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**Population dynamics of *Cacopsylla melanoneura* (Hemiptera: Psyllidae) in Northeast Italy and its role in the Apple proliferation epidemiology in apple orchards**

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26 **Population dynamics of *Cacopsylla melanoneura* (Hemiptera: Psyllidae) in Northeast**  
27 **Italy and its role in the Apple proliferation epidemiology in apple orchards**

28

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34

35 **Abstract**

36 In the present study, incidence of ‘*Candidatus Phytoplasma mali*’ in an experimental apple  
37 orchard in Northeast Italy, in addition to abundance and phytoplasma infectivity of *Cacopsylla*  
38 *melanoneura* (Hemiptera: Psyllidae) were determined and the role of this psyllid as a vector of  
39 ‘*Ca. P. mali*’ in this region were reviewed. Insect samples collected in the orchard by the beating  
40 method indicated high abundance of *C. melanoneura*, (up to 7.92 specimens/branch); however  
41 the psyllid *C. picta* was not observed. Molecular analyses revealed presence of ‘*Ca. P. mali*’ in  
42 6.25% of overwintered psyllids. This infection rate is quite high in comparison to other localities  
43 where *C. melanoneura* is known as the main vector of the phytoplasma. This finding supports  
44 the assumption that *C. melanoneura* also is paramount in the epidemiology of the apple  
45 proliferation disease also in Northeast Italy. Moreover, we correlated immigration dynamics to  
46 the temperatures registered in the apple orchard, and defined an immigration index to predict the  
47 progressive arrival of the overwintered adults from winter sites. Psyllids start to reach the apple  
48 orchards when either the average of the maximum temperature of the seven days is above 9.5°C  
49 or the immigration index has a positive value. This index will be a useful tool for the growers to  
50 prevent apple proliferation phytoplasma spread with well-timed insecticide treatments targeted  
51 against *C. melanoneura*. However, further research is needed to validate or adjust the index to  
52 other apple growing regions, which may affect more efficacious management of this disease and  
53 psyllid vector.

54 .

55

56 **KEY WORDS:** *psyllid vector*, ‘*Candidatus Phytoplasma mali*’, *immigration dynamics*,  
57 *temperature*, *apple orchards*, *overwintered adults*,

## 58 **Introduction**

59 Apple proliferation is a serious disease which has caused significant economic losses over the  
60 past ten years in all European apple-growing regions (Kunze 1989). Fruit weight is often reduced  
61 by 30-60%, the fruit color is unsatisfactory and the taste is poor, with the result that as much as  
62 80% of the fruits is unmarketable.

63 The disease is induced by '*Candidatus Phytoplasma mali*', a phytoplasma that colonizes the  
64 phloem system of apple plants and is transmitted by insect vectors during their trophic activity.

65 The pathogen is acquired passively during feeding in the phloem of infected plants, moves  
66 through the intestine and pass intracellularly through the epithelial cells to enter the hemocoel.

67 Then the phytoplasma circulates in the hemolymph, replicate and finally penetrates specific cells  
68 of the salivary glands. With the next feeding, the insect can transmit the phytoplasma to a healthy  
69 plant. Affected plants lack vigor and fruits are markedly reduced in size with poor flavor and low  
70 sugar and acidity content (Osler and Loi 1986). Since the first incidence occurred in the Trentino  
71 region (northeast Italy) in the mid-1990s, many studies were carried out concerning the spread of

72 the phytoplasma and the insect vectors. High percentages of symptomatic plants were first

73 observed in several orchards of Trentino (Vindimian and Delaiti 1996, Vindimian et al. 2000)

74 affecting several varieties, mainly Golden Delicious, Florina and Renetta del Canada. Studies on

75 insect vectors revealed the important role of the Hemiptera, genus *Cacopsylla* in the transmission  
76 of this phytoplasma. In Trentino two species, *Cacopsylla melanoneura* (Förster) and *C. picta*

77 (Förster), are regularly present in the orchards. Contrary to Northwestern Italy where *C.*

78 *melanoneura* is the primary vector of 'Ca. P. mali' (Tedeschi et al. 2002, 2003; Tedeschi and

79 Alma 2004), in Trentino low phytoplasma infection rate in this species and very low

80 transmission efficiency by this psyllid were recorded (Mattedi et al. 2007, 2008). But in a recent

81 report elevated phytoplasma infection rates in *C. melanoneura* from Trentino region were  
82 correlated with the infection level in the plants (Malagnini et al. 2010). On the other hand, *C.*  
83 *picta* showed higher natural infection rate and transmission efficiency even at low density  
84 (Frisinghelli et al. 2000, Forno et al. 2002, Mattedi et al. 2007, 2008) in accordance also with  
85 German results (Jarausch et al. 2003, 2004, 2008, Mayer et al. 2009). Both these insects have a  
86 quite complex life cycle. The overwintered adults reach the apple orchards in winter, in the case  
87 of *C. melanoneura* (Tedeschi et al. 2002; Mattedi et al. 2007) and at the end of March in the case  
88 of *C. picta* (Mattedi et al. 2007). On this host plant they mate, lay eggs and develop. In late  
89 spring the newly emerged adults rapidly move to shelter plants, mainly conifers, for aestivation  
90 and overwintering.

91 Preliminary evidence suggests that overwintered adults are already infected when they re-  
92 migrate into apple orchards (Jarausch et al. 2004; Mattedi et al. 2008), so well-timed treatments  
93 are very important to control the first individuals that reach the orchards. For this reason a  
94 phenology model will be a useful support for vector management decisions. Many forecasting  
95 models have been produced for other psyllid species, using means of driving variables, mainly  
96 temperature, and based on developmental thresholds (DT) and degree-days (DD) (Beránková and  
97 Kocourek 1994, Kapatos and Stratopoulou 1999, Kumral et al. 2008, Morgan and Solomon  
98 1993; Schaub et al. 2005). These models refer to some phases of the life cycle and predict when  
99 a developmental stage (generally the most damaging stage) will appear. None of these models  
100 concerns the immigration period for psyllids that move between different host-plant species or  
101 exploit non-host plant species as overwintering sites.

102 In the present study we analyzed in detail the incidence of ‘*Ca P. mali*’ in an experimental  
103 orchards in Northeast Italy in addition to the abundance and phytoplasma infection of *C.*

104 *melanoneura*, with the aim to revise the role of this psyllid as a vector of ‘Ca P. mali’ in this  
105 region. Moreover, we propose an index based on the maximum temperatures registered in the  
106 apple orchard, to predict the arrival of the overwintered adults. This index will be a useful  
107 management tool for the growers to prevent phytoplasma spread thanks to well-timed insecticide  
108 treatments.

109

110

## Materials and methods

### 111 Field samplings

112 The study was carried out over five growing seasons (2006-2010) in a conventionally treated 3  
113 hectare apple orchard of the IASMA Research and Innovation Center, Fondazione E.Mach  
114 (Borgo Valsugana, 419 m a.s.l., Trento, Italy). Observations on the incidence of Apple  
115 proliferation disease and the population dynamics of *C. melanoneura* were performed in 4  
116 untreated plots (area 1500 m<sup>2</sup>), which were randomly selected in the orchard. The main apple  
117 variety was Golden delicious, with 15-25 years old trees, 4.0±0.5 m high, and spaced 0,5-1.6 m  
118 within a row and 4.0-4.6 m between rows. The number of symptomatic trees was recorded at the  
119 end of September and a total number of twenty-one samples was randomly collected from  
120 symptomatic plants to be analyzed with molecular assays. During each season, insect monitoring  
121 started before the immigration in the orchard of the first overwintering adults (January/February)  
122 and it lasted till the emergence of the springtime generation (May/June). Adults were collected  
123 every 7 days, by means of beating method: for each replication plot, 25 branches (50±10 cm in  
124 length) were considered and every branch was shaken 2 times above a beating tray (diameter 7  
125 cm, 60 x 40 cm of cloth). The collected adults were counted and identified in the laboratory by  
126 both morphological, examining female and male terminalia (Ossiannilsson, 1992) and molecular

127 tools (Tedeschi and Nardi 2010), then analyzed for phytoplasma presence. An in-depth study on  
128 the frequency of '*Ca. Phytoplasma mali*'-positive psyllids was carried out in 2008 and a total  
129 number of 194 batches, each of 5 specimens, was analyzed. The number of eggs and young  
130 stages was assessed by examining under the microscope 30 apical shoots (20-25 cm long) from  
131 each replication, randomly selected in the central rows of each plot. These controls were  
132 performed every 7 days, from the beginning of the oviposition until the emergence of the  
133 springtime generation.

134

### 135 **Phytoplasma detection and species identification**

136 Plant DNA was isolated from 100 mg (wet weight) of phloem tissue from symptomatic plants,  
137 previously ground with liquid nitrogen in a sterile mortar, using the QIAGEN's DNeasy® Plant  
138 Mini Kit (Qiagen, Hilden, Germany). DNA was eluted in 100 µl of elution buffer and kept at -  
139 20°C until used. Total DNA was extracted from batches of five adult psyllids following a  
140 protocol adapted from Marzachi et al. (1998) and previously applied to psyllids (Tedeschi et al.  
141 2002). The final product was resuspended in 50 µl of TE.

142 Insect and plant DNAs were amplified firstly with the phytoplasma universal primer pair P1/P7  
143 (Schneider et al. 1995) and then in nested PCR with the primers fO1/rO1 (Lorenz et al. 1995)  
144 specific for the AP-group phytoplasmas, after a 1:40 dilution. Reaction conditions were as in the  
145 original papers. Contamination by amplicons was avoided by using separate rooms and material  
146 as well as decontamination procedures (UV exposure and bleaching of materials and surfaces).  
147 Moreover, for each amplification, a negative control containing Milli-Q water was  
148 included. Amplification products were analyzed by 1% agarose gel electrophoresis, stained with  
149 ethidium bromide, and visualized on a U.V. transilluminator. Specific '*Ca. Phytoplasma mali*'



150 profiles were obtained by RFLP analysis with endonuclease SspI, digesting seven microliters of  
151 the amplification product with 3U of SspI for 4.5 h at 37°C.

152 The proportion of infected insects was estimated by its maximum-likelihood estimator,  $\hat{p}$ ,  
153 calculated according with Swallow (1985):  $\hat{p} = 1 - H^{1/k}$ , where H is the observed fraction of  
154 healthy groups and k is the number of insects per group, five in this case.

155 The psyllid identification by morphological analyses was confirmed by molecular analyses using  
156 the primer pairs MEL fw/MEL rev developed for *C. melanoneura* (Tedeschi and Nardi 2010).

157 Thirty-two randomly selected individuals were used to confirm morphological observations.

158 Reaction conditions were as in the original papers.

159

#### 160 **Population dynamics and index of immigration**

161 The population trend of *C. melanoneura* in the apple orchards was based on data collected during  
162 the years 2006-2010 for adults and 2006-2008 for eggs and juveniles. In order to identify which

163 environmental parameters in the orchards were possibly involved in *C. melanoneura*

164 colonization we developed an original model according to the following procedure. Starting,

165 from 2006 the maximum, and median daily and hourly temperatures were recorded at 2 meters

166 above the ground from a meteorological station inside the apple orchard. For daily temperatures

167 we also calculated the average of the seven days ( $T_{7n}$ ) preceding any sampling date ( $a_n$ ). Seven

168 days was chosen since field samplings were conducted with such a periodicity. Temperature

169 trends were associated with the insect dynamics, from the date of first detection ( $a_0$ ) to the peak

170 of captures ( $a_{max}$ ). In the first instance, the absolute highest temperature among the 7 days

171 preceding  $a_0$  ( $T_{0max}$ ) was taken and then the minimum across the years among the  $T_{0max}$ . This

172 minimum was defined as hypothetical threshold temperature (**Tth**) of psylla orchard

173 immigration. The  $T_{th}$ , calculated both for median and maximal temperatures was checked  
174 whether it had been previously passed without eliciting the psyllid immigration and we selected  
175 only those that were not passed. The same procedure was done for the  $T_{7n}$  where a relative  
176 hypothetical threshold ( $T_{7th}$ ) was defined.

177 The average of degree days were counted with temperature above the threshold for any  $T_{7n}$  ( $dd_n$ ).

178 The index of immigration was defined as:

179

$$180 \mathbf{Ii} = [ (T_{7n} - T_{7th}) + dd_n ]$$

181 The immigrated population ( $\mathbf{Ip}$ ) as:

$$182 (p_n - p_{n-1})$$

183 where  $(p_n - p_{n-1})$  is the difference of sampled adults (expressed as % referred to the population  
184 peak) between two consecutive samplings.

185 A simple regression analysis was performed between  $\mathbf{Ii}$  and  $\mathbf{Ip}$ , from the  $a_0$  to the  $a_{max}$  of each  
186 year (2006-2010). If the regression was significant then the previsions were verified concerning  
187 the detection of any  $a_0$  by calculating  $\mathbf{Ii}$  related to any sampling from 2006 to 2010 *a posteriori*.

188 The first positive value of  $\mathbf{Ii}$  was assessed whether it was associated to the first psylla detection  
189 in the field. The same procedure was followed for historical data taken from the same orchard in  
190 the period 2002-2004. Eventually, all data were associated to the apple phenology, in particular  
191 bud breaking and first flowering.

192

193

## Results

194 **Apple proliferation incidence**

195 The symptoms observed in the orchards were predominantly witches' brooms, reddening of the  
196 leaves, enlarged stipulae, abnormally long flower stalks, flowering out of season and small fruits.  
197 Basing on the percentage of symptomatic trees, the incidence of apple proliferation disease  
198 ranged from 60 to 100%, according to the plot, with a mean annual increase of 5%.

199

#### 200 **Psyllid identification and phytoplasma detection**

201 Following the morphological observations, almost all the psyllids collected in the experimental  
202 plots were identified as *C. melanoneura*. *C. mali* was sporadically observed; whereas, *C. picta*  
203 was never found. Molecular analyses confirmed the identifications of *C. melanoneura*.

204

205 The PCR analyses performed with primer pair fO1/rO1 gave AP-group specific amplicons of the  
206 expected size (1050 bp) with both plant and insect DNA. No amplification products were  
207 obtained from the negative controls. All 21 samples of symptomatic plants were positive to AP-  
208 group phytoplasmas and the RFLP with *SspI* restriction enzyme confirmed the presence of 'Ca.  
209 Phytoplasma mali'. The results of PCR detection in the insects are shown in table 1. One  
210 hundred and seventy-four samples of overwintered adults, 5 samples of nymphs and 15 samples  
211 of newly emerged adults were tested. Forty-eight out of 174 batches of overwintered psyllids  
212 were positive for 'Ca. Phytoplasma mali', with an estimation of 6.25% of infected *C.*  
213 *melanoneura*. No amplification was obtained from nymphs and newly emerged adults.

214

#### 215 **Population dynamics and index of immigration**

216 The population trend of *C. melanoneura* overwintered adults was extremely variable during the  
217 years . The immigrant adults were recorded starting from the beginning of February in 2008,

218 while in 2006 they were delayed to mid-March. The peak of overwintered adults was reported  
219 between the 10th and the 13th week, depending of the year, but it was mostly concentrated in the  
220 second half of March. Eggs of *C. melanoneura* were observed on apple branches starting from  
221 the beginning of March in 2008 and the last ten days of the month in 2006 and 2007. The  
222 oviposition lasted until mid-April in 2007 and the beginning of May in 2006 and 2008. Young  
223 stages were recorded from the beginning of April in 2007 and 2008 and the end of the same  
224 month in 2006. Nymphs remained in the orchards until the beginning of May in 2007 and the end  
225 of May in 2006 and 2008 (Fig. 1).

226 Combining the population dynamics of *C. melanoneura* with the apple phenology (Table 2), a  
227 good correspondence between overwintered adult peak – first egg detection and apple bud  
228 breaking was found, with the peak of egg always preceding the first flowering.

229 Values and indexes referred to the psylla migration analysis are reported in table 3. The **Tth**  
230 calculated from maximum (12.8°C) and median (3.3°C) temperatures did not explain the first  
231 appearance of the psylla in the orchard, and no correlation was found with the insect migration  
232 into the orchard. Similarly, the **T<sub>7th</sub>** taken from median temperatures (2.0°C) did not represent  
233 an effective threshold value, because it has been passed several times in the years without  
234 triggering the appearance of psylla in the orchard. Instead, the **T<sub>7th</sub>** calculated from maximum  
235 values (9.5°C) was found to be a candidate for a possible migration threshold. The regression  
236 analysis between **I<sub>p</sub>** and **I<sub>i</sub>** (Fig.2) was highly significant ( $F = 24.2$ ;  $df = 1,26$ ;  $p < 0.001$ ).

237 Positive values of **I<sub>i</sub>** corresponded with the first appearance of the psylla in the orchard in 2006  
238 and 2008-10. Instead, in 2007 values slightly above zero (1.5 and 0.9) in the first five weeks did  
239 not correspond to the first presence. However, when the **I<sub>i</sub>** reached for a more relevant value

240 (6.5), individuals were eventually found. Positive **Ii** fitted in verifying all the **a<sub>0</sub>**, also for  
241 historical data of 2002-2004.

242

243

## Discussion

244 The present research provides important and new information on the epidemiology of apple  
245 proliferation in northeast Italy and develops an index of immigration that enables well-timed  
246 control measures against the insect vectors. The role of *C. melanoneura* as vector of ‘*Ca.*  
247 *Phytoplasma mali*’ has been revised in this area confirming the results obtained by Malagnini et  
248 al. (2010) on psyllid infectivity. Previous reports concerning Trentino region pointed out the  
249 predominance of *C. picta* in Val d’Adige and *C. melanoneura* in Val di Sole and Val di Non (up  
250 to 2 overwintered adults/branch) (Mattedi et al. 2007, 2008). Transmission trials and  
251 phytoplasma quantification in insect bodies revealed a low transmission efficiency for *C.*  
252 *melanoneura* while an important increase in phytoplasma concentration was observed only in *C.*  
253 *picta*, indicating an efficient phytoplasma multiplication in this species (Pedrazzoli et al. 2007).  
254 For this reason it is now popularly held belief that *C. picta* is the most important vector of ‘*Ca.*  
255 *Phytoplasma mali*’ in northeast Italy, as well as in Germany (Jarausch et al. 2003, 2004, 2008;  
256 Mayer et al. 2009), while in northwestern Italy, *C. melanoneura* represents the only psyllid  
257 vector of this phytoplasma (due also to the absence of *C. picta*).  
258 Evidence supports the role of *C. melanoneura* as a vector in Valsugana, a valley in the south east  
259 of the Trentino region with a long tradition in apple production. This area is characterized by an  
260 high incidence of the apple proliferation disease and the only important psyllid species which  
261 was found in the repeated collections trough a five year period was *C. melanoneura*; *C. picta* was  
262 never recorded. The molecular analyses revealed the presence of ‘*Ca. Phytoplasma mali*’ (as the

263 Swallow's estimated proportion  $p^{\wedge}$ ) in 6.25% of overwintered psyllids, confirming roughly the  
264 results obtained by Malagnini et al. (2010) with specimens coming from the same area. This  
265 discrepancy may be due to the different number of psyllids analyzed. During the peak presence  
266 there were up to 7.92 overwintered adults/branch in 2007, and from the beginning until the end  
267 of March in all the three years the number of recorded *C. melanoneura* was almost always higher  
268 than 2 psyllids/branch. Thus, in this valley, *C. melanoneura* should be considered the only  
269 significant vector associated with the rapid spread of this disease.

270 The infection rate of the overwintered adults tested high in comparison to other localities where  
271 *C. melanoneura* is already known as the main vector of 'Ca. phytoplasma mali' (an estimation of  
272 6.25% vs 3.6% of 'Ca. Phytoplasma mali'-positive insects) (Tedeschi et al. 2003). This fact  
273 strengthens the evidence that *C. melanoneura* has an important role in the epidemiology of the  
274 apple proliferation disease also in northeast Italy, where its control is already regulated by  
275 insecticide treatments (Baldessari et al. 2007, 2009).

276 Once ascertained that *C. melanoneura* represents an important risk for apple growers, a new  
277 approach to the management of this vector needs to be developed. Data collected during the  
278 years concerning the population dynamics of this species, the apple phenology and the weather  
279 parameters allowed us to define an index to predict the re-migration of overwintered adults into  
280 apple orchards. The aim was to provide to the growers an easy to use tool which would predict  
281 the time of arrival of *C. melanoneura*. in order to refine the pest management decisions. The  
282 efficiency of an insecticide treatment depends on the product and on the timing of application in  
283 order to affect the most sensitive or harmful stage on the crop. In the case of *C. melanoneura*,  
284 overwintered adults showed, in comparison with all the other stages, the highest population  
285 density, the highest percentage of 'Ca. Phytoplasma mali'-positive specimens, and the longest

286 time spent in apple orchards. All these characteristics suggest that this is the crucial role of this  
287 stage in vectoring AP-phytoplasma (Tedeschi et al. 2002, 2003). For this reason the treatments  
288 should be focused on the overwintered adults as soon as they start to colonize apple orchards.  
289 As a consequence, we established a index of immigration related to the immigrant psylla adults.  
290 Similar studies were built in the past to forecast the occurrence of a particular life stage of a pest  
291 with the aim to improve its control (Beránková and Kocourek 1994, Kapatos and Stratopoulou  
292 1999, Kumral et al. 2008, Morgan and Solomon 1993, Schaub et al. 2005), but never to predict  
293 the adult immigration in the orchards. Here we propose an empirical model which cannot be  
294 supported by laboratory trials due to the impossibility of reproducing the entire biological cycle  
295 of *C. melanoneura* in controlled conditions. This correlation is based on the temperatures  
296 recorded in the apple orchards, a variable that can be easily monitored by the growers or at least  
297 by the phytosanitary services.

298 It is known that temperature influences apple phenology and that the migration could also be  
299 influenced by certain phenological stages of the trees. Immigration into orchards take place  
300 during budding, which may be detectable by the overwintering psylla, thereby attracting them to  
301 the stimuli associated to budding.

302 However, the distances occurring between psyllid host plants and shelter plants can be  
303 considerable (Čermák and Lauterer 2008, Thebaud et al. 2009), thus it is improbable and  
304 temperature is most likely the critical factor. There was no correlation between immigration  
305 dynamics and apple phenology demonstrated, however oviposition occurs at bud burst while egg  
306 peak and hatchings are always before the first flowering. This confirmed a good degree of  
307 synchrony between *C. melanoneura* and host-plant growth, being linked with temperatures as

308 stated for psyllids in general by Hodkinson (2009). These data are likewise useful for the  
309 growers for possible further treatments during the season.

310 In the present study, the hypothetical threshold calculated as an average of the maximum  
311 temperatures of the seven days (**T<sub>7th</sub>**) proved to be a good tool to forecast immigration, by  
312 calculating a proper Index of immigration (**Ii**). Psyllids started to reach the apple orchards when  
313 the **T<sub>7th</sub>** was 9.5°C. Also including in the model single episodes, meant as hours above this  
314 threshold, we could individuate with extremely precision the time of first occurrence and the  
315 following immigration trend for a period of 9 years. It is feasible that any **Ii** over 0 can elicit  
316 psyllid migration, with direct correlation between **Ii** value and number of migrant specimens, and  
317 our failure in detecting individuals in correspondence of **Ii** < 2 depended likely on the extremely  
318 low number occurring in the field in those circumstances.

319 On the other hand, there are still some relevant limits that we need to point out. The calculated  
320 threshold fits well for apple orchards located in the Valsugana valley, but not necessarily for  
321 other locations, where the correlation needs to be validated by adjusting the threshold value,  
322 either according to historical collection data or by programming periodical field collections.

323 Other geographical factors associated with the winter sites location (e.g. the regional orography,  
324 the main air streams and distance from apple orchards) may differently affect the psylla  
325 migration process and influence its presence/absence, both in terms of time and quantity, in a  
326 given apple orchard.

327 A straight correlation between maximum temperature and adult mobility was found in addition  
328 to a, temperature threshold that, independently on the period in the winter, favors the psylla to  
329 abandon overwintering sites. However, more research is required to set up a proper forecasting  
330 model, which could be applied in different apple-growing regions.



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423 **Table 1 - Estimated proportion ( $p^{\wedge}$ ) of ‘*Candidatus Phytoplasma mali*’-infected *Cacopsylla***  
 424 ***melanoneura* (Förster) collected by beat tray samplings in 2008 in the experimental plots**  
 425

	Date	AP+/tot	$p^{\wedge}$		AP+/tot	$p^{\wedge}$
overwintered	1 February	0/3	0	}	48/174	6.25
	8 February	5/10	12.94			
	15 February	6/8	24.2			
	22 February	1/8	2.63			
	28 February	5/30	3.58			
	7 March	11/30	8.73			
	13 March	8/30	6.01			
	21 March	5/30	3.58			
	28 March	6/20	6.88			
	4 April	1/5	4.36			
nymphs	15 May	0/15	0	}	0/15	0
offspring	16 April	0/1	0	}	0/5	0
	15 May	0/4	0			

426

427

428 **Table 2 - Number of weeks when an event of psylla or apple phenology was recorded for**  
 429 **each year of investigation (2006-2010). For the historical data (2002-2004) only the first**  
 430 **detection and the peak of captures of psylla were available.**

431

	2002	2003	2004	2006	2007	2008	2009	2010
First Psylla	5	8	6	11	7	4	8	9
Psylla Peak	10	10	11	13	11	10	12	12
First Egg	-	-	-	13	11	10	12	12
Egg Peak	-	-	-	14	13	14	14	13
Bud break	-	-	-	13	10	11	12	12
Flowering	-	-	-	16	14	14	15	15

432

433

434 **Table 3 - Absolute (T) and average of 7 days (T7) median (med) and maximal (max)**  
 435 **temperature (°C) associated with the first psylla detection (suffix a<sub>0</sub>) and with periods**  
 436 **before the first detection (suffix a<sub>-n</sub>) in the years 2002-2004 and 2006-2010 . Ii is the**  
 437 **Immigration index. In bold are indicated the minimal a<sub>0</sub> and maximal a<sub>-n</sub> values across the**  
 438 **years for each parameter.**

439

	2002	2003	2004	2006	2007	2008	2009	2010
<i>Ta<sub>0med</sub></i>	-	-	-	4.9	7.5	12.9	<b>3.3</b>	5.4
<i>Ta<sub>-nmed</sub></i>	-	-	-	4.4	<b>8.5</b>	4.2	4.5	4.4
<i>Ta<sub>0max</sub></i>	-	-	-	12.8	16.4	20.3	<b>12.5</b>	13.0
<i>Ta<sub>-nmax</sub></i>	-	-	-	11.8	<b>21.8</b>	11.4	9.6	9.8
<i>T7a<sub>0 med</sub></i>	-	-	-	3.5	5.1	5.3	<b>2,0</b>	4.5
<i>T7a<sub>-n med</sub></i>	-	-	-	2.3	<b>3.7</b>	3.1	<b>3.7</b>	3.0
<i>T7a<sub>0 max</sub></i>	9.8	10.2	10.2	10.1	12.1	11.2	<b>9.5</b>	10.4
<i>T7a<sub>-nmax</sub></i>	5.8	6.6	7.7	8.8	<b>9.4</b>	7.0	8.0	7.7

440

441



442 **Table 4. Calculated Index of immigration (Ii) and Immigrated population (Ip) from the**  
 443 **first week of January until the population peak, in the periods 2002-2004 and 2006-2010.**  
 444 **Samplings (s) were conducted weekly. In gray cells, in bold, are highlighted values of first**  
 445 **positive Ii and first Psylla detection in the orchard.**  
 446

447

s	2002		2003		2004		2006		2007		2008		2009		2010	
	Ii	Ip	Ii	Ip	Ii	Ip	Ii	Ip	Ii	Ip	Ii	Ip	Ii	Ip	Ii	Ip
1	-8.0	0	-7.0	0	-7.5	0	-7.0	0	-3,2	0	-7.9	0	-9.5	0	-6.7	0
2	-6.4	0	-9.0	0	-5.2	0	-8.3	0	-0,4	0	-4.8	0	-6.3	0	-6.0	0
3	-6.1	0	-7.0	0	-6.0	0	-8.2	0	<b>1.5</b>	0	-2.1	0	-5.6	0	-6.3	0
4	-3.6	0	-2.9	0	-8.2	0	-7.0	0	-3.9	0	<b>6.1</b>	<b>0.03</b>	-3.8	0	-7.5	0
5	<b>2.2</b>	<b>0.04</b>	-4.9	0	-1.2	0	-1.7	0	0.9	0	0.0	0.05	-0.9	0	-6.6	0
6	4.3	0.09	-5.0	0	<b>2.3</b>	<b>0.07</b>	-5.1	0	-1.2	0	1.4	-	-2.6	0	-5.3	0
7	-1.3	-0.09	-1.7	0	2.3	0.11	-2.8	0	6.5	<b>0.01</b>	-0.2	0.00	-2.6	0	-3.3	0
8	4.0	0.27	<b>3.4</b>	<b>0.05</b>	-5.7	-0.04	-3.4	0	7.8	0.01	9.3	0.50	<b>1.5</b>	<b>0.04</b>	-1.5	0
9	5.1	0.08	6.9	0.50	-0.3	-0.07	-2.5	0	15.3	0.50	12.2	0.26	2.3	0.15	<b>2.8</b>	<b>0.01</b>
10	14.6	0.61	11.3	0.45	3.2	0.07	-0.1	0	12.2	0.13	4.1	0.19	6.9	0.22	-1.6	0.02
11					6.1	0.85	<b>3.2</b>	<b>0.41</b>	9.2	0.35			11.4	0.60	6.9	0.17
12							7.8	0.50							15.2	0.81
13							10.8	0.10								

448

449

450 **Figure Captions**

451 Fig. 1. Presence of eggs and nymphal stages of *Cacopsylla melanoneura* (Förster) in the orchard  
452 in 2006-2008.

453 Fig. 2. Simple Regression analysis ( $F = 24.2$ ;  $df = 1,26$ ;  $p < 0.001$ ) between Immigration Index  
454 (**Ii**) and Immigrated population (**Ip**) calculated from the average of maximal temperature of the 7  
455 days preceding any adult sampling of the period 2002-2010.

456

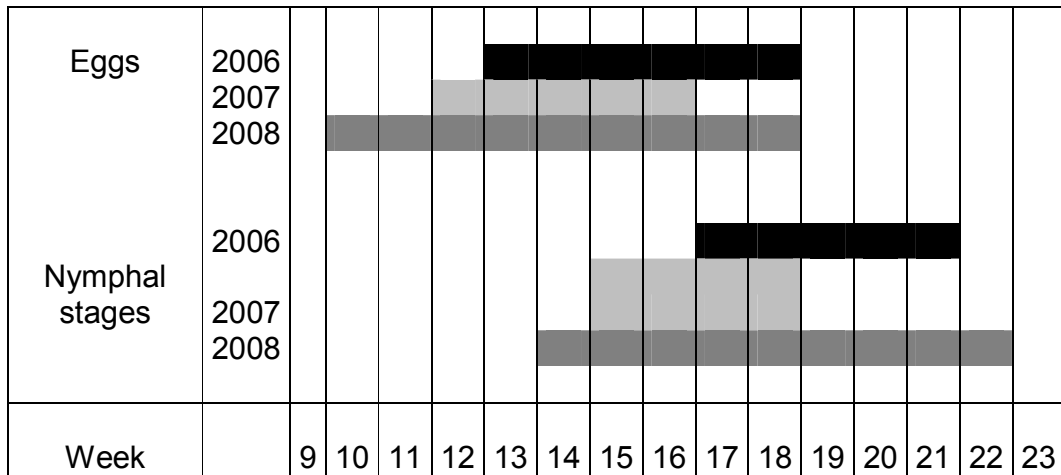
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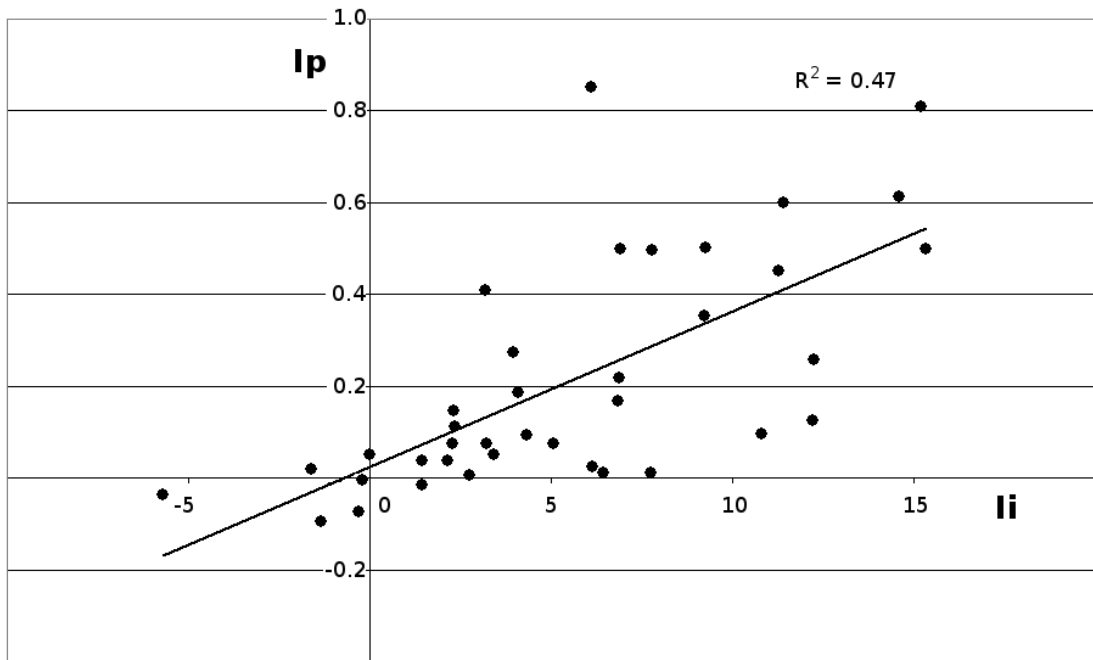


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464 Fig. 1

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468

469 Fig. 2