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The pine processionary moth *Thaumetopoea pityocampa* (Lepidoptera, Notodontidae) in Carinthia, Austria

Sonja Mader*, Lukas Michor*, Andrea Battisti, Paul Schellander, Hugo Brandstätter, Christian Wieser, Martin Schebeck† & Christian Stauffer†
*equally contributing first authors, †equally contributing senior authors

Abstract: The pine processionary moth (PPM), *Thaumetopoea pityocampa*, is a harmful insect as the urticating hairs of late-instar larvae can cause severe allergic reactions in humans and other mammals. The biology of PPM is quite unique as larvae are active in the cold season and leave their nests to feed on pine needles during night, when night temperatures rise above 0 °C and day temperatures inside the nests reach +9 °C. Until recently, reports of PPM in Carinthia were very scarce. The first PPM outbreak in the area of Villach was observed in 2016/17 on the southern slope of the Dobratsch mountain; a few PPM nests were also recorded in the Gail valley (Schütt) at the same time. In this study, we performed a comprehensive survey on PPM occurrence in Carinthia and report the presence of PPM nests from Presseggen (near Hermagor) to Zauchen (near Villach), as well as near the Faakersee, an important recreation area. Furthermore, the overwinter survival of caterpillars in the Gail valley was investigated. Our results showed that caterpillars are able to survive winter in this part of the PPM range. Therefore, infestations are likely to increase in the upcoming years and PPM might extend its range.

Keywords: health risk, overwintering, invasion history, range shifts, climate change

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Introduction

The pine processionary moth (PPM) *Thaumetopoea pityocampa* causes serious allergic reactions in humans and other mammals due to the urticating setae of caterpillars (Moneo et al. 2015). Third- to fifth-instar larvae release these setae (~200 µm) when threatened, for example, by humans or natural enemies (Auger-Rozenberg et al. 2015). Setae contain the nettle-venom protein thaumetopoein which can cause skin irritation, conjunctivitis, inflammation of the throat, asthma, fever and anaphylactic reactions (Quartucci 2022). Even after several years, setae remaining in older nests can still cause these symptoms (Hase 1939). Aside from posing a health risk, PPM is an important defoliator in pine forests, as even low levels of defoliation can significantly reduce tree health (Jactel et al. 2015).

Fig. 1: Pine processionary moth caterpillars during head-to-tail procession in early spring at the southern slope of Dobratsch mountain in April 2022. Photo: C. Stauffer **Fig. 2:** Silk nest of the pine processionary moth in an early stage in September 2021. During the winter months, mostly male caterpillars expand the nest that buffers from harsh conditions. Photo: L. Michor

Outbreaks of PPM mainly occur in the Mediterranean region (Masutti & Battisti 1990), but it also inhabits regions like Western France (EPPO 2004, Kerdelhué et al. 2009). From the late 1990s onwards, migration of PPM towards higher latitudes and altitudes has been recorded which was attributed to climate warming (Battisti et al. 2005, Rosenzweig et al. 2007). According to Robinet et al. (2007), increasing temperatures since the year 2000 allowed PPM to spread even to the Paris Basin and its range is expanding north by about 5.6 km per year.

The caterpillars prefer to feed on needles of *Pinus nigra*, but they also infest other pine species, like *Pinus sylvestris*, and *Cedrus* spp. (EPPO 2004). PPM caterpillars feed between September and May (Démolin 1969, Pimentel et al. 2010). Uemura et al. (2023) found that third- and fourth-instar larvae build a winter nest which buffers from cold winter conditions. Right before sunset, with no rain and temperatures above 12 °C, larger male larvae spin silk to expand and strengthen the nest. Female larvae remain inside the nest and only emerge at night to join the male larvae for feeding (Uemura et al. 2023). From February to May, the caterpillars leave the trees in typical head-to-tail processions (Fig. 1) and pupate in the soil (Démolin 1971). The pupae remain in the soil and undergo diapause. Under specific circumstances, pupae can undergo diapause lasting for several years (Geri 1983a, b). Adults emerge between June and September (Démolin 1969, Pimentel et al. 2010). Females have average dispersal distances of 1.9 km, whereas males fly on average 10.9 km. Single individuals were also found to disperse over wider distances, in particular males (Démolin 1969). Adult females have a limited life span of one to two days, where they lay 150 to 350 eggs (Zovi et al. 2008, Pimentel et al. 2012). Eggs are deposited on pine needles or on twigs and are covered with scales from the abdomen by the female. Caterpillars hatch between July and October and start to build a nest (Fig. 2).

The population dynamics of PPM is strongly influenced by climatic parameters. Winter temperature is the most important limiting factor for the development and spread of PPM (Huchon & Démolin 1971, Battisti et al. 2005). Larvae of the fourth instar only feed under two conditions: when temperatures (i) remain above 0 °C at night and

Fig. 3: Two male specimens of the pine processionary moth collected by Alexander Kau 2 August 1936 (left) and 9 August 1952 (right) in the area of Villach. Picture taken from the collection of the Landesmuseum Kärnten. Photo: L. Michor

(ii) have reached +9 °C inside the nest during the previous daytime. Since nests of PPM are exposed to sunlight, a temperature of +9 °C is likely to be reached, even when ambient temperatures drop far below this threshold (Battisti et al. 2005). A study by Hoch et al. (2009) showed that the larvae can survive temperatures as low as -17 °C for one hour.

PPM has been recorded in Carinthia since the first half of the 20th century. The Lepidoptera collection of the Natural History Museum Vienna possesses two adult specimens of PPM (one female and one male), however, the labels harbor not much information besides the coordinates *46,6074/13,8387* (train station of Villach), the location *Villach* and the altitude *510 m* of collection. No collector or year of collection is noted. Judging by the label, however, a collection before 1950 can be assumed. Furthermore, the database of the Landesmuseum Kärnten (Klagenfurt) contains 19 moths records from Carinthia. The two oldest findings of moths date back to 1936 and 1952 and were collected in the area of Villach (Fig. 3). Thurner (1948) cites Alexander Kau as the collector of these two male specimens sampled in the area of Villach using light traps. Between 1952 and 1999 no literature records of PPM occurrence in Carinthia could be found. Between 1999 and 2016, only a few PPM adults were recorded by the Landesmuseum Kärnten (Christian Wieser, personal communication) (Tab. 1).

Hoch et al. (2017) report that the first outbreak of PPM in Carinthia occurred in 2016/2017. An area of about 5 ha on the southern slope of the Dobratsch mountain was infested. *Pinus nigra* trees located on steep, sun-exposed slopes were severely affected while feeding on *P. sylvestris* at the same site occurred at much lower frequencies. Upon further observations, older nests were found dating back to 2015 or earlier (Hoch et al. 2017).

Tab. 1: Locations with pine processionary moth (adults) collected with light traps in Carinthia (Christian Wieser, personal communication).

Location	Date	N moths	Collector	Altitude [m]
Mussen East	04.07.1999	1	N.A.	1,770
Tallacher Feld	07.07.2000	1	Wieser, Ch.	485
Schütt	14.07.2010	1	Wieser, Ch.	900
Südrast Dreiländereck	01.09.2016	1	Vilgut, M.	540

Here we aimed to survey the occurrence of PPM nests in the southern part of Carinthia, i.e. the Dobratsch mountain and the area of Arnoldstein/Gail valley, to assess the current distribution of this species. Furthermore, we installed traps on tree trunks of pines to collect descending caterpillars in the Gail valley to assess the survival of the caterpillars after the winter 2022/23.

Material and methods

Documentation of PPM in Carinthia

The map tools *d-maps* and *mapcarta* were used to map the nests detected during several trips from 23 September 2022 to 16 March 2023. The southern slopes of Dobratsch mountain were reached by foot (no forest road infrastructure is available) and were monitored by naked eye, binoculars and cameras. Motorways, highways and forest roads in lower altitudes were examined by car.

Trapping of caterpillars in early spring

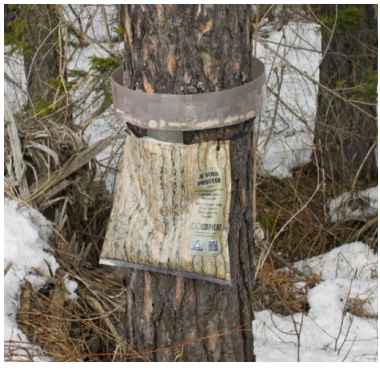

Fig. 4: Ecopiège® traps capturing the descending pine processionary moth caterpillars in a plastic bag filled with soil. Traps were attached to the trunks of five *Pinus sylvestris* trees. Photo: L. Michor

To evaluate the number of caterpillars descending from the trees (for subsequent pupation in the soil), traps of the company Ecopiège® (ZAE l'Usine, 11 rue de la Retirada, 66670 Bages, France) were installed at a height of ~1,3 m on the trunk of *P. sylvestris* trees in early spring 2023 (Fig. 4). Once caterpillars of the fifth instar were ready to pupate, they descended along the tree trunk in head-to-tail processions towards the ground. Traps captured the descending caterpillars in a plastic bag filled with soil. The trees selected were all infested with one nest. The trap consisted of a plastic barrier blocking the caterpillars' procession. Below, a strapping band was attached to the plastic bag with a cable tie. As the bag was filled with soil, caterpillars were able to pupate there.

In total, five traps, labeled B-EK1 to B-EK 5, were placed at different locations of the Gail valley (Tab. 2) to record whether caterpillars can survive winter temperatures. The traps were installed on 8 February 2023. Four of the five traps were removed on 8 May 2023. On 11 April 2023, the fifth trap was removed. The number of trapped pupae was determined end of May 2023 as we let the caterpillars pupate within the bag.

Results

The aim of this study was to record the current distribution of the pine processionary moth *T. pityocampa* in southern Carinthia and to record if caterpillars can survive the low winter temperatures of the Gail valley (Schütt). Fig. 5 shows the records of PPM infestation in the years 2022/2023 in the area of Dobratsch mountain and the Gail valley (Schütt). In higher altitudes (650–1,100 m), pine trees of the south-exposed slopes of Dobratsch

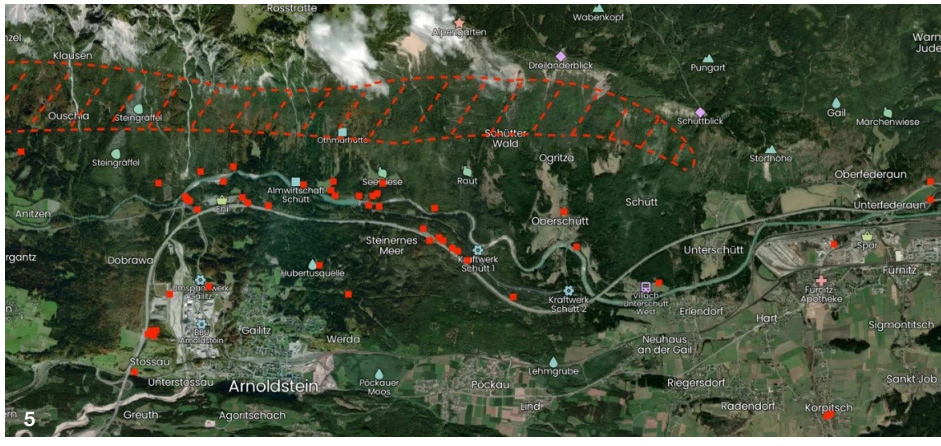

Fig. 5: Distribution of pine processionary moth nests in the region of Dobratsch mountain (850–1,000 m)/ Arnoldstein/Gail valley (Schütt) (500–650 m) from autumn 2022 until spring 2023. Red dots: individual nests; red shaded areas: extensive infestation of wider regions where more than 100 nests/ha were found – this was at the sun-exposed regions and the infestations were not continuous but patchy. Google maps, modified by L. Michor **Fig. 6:** Extensive pine processionary moth infestation at the Dobratsch mountain at an altitude of >800 m. Photo: L. Michor

mountain were found to be infested with PPM nests (Fig. 6). A nest was even detected at an altitude of 1,820 m. In heavily infested regions, roughly more than 100 nests/ha were detected, sometimes even up to 1,000 nests/ha. This extensive infestation by PPM was detected on the southern slope of Dobratsch mountain and was at sun-exposed regions and the infestations were not continuous but patchy (Fig. 5).

In the Gail valley, only individual nests per tree were found, mostly on the top of the tree, at altitudes between 500–650 m. Nests were dispersed over the whole valley and in total 62 trees were detected to be infested (Fig. 5). The western-most infestation was found in Presseggen close to Hermagor and the eastern-most infestation was found in Zauchen close to Villach (both locations are not shown in Fig. 5). The closest nest to the city of Villach was detected in Neufellach and one infested tree less than 10 km from Faakersee was found. Generally, in Gail valley, one nest per tree was detected, but close to Arnoldstein/Hohenturn, a tree had two nests and in Korpitsch, a tree had even four nests.

Traps installed on tree trunks (Fig. 4) in the Gail valley served to assess the survival of caterpillars after the winter 2022/2023. In total, five traps were installed (Tab. 2). Numbers of pupae per trap were assessed on 25 May 2023 to allow time for pupation. Between 46 and 77 pupae were detected and only a few caterpillars had not pupated (Tab. 2). Trap B-EK3 did not contain any PPM caterpillars or pupae.

Tab. 2: Details of the locations and numbers of the traps installed at the trunk of five *Pinus sylvestris* trees in the Gail valley (Fig. 4). Traps were installed in February 2023 and removed in April/May 2023. Pine processionary moth caterpillars were allowed to pupate within the traps and collected end of May 2023. Some caterpillars in parentheses did not pupate by that time.

Trap ID	Location	Number of pupae (caterpillars)
B-EK 1	West of Bären bridge	57 (1)
B-EK 2	Bären bridge	72 (3)
B-EK 3	Nepomuk bridge	0 (0)
B-EK 4	Train Bogensberger	46 (1)
B-EK 5	Oberschütt	77 (0)

Discussion

Since 2015, records of pine processionary moth (*T. pityocampa*) nests in Carinthia have increased, particularly on the southern slopes of Dobratsch mountain. Inside the nests, the caterpillars develop well on sun-exposed slopes where temperatures reach values far above those of the valley. Here, they find suitable conditions for development (Hoch et al. 2017). Around 100–1,000 nests were observed on some exposed zones per ha on the southern slopes of Dobratsch mountain at an altitude above 800 m. The extensive infestations were not continuous but patchy. In future, remote sensing approaches applying drones could be useful for a more efficient monitoring as a further spread of PPM is expected (Garcia et al. 2023).

In the past, PPM adults have been continuously recorded using light traps. In the last eight years, extensive infestation was recorded on the southern slopes of Dobratsch mountain which is an area difficult to access as forest roads or trails are missing. We propose the hypothesis that these PPM infestations might have been undetected before 2015; thus, a native population of PPM might already have been present on Dobratsch mountain a long time before. Consequently, the PPM nests from the Gail valley might derive from Dobratsch mountain. The alternative hypothesis is that PPM from the Gail valley as well

as Dobratsch mountain originates from Italy or Slovenia. The natural distribution of PPM closest to these regions are Ugovizza (Italy) and/or the area of Log pod Mangartom (Slovenia), both at a distance of approximately 20 km from the Carinthian sites. Such a distance could be overcome by PPM either via active flight or via transportation of moths by vehicles or transportation of pupae with soil material (Démolin 1969, Roques et al. 2015). To clarify the origin of the Carinthian PPM population it would be interesting to apply genomic tools in order to assess the demographic history in detail (Kerdelhué et al. 2015).

Since 2015, PPM has survived in Carinthia, considering the heavy infestation on the southern slopes of Dobratsch mountain. Moreover, the traps installed at tree trunks to detect descending caterpillars showed that they are able to survive winter in Gail valley (Schütt) (Tab. 2). The only trap where no caterpillars were monitored was trap B-EK 3. The respective nest on that tree was weakly developed when the trap was installed. According to Roques et al. (2015), larger nests of PPM caterpillars are more likely to survive. It is likely that the colony of the nest where trap B-EK 3 was installed did not reach a size large enough to ensure the survival of caterpillars. Nevertheless, the findings of the four other traps show that caterpillars survived winter in the Gail valley and suggest an increased spread of the moth in 2024.

Especially in urban and touristic areas, such as the regions around Villach or the Faakersee, a spread and increase of the population densities would have a huge impact on human and animal health. Management strategies as described by Martin et al. (2015) could be applied. An important first measure is to inform the public about the threats of PPM to human and pet health. This information should be similar to the information campaigns done for the oak processionary moth, e.g. in parks in Vienna or the Viennese forests. Information on the allergic reactions and that people, as well as pets, should keep a safe distance from the PPM nests should be provided, especially during the time of processions in spring. For extensive infestation areas it might also be necessary to limit the access to the public – also here examples from the oak processionary moth in parks in Vienna exist.

To control infestations of PPM, removal of nests and egg masses are efficient measures (Martin et al. 2015). To be successful, egg masses must be collected before the caterpillars of the first instar hatch. Yet, this method comes with several drawbacks as it is a time-consuming and expensive process that requires a great number of workers and egg masses are often difficult to spot. Nests can be removed during fall or winter. In fall, they can be difficult to see, since they are still rather small. Nests in winter can be spotted easily if no snow is covering the trees and if the area is accessible, but nests are often difficult to reach in the crowns. Removal of the nests often requires cranes and workers have to wear protective clothing. Another way to control PPM is to capture caterpillars in traps as described in this study (Fig. 4). Larval trapping can be a successful method particularly for urban trees in parks and gardens (Martin et al. 2015). However, the effectiveness of this method is directly related to the quality of trap installation and might fail when they are mounted incorrectly. In regions of high public attendance, these methods could be combined to achieve better effectiveness.

Considering the data of the present study, PPM will likely spread in the Gail valley (Schütt) in the future due to expected climate warming, potentially causing serious issues for the general public and tourism. The infestations reported here reflect a clear increase in the moth's occurrence in the respective regions. It will be advisable to set definite goals and execute curative measures to prevent harm by the spread of PPM.

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Addresses of the authors

Sonja Mader, Lukas Michor, Martin Schebeck, Christian Stauffer,
Institute of Forest Entomology, Forest Pathology and Forest Protection, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences Vienna, BOKU, Peter-Jordan-Straße 82/I, 1190 Vienna, Austria. E-mail: sonja.mader@boku.ac.at, lukas.michor@hotmail.com, martin.schebeck@boku.ac.at, christian.stauffer@boku.ac.at

Andrea Battisti, Department of Agronomy, Animals, Food, Natural Resources and Environment (DAFNAE), University of Padova, Viale dell'Università 16, 35020 Legnaro, Italy. E-mail: andrea.battisti@unipd.it

Paul Schellander, Amt der Kärntner Landesregierung, Arnulfplatz 1, 9020 Klagenfurt, Austria. E-mail: paul.schellander@ktn.gv.at

Hugo Brandstätter, Bezirkshauptmannschaft Villach – Land, Forstaufsichtsstation Arnoldstein, Industriestraße 1, 9601 Arnoldstein

Christian Wieser, Landesmuseum Kärnten, Museumgasse 2, 9021 Klagenfurt, Austria. E-mail: christian.wieser@kaernten.museum