The pine processionary, a model for the effects of global warming

1. One of the few insects with winter larval development

Figure 1. Typical larval nest of a pine processionary in November in Aveyron. Left: external appearance; right: open nest to show the stinging caterpillars [Source : ©Roques]

The pine processionary, *Thaumetopoea pityocampa* (Den. & Schiff.) (Lepidoptera: Notodontidae), is an insect of Mediterranean origin. Its caterpillars develop in a gregarious way on pines, and possibly other conifers (cedars, Douglas fir, etc...), in colonies easily recognizable by their silky white nests, well visible in winter (Figure 1).

Unlike most other insects, the larval development of the pine processionary occurs during fall and winter and is highly sensitive to slight temperature variations. Winter warming increases the survival of the caterpillars and allows them to complete their development in areas where climatic conditions were previously hostile to them. The climatic constraints modulating this development have been precisely established since the mid-2000s:

- The lethal temperature, below which not all processionary colonies can survive, has been estimated at -16°C, a value that is now very rarely reached in most parts of Western Europe.
- But beyond their survival, caterpillars must also feed to complete their development until pupation. They leave the nest at night to devour pine needles, this night outing being subject to two conditions [1]:

- The nest must have had a minimum temperature of 9°C during the day (activation temperature);
- The air temperature must be above 0°C during this night (supply temperature).

This allows us to calculate the mortality and the number of nights that the caterpillars can feed during winter, and conversely the number of consecutive days of famine, which must remain limited to allow for full development [2].

2. From the late 1970s, a gradual lifting of thermal constraints limiting the insect's range was achieved

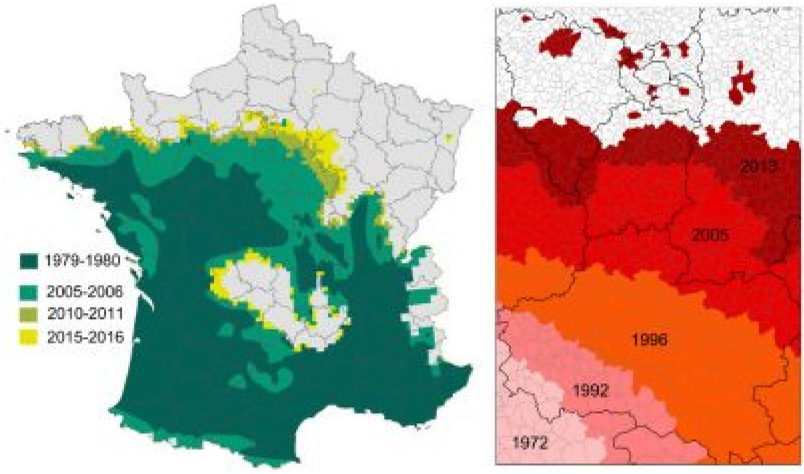

Figure 2. Expansion of the pine processionary in France. Left: Global movements of expansion fronts at different dates between 1979 and winter 2015-2016. On the right: detail of the expansion in the south of the Paris basin between 1972 and 2011. Source: Left, © Jérôme Rousselet, INRA; right, after Roques et al. 2015, reference [4]; © Roques]

Winter warming in northern and mountainous areas has greatly reduced the risk of mortality, allowing processionary populations to colonize previously unfavourable areas and extend their distribution in latitude and altitude. For example, an unfavourable climatic zone, constituting a barrier, used to exist in the south of the Paris basin. This barrier was lifted in 1996 in direct relation to the increase in winter temperatures and, at the beginning of the 2000s, the entire Paris Basin became favourable to the insect's establishment, the only limit to its progression being the low flying capacity of females [3]. A continuous northward expansion of more than 120 km was observed between 1972 and 2017, at an average speed of 2.6 km per year, with an acceleration to 5.5 km/year since the early 2000s (Figure 2). This expansion in the Paris Basin was concomitant with an average increase in winter temperature of 1.1°C. The same expansion was observed in the other northern regions of France and at altitude (Alps, Pyrenees, Massif Central) as shown by the geo-referenced mapping of the movement of the expansion fronts until 2016 (Figure 2). Similar phenomena have been observed throughout southern Europe, from Brittany to Turkey [4] (Figure 3).

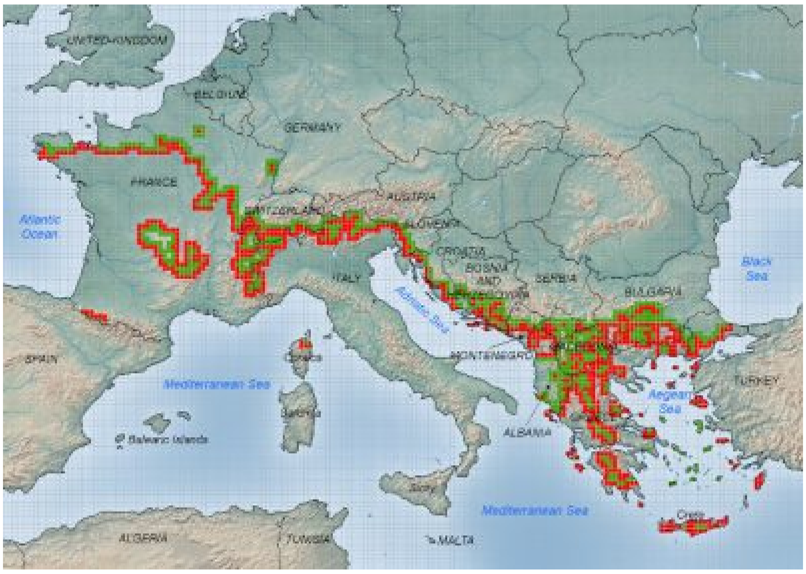

Figure 3. Mapping of the European expansion front of the pine processionary during the winter of 2011-2012, according to a 16 km by 16 km grid. The red squares represent the northernmost and highest areas where colonies have been documented. The green squares represent the first areas where no further colony has been observed [Source: from Roques et al. 2015, référence [4] ; © Roques]

These data have made the pine processionary one of the model species for studying the consequences of climate change, selected in France by the *Observatoire National sur les Effets du Réchauffement Climatique* (bioindicator ONERC since 2006) and internationally by the *Intergovernmental Panel on Climate Change* (IPCC, cited in the 4th report in 2007).

3. An unsuspected role of man in the expansion

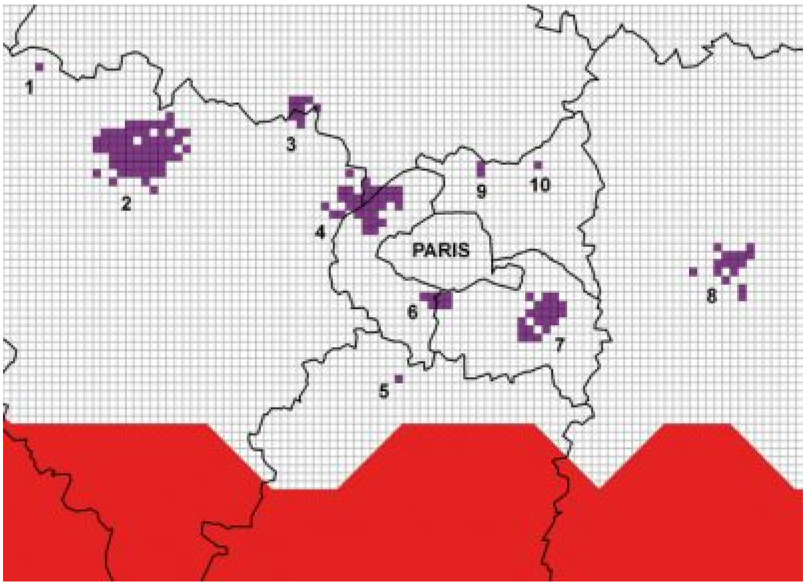

Figure 4. Areas of the Paris region with isolated colonies beyond the expansion front during the winter of 2011-2012. The grid corresponds to observation cells measuring 1 km by 1 km. Each purple-colored cell indicates the presence of at least one colony. The natural expansion front is shown in red. Location of colonies and date of first detection: 1, Moisson - Mousseaux-sur-Seine (2012); 2, Flins - Aubergenville (2008) ; 3, Eragny - Conflans-Sainte-Honorine (2008) ; 4, Nanterre (2007); 5, Palaiseau (2012) ; 6, Bagneux - Arcueil (2010); 7, Saint-Maur-des-Fossés (2008); 8, Disneyland - Bailly- Romainvilliers (2003); 9, La Courneuve (2012); 10, Aulnay-sous-bois (2012). Source: based on Roques et al. 2015, reference [4]; © Roques]

About ten isolated colonies have been successively discovered beyond the expansion front since the mid-2000s in the Paris region (Figure 4) but also in Alsace and Aisne [4]. The distance to the front, between 50 and 300 km, is much greater than the natural dispersal capacities of female butterflies (from a few hundred metres to a few kilometres [5]). The genetic typing of individuals in these colonies shows that most of them do not originate from the expansion front, but come from populations hundreds of kilometres apart, from southeast and southwestern France, as well as from Italy [6]. In addition, the parasitic complex of these isolated colonies is reduced to pupae parasites. These combined elements suggest a decisive role for humans in the emergence of these colonies through the trade in pines from southern nurseries, with insects travelling as pupae in the soil clods accompanying these pines. The nature of the sites where the colonies appeared, which all correspond to highly anthropized habitats with pines planted for ornamental purposes (highway and roundabouts, cemeteries, factory, university, or low-cost housing estates, etc.), largely supports this hypothesis. While it is likely that such transport and plantations existed before the 2000s, the unfavourable climatic conditions in the Paris region and in the North did not allow processionaires to settle there.

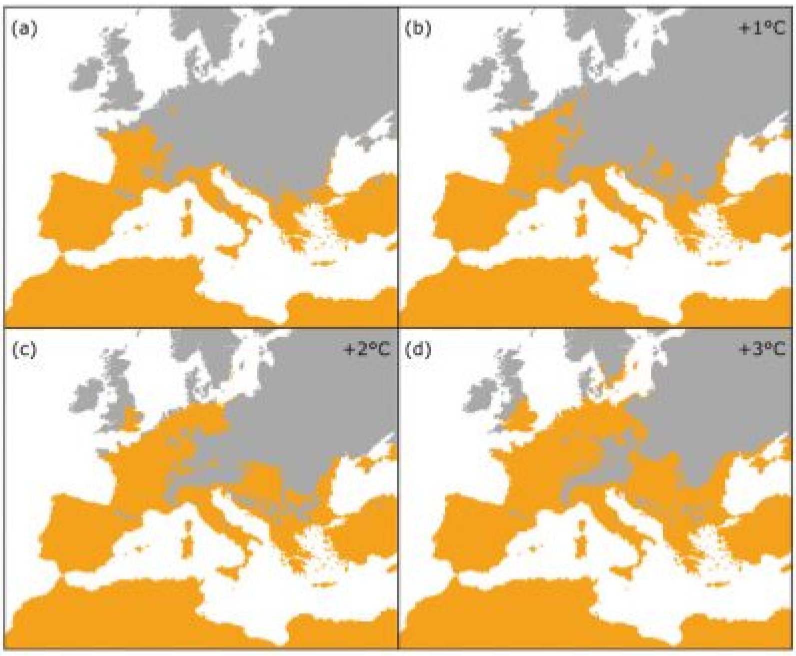

Figure 5. Modelling of areas favourable to the establishment of processionary colonies according to (a) current temperatures, (b) an average increase of +1°C, (c) an average increase of +2°C, and (d) an average increase of +3°C temperature. The orange colored areas are those where the model gives a probability of presence greater than 50%. Source: after Roques et al., 2015, reference [4]; © Christelle Robinet]

This expansion also leads highly stinging caterpillars to enter peri-urban and urban areas, as well as mountain tourist areas. The first colonies were discovered in 2015 in Paris intramuros, transforming the insect from a forest pest to an urban health nuisance for humans and domestic animals [7].

Notes et références

[1] Battisti A., Stastny M., Netherer S., Robinet C., Schopf A., Roques A., et al. (2005) Expansion of geographic range in pine processionary moth caused by increasing winter temperatures. *Ecological Applications* **15**, 2084-2096.

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[6] Robinet C, Imbert C.E., Rousselet J., Sauvard D., Garcia J., et al. (2012). Warming up combined with the trade of large trees allowed long-distance jumps of pine processionary moth in Europe. *Biological Invasions* **14**, 1557–1569.

[7] Moneo I., Battisti A., Dufour B., Garcia-Ortiz J.C., González-Muñoz M. et al. (2015). Medical and veterinary impact of the urticating processionary larvae. pp. 359- 410 *In* Roques A. (Ed.) *Processionary Moths and Climate Change: An Update.* Springer/

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