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

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## 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 first presence in the orchard differs between vectors and between the different South Tyrol regions. Depending on temperature and region, the first adults of *C. melanoneura* remigrants are mostly predicted in January while first *C. picta* remigrants are mostly predicted to be present in the orchard between March and April. 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’ (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 et al. 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 apple trees (*Malus* spp.). The new generation (“emigrants”) then leave for the overwintering sites in mid summer (Mayer et al. 2009, Tedeschi et al. 2012, Tedeschi et al. 2002).

*C. picta* is also univoltine, but feeds monophagously on apple trees. *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.

## 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” (Fischnaller et al. 2017) and the South Tyrol advisory council “Südtiroler Beratungsring”. 178 orchards were surveyed 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 Burckhardt (2010), Burckhardt and Lauterer (2009) and Ossiannilsson (1992).

### 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 number of weather stations per region was: 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). Although being developed initially only for *C. melanoneura* in the Valsugana valley, we applied TempIA for both AP psyllid vectors. 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.

We only considered remigrants of *C. melanoneura* and *C. picta* and the apple regions “Burggrafenamt” and “Vinschgau” for the TempIA model because emigrants and other apple growing regions simply did not have enough years with data or lacked absences before the first annual capture, and therefore prevent reliable conclusions about their temperature thresholds.

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 5.65°C and 9.77°C for the regions Burggrafenamt and Vinschgau (Fig. 1a). Across both regions, the first presence of *C. melanoneura* is mostly predicted to start in January, except for Vinschgau in 2014 where immigration was predicted not until early March.

The TempIA model predicted that the first presences of *C. picta* remigrants in the apple orchards were mostly between March and April (Fig. 1b). The T7th values are 12.73°C and 13.82°C for Burggrafenamt and Vinschgau, respectively. In both regions in 2015, the temperature threshold was already exceeded in January.

Figure 1. Immigration index and temperature thresholds for remigrants of (a) *Cacopsylla melanoneura* and (b) *Cacopsylla picta* by region. The horizontal lines indicate the thresholds for temperature (red, T7th) and immigration index (grey, li). The red line is the mean hourly temperature and the grey line is the immigration index. Vertical lines indicate the date when the temperature (red) or the immigration index (grey) thresholds are reached. Red points are species absences and blue points are presences. The insect vector presence in the orchard can be expected either when Ii > 0 or the hourly temperature exceeds T7th.

## 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. 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, Vinschgau) shows differences in their estimated temperature thresholds, ranging from 5.65°C to 9.77°C. Tedeschi et al. (2012) calculated the T7th for Trentino to be around 9.5°C, which lies within our calculated threshold range, confirming its plausibility. Figure 1a shows that the TempIA predictions (indicated by either Ii > 0 or T7th <= hourly temperature) were mostly similar between the years, indicating a first presence of *C. melanoneura* remigrants in January.

### 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).

### Limitations of the temperature-based immigration model

The TempIA model assumes that the insect vector presence in the orchard is triggered by temperature. In Figure 1b, the model predicted the first presence of *C. picta* in Burggrafenamt in 2015 in January which clearly disagrees with our survey observations of this vector and Mattedi et al. (2008). The mismatch may be explained by the fact that temperature is most likely related to the flight activity of the insect vector at its overwintering site. No information however is available about the exact location and elevation about the overwintering sites of both insect vectors in South Tyrol. We used weather stations in the orchards as indirect means to measure the first flight activity, however factors such as distance, geographical layout, air currents influence the psyllid immigration process into the apple orchards (Tedeschi et al. 2012). Hence, the model can be further improved by a) a better calibration using more years of survey data; or b) temperature measurements directly taken at the overwintering sites.

### Conclusions

We established a temperature-based immigration analysis for the two 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>

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