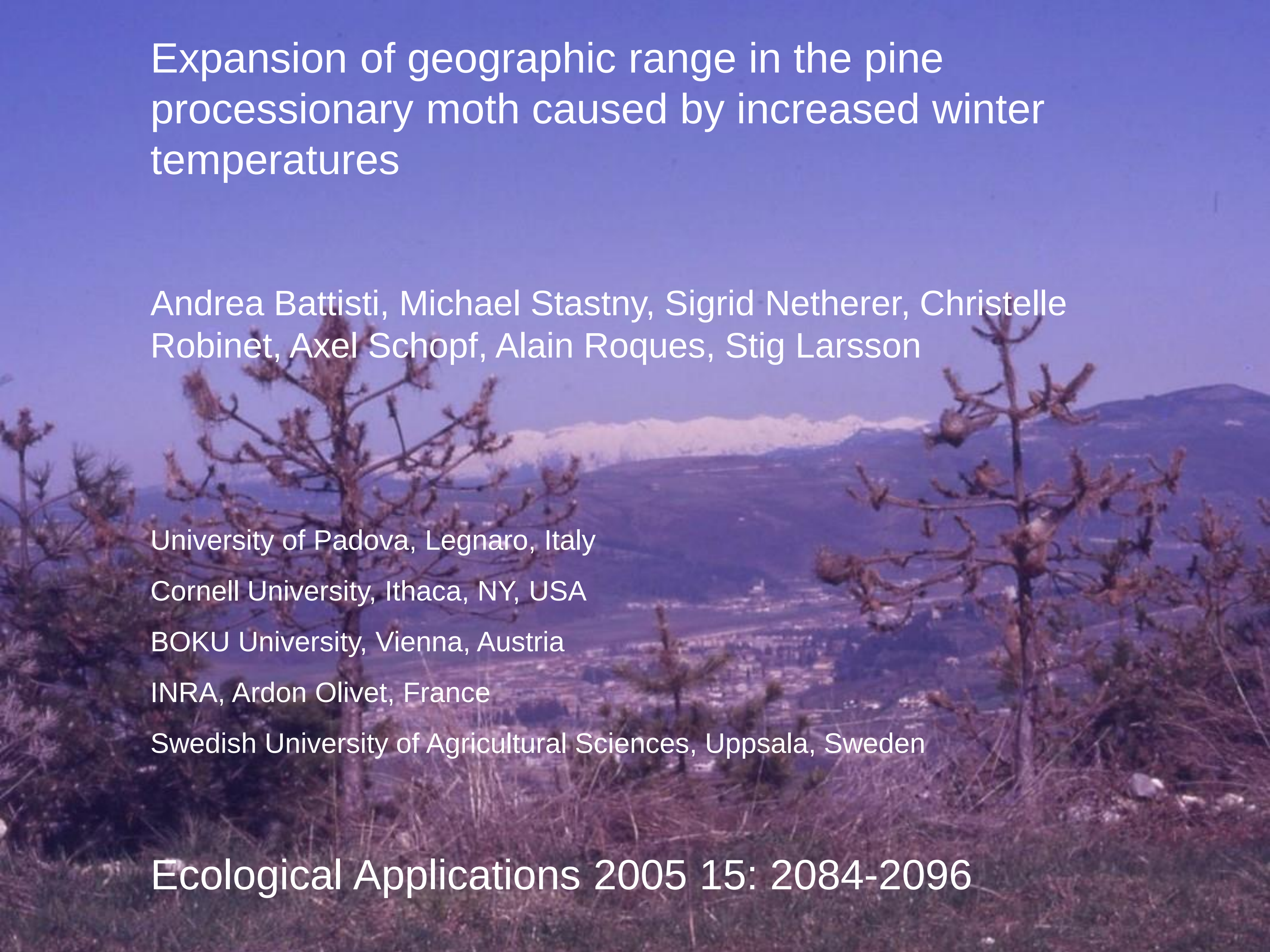

Expansion of geographic range in the pine processionary moth caused by increased winter temperatures

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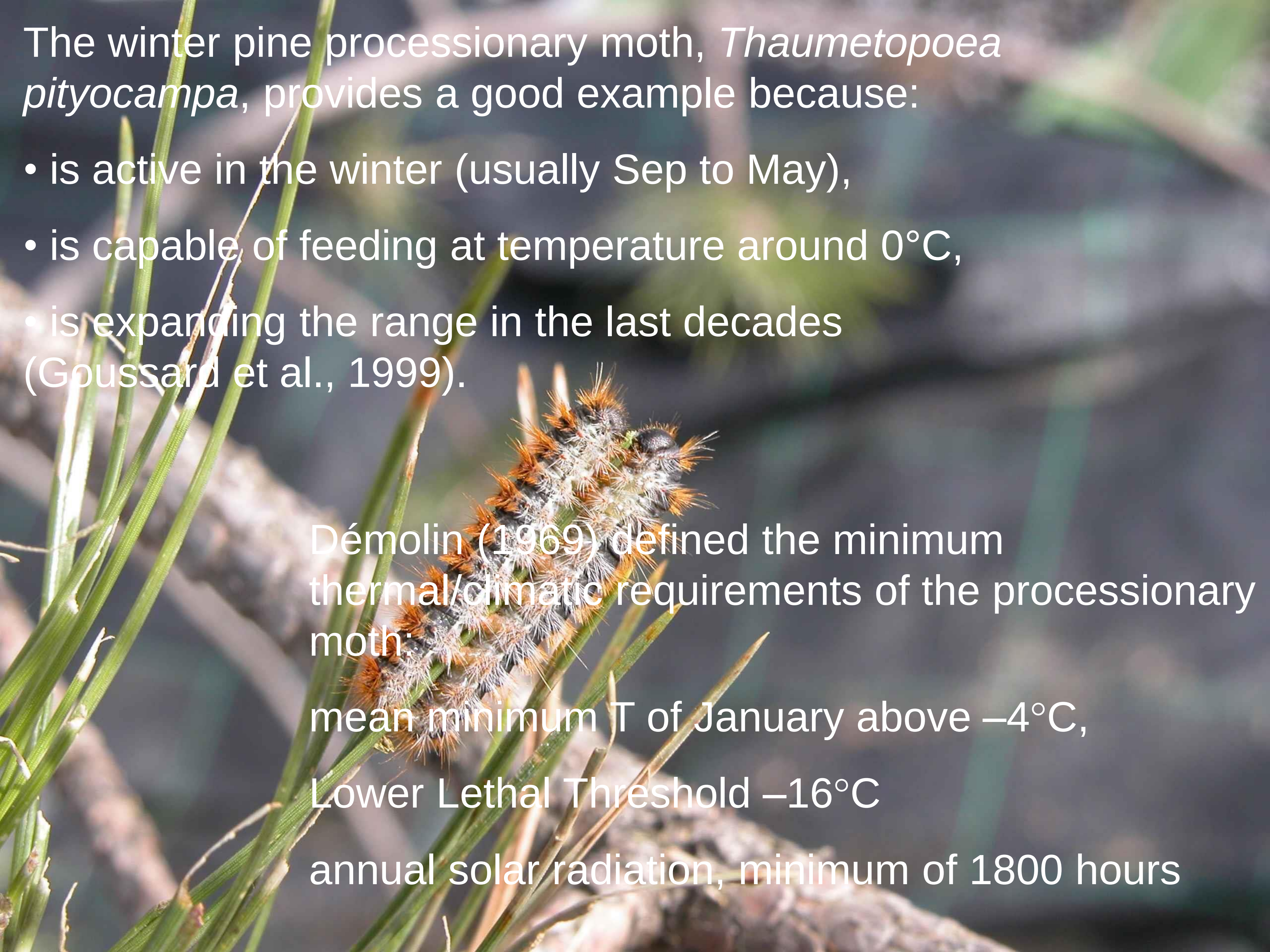
Recent distributional changes have been documented for plants, migratory birds, and temperate-zone butterflies (Parmesan et al. 1999, Walther et al. 2002, Parmesan and Yohe 2003).

However, a causal relationship between climatic factors and species range limits is often difficult to determine.

Insects are suitable test organisms because they are very sensitive to temperature.

Insects developing through the winter may respond to shifts in winter temperature, which have increased more than summer temperatures.



The winter pine processionary moth, *Thaumetopoea pityocampa*, provides a good example because:

- is active in the winter (usually Sep to May),
- is capable of feeding at temperature around 0°C,
- is expanding the range in the last decades (Goussard et al., 1999).

Démolin (1969) defined the minimum thermal/climatic requirements of the processionary moth:

mean minimum T of January above –4°C,

Lower Lethal Threshold –16°C

annual solar radiation, minimum of 1800 hours

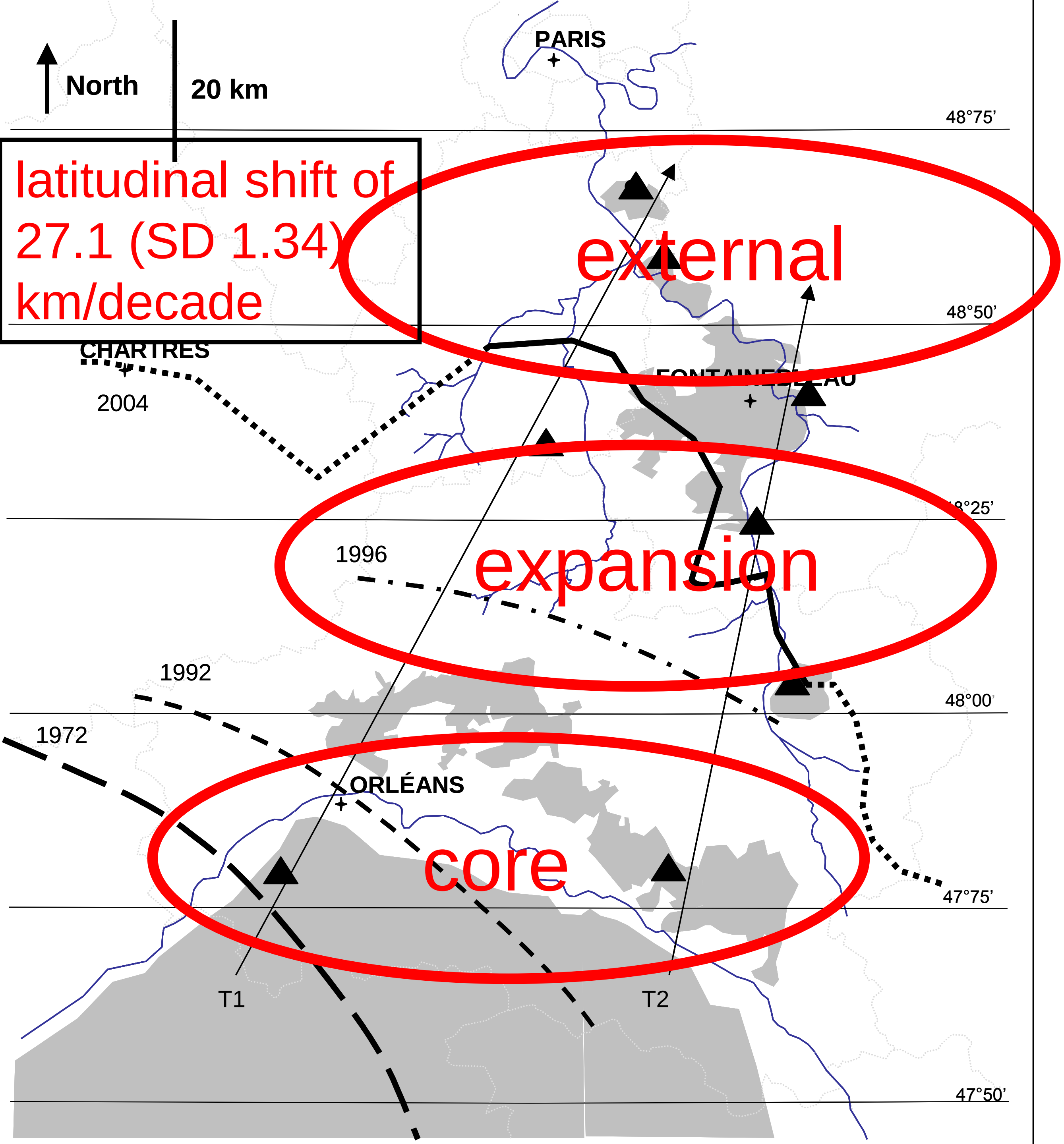
In this study, we sought a mechanistic understanding of the range expansion in *T. pityocampa*.

We explored **natural temperature gradients (latitude and altitude) as spatial analogues for climate change** by rearing cohorts of larvae in three zones along each gradient:

- the **core zone** (where the moth has been present for over 30 years),
- the **expansion zone** (where recent colonization has occurred),
- the **external zone** (outside its 2003 distribution)

We tested a mechanistic model for winter feeding that was developed from laboratory data.

The model is based on the combined effect of daytime nest temperature, which induces feeding, and minimum temperature for night feeding.



latitudinal shift of 27.1 (SD 1.34) km/decade

Site 1

Paris Basin

Two transects

▲ colony and T

Grey: forest

Lines: range edge at given year

Site 2

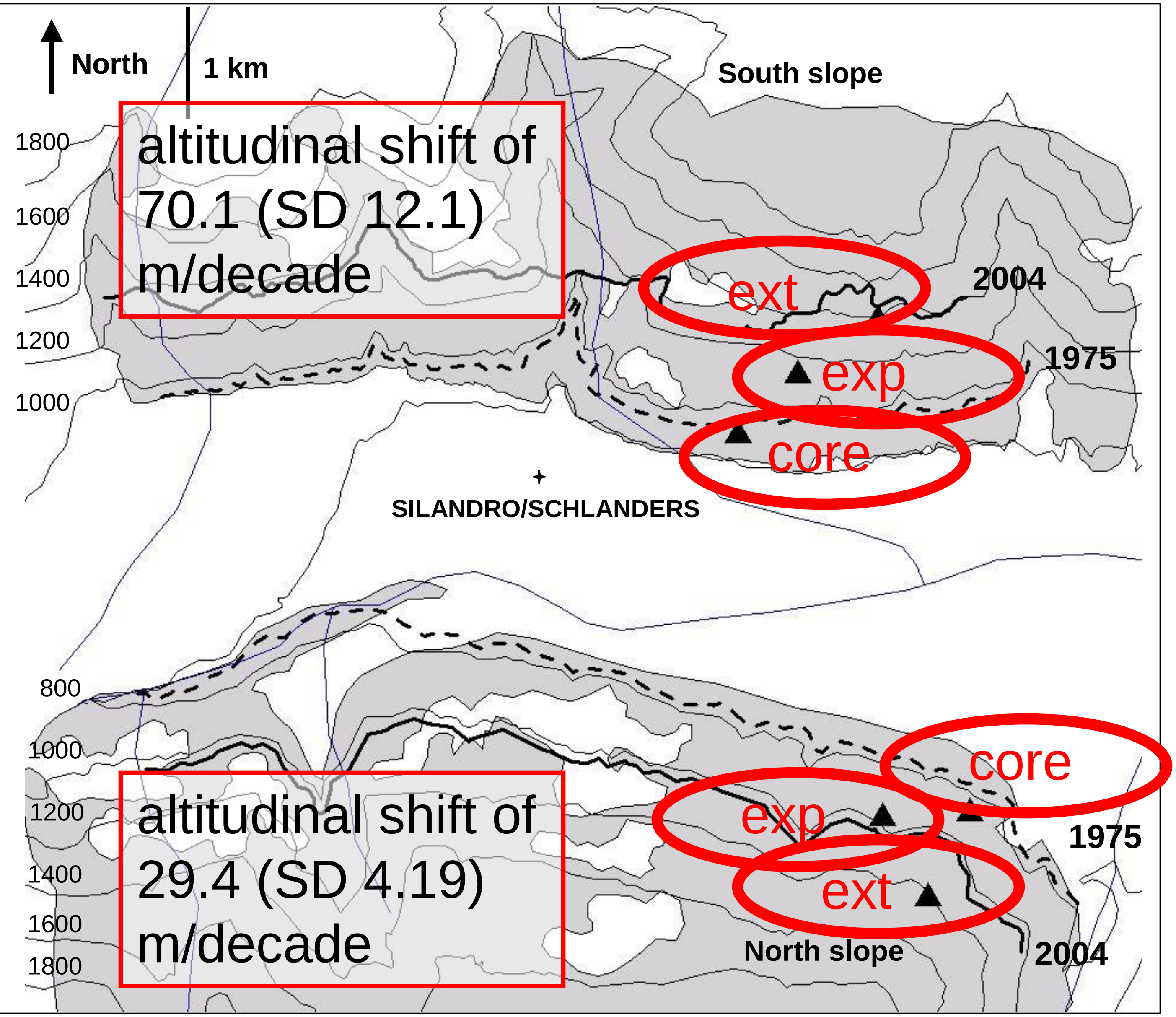
Venosta/Vinschgau – Alps, Italy

Two transects

▲ colony and T

Grey: forest

Lines: range edge at given year



altitudinal shift of 70.1 (SD 12.1) m/decade

altitudinal shift of 29.4 (SD 4.19) m/decade

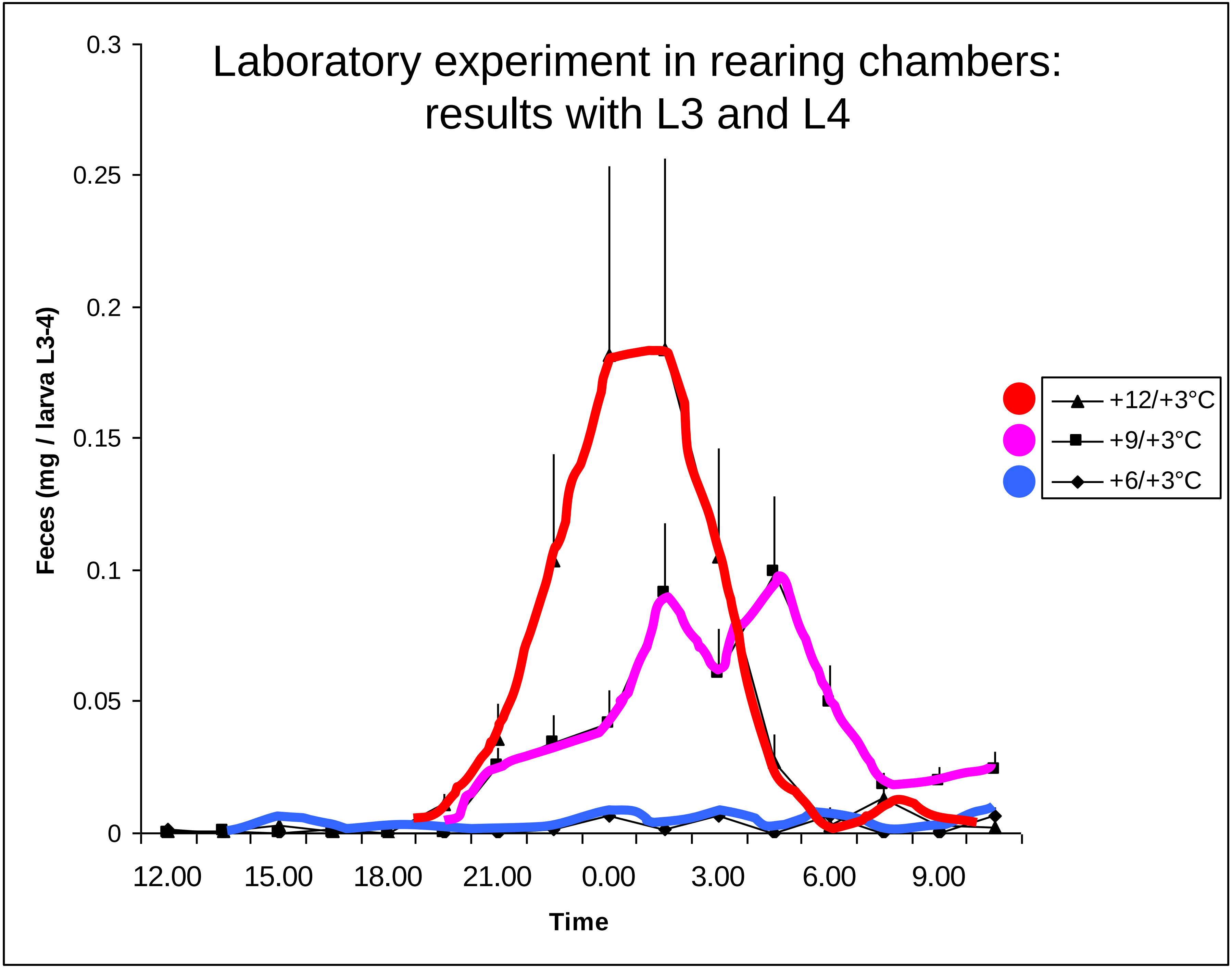
Hourly records of air and nest temperature

Data on incoming solar radiation (insolation)

Laboratory experiment in rearing chambers:

- short-day photoperiod (8 L:16 D, light from 8 am to 4 pm)
- constant night temperatures of either +3°C and –3°C
- four temperature regimes for the light phase: +3, +6, +9 and +12°C

Laboratory experiment in rearing chambers: results with L3 and L4



Model definition

Cold period: between the first and the last week with daily T minimum mean < 0°C

Paris Basin: January – February

Venosta: December - February

Thresholds

- Daily nest temperature, responsible for inducing subsequent night feeding,

  “Activation Temperature” AT **> 9°C**

- Night air temperature, allowing larval feeding,

  “Potential Feeding Temperature” PFT **> 0°C**

When AT > 9°C for at least one hour during the day

and

PFT is satisfied for a given number of hours during the night (number of hours with T > 0°C)

we achieve the “Realized Feeding Threshold” (RFT), representing the number of hours during which feeding may have occurred.

RFT can be calculated also as a number of days.

Model testing: performance – Paris Basin

Area and site	**Pre-cold period Aug-Nov**		**Cold period Dec-Feb**	**Post-cold period March-May**	
	% surv	**% L4**	**% surv**	**% surv**	**larvae /colony**
T1 core	**90 a**	**100**	**78 a**	**70 a**	**70.4 ± 46.1 a**
T1 expansion	**60 a**	**100**	**83 a**	**50 a**	**17.6 ± 16.5 b**
T1 external	**70 a**	**100**	**64 b**	**45 a**	**27.8 ± 30.5 b**
T2 core	**100 a**	**100**	**100 a**	**100 a**	**54.2 ± 33.7 a**
T2 expansion	**95 a**	**100**	**42 b**	**40 b**	**57.0 ± 26.3 a**
T2 external	**100 a**	**100**	**20 b**	**20 b**	**37.0 ± 28.3 a**

Model testing: performance – Venosta/Vinschgau

Area and site	Pre-cold period Aug-Nov		Cold period Dec-Feb	Post-cold period (March-May)	
	%surv	% L4	% surv	%surv	larvae /colony
South core	59 a	69.2	54 a	32 a	119.9 ± 41.1 a
South expansion	64 a	35.7	29 a	18 b	57.2 ± 30.2 b
South external	39 a	0.0	44 a	17 b	22.6 ± 3.5 b
North core	29 a	16.7	83 a	24 a	81.7 ± 73.9 a
North expansion	48 a	10.0	18 b	10 b	36.5 ± 7.3 b
North external	68 a	0.0	10 b	7 b	31.3 ± 0.0 b

Model testing: predicted feeding – Paris Basin

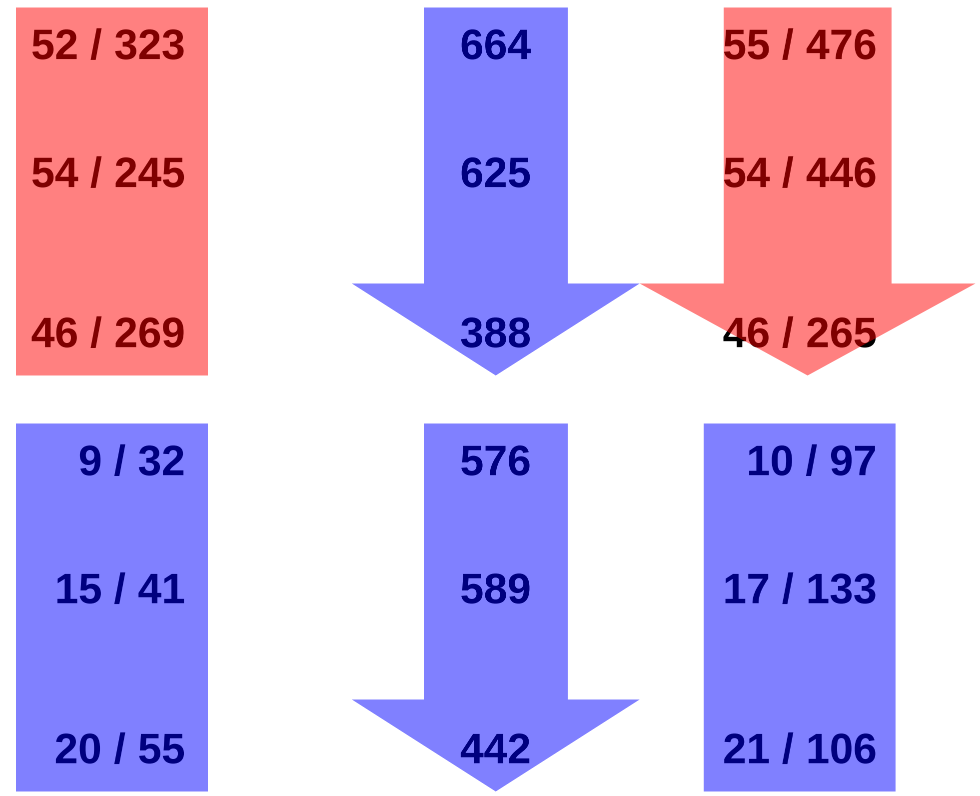
Cold period: 58 days (1 Jan – 27 Feb)

	Day insolation	Night temperature	
Area and site	**AT days / hours**	**PFT hours**	**RFT days / hours**
T1 core	**31 / 213**	**468**	**22 / 273**
T1 expansion	**21 / 135**	**504**	**16 / 201**
T1 external	**24 / 153**	**492**	**16 / 201**
T2 core	**21 / 135**	**456**	**17 / 228**
T2 expansion	**14 / 96**	**489**	**13 / 165**
T2 external	**14 / 96**	**453**	**11 / 141**

Model testing: predicted feeding – Venosta/Vinschgau

Cold period: 91 days (3 Dec – 4 Mar)

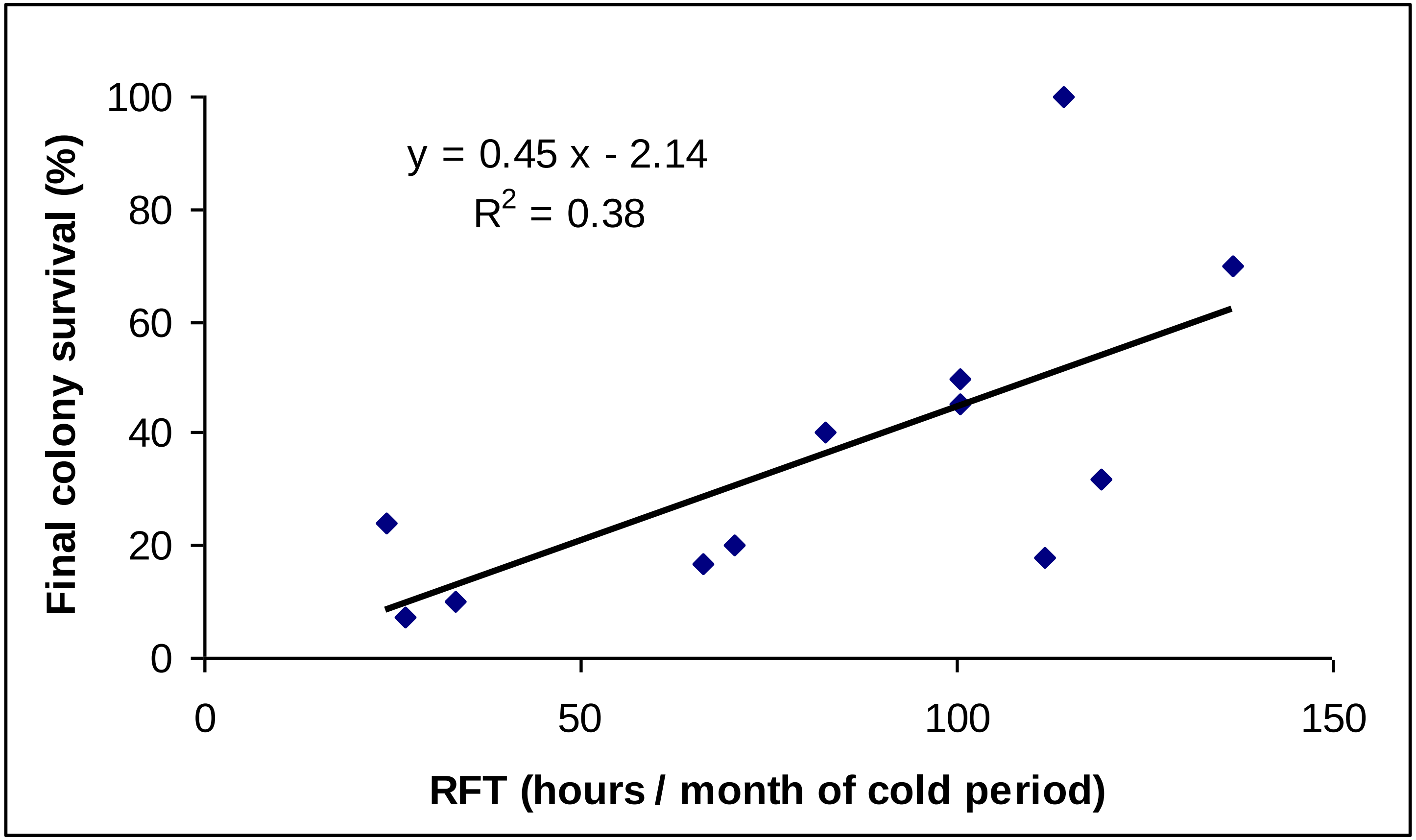
Day insolation Night temperature



Area and site	**AT** **days / hours**	**PFT** **hours**	**RFT** **days / hours**
South core	**52 / 323**	**664**	**55 / 476**
South expansion	**54 / 245**	**625**	**54 / 446**
South external	**46 / 269**	**388**	**46 / 265**
North core	**9 / 32**	**576**	**10 / 97**
North expansion	**15 / 41**	**589**	**17 / 133**
North external	**20 / 55**	**442**	**21 / 106**

Model testing: predicted feeding vs. performance

RFT was standardized for the two regions by dividing the total RFT by the months of the respective cold period and regressed against % colony survival.



Conclusions

- Survival is possible because winter feeding. More frequent feeding and, in turn, shorter starvation periods, accelerate development and enhance survival in areas with previously prohibitive climatic conditions.

- The magnitude of expansion in *T. pityocampa* is consistent with, or exceeds, the general predictions of responses to climate change (Parmesan et al. 1999, Hill et al. 2002, Walther et al. 2002, Parmesan and Yohe 2003).

- Given that a shift in one degree of latitude roughly corresponds to a rise of 122 m in altitude (Hopkins 1938), the estimate of latitudinal expansion (27 km/decade) is consistent with that of altitudinal expansion on the north slope (29 m/decade).

- In spite of all the unpredictable facts affecting survival (e.g. LLT), but buffered by extended diapause, it is reasonable to assume that the geographic range of *T. pityocampa* will continue to expand in response to increasing mean temperatures.

- Insufficient insolation may limit the northward expansion; areas approximately two degrees farther north (about 220 km) of upper latitude edge cannot support winter feeding.

- Insolation is less important than night temperature as a limiting factor for the expansion on southern slopes of mountains.

- Climate-based models that combine mean day and night temperatures, probability of LLT, and insolation, are likely to provide the best predictive power in range dynamics of *T. pityocampa*.

⬇

Poster of Pennerstorfer et al., Modelling the range expansion of the Pine Processionary Moth *(Thaumetopoea pityocampa)* in complex alpine terrain.

Upper Venosta/Vischgau valley