) supposed that the flight may be dependent, as in many other cases, on the phenological date, which is mostly dependent on the temperature. He chose the beginning of blooming of *Tilia platyphyllos* Scop. as a reference, which corresponded relatively well with the median flight date of carrot psyllid in Czechoslovakia. However, he found later that it is not the same in more northern countries.

Departure from the host-plant in sucking insects is mostly dependent on the concentration of essential amino acids, e.g. in aphids (Weismann & Vallo 1963). The level of soluble nitrogen is also considered important for psyllids (e.g. *Psylla* species on *Salix* in Alaska and Hodkinson *et al.* 1979). Global work on variation and adaptation of psyllids by Hodkinson (2009) postulated a high degree of synchrony between psyllid and host-plant growth in both temperate and tropical conditions. He also concluded that the main factor affecting the production of different seasonal forms in all psyllids is photoperiod. Based on my results, however, *T. apicalis* is apparently an exception.

Obviously in many insects (e.g. *Psylla pyricola* – Olfield 1975; *Aphis fabae* – Nunes & Hardie 2000; *Macrosiphum euphorbie* – Lamb & MacKay 1997), there exist several populations showing different photoperiodic responses at different latitudes or geographic areas. In contrast, it seems that in various latitudes *Trioza apicalis* has almost the same requirement for daylength, i.e. about 17 h of light. This daylength was also estimated in the laboratory by Valterová *et al.* (1997) in Sweden, at almost the same latitude as South Finland (cca 60°). It is also interesting that *Trioza apicalis* has almost the same daylength requirement when comparing data from München and Olomouc. In Olomouc, the median flight is significantly earlier than in München. In June, the day is a little longer in Olomouc than in München, and thus the flight is earlier. This indicates that populations in München are waiting for the same daylength as in Olomouc. The day prolongation has influence up to about 57° latitude, where the main flight occurs by 5 days earlier on average than in Olomouc.

The great problem is in Finland, where the median flight was on average on June 22, when the actual daylength in nature is 19 h 22 min, by more than 2 h longer than in the laboratory. I think that the lower temperatures counteract the effects of daylength towards the north. Actual flight in the field arises as a compromise between daylength and temperature. I estimate that towards about 56° latitude, daylength is more important than temperature. From about this latitude, gradually the cold conditions become more important, and the influence of cold is apparently maximal at the northern limit of carrot growing in Finland. The extraordinary selection pressure of cold conditions in Finland is so severe that there the accommodation to length of day probably will appear sooner than in other countries (see also Láska 2011).

The practical result for agriculture is that the smaller carrot plants in the north are damaged by the same number of psyllids much more than in central Europe.

Acknowledgements. We are very obliged to Dr. Serge Fischer, Station Fédérale de Recherches en Production Végétale de Changins, Nyon, for sending us the tables of catches of carrot psyllid from the years 1998–2009 in Switzerland. We thank to Doc. Martin Jurek from Palacky University Olomouc for information about daylengths at several latitudes and for meteorological data from Kokemäki and Olomouc. Special thanks for repeated substantial improvements of my English are due to Prof. Francis Gilbert, Nottingham.

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Received for publication December 13, 2012
Accepted after corrections March 3, 2013

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