A temperature-based immigration model for predicting the flight onset of *Cacopsylla melanoneura* and *C. picta*, vectors of apple proliferation disease, in South Tyrol, Italy

Authors: Bernd Panassiti1,\*, Nicolas Sander2, Valerio Mazzoni3, Stefanie Fischnaller1, Martin Parth1, Manuel Messner1, Katrin Janik1, Florian Hartig4

1 Laimburg Research Centre, Auer, Italy

2 Biometry and Environmental System Analysis, Faculty of Environment and Natural

Resources, University of Freiburg, Germany

3 IASMA, Fondazione E. Mach, Via E. Mach 1, 38010, San Michele all’Adige (TN), Italy

4 University of Regensburg, Theoretical Ecology, Universitätsstraße 31, D-93053 Regensburg, Germany

\* email corresponding author: bernd.panassiti@gmail.com

Key-words: Apple proliferation, crop protection, pest management, phytoplasma, population dynamics, psyllid, temperature sum model

## Abstract

Insects in temperate regions usually emerge in spring based on climatic cues. Temperature-based models that predict the first flight onset of pest insects in crop fields are therefore useful tools for agriculture and crop protection. Here, we apply such a temperature-based model for *Cacopsylla melanoneura* and *C. picta* (Hemiptera - Psyllidae) in South Tyrol (Northern Italy). These psyllids are the main vectors of apple proliferation, an economically important phytoplasma disease. We find that the flight onset differs between vectors and between the different South Tyrol regions. Depending on temperature and region, the first adults of *C. melanoneura* and *C. picta* remigrants are predicted to be presented in the orchard between January and mid of March. Provided further validation, the presented temperature-based immigration model can be used as a tool to predict of first vector appearance in the apple orchards in South Tyrol.

## Zusammenfassung:

Die Aktivität von Insekten ist stark Temperatur-abhängig. Temperatursummenmodelle, welche den Beginn der Flugaktivität von Schädlingsinsekten voraussagen sind daher sinnvolle Tools im Pflanzenschutz. In dieser Untersuchung wenden wir ein auf temperatur-basierendes Modell auf *Cacopsylla melanoneura* and *C. picta* (Hemiptera - Psyllidae) in Südtirol (Norditalien) an. Beide Psylliden sind die Hauptüberträger der Apfeltriebsuchtkrankheit, eine ökonomisch bedeutende Phytoplasmenkrankheit. Wir fanden heraus, dass sich der Flugbeginn zwischen den Vektoren und den einzelnen Regionen Südtirol’s unterscheidet. Abhängig von Temperatur und Region, wurden die ersten adulten Tiere von *C. melanoneura* und *C. picta* in der Apfelwiese zwischen Januar beziehungsweise Mitte März vorausgesagt. Zusammenfassend kann man sagen, dass der Flugbeginn abhängig der Vektorart, Jahr und Region ist. Nach weiterer Validierung, könnte das vorgestellte Temperatursummenmodell zur Vorhersage des ersten Auftretens beider AP-Vektoren in den Apfelwiesen in Südtirol genutzt werden.

## Introduction

Insects are ectothermic and thus dependent on warm air temperatures for activity (Mellanby, 1939). Moreover, studies using light trapping of flying insects have shown that warmer temperatures increase catches due to increased flight activity (McGeachie, 1989; Jonason et al., 2014). Temperature-based models are therefore useful tools for predicting the flight onset of pest insects, i.e. the first encounter of adults of a pest insect in a crop field. In crop protection, these models are successfully applied to support pest management strategies. An example of it is the web-tool ‘Vitimeteo’ (www.vitimeteo.de , see Bleyer et al. 2014), which contains a module called “VM Schwarzholz”. This module predicts the flight onset of the planthopper *Hyalesthes obsoletus*, vector of the grapevine phytoplasma disease ‘bois noir’. Such temperature-based models often rely on temperature sums to derive regional thresholds, as it is the case for *H. obsoletus* (Maixner and Langer 2006).

Apple proliferation (AP) is a phytoplasma disease causing severe economic damage in European apple production areas (Kunze 1989). AP is vectored by two psyllid species, *Cacopsylla melanoneura* (Förster) and *C. picta* (Förster) (Hemiptera - Psyllidae) (Frisinghelli et al. 2000, Jarausch et al. 2003, Tedeschi et al. 2002). Recently, *C. picta* was found to transovarially transmit the AP phytoplasma to its offspring, and is hence considered the more effective AP vector (Mittelberger et al. 2016).

The life cycle of both vectors is summarized by Jarausch and Jarausch (2010). In brief, *C. melanoneura* is univoltine and hibernates in adult stage on overwintering plants, mostly conifers (Lal 1934, Novak and Achtziger 1995, Ossiannilsson 1992, Pizzinat, 2011). In South Tyrol, the coniferous forests are mainly restricted to the valley’s hillsides. Early in the year, *C. melanoneura* adults (so called “remigrants”) migrate to their host plants for oviposition. Being oligophagous, the species uses different Rosaceae species as host plants, for example hawthorn (*Crataegus* spp.) and *Malus* spp. The new generation (“emigrants”) then leave for the overwintering sites in mid summer (Tedeschi, 2002; Tedeschi, 2012 Mayer et al., 2009).

*C. picta* is also univoltine, but feeds monophagously on *Malus* spp.. *C. picta* presence in the orchard is timely delayed compared to *C. melanoneura*. *C. picta* re-migrates into the apple orchard in March/ April and the new generation emigrates to the overwintering sites in late summer.

Although the lifecycle of the vectors is relatively well understood, no predictive models for the onset of their remigration into orchards in South Tyrol are so far available. Therefore, the aim of this study was to analyze how the remigration timing depends on temperature for the two AP vectors in all apple growing regions in South Tyrol.

## Study site

The study area included the six main apple growing regions of South Tyrol, Northern Italy: Bozen, Burggrafenamt, Eisacktal, Salten-Schlern, Überetsch-Unterland and Vinschgau. Located in the southern side of the Alps, the landscape of South Tyrol is dominated by valleys at elevations as low as 200 m a.s.l. and mountain peaks reaching 3000 m a.s.l.. The elevations of the surveyed orchards ranged between 200 m a.s.l. in the valleys and 1000 m a.s.l. in the adjacent hill sides. The annual mean temperature in the apple growing areas is about 15°C.

## Material and methods

### Psyllid vector sampling

Monitoring data on both AP vectors, *C. melanoneura* and *C. picta*, were provided by both the “Laimburg Research Centre” for details: Fischnalller, page xxxx or Fischnaller, 2017and the South Tyrol advisory council “Südtiroler Beratungsring”. 178 orchards were surveyed one to four times each between 2013 and 2016. Psyllid vectors were collected using yellow sticky traps and the “beating tray”-method (Horton 1999, Muther and Vogt 2003). As for the latter, 20 to 200 apple trees, depending on orchard size, were randomly selected for vector sampling. Species identification followed the keys by Ossiannilsson (1992),Burckhard and Lauterer (2009), Burckhard (2010).

### Weather data

Daily minimum, mean and maximum air temperatures were obtained from weather stations provided by the Hydrographic Office of the Autonomous Province Bozen (<http://www.provinz.bz.it/wetter/home.asp>, downloaded October 2016). The regional distribution of the weather stations was as follows: 1 Bozen, 7 Burggrafenamt, 8 Eisacktal, 5 Salten-Schlern, 4 Überetsch-Unterland, 4 Vinschgau.

### Regional temperature-based immigration analysis

Following the methods outlined in Tedeschi et al. (2012), we applied a temperature-based immigration analysis (TempIA) for both AP psyllid vectors for each of the apple growing regions in South Tyrol. The TempIA is based on two indices, a temperature threshold and an immigration index. Psyllid immigration is triggered by having the immigration index become positive.

The TempIA calculation was as follows:

1. Average 10 minute weather data from weather stations to 1 hour temperatures (**Thourly**)
2. Combine beating and yellow trap data for *C. melanoneura* & *C. picta* for both generations (parental (P) & filial (F1))
3. Calculate date of first captured presence per subregion and species (**a0**)
4. Take the mean of all weather stations’ average hourly data within the same subregion

(**Thourlyregion**)

1. Calculate the max. temperature (**T0max**) within 7 days preceding date of first presence (a0), from

Thourlyregion

1. Min. of T0max over all years for the same subregion gives subregional **T7th**
2. Hourly immigration index (**Ii**) for each region.

The immigration index (Ii) is based on the following equation:

|  |  |
| --- | --- |
| Ii = [(T7n T7th) + ddn] | (1.1) |

where Ii = Immigration index; T7n = Mean temperature in the 7 days before observation; T7th = Highest hourly temperature in the 7 days before observation; and ddn = Medium daily number of hours in 7 days before observation with temperatures > T7th.

The R-code for the calculation of the temperature thresholds and immigration indices are provided in Appendix A.

## Results

Mean max daily temperatures in 7 days before first occurrence of *C. melanoneura* remigrants were 16.5°C, 5.7°C, 6.3°C, 5.8°C, 15.7°C and 6.9°C for the regions Bozen, Burggrafenamt, Eisacktal, Salten-Schlern, Überetsch-Unterland and Vinschgau (Fig. 1 and 2). There is significant variation between years in regards to when the thresholds are exceeded. The immigration starting dates range from early January up to the middle of March.

*C. picta*, being the rarer of the two species, has very few positive data points. For the two regions with some available presence data, the T7th values are higher than for *C. melanoneura* due to later start of orchard immigration of *C. picta* (Fig. 3 and 4).

Figure 1. Immigration index and threshold for *Cacopsylla melanoneura* remigrants by region.

Figure 2. Immigration index and threshold for *Cacopsylla melanoneura* emigrants by region.

Figure 3. Immigration index and threshold for *C. picta* remigrants by region.

Figure 4. Immigration index and threshold for *C. picta* emigrants by region.

In the data, there often seems to be presencens before the absences - can it be that the starting date is missed because monitoring started too late? I would expect that there should be first absences, and then suddenly presences.

## Discussion

To predict the flight onset of the two AP vectors, *C. melanoneura* and *C. picta*, in South Tyrol/ Northern Italy, we applied the temperature-based immigration analysis developed by Tedeschi et al. (2012). Its goal is to determine an absolute temperature threshold and index, which represent the temperature trigger for vector re-migration into the apple orchards. For one, this allowed us to potentially define a temperature immigration threshold for each of the region, which is not covered by a statistical model and can be further compared to other studies. The second reason is one of practicality, in that such temperature threshold analyses, if deemed accurate enough, are very easy to provide to farmers for management decisions at the beginning of the migration season when pest control is of critical importance.

### Immigration-thresholds for *C. melanoneura*

The analysis for the regions with a sufficient amount of *C. melanoneura* observations (Burggrafenamt, Eisacktal, Salten-Schlern, Vinschgau) shows differences in their estimated temperature thresholds, ranging from 7.99°C to 10.47°C. Tedeschi et al. (2012) calculated the T7th for Trentino to be around 9.5°C, which lies in the middle of our calculated threshold range, confirming their plausibility. The found threshold differences either suggests that the migration behavior of *C. melanoneura* is not solely triggered by temperature or hints at the existence of regional subpopulations that immigrate at different times. As shown in Figure 1, the immigration start (either when Ii > 0 or the hourly temperature exceeds T7th) varies extremely between the years. For 2013 and 2015, the analysis indicates immigration to start as early as the beginning of January, whereas for 2014, it does not begin until early March. Unfortunately, the other apple growing regions simply did not have enough years with data or lack *C. melanoneura* absences before the first annual capture, and therefore prevent reliable conclusions about their temperature thresholds.

### Immigration-thresholds for *C. picta*

*C. picta* captures were low or absent across all apple growing regions in South Tyrol. For regions with some data on *C. picta*, the preliminary threshold estimates do indicate that *C. picta* begins orchard immigration at higher temperatures than *C. melanoneura*. This matches our expectations from the migratory patterns as well as previous studies, which show that *C. picta*’s immigration starts at a later date with consequently higher ambient temperatures than *C. melanoneura* (Mattedi et al. 2008).

### Conclusions

We established a temperature-based immigration analysis for the AP vectors *C. melanoneura* and *C. picta* in South Tyrol, Italy. The analysis indicated that the flight onset is species and region specific. Additional data and validation is necessary, in order to make regionally customized thresholds, and the different immigration starting dates they reflect, reliable enough for adapting management choices.

## Appendix

Appendix A: R-code for the temperature immigration analysis.

<https://github.com/berndpanassiti/Temperature-based_immigration_analysis/blob/master/r-code/TempIA.md>

## References

Bleyer G., Kassemeyer H.-H., Breuer M., Krause R., Augenstein B., Viret O., Dubuis P.-H., Fabre A.-L., Bloesch B., Kehrli P., Siegfried W., Naef A., Hill G. K., Mattedi L. and Varner M. (2014). Presentation of the VitiMeteo forecasting system - current state at the 10th anniversary of the system. - IOBC WPRS BULLETIN 105, 113-123.

Frisinghelli C., Delaiti L., Grando M. S., Forti D. and Vindimian M. E. (2000). *Cacopsylla costalis* (Flor 1861), as a vector of apple proliferation in Trentino. - Journal of Phytopathology 148, 425–431.

Horton D. R. (1999). Monitoring of pear psylla for pest management decisions and research. - Integrated Pest Management Reviews 4, 1-20.

Jarausch B. and Jarausch W. (2010). Psyllid vectors and their control. In: P. G. Weintraub and P. Jones (Eds.), Phytoplasmas genomes, plant hosts, and vectors (pp. 250-271). Cambridge, USA: CABI North American Office.

Jarausch B., Schwind N., Jarausch W., Krczal G., Dickler E. and Seemüller E. (2003). First report of *Cacopsylla picta* as a vector of apple proliferation phytoplasma in Germany. - Plant Disease 87.

Fischnaller S., Messner M.; Parth M.; Stocker R.; Kerschbamer C.; Janik K. (2017). Apfeltriebsuchtüberträger – 3 Jahre Freilandforschung. Obstbau Weinbau 2.

Kunze L. (1989). Apple proliferation. In: P. R. Fridlund (Ed.), Virus and viruslike diseases of pome fruits and simulating noninfectious disorders (pp. 99-113). Washington: Cooperative Extension College of Agriculture and Home Economics, Washington State University, Pullmann.

Lal K. B. (1934). The biology of Scottish Psyllidae. - Transactions of the Royal Entomological Society of London 82, 363-385.

Maixner M. and Langer M. (2006). Prediction of the flight of *Hyalesthes obsoletus*, vector of stolbur phytoplasma, using temperature sums. - IOBC/WPRS Bulletin 29, 161-166.

Mattedi L., Forno F., Cainelli C., Grando M. S. and Jarausch W. (2008). Research on ‘*Candidatus* Phytoplasma’ mali transmission by insect vectors in Trentino. - Acta Horticulturae 781, 369–374.

Mittelberger C., Obkircher L., Oettl S., Oppedisano T., Pedrazzoli F., Panassiti B., Kerschbamer C., Anfora G. and Janik K. (2016). The insect vector *Cacopsylla picta* vertically transmits the bacterium ‘*Candidatus* Phytoplasma mali’ to its progeny. - Plant Pathology *in press*, n/a-n/a.

Muther J. and Vogt H. (2003). Sampling methods in orchard trials: A comparison between beating and inventory sampling. - IOBC WPRS BULLETIN 26, 67-72.

Novak H. and Achtziger R. (1995). Influence of heteropteran predators (Het., Anthocoridae, Miridae) on larval populations of hawthorn psyllids (Hom., Psyllidae). - Journal of Applied Entomology 119, 479-486.

Ossiannilsson F. (1992). The Psylloidea (Homoptera) of Fennoscandia and Demark. Leiden; New York: E.J. Brill.

Tedeschi R., Baldessari M., Mazzoni V., Trona F. and Angeli G. (2012). Population dynamics of *Cacopsylla melanoneura* (Hemiptera: Psyllidae) in northeast Italy and its role in the apple proliferation epidemiology in apple orchards. - Journal of Economic Entomology 105, 322–328.

Tedeschi R., Bosco D. and Alma A. (2002). Population dynamics of *Cacopsylla melanoneura* (Homoptera: Psyllidae), a vector of apple proliferation phytoplasma in northwestern Italy. - Journal of Economic Entomology 95, 544-551.