Model applicability and references

1. Modelling and model applicability

The phenological development of oak processionary moth (OPM, *Thaumetopoea processionea*) on *Quercus robur* is calculated and predicted for 7 days, based on hourly mean of air temperature, and updated daily. For this, the following models are applied:

Phenological event	Model	Reference index
Q. robur bud swelling	Halbig et al., unpublished	4
Q. robur leaf unfolding	Menzel 1997	6
OPM L1 hatching	Custers 2003	1
	Meurisse et al. 2012	7
	Wagenhoff et al. 2014	9
OPM from L1 feeding start to adult eclosion	Halbig et al., unpublished	4

The models operate by accumulating air temperature above a certain threshold to the specific sum of effective temperatures to compute the occurrence of the distinct development stages of *Q. robur* buds and OPM. To predict *Q. robur* bud development and OPM L1 hatching, the number of chilling days is additionally incorporated, which is negatively correlated with the sum of effective temperatures. Air temperature data and their **7-day forecast** are provided by DWD (German Meteorological Service). Depending on weather forecast, the predicted date of the phenological event can vary. The predictions of *Q. robur* leaf unfolding are supplemented with *in situ* observations by DWD if available for the respective site.

Apart from giving L1 mortality during the starvation period (see below 3.), the early warning system PHENTHAUproc does not aim at OPM population density assessment, but it exclusively describes and predicts the **phenological development** of OPM and its host tree *Q. robur*. This serves to determine the **hazard period** during the year as well as to **support decisions** on planning measures to protect human/animal health and oak tree vitality.

Moreover, the area-based prototype of PHENTHAUproc does not show the actual OPM distribution in Germany on the map, but OPM phenology in its potential range in Germany up to 800 m a.s.l.

2. Oak bud development and period of prophylactic agent application

OPM development on *Q. petraea* and other oak species can deviate from its development on *Q. robur*. Classification of oak bud development is based on BBCH-code (Meier 2018). In PHENTHAUproc, bud swelling (BBCH 01, **Fig. 1**) and leaf unfolding (BBCH 11, **Fig. 2**) are shown. Modelling was based on observation data of different *Q. robur* trees monitored over 10 successive years. Actual *in situ* bud development of individual oak trees can vary locally up to three weeks.

The period of prophylactic application of plant protection agents and biocides, which require uptake by feeding, starts with oak leaf unfolding (BBCH 11). **Minimum leaf size** of 2.5 cm diameter (**Fig. 2**) and maximum whole-tree leaf unfolding of 60-70 % are the prerequisites for application (Delb et al. 2019).

Preventive biocide application ends with the completion of OPM L3 stage when the susceptibility of the larvae to agents as *Bacillus thuringiensis* (*B.t.*) decreases, and the number of setae produced by the larvae rises.

Fig. 1: OPM L1 larvae on swollen *Q. robur* buds, BBCH 01 (photo: Halbig)

Fig. 2: OPM L1 larvae on unfolding *Q. robur* leaves, BBCH 11 (photo: Halbig)

The agent application period in the graph is displayed as green bar and separately from OPM development. As DWD *in situ* observations refer to single trees, deviations from the modelled start of oak leaf unfolding may occur. The light green bar indicates an *in situ* observation before the prediction (**Fig. 3**). The actual start of practical measure application stringently needs **situational on-site** bud stage **assessment** of the trees which should be treated by experts, regarding the leaf unfolding stage criteria mentioned above.

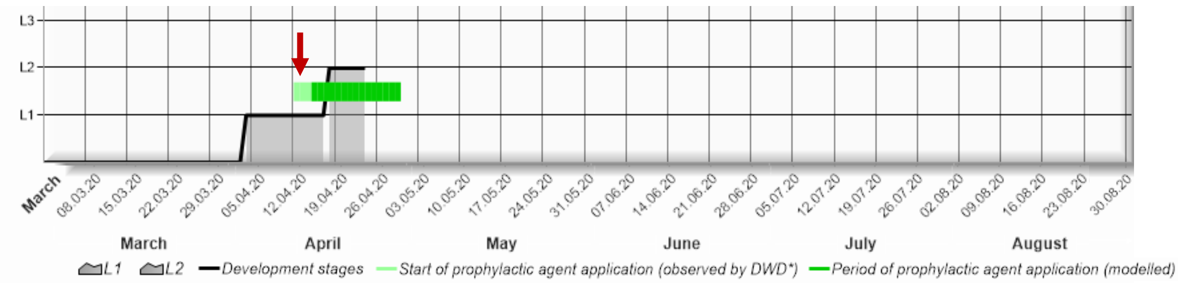

Fig. 3: Screenshot of PHENTHAUproc for Freiburg in 2020; red arrow: DWD *in situ* observation of *Q. robur* leaf unfolding (BBCH 11) before the predicted start of leaf unfolding

3. L1 hatching and starvation tolerance

Three distinct models are used to determine L1 hatching (Custers 2003, Meurisse et al. 2012, Wagenhoff et al. 2014). But only the earliest predicted date is displayed and subsequently used to set L1 feeding start. The larvae usually hatch before oak bud swelling.

The **starvation period** (**Fig. 4**) until feeding start influences the survival of L1 larvae (Wagenhoff et al. 2013) as well as *in situ* population density and hazard potential. At higher air temperatures, the starvation tolerance is lower due to enhanced energy consumption of the larvae. Therefore, the thresholds for L1 mortality are based on temperature sum (Wagenhoff et al. 2013, Halbig et al. unpublished) instead of time data. In consequence of individual-tree variability of oak bud development as well as L1 hatching, local survival and further development of single OPM colonies and concomitant health hazards cannot be excluded despite predictions of 100 % L1 mortality.

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Fig. 4: Starving OPM L1 larvae waiting for bud swelling on closed *Q. robur* buds, BBCH 00 (photo: Halbig)

4. OPM development from L1 feeding start to adult eclosion

Starting with L1 feeding, the predicted development refers to the date when 50 % of the OPM individuals at the respective site have reached the stage (**Fig. 5**). This corresponds to **mean OPM development speed** (Halbig et al. unpublished). Due to the natural variability, two subsequent OPM stages may be present at the same time. The variation of the predicted mean OPM development, displayed by dashed lines, is based on the 95 % confidence interval.

The entire OPM adult flight period extends over approx. 2 months. The prediction gives the date when 50 % of the moths (males and females) have eclosed. Mechanical measures as pupation tent removal to reduce OPM population density are not effective anymore. Start and end of the adult flight period are not shown.

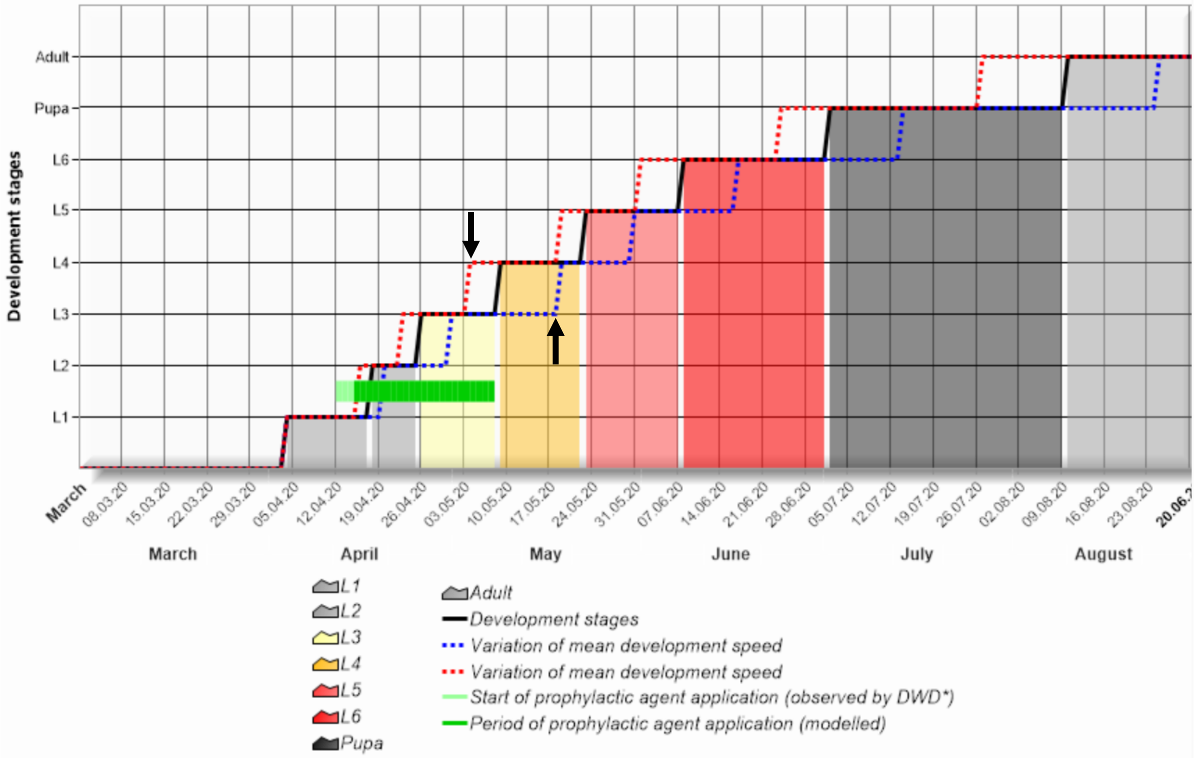

Fig. 5: Screenshot of PHENTHAUproc at Freiburg in 2020; dashed lines (arrows) describe the variability of mean OPM development speed (95 % confidence interval)

5. Further information

- Current information on OPM, supplied by FVA, Dept. of Forest Protection:
    - https://www.fva-bw.de/publikationen/schriftreihen
    - https://www.waldwissen.net

- Subscription to the OPM newsletter provided by FVA, Dept. of Forest Protection: https://www.fva-bw.de/top-meta-navigation/fachabteilungen/waldschutz/newsletter-bestellung

Contact

Regarding **OPM in southwest German forests** and usage of the early warning system **PHENTHAUproc**, contact FVA:

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6. References

1) Custers, C. J. L. (2003). Climate change and trophic synchronisation. A case study of the oak processionary caterpillar. Masters's thesis. Studentsverlag Wageningen University.

2) Delb, H., Halbig, P., Seitz, G. & Wagenhoff, E. (2019). Der Eichenprozessionsspinner als Profiteur des Klimawandels: Müssen Baum und Mensch mit dieser Gefahr leben?. Jahrbuch der Baumpflege 2019, 23. Jg., 201–213, ISBN 978–3–87815–263–7.

3) DWD - Deutscher Wetterdienst (2023): Klimaüberwachung, Phänologie, Daten Deutschland DWD. https://www.dwd.de/DE/klimaumwelt/klimaueberwachung/phaenologie/daten_deutschland/jahresmelder/fotogalerie/stiel_eiche_blattentfaltung.html?nn=586878

4) Halbig, P., Stelzer, A.-S., Baier, P., Pennerstorfer, J., Delb, H., & Schopf, A. (unpublished). PHENTHAUproc – An early warning and decision support system for hazard assessment and control of oak processionary moth (*Thaumetopoea processionea*).

5) Meier, U. (2018). Entwicklungsstadien mono- und dikotyler Pflanzen: BBCH Monografie. Open Agrar Repositorium. https://www.openagrar.de/receive/openagrar_mods_00042352

6) Menzel, A. (1997). Phänologie von Waldbäumen unter sich ändernden Klimabedingungen: Auswertung der Beobachtungen in den internationalen phänologischen Gärten und Möglichkeiten der Modellierung von Phänodaten. Forstliche Forschungsberichte München Nr. 164, 179 p.

7) Meurisse, N., Hoch, G., Schopf, A., Battisti, A., & Grégoire, J. C. (2012). Low temperature tolerance and starvation ability of the oak processionary moth: implications in a context of increasing epidemics. Agricultural and Forest Entomology, 14(3), 239-250. https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1461-9563.2011.00562.x

8) Wagenhoff, E., Blum, R., Engel, K., Veit, H., & Delb, H. (2013). Temporal synchrony of *Thaumetopoea processionea* egg hatch and *Quercus robur* budburst. Journal of Pest Science, 86(2), 193-202. https://link.springer.com/article/10.1007/s10340-012-0457-7

9) Wagenhoff, E., Wagenhoff, A., Blum, R., Veit, H., Zapf, D., & Delb, H. (2014): Does the prediction of the time of egg hatch of *Thaumetopoea processionea* (Lepidoptera: Notodontidae) using a frost day/temperature sum model provide evidence of an increasing temporal mismatch between the time of egg hatch and that of budburst of *Quercus robur* due to recent global warming?. European Journal of Entomology, 111(2), 207-215. https://www.eje.cz/pdfs/eje/2014/02/07.pdf

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