Range expansion of the Pine Processionary Moth in Europe - I. Mechanisms underlying PPM expansion in France in relation to global warming

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RANGE EXPANSION OF THE PINE PROCESSIONARY MOTH IN EUROPE. I-MECHANISMS UNDERLYING PPM EXPANSION IN FRANCE IN RELATION TO GLOBAL WARMING

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Abstract

Pine processionary moth (PPM) constitutes a good model for studying the response of forest insects to global warming. PPM is a Mediterranean insect clearly expanding polewards. Its larval development occurs during winter and is therefore highly sensitive to minor changes in weather conditions. Moreover, the larvae build large white winter « nests », which could be easily surveyed by foresters to estimate the levels of infestation. PPM is the most important species of forest defoliator in southern Europe but it also impacts health of humans and pets because of its urticating hairs (dermatitis). Previous studies revealed that PPM cycle is largely controlled by winter weather conditions, the requirements for larval survival being assessed as follows: mean January minimum higher than -4 °C, annual solar radiation larger than 1800 h (to heat nests during winter), whilst lethal temperature was estimated at -16 °C. However, PPM surveys done since the 1960s using a permanent network of pine stands in France revealed a significant progression in both latitude and altitude between 1992 and 2002. This expansion seemed to coincide with a large increase in winter temperatures and in insolation as well but no clear evidence was provided for such relationships.

Therefore, an European Project entitled PROMOTH ("Global change and pine processionary moth: a new challenge for integrated pest management") was initiated since 2002 to address the following targets: (i) analysis of the genetic structuration of PPM populations in core and expanding areas using microsatellite markers; (ii) cartography and modelling of the expansion development in space and time; (iii) identify the physiological responses of the larvae to local variations in climate; and (iv) compare the parasitism in core and expanding areas.

To analyze the genetic structuration of PPM populations, larvae were sampled in more than 50 sites throughout the core and expanding areas in France. Microsatellite analysis (5 loci) did not show any isolation by distance in the core area when the flight-of-bird distances are considered. However, when the values of Fixation index (Fst) were plotted against distances circumventing Massif Central, isolation by distance was verified (Mantel test). We therefore hypothesized the existence of two corridors (northwestern and northeastern) for gene flow corresponding to different ways of expansion from the Mediterranean area, the populations still communicating by the southern Mediterranean range. In the expansion area of Paris Basin, the populations of the northern front appeared slightly but significantly divergent from these of the core area and from these of the Eastern Front, suggesting two ways for expansion in that area.

In the Paris Basin, the shift of the latitudinal front was estimated to have progressed of 86.7 km between 1972 and 2004, with a notable acceleration (55.6 km) during the last 10 years. The expansion coincided with a rapid increase in minimum winter temperature in both core and front area (+1.1 °C and + 0.9 °C, respectively). To test for larval survival potential, we used natural gradients to simulate weather conditions experienced by larvae during winter. From 2002 to 2004, larval colonies were translocated from core to front (two sites) and post-front areas (two sites) along two transects, using either two egg masses (2002) or 200 1st- instar larvae (2003- 2004) implanted per tree on 10 trees per site. A datalogger was used in each site to record the weather variables (T, RH, Isolation) on tree and into nest (probe). The same experiment was done in the French Alps to compare the survival at the altitudinal front. Under the 2002-2004 conditions, PPM larvae survived largely above the present front line in Paris Basin. In the southern Alps, PPM larvae also survived at altitudes much higher (>1800 m) than the current front line (1250 m). In two sites of the Alps, lethal temperatures

were reached (-16.7 °C and -18 °C) but a few larvae survived.

Larva survival was directly related to feeding activity during the cold period (= period during which the weekly mean of minimum daily T° < 0 °C). Day temperature of the nest must be higher than 9 °C to induce feeding during the next night but feeding effectively occurs if night air temperature is higher than 0 °C. If one of these two conditions is not respected, larvae starve. We tentatively modelled the mean number of days of potential feeding for larvae and the mean number of consecutive days of larval starvation in Paris Basin for the periods 1991-1996 and 2000-2004 and showed that the second period was significantly more favourable to larval development. In the Alps, larva survival appeared to be positively correlated the mean of maximum temperatures in January, warmer conditions during 2002-2003 having favoured higher survival.

PPM expansion also depends on the flight capabilities of adults. Because they are too heavy, females usually fly only over short distances but flight mill experiments revealed some of them can fly 3 km at least, ie. more than previously considered. Pheromone trappings far above the front showed that males are patrolling 23 km at least above the front in both Paris Basin and in the Alps. In the latter situation, male flight capabilities allow gene flow between disconnected systems of Alpine valleys, and Italian and French populations are probably connected despite the Alpine barrier. In addition, a significantly fewer egg parasitism near the front probably facilitated the expansion (2-12% vs. 22-35% in core areas).

In conclusion, we can wonder whether the expansion could be unlimited with continuous warming. In other words, is PPM capable of reaching UK, Northeastern France, Germany and Central Europe? Indeed, susceptible hosts exist far above the front. Systematic plantations of pines along motorways also favour significantly the expansion, acting as relays for PPM progression. However, there seems to exist a daylength limit to expansion: daylength (and subsequent isolation) must allow effective nest heating during day to reach 9 °C. A tentative model for PPM expansion using different kinds of meteorological simulations for the next 50 years is under way.