

## CLIMATE CHANGE AND EXPANSION OF THE PINE PROCESSIONARY MOTH, *THAUMETOPOEA PITYOCAMPA*, IN NORTHERN ITALY

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### Abstract

We studied the occurrence of *Thaumetopoea pityocampa* in two alpine valleys (Friuli Venezia Giulia district, north-eastern Italy), in order to know the response of the pine processionary moth to the hot summer of 2003. Extreme nests were located in the two valleys during three life-cycles. Moreover we studied the relationships between catch in pheromone traps and infestation level at the same sites. The numerous nights with high temperature in 2003 have facilitated the flight of the females and the colonization of new areas. This expansion has confirmed the successful colonization of the novel host *P. mugo*, previously recorded as occasional host of the pine processionary moth.

Keywords: *Thaumetopoea pityocampa*, *Pinus sp.*, range, temperature, monitoring

### 1. Introduction

Global warming is predicted to cause distributional changes in organisms whose geographic ranges are controlled by temperature (Ungerer et al. 1999). A recent latitudinal and altitudinal expansion of the pine processionary moth, *Thaumetopoea pityocampa* (Denis et Schiffermüller) (Lep. Notodontidae) has been reported (Battisti et al. 2005). In north-central France (Paris Basin), its range boundary has shifted by 87 km northwards between 1972 and 2004; in northern Italy (Alps), an altitudinal shift of 110-230 m upwards occurred between 1975 and 2004. By experimentally linking winter temperature, feeding activity, and survival of *T. pityocampa* larvae, these authors attributed the expansions to increased winter survival due to a warming trend over the past three decades. Given that the present distribution of the oligophagous *T. pityocampa* is not constrained by the distribution of its present or potential hosts (Stastny et al. 2006), and that warmer winters will cause the number of hours of feeding to increase and the probability of the lower lethal temperature to decrease, a further latitudinal and altitudinal expansion is expected.

Climatic anomalies may produce, or accelerate, geographic range expansions of species limited by temperature or other climatic variables (Carroll et al. 2003). Battisti et al. (2006) reported a recent rapid shift of the range limit of *T. pityocampa* during the record hot summer of 2003 in southern Europe, that has the potential to be both permanent, and to have important implications on species range dynamics in general. The colonization of extreme, high-elevation sites was attributed to increased nocturnal dispersal of females during the unusually warm night temperatures in June–August 2003. Importantly, the colonies established at extreme sites survived the winter and produced offspring in 2004, although the range did not expand further due to low night temperatures that year.

Pheromone trapping has been considered for a long time as a mean to monitor populations of *T. pityocampa* and to explore gene flow at extreme sites (Salvato et al. 2005). The pheromone trapping method relies on a positive relationship between trap capture and local population density (Thorpe et al. 1993). Unfortunately, most of the field studies so far have failed to find a correlation between the number of males caught in pheromone traps and local infestation levels, traditionally expressed as the number of nests per tree. Jactel et al. (2006), however, detected a positive and significant correlation between the number of males and the level of infestation in the following generation. These findings suggest that pheromone-baited traps, operated according the framework proposed by Jactel et al. (2006), provide a suitable tool for monitoring of *T. pityocampa* populations.

In this paper, we describe the situation of a two alpine valleys in the expansion area of *T. pityocampa* in north-eastern Italy, by comparing surveys carried out in the past with the present distribution. We used nest censuses and pheromone trap catches as indicators of population density.

## 2. Materials and methods

### 2.1 Study area and organism

The study area is located in the Friuli Venezia Giulia region, north-eastern Italy, and it includes the two alpine valleys Cimoliana and Settimana, in an altitudinal range between 600 and 1100 m (Fig. 1 and 2). Both natural pine forest and pine plantations are widespread in this area. In the lower part of the valleys the main species is *Pinus nigra*, occurring mainly on south-eastern slopes; this species is progressively replaced by *Pinus sylvestris* in the upper, colder parts of valleys. The creeping pine *Pinus mugo* is commonly associated with the other two pine species, and it forms pure stands beyond the tree line. Most of pine forests have high tree density and low height and diameter, because of low soil fertility and steep slope, making landslide frequent.

Larvae of the winter pine processionary moth *Thaumetopoea pityocampa* feed gregariously on pine foliage during the winter. Pupation occurs in spring, and adult emergence in summer is immediately followed by mating and oviposition. Females typically live only one night. The insect is distributed throughout the Mediterranean, and has long been known to produce spectacular outbreaks (Matthioli, 1568). Forest inventories generally report a scattered distribution of outbreaks, with usually no more than two years of strong defoliation in a row, after which most of the trees recover (Masutti & Battisti, 1990).

### 2.2 Insect survey

There are records of processionary moth occurrence in the study area in the last 20 years, made available by the Forest Service of Friuli Venezia Giulia district, indicating the presence of medium and intense defoliation events in the study area. In an attempt to describe the upper limit of moth's range, we surveyed the localization of the extreme colony tents ('nests') during 2002-2004. The winter nests were used to outline the boundary range as they are easy visible. Furthermore, a sample of these was collected and inspected in the laboratory to verify the survival of the larvae. For each of the two studied cycles (2002-03 and 2003-04), the area was divided in homogenous zones as far as nest density, indicated as the number of nests on forty pine trees. Density was compared between years by Student t-test.

We had access to data from a pheromone trap monitoring network working in the area in 1987-1991 and 1993. There were 5 traps in Cimoliana valley and 4 in Settimana valley. In the

summer of 2003 a set of similar type of funnel traps (Supergreen), loaded with 0.2 mg of pheromone, was located in the same places. Two additional traps were used in each valley, located at the site where the extreme nest was pointed out in the winter and 300-400 m upstream. The traps were checked every week from July to September.

### 3. Results

#### 3.1 Outbreak history

During the last 20 years, three attacks of pine processionary moth were recorded, precisely in 1988-89, 1992-93, and 1998-99. In the Cimoliana valley, the damaged area (11.2 ha with a defoliation higher than 25%) was located on the south-eastern slope of the lower part of the valley, mainly on *P. nigra* (Fig. 1). In the Settimana valley, the outbreak occurred in an area of 14 ha of pure plantation of *P. nigra*, at the beginning of the valley on the southern slope (Fig. 2). A second outbreak occurred only in the Cimoliana valley in 1998-99, on an area of 27.6 ha located in the same area of previous years, with a defoliation of 45% (Fig. 1). The catch of males in pheromone traps was not correlated with the outbreak of 1988-89 (Fig. 3). The captures were elevated in the first year of sampling, decreasing in the subsequent years around 20 males/trap, and increasing in 2003, when the mean catch was captured about 100 males.

The weekly catches offered the possibility to assess the seasonal phenology. Male emergence started at the end of June and peaked on 19 of July (Fig. 4). There was a second and smaller peak before mid August, and the catch was over at the beginning of September. The catch pattern was similar in all years of monitoring. Traps located at the site where the extreme nest was found in the previous winter, captured 14 males in Cimoliana and 9 males in Settimana valley. Traps located 300-400 m upstream the extreme nest, captured three males only in Cimoliana valley.

#### 3.2 Range expansion

The nest density did not show any variation between the two years in both valleys. In the Cimoliana valley, there were 11.36 nests (SD=5.23, n=11) on forty pine trees in 2002-03 and 11.54 (SD=5.75; n = 11) in 2003-04. In the Settimana valley the mean density was higher than in the Cimoliana valley in particular 21.14 nests on forty plants (SD =9.02, n=7) in 2002-03, and 26.42 (SD=16.26, n=7) in 2003-04 . No significant differences were observed between the two years in both valleys. The zones showed variable density, the most attacked having more than one nest per tree, but defoliation was limited, excepted in few spots. The range boundaries varied during the sampling period. In the 2002-03 several nests were recorded on the south-eastern slope of both valleys from the river bed, mainly on *P. mugo*, to the pines groups growing on outcrops of the valley's slopes up to an elevation of about 1000 m. In the valley bottom there were small nests up to an elevation of 850 m. During the following season (2003-04) the insect range expanded, and the extreme nests were found at a higher altitude in the valley bottom (900 m), at a distance of about 300 m. In 2004-05 the range edges did not show any variation with respect to the previous season.

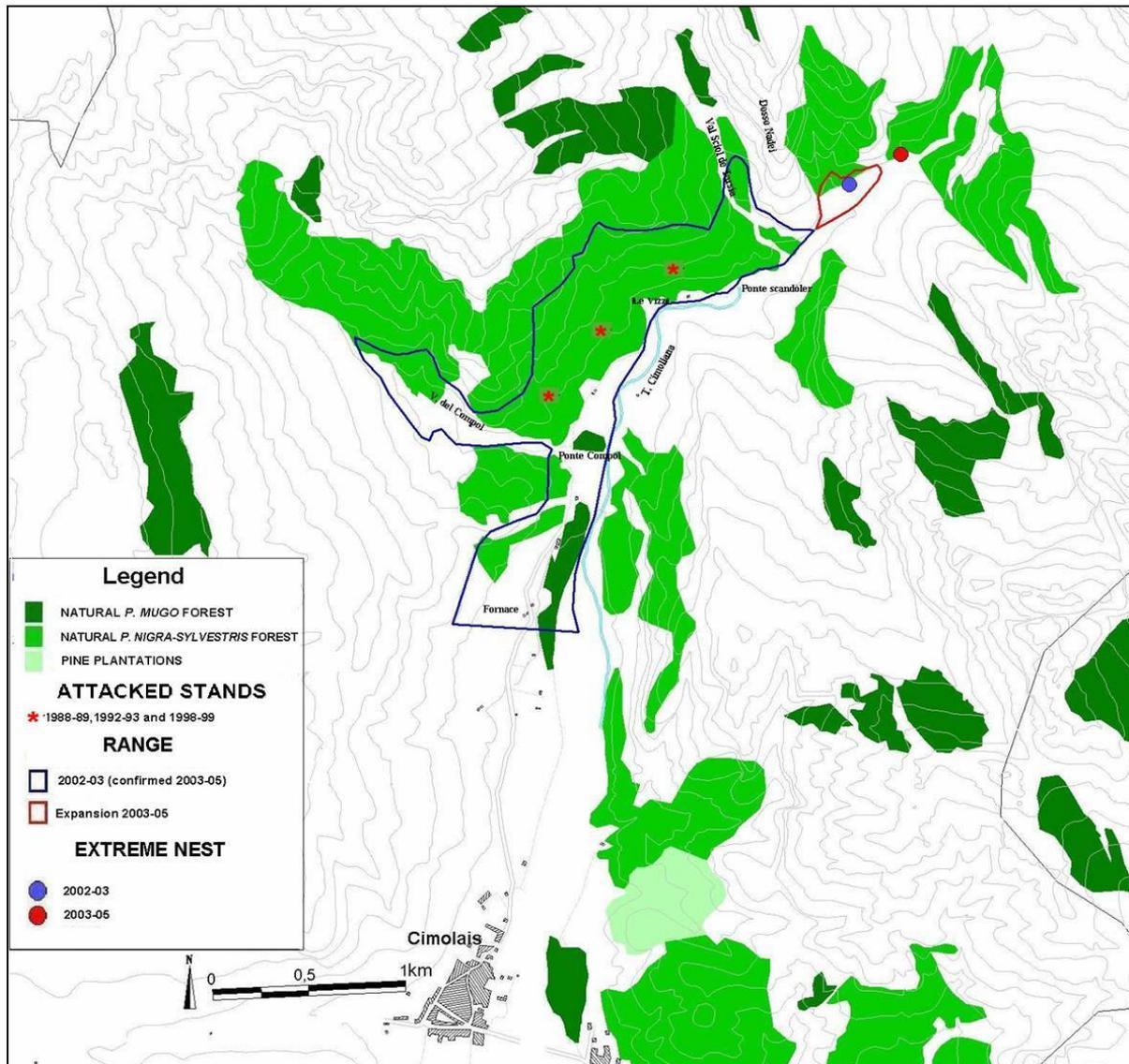


Figure 1. Map of the Cimoliana valley, north-eastern Italy, with the indication of the pine forests, the attacked stands, the range edge limited to the 2002-05 survey and the expansion range.

In the Settimana valley, the processionary was initially established on the most sun exposed slopes on both sides of the river, with the extreme nests around 900 m of elevation. In the 2003-04 the moth expanded further north and on shaded slopes, with extreme nests around 920 m and distant 880 m from those of previous cycle. In this case the most colonized host was *Pinus mugo*. As in the Cimoliana valley, there was no variation in the cycle 2004-05.

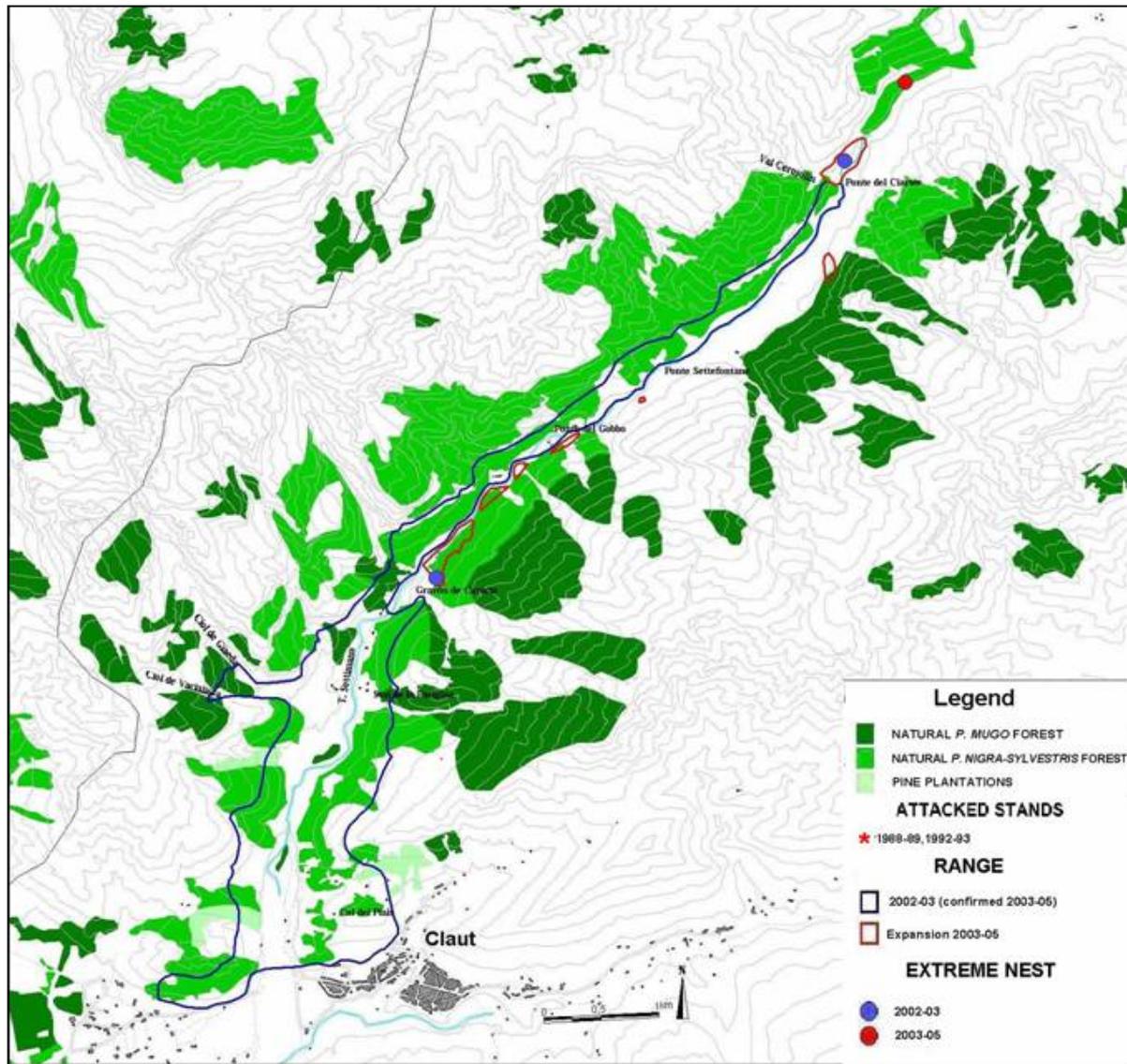


Figure 2. Map of the Settimana valley, north-eastern Italy, with the indication of the pine forests, the attacked stands, the range edge limited to the 2002-05 survey and the expansion range.

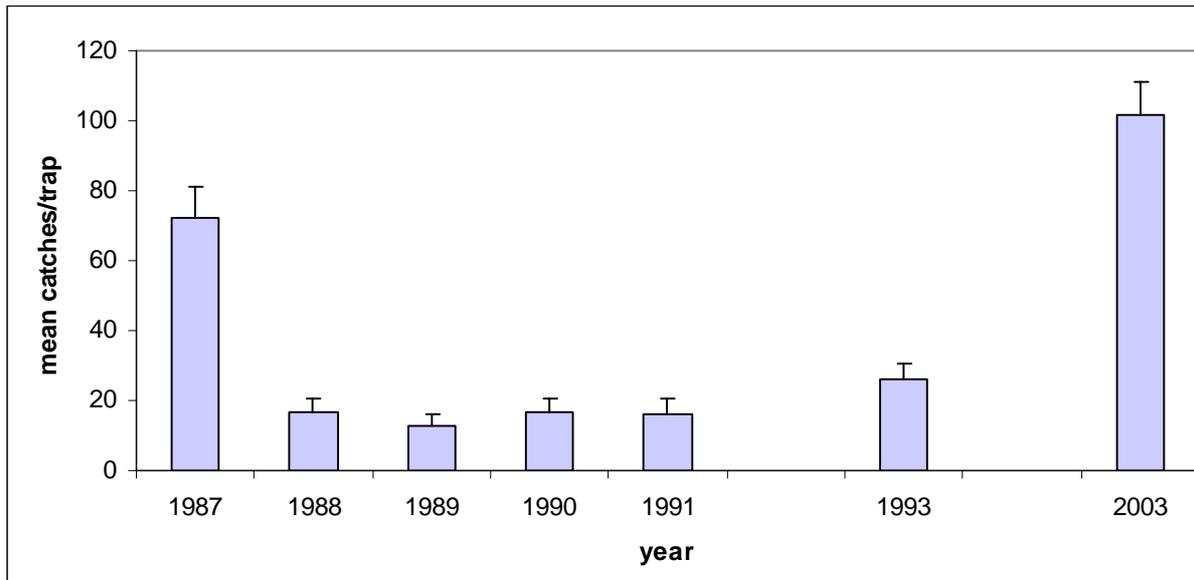


Figure 3. Catches of adult males (mean + 1 SE) in pheromone traps (n=5) during sampling years.

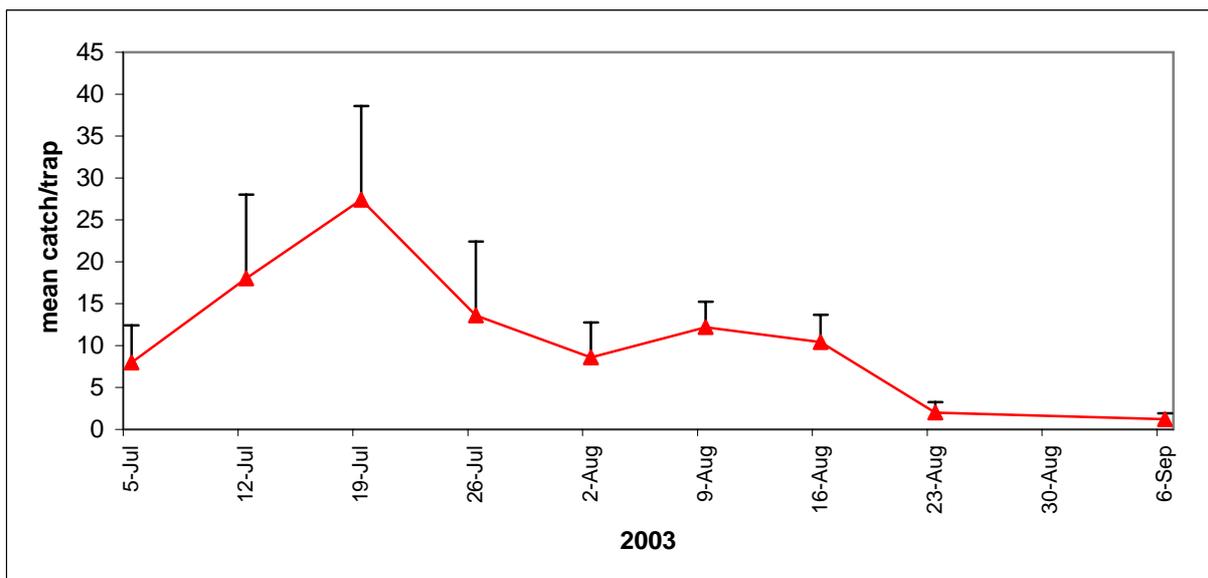


Figure 4. Catch of adult males (mean + 1 SD) in pheromone traps (n=5) in 2003

#### 4. Discussion and conclusion

In the study period, intense defoliation events occurred every four to six years in Cimoliana valley and every four years in Settimana valley, showing thus some periodicity. Several authors described similar periodical outbreaks, every three-seven years in a Mediterranean pine plantation (Longo et al. 1989), six-seven years in an alpine area (Nicolini 1987), four-six years in Trieste Karst and in the pre-alpine areas of Friuli Venezia Giulia (Stergulc & Frigimelica 1999), six years in France (Abgrall & Bouhot 1990). After a year of intense defoliation, the population density decreases quickly as a consequence of both change in food

quality and activity of the natural enemies (Battisti 1988, Masutti & Battisti 1990, Hodar et al. 2004). The enemies usually do not contain the eruptive phase but may have an important function in the successive phases. However, outbreaks are not as regular as those described for the larch bud moth *Zeiraphera diniana* (Turchin et al. 2003), and in the last twenty years there was no indication of intense defoliations in the two valleys. Therefore population dynamics seem to depend also on other unpredictable factors, such as climatic conditions on a large scale, and the occurrence of extended diapause on a small scale.

The captures of pheromone trap did not allow a satisfactory prediction of the outbreaks, as in 1988 the catch value was low but in the following winter there was strong infestation with defoliation; on the contrary, in 1987 and 2003 numerous males were captured, but in following winter there was no indication of intense defoliation was observed. The difficulty to find a relation between catch and infestation was shown (Tiberi & Niccoli 1984, Roversi 1985, Devkota et al. 1992), however Jactel et al. (2006) recently showed a good correlation between male catch and nest density. The possible reasons of the different outcome rely on the monitoring design. In our study, as in many monitoring activities, the traps were placed on the border of the forest, often near roads, to facilitate the periodical inspections. The conditions in this location can be very different with respect to the forest, thereby the enhanced attractive power of the traps does not mirror the actual density of the insect. Moreover, the area of nest census is much wider than that of Jactel et al. (2006) trial. Many studies analyzed and argued the climate change phenomenon occurring in the last decades (IPPC 2001), including the exceptionally hot summer of 2003 (Luterbacher et al. 2004; Beniston 2004). Climate change has been invoked to explain numerous variations in natural ecosystem such as range expansion (Hill et al. 1999, Wilson et al. 2005), phenological changes (Stefanescu et al. 2003), and acceptance of new hosts (Gutierrez & Thomas 2000). We can recognize the 2003 summer as one possible factor that has determined the range expansion of the insect in the two valleys. The numerous nights with high temperature may have facilitated the flight of the females and the colonization of new areas, as shown by Battisti et al. (2006). This expansion has confirmed the successful colonization of the novel host *P. mugo*, previously recorded as occasional host of the pine processionary moth (Benigni & Battisti 1999, Stergulc et al. 2000). Stastny et al. (2006) recently showed with laboratory and field trials that the relative growth rate and the mortality of larvae did not differ among three pine species growing in the expansion range of the moth, *P. nigra* (primary host), *P. sylvestris* (secondary host), and *P. mugo* (novel host). The reason of low occurrence and absence of outbreaks on *P. mugo* was previously explained by the separation of the ranges and by the low performance of the colonies (Devkota 1990). Since large stands of creeping pine occur in areas next to the insect range edge, we hypothesize that the pine processionary moth will colonize them, if climate change will maintain the current trend and strength. The main question is if the colonization, especially that due to the extreme 2003 event, will be followed by a successful establishment at the new locations. We hypothesize that some natural-history traits of the processionary moth may allow a long-term persistence of the population. According to Gaston (2003), the establishment depends on availability of critical resources, viable effective population size, and climatic factors. We have seen that the host plant is not a limiting factor (Stastny et al. 2006); as the female deposits all her eggs in a single batch, in case of colony survival, there will be some tens of adults ready to persist in the same areas or establish in nearby zones. Moreover, the larvae can feed at low temperatures and this allows them to survive winters beyond the range edge (Battisti et al., 2005). A further element is the prolonged diapause at the pupal stage. The study of factors regulating the diapause is complex and numerous aspects remain unknown. Markalas (1989) identified as main factors the soil moisture and the fat reserves of insect at the time of pupation. The prolonged diapause, extended up to 5-7 years (Démolin 1969) or 9 years (Halperin 1990), is

an insurance against local extinction: even if the lethal temperatures or starvation kill all the colonies in a unfavourable year, other members of the same cohort can survive as diapausing pupae in the soil, and some of them may emerge in a favourable year. This behaviour is known for many insects (Hanski 1988, Menu et al. 2000) and it is an example of bet-hedging strategy.

## 5. Acknowledgements

We gratefully acknowledge support for this work from EU project Promoth QLK5-CT-2002-00852 and project BAUSINVE (Forest Service of Friuli Venezia Giulia). Cartographic maps and population data were kindly provided by Friuli Venezia Giulia District. Emiliano Buffo, Massimo Cappucci, and Daniel Zovi provided assistance in the field and the laboratory.

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