THAUMETOPOEA PROCESSIONEA IN THE NETHERLANDS: PRESENT STATUS AND MANAGEMENT PERSPECTIVES (LEPIDOPTERA: NOTODONTIDAE)

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Summary

Thaumetopoea processionea has become a serious problem at many localities in the Netherlands since its rediscovery in Reusel in 1987. Its caterpillars completely defoliated many oaks in the southernmost provinces Noord-Brabant and Limburg over the last three years. Urticating hairs of larvae of the species caused serious problems in man and animal. Information on biology, distribution, parasitoids, monitoring and control methods of the species is summarised from literature and own experiences.

INTRODUCTION

After more than a century the oak processionary caterpillar (*Thaumetopoea processionea* Linnaeus.) has re-entered the Dutch fauna in large numbers. Since its rediscovery in the vicinity of Reusel in 1987 (Stigter & Romeijn, 1992), the dispersal of this highly interesting species in the following years was impressive. Soon after the first report more records of larvae and adults were received from other parts of the Province of Noord-Brabant and a few years later the occurrence of the species was also reported from the Province of Limburg (Rutten, 1994). Caterpillars were found on nurseries in Noord-Brabant in 1995 (Stigter & Sonnemans, 1995; Stigter, 1996). Moreover, caterpillars were observed at many localities in the Province of Zeeland in 1996. It is striking that a species considered to be extinct (Lempke, 1976) has grown into such a nuisance over the past three years. The processionary caterpillar can be recognised by its enormous communal nests. The species is notorious for its thousands of urticating hairs and the severely allergic reactions they can cause in man and animal (Oudemans, 1900). Mainly because of the latter aspect the species has been called pest of the century by the press. Especially in 1996 feelings about *Thaumetopoea processionea* rose high in Brabant and Limburg in the course of the summer and because of its economic, ecological and health aspects the problem was as much a political as a policy issue.

In neighbouring countries the species did not remain unnoticed either. After being absent for many years the processionary caterpillar was rediscovered in Belgium in 1971 (Roskams, 1995) and seven years later the species was a nuisance in large parts of the Antwerp province. Also in many parts of Germany the species increased in numbers respectably since the beginning of the eighties (Bogenschütz et al., 1988) and it is expanding in an explosive manner in the Southwest of this country (Anonymus, 1996 a). A similar situation developed in the vicinity of Vienna, Austria (Tomiczek & Krehan, 1996) and parts of Hungary (Moraal, personal communication, 1996).

BIOLOGY AND DESCRIPTION

The processionary caterpillar mainly lives on common oak (*Quercus robur* Linnaeus) and has one generation a year (Ter Haar, 1924). Its flying time covers the period end July - half September. After copulation the eggs (30-200) are deposited by the females on the top ends of annual and biannual thin shoots mainly. The eggs are oblong and are laid in a hexagonal plate, mainly on south exposed parts of the shoots. The egg batches mostly consists of seven rows of eggs next to one another (Maksymov, 1978). There is a linear correlation between the length of the egg batch and the number of eggs (Dissescu & Ceianu, 1968). The eggs, which are covered with hairs of the female's abdomen, hibernate.

Usually the caterpillars appear at the end of April, synchronically to budding of the common oak. However, it is noteworthy that over the past two years (1995 and 1996) larvae hatched long before budding. In spite of the lack of food the first instar larvae were able to survive this period. They are orange-like in colour and live in small colonies. In early spring the larvae are mainly to be found at the lower parts of thicker branches. From their third larval stage the caterpillars possess their first urticating hairs, which develop on the eleventh dorsal segment. The hairs are about 0.1 - 0.13 mm in length. During the fourth larval stage urticating hairs are also present on the tenth segment and during the fifth and sixth stage they also develop on the fourth to ninth segment (Maksymov, 1978). Urticating hairs are easily removed by touching the caterpillars.

Fully grown caterpillars are bluish grey above the spiracular line and greenish blue at the lower part of that line. The body is covered with long white hairs planted in reddish warts. The dorsal part of the caterpillar consists of a number of dark-coloured velvet-like 'mirrors', which are densely covered with thousands of short urticating hairs. The head is blackish brown. Adults can grow to approximately 24 mm. During the first three larval stages the caterpillars do not yet produce a true nest, but they spin together some leaves and twigs under which they retreat during the day. Not until their fifth larval stage they develop their typical nests against trunks and thicker branches. Sometimes the nests are at the foot of the trunk. The nests consist of dense webs containing numerous exuviae, hairs and excrement's and are sometimes one and a half meters long and some decimetres wide, containing thousands of caterpillars. Nests of such a size are no exception, but in general the nests are not bigger than a rugbyball. At the beginning of the summer (1996) we observed that solitary smaller colonies of caterpillars united into larger ones, sometimes building enormous nests. Such behaviour was observed in large parts of Noord-Brabant and Limburg west of the river the Maas and at some localities in Zeeland. Apparently, such behaviour is induced by a distinct survival strategy: 'Together we are strong'. From the nests, where caterpillars stay during the day, they proceed in their characteristic procession to the tops of trees in search of food. After large-scale defoliation the caterpillars migrated to new food sources because of the lack of food. Since the beginning of our observations such migrating behaviour of the caterpillars occurred for the first time in large areas below the line Baarle-Nassau, Tilburg, Eindhoven-Valkenswaard in 1996. Whenever the species reaches its 'nuisance force' hardly any distinct nests are made. At this stage the caterpillars form a dense 'carpet' against branches and trunks.

The caterpillars pupate inside the nests. From webs and hairs the full grown caterpillars of *T. processionea* produce firm cocoons in which they pupate. Cocoons containing pupae are built close together, making the nest look like a bumble bee's one (Ter Haar, 1924). In accordance with Oudemans (1900) Spijkers got indications that pupae are able to overwinter. These indications will have to be investigated into detail in future years.

The forewings of the adults are yellowish-grey with three blackish-grey transverse lines and an indistinct dorsal patch. In females these dark transverse lines are often indistinct. The hindwings are whitish with diffuse grey postmedian fascia. Males are marked more clearly and they are often remarkably smaller than females. The dorsal part

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is, just like the forewings are, yellowish-grey in colour and in the female the last abdominal segment has a patch of dark short hair. The eggs are covered with these dark-coloured hairs. Specimens caught in a light trap in 1996 varied distinctively in size. Probably this was due to varying foodconditions, during their development. Apparently flights were terminated at a later stage in 1996, because two males were caught in a light trap on September 29.

DISTRIBUTION

Thaumetopoea occurs in South and Central Europe. According to Maksymov (1978) the species also occurs in England, but Carter (1984) explicitly mentions that it does not occur in this country. In various countries it regularly happens that the species temporarily develops high numbers, consequently becoming a nuisance, and causing significant damage to sylviculture (Maksymov, 1978).

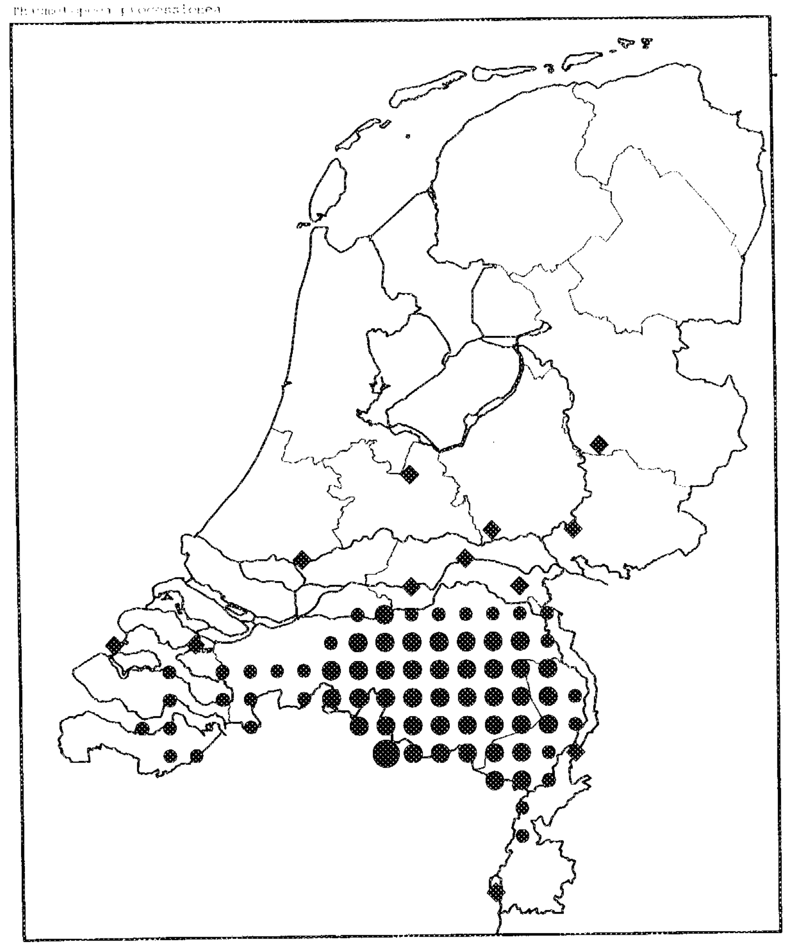

Figure 1. *Distribution of* Thaumetopoea processionea *in The Netherlands. Symbols: large (1987), middle (1988 - 1994), small (1995 -1996), diamond (males caught in light traps) (map prepared with ORDE).*

HOSTPLANTS

The main hostplant of the processionary caterpillar in the Netherlands and Belgium is common oak (*Quercus robur* Linnaeus). However, caterpillar colonies were also found on sessile oak (*Quecus petraea* (Mattuschka)) and to an increasing extent also on American oak (*Quercus rubra* Linnaeus). Carter (1984) mentions walnut (*Juglans regia* Linnaeus) as possible host plant and Gómez Bustillo (1978) refers to its occurrence on coniferous trees. In the Netherlands caterpillars were not only reported from oak but occasionally also from *Acacia*, *Betula*, *Crataegus*, *Fagus* and *Sorbus*. Reports from caterpillars feeding on those trees and developing into moths, however, are confined to beech.

OCCURRENCE IN THE NETHERLANDS AND BELGIUM

The Netherlands *Thaumetopoea processionea* lives near the Northwest limit of its distribution. In this country the processionary caterpillar is able to manifest itself over a shorter or longer period of time, depending on physical conditions.

Although definitely not a common species, in the Netherlands it was occasionally observed locally in high numbers in the nineteenth century. In literature reports can be found on large numbers of moths in the vicinity of 's-Hertogenbosch in 1859, mass occurrence in the summer of 1877, and observations in the vicinity of Nijmegen around 1878 (Lempke, 1937, 1959). It was not until 1987 that the species was again caught in Reusel (Noord-Brabant), where some tens of moths, were caught in a light-trap by H. Spijker (Lempke, 1989). Because of its occurrence in Belgium these catches were not entirely unexpected (Janssen, 1977; Janssen, 1977-1988). At the beginning of the seventies the processionary caterpillar was present at many localities in the Antwerp Kempen. In the Netherlands the species was present in large numbers at several localities below the line Breda-Tilburg-Eindhoven-Budel in 1991 (Stigter & Romeijn, 1992; Geraedts, 1996 a & b). From 1993 onwards the processionary caterpillar was a common appearance in this region and it was mentioned at regular intervals in the press and attention was paid to the item at several television programs. Especially in 1995 its dispersal was remarkably fast and at many localities numbers increased drastically. Small colonies were also observed locally in Zeeland and Zeeuwsch-Vlaanderen in 1996. Its main expansion, however, was turned eastwards (Limburg). Reports that the processionary caterpillar had advanced as far as the Amsterdam Vondelpark are however based on incorrect observations.

It is not clear whether re-colonisation of the processionary caterpillar will be permanent. In countries where the species is common, population fluctuate heavily. Weather conditions, food quality, food supply and the presence and abundance of natural enemies play an important role in this process (Speight & Wainhouse, 1989).

COURSE OF THE PLAGUE

Insect plagues are a natural phenomenon. Under the influence of local, often physical conditions, some species are able to increase their numbers drastically within a short span of time. Some good examples in the Netherlands are the nun moth (*Lymantria monacha* Linnaeus) and the gypsy moth (*Lymantria dispar* Linnaeus) (Doom, 1979; van Frankenhuyzen, 1981).

It is known that dry and warm periods are favourable for the larval development of the gypsy moth because the food quality of leaves during that stage is better as a result of a higher sugar content leading to a faster development. Consequently mortality is lower (Moraal, 1996).

Usually the development of a pest covers four phases; i.e.: two preliminary years, one eruptive year and the critical year of overpopulation (Doom, 1979). So far, apart from the decline of the plague, five clearly distinctive phases could be distinguished in the population development of *T. processionea*, with the exception of the decline of the plague.
The phases will be listed below.

Phase 0: Exploration

During this initial phase only males are observed. Preceding the observation of the first caterpillars, between 1900 and the beginning of the eighties, initially males were only observed incidentally at great intervals, but gradually the frequency of their occurrence increased. Under favourable weather conditions males of the processionary caterpillar may cover large distances. Flight distances of 50 - 100 kilometres are no exception. As a result, in present situation male moths can be found all over the Netherlands. Depending on the weather conditions and distance to breeding places, their numbers may vary from one to some tens of specimens. During this phase colonisation does not happen because no female dispersal is involved.

Characteristics during phase 0: no females or nests, some males

Phase 1: First infestation
Dispersing females colonise new sites. Whenever the females hatch, they are unwieldy and heavy as a result of which their flying abilities are limited. Copulation often takes place within or on the nest from which they hatch (Eckstein, 1915) and the first egg batches are deposited at or in the direct vicinity of this nest. These egg batches are large, varying in size from approximately 100 to 200 eggs (Stigter & Das, 1996). According to research carried out by a Benelux working group Noctuidae showed that the distances covered by dispersing females of *T. processionea* are between five and twenty kilometres per year. Those distances, however, are highly dependent on the weather conditions during the flying period and to a certain extent also on to the quality and structure of the habitat to be crossed. One single female is able to colonise an entire new area. The following year a number of small nests, often not bigger than a tennisball, is formed. However, it is assumed that in some cases colonisation occurred by larger numbers of females, which were passively dispersed by extreme weather conditions such as thunder storms and other air currents by which larger distances could be bridged. Such a situation occurred in Waalwijk in 1991.

Usually, the centre of the infestation is surrounded by an approximately 1-20 kilometre wide zone in which nests are relatively small and rare. Only a few small nests can be found in those stands by carefully inspecting a lot of trees. Most nests will remain unnoticed by laymen during that stage, and many males and only a few females may be caught in light traps. Usually this phase is rather short (one to two years).

In many instances phase two will start within two years after the beginning of the colonisation process and during this phase still no mention is made on damage nor nuisance.

Characteristics phase 1: Spread occurrence of small nests, no damage or nuisance.

Phase 2: Colonisation

After foundation the population can expand. From the colonised tree its surroundings will soon be infested. The first years after settling the nests will mostly be small. However, larger nests can develop locally within two to three years. At the end of this phase smaller or largerer nests can be found on almost every oak tree. However, at this stage mass damage by defoliation is not yet the case, but here and there some branches may be defoliated. Different groups of larvae on American oak assemble into a single large one and form one large communal nest. The caterpillars march in line between feeding sites and their communal nest. On other trees communal nests are not yet present. During this period people allergic to urticating hairs start to suffer from irritation. The numbers of males caught in light traps increase drastically. Some hundreds of males and some tens of females may caught per night.

Characteristics phase 2: One or some small clearly recognisable nests on avenue trees. Little defoliation, no infestation of forest areas. People allergic to urticating hairs suffer from irritation. Processions mainly consist of one single line and are not voluminous.

Phase 3: Plague stage

During this period thousands of caterpillars are present on almost every tree and in avenue trees tens even of thousands of caterpillars can be present per oak. Nests are hardly or no longer produced during this stage. The trees are often covered by a thick carpet-like layer of caterpillars. Their behaviour is restless and during the day they move continuously. The processions are wide and 30 to 80 larvae can march next to each other. Spontaneously large circular processions develop which seem to be moving continuously. Moreover, large-scale defoliation takes place in oak stands, including midsummer growth and third fresh shoots. Lack of food resulting from such defoliation forces the caterpillars to search for other food sources (migrating phase). Consequently, they also attack other trees and shrubs. Now a classic plague is a fact. However, starvation of larvae is still minimal, but because of the lack of food part of the caterpillars is showing dwarfism. The plague reaches its height and nuisance is at its peak level. People sensitive too urticating hairs suffer from irritated skin (itching), burning eyes and mucous membranes, even at several kilometres distance from the centres of infestation. The need for drastic control measures is increasing. Mass flights of thousands of moths can now be observed.

Characteristics phase 3: Complete defoliation of oaks along avenues and in woods, mass and continuous daily as well as nocturnal procession, mass-flights of moths. Drift of urticating hairs causing irritation to a high extent.

Phase 4: Collapse

Thousands of larvae hatch from last year's eggs, causing enormous damage. Halfway of their development (L3 - L4) trees already become defoliated and the caterpillars show disturbed behaviour. Because of the lack of food and the disturbance of their feeding behaviour the mortality rate increases. Moreover, surviving caterpillars are heavily parasitized by an abundance of natural enemies such as tachinid flies and ichneumon wasps. The population collapses and the oak trees recover by the development of new foliage of the midsummer growth. Nuisance will be less compared to the former phase because juveniles possess less urticating hairs than older ones. Nevertheless, their mass-occurrence may still cause nuisance, especially in June.

So far, this phase was not yet reached in the province of Noord-Brabant during the summer of 1996. However, it is expected that phase 4 will become reality in 1997, at least South of Hilvarenbeek, the "old centre" of the current plague.

Characteristics phase 4: Mass defoliation of trees along roads and in woods followed by recovery. Mass mortality among juveniles. Large numbers of natural enemies. No or hardly any moths.

DANGER TO MAN

Caterpillars of a number of moth species may present danger to man. Problems caused by caterpillars of the brown-tail moth (*Euproctis chrysorrhoea* Linnaeus) have been known in the Netherlands for many years, especially to people recreating on the Wadden Islands and the isles of the provinces Zuid-Holland and Zeeland in the south-western part of the country. Lately in certain areas the processionary caterpillar can be added to the species causing this kind of nuisance, even to a higher extent than other species. In the processionary caterpillar the hazards are caused by the many thousands of urticating hairs (approximately 0.1 - 0.2 mm long) developing on the larvae from the third stage onwards. The urticating hairs are like small arrows with tiny barbs. They are easily released by touching the caterpillar or their nests and they can float on air. Because of their shape the hairs can easily penetrate the superficial layers of the skin and also eyes and upper bronchial tubes can become irritated by floating hairs. Moreover, hairs can be carried away on the wind passively, for instance after pruning activities and turbulence caused by traffic movements hairs can be spread over large distances. Exposure to urticating hairs mainly takes place throughout inhaling or skin contact and to a lesser extent through direct contact with the caterpillars. After penetrating the urticating hairs can cause small painful little wounds. Moreover, the hairs can secrete a kind of 'poison' in the form of an non-human protein, *thaumetopoiene*, activating a number of enzymes, such as phospholipase A. This results in the production and release of histamine and probably other vasoactive (vasodilatating) substances (Robles, 1996). Because there is no straight-forward indication of specific defence, it cannot be proven this involves a specific repellent (no specific IgE), and therefor the clinical symptoms, which are rather identical to allergic reactions, are called pseudo-allergic reactions (Jans, 1996). Experiences of recent years show that at renewed contact or continuous exposure of the skin the reactions can become stronger. Reactions occurring directly or indirectly after contact with urticating hairs are diverse. Apart from specific complaints such as irritation of the skin, eyes and upper bronchial tubes, more common complaints can occur which manifest as follows.

After skin contact a painful, red irritation of the skin and strong itching may develop within eight hours. The skin shows lumps and even fluid-filled vesicles. Mostly these complaints disappear within two weeks, provided no renewed contact takes place. In case the urticating hairs penetrate the eyes they cause painful irritation and swelling, as well as redness and itching within one to four hours. Hairs sometimes penetrate deeper into the eye where they can cause a serious lumpy inflammation.

After being inhaled urticating hairs can cause irritation or inflammation of the mucous membrane of the upper bronchial tubes (nose, throat and bronchial tubes). Complaints are identical to cara in some cases whereas in other ones a painful throat and difficulties at swallowing occur. In some cases cara-like symptoms and pseudo-allergic bronchitis occur. There are people who develop fever and general depression after contact with urticating hairs. Contrary to Ter Haar (1924) reporting that there is a risk of deadly injuries after a mass infection, Jans (1996) has stated that this is not likely to happen these days.

RESEARCH

Field trials to find the most effective control method of the processionary caterpillar were carried out in 1996. Larvae of *Thaumetopoea processionea* often cause nuisance in situations where spraying chemical compounds are not appropriate because of technical as well as ecological objections. However, alternatively some compounds can be applied by means of micro-injection or implantation into the xylem of the trees. The compound thus applied spreads with the sap circulation through the entire crown and may be effective against insects and mites eating or sucking the leaves.

Field trials were carried out by injecting seven year old avenue trees of common oak (*Q. robur* L.) with either Orthene, Vertimec or a biological compound at Oerle in Noord-Brabant at the end of May. The biological compound used, the so-called Neem seed extract is a naturally derived product from the seeds of the Neem tree (*Azadirachta indica*). Implantation was carried out with Acecap capsules (Anonymus, 1996 b). Furthermore, trials were carried out a foliar spray of *Bacillus thuringiensis* var. *kurstaki* (Btk). At the time of the experiments the caterpillars of *T. processionea* were in their second and third larval stage.

About a week after treatment the objects injected with Orthene and Vertimec clearly showed effects and even no more caterpillars were present in the highest dosage of Orthene. Three different treatments with Neem seed extract did not yield uniform results and the number of trees that were treated (four per treatment) proved to be too limited for a reliable evaluation. After more than a week foliar spraying with Biobit (Btk) yielded a mortality rate of over 90%. It appeared that control of the caterpillars has to be performed during their right larval stage in order to obtain an optimal efficacy of the tested compounds. During their first larval stage the caterpillars consume very little, so in any case they should not be controlled at that stage (Kortenhoff & Wiegers, 1996). With respect to managing the caterpillars nuisance to man it is important to control them - whenever necessary - before the fourth larval stage is reached and still no urticating hairs are present. The results from the trials have been summarised in table 1.

Tabel 1. *Results of treatments (injections, implantations and foliar-sprayings) against processionary caterpillar in 1996. N: number of treated trees (all trees with caterpillars); DB: date of treatment; NE: number of trees with caterpillars at the end of the experiment. Date 0: May 22 (May 28 for Neem 0,08 and 0,15); date 1: June 3; date 2: June 20*

			Number of caterpillars (mean ± standard error)			
			before treatment	after treatment		
Treatment	N	DB	date 0	date 1	date 2	NE
Untreated	15	23/5	286 (± 104,3)	405 (± 144,7)	374 (± 185,2)	15
Orthene [2]	15	23/5	467 (± 203,4)	49 (± 43,6)	0	0
Orthene [4]	15	23/5	356 (± 207,0)	0	0	0
Acecap	15	24/5	377 (± 142,9)	219 (± 116,1)	10	3
Vertimec	15	30/5	244 (± 74,2)	14 (± 15,5)	5	2
Neemolie	4	23/5	313 (± 316,1)	497 (± 532,3)	131	3
Neem 0,08	4	28/5	235 (± 252,4)	104 (± 181,4)	38 (± 46,6)	4
Neem 0,15	4	28/5	340 (± 356,0)	862 (± 827,0)	325 (± 308,9)	4
Biobit [lv]	15	30/5	384 (± 351,0)	25 (± 34,9)	0	0
Biobit [hv]	15	30/5	328 (± 276,6)	45 (± 46,2)	48 (± 49,9)	4

Orthene 2 : twofold dosis
Orthene 4 : fourfold dosis
Biobit lv : low volume = 2 litre water per tree
Biobit hv : high volume = 5 litre water per tree

Research into the applicability of a pheromone

Pheromones can be used as sex attractants for the control of insect pests. In various cultures such as cotton in the tropics and fruit cultures in parts of Europe, this technique is successfully applied on a larger scale. The principle behind this method is disturbance of mating. Through vaporisation of a certain amount of a pheromone in the respective area, males are no longer able to find females and to mate , thus limiting the number of offspring. On an experimental scale research into the possible use of pheromones against the processionary caterpillar was carried out in 1996. Results from these first experiments, however, were disappointing. This was mainly caused by the fact that the specific pheromone of *T. processionea* was not available. For that reason, the Research Institute for Plant Protection (IPO-DLO) and the Plant Protection Service (PD) carried out a preliminary trail with the pheromone of the closely related *T. pityocampa*. From literature it was known that *T. processionea* would also respond to this pheromone. In practice this was unfortunately not the case. Identification of the pheromone and additional research is necessary to further developing this method.

Parasitoids

Our observations showed that the processionary caterpillar can be parasitized by various species of tachinid flies (Diptera: Tachinidae), which kill large numbers of caterpillars. In 1996 the tachinid *Pales processionea* (Ratzeburg) (= *Pales opulenta* (Herting)) was bred from several samples. This species is monophagous and depends on the processionary caterpillar (Herting, 1990). For food the tachinid flies lay their micro-eggs on the leaves of oak and enter the caterpillar's body with the leaves eaten. Inside the larvae they soon hatch and the maggots can finish the job. There is very little know about the life history and the parasitizing strategy of this tachinid fly. During the flight period (July-August) of moths of the processionary caterpillar there is second generation of *P. processionea*. It is possible that the flies of this second generation deposit their eggs on the newly laid egg-batches of the moths and overwinter. When the young caterpillars hatch in spring by eating their way out through the egg shell, they also may consume these tachinid eggs.
At the end of the eighties the most common Tachinid parasite of *T. processionea* found in the South of Germany was *Pales processionea* (Ratzeburg). Bogenschütz (1988) reported this species be parasitize up to about 20%. In The Netherlands comparable parasitizing levels were found in 1996 (Zeegers, in litt. 1996).

In 1994 a second tachinid fly was reared from the pupae of the processionary caterpillar: *Carcelia iliaca* (Ratzeburg) (= *Carcelia processionea* (non Ratzeburg): auct.) (de Goffau, 1995). This species lives also monophagous on *T. processionea*. According to Maksymov (1978) *C. iliaca* is parasitizing on the third and fourth larval stage of the caterpillar. Especially this tachinid fly lays their macro-type eggs on the body of its host. Their is one generation a year. The fully grown maggots hibernate inside the cocoons of its host and the flies of the new generation appear in April and May of the following year. During the period of May and June, egglaying flies can easily be found on the nests of the processionary caterpillar.

Apart from tachinid flies also a number of species of ichneumon wasps were reared and also caught from caterpillars nests. Remarkable was the behaviour of *Pimpla turionellae* (Linnaeus). The wasps of this species were observed flying in large numbers around nests at the foot of the trunk. *Pimpla turionella* is a species parasitizing pupae of a number of different moths. In addition to *Pimpla* species two specimens of another ichneumoid species, *Theronia atalantae* (Poda), were reared from a caterpillars nest at Veldhoven. This species in turn is a hyperparasite of pupae of *Pimpla* species (Zwakhals, in litt. 1996).

Unfortunately, data on the degree of parasitism in field populations of *T. processionea* are very limited. No doubt this is caused by the risk of being exposed to they urticating hairs. Nevertheless, the first author started a small-scale rearing experiment 1996. During these experiments he found 20-30% parasitizing, mainly caused by Tachinids. From practice, however, there are some reports on caterpillars' nests that were parasitized completely.

One predator, a groundbeetle (*Calasoma sycophanta* Linnaeus) is known to be a major enemy of the processionary caterpillar (Ter Haar, 1924; Ferrero, 1985). In 1995 it was reported in the press that this extremely rare beetle re-occurred in the Netherlands. Further investigations proved that this was not the case and up till no recent records of this species are known.

CONTROL MEASURES

In accordance with the familiar scenario (phase 4) the plague is expected to collapse in due course. In some areas this may already happen in 1997. However, as the nuisance caused by the caterpillars can be respectable, it is impossible to wait for the natural process to happen. Therefore, local control measures in densely populated areas will sometimes be necessary. Nuisance by the processionary caterpillar mainly occurs under circumstances where foliar sprayings with chemical compounds are impossible because of technical and environmental objections. It is obvious that control measures should cause the least possible side-effects to man and environment. In order to investigate the necessity of control measures a decision model has been designed, helping those responsible for the management of oak stands and local politicians to determine whether control is necessary. Nature Reserves and woods are excluded from such control measures, because these areas serve as ecological buffers. However, within a short span of time recolonisation of insects and mites can take place from these excluded areas to those areas where control measures were carried out. In case the nuisance is obvious, Nature Reserve and woods can be closed to the public temporarily. The most important parameters in the model are: kind of habitat, average number of egg batches on twenty meter shoot length, and height of the trees. The model enables owners and managers of oak stands to properly decide on measures that bear no risk to nature and environment. Possible control measures are:

I. Mechanical

Mechanical methods involved exhausting and burning caterpillars and entire nests. In recent years a lot of experience was gained with this method. At the initial stage of the population a household vacuum cleaner was used, but later on an industrial vacuum cleaner was used whereas more recently vacuum manure tanks and piston type pumps have been used. The method is effective, selective and harmless to man and environment. However, the result can be insufficient on taller trees because new colonies of caterpillars continue to colonise the lower part of the trunk from the crown. In practice exhausting caterpillars and nests in combination with burning them with a flame-thrower turned out to be very effective in plantations with a tree-height of three to fifteen meters. In 1997 it will be further investigated whether the results of these methods can be optimised.

II. Foliar spraying with a biological compound

The biological compound *Bacillus thuringiensis* var. *kurstaki* (Btk) has been on the market for some years in the Netherlands for use in sylviculture and common green. The compound is selective against caterpillars and its toxicity to mammals (including man) is low, whereas it has hardly any effect on natural enemies. From research carried out in 1996 it has been concluded that the compound has an excellent effect on second- and third-stage caterpillars of *T. processionea* (Kortenhoff & Wiegers, 1996).

III. Foliar spraying with chemical insecticides

In the Netherlands two compounds have been authorised to be used in common green and sylviculture. These compounds are diflubenzuron and teflubenzuron. Both compounds are often used for the control of caterpillars in agriculture as well as horticulture. They belong to the group of selective crop protection compounds sparing natural enemies as much as possible. The compounds act as a stomach poison and have to be consumed by the caterpillars. Its efficacy is based on deregulating the moulting mechanism, causing the caterpillars to die soon after application. In many European regions diflubenzuron is applied to control caterpillar plagues in sylviculture. However, large-scale application of such compounds in the Netherlands is considered to be undesirable. In exceptional cases only, the decision model presented recommends application of both compounds in non-urban areas with a high infection rate (on average more than five egg batches per twenty meters shoot length) and a tree height between fifteen and twenty five meters.

IV. Micro-injection with an insecticide

Since 1994, an injection compound has been authorised for use in the Netherlands. It involves a method that was developed in this country at the beginning of the eighties, by which an insecticide is injected into the xylem of the tree. It appeared that in this way nuisance causing insects and mites can be controlled effectively in urban areas. The injected compound is transported to the leaves of the tree by its sap flow. Whenever the caterpillars consume the leaves their nervous system is damaged and they will die very soon afterwards. This method has been developed especially for application in densely populated (urban) areas, and it is also suitable for application in trees with a height of over twenty five meters, because foliar sprayings from ground level are irresponsible from a technical point of view. Large-scale use of this method, however, is undesirable, because the compound works against a broad spectrum of non-target leaf-consuming and sucking insects and mites.

DISCUSSION

Populations of *Thaumetopoea processionea* were probably able to increase gradually and practically unnoticed in the Netherlands since 1987. Its expansion mostly remained unnoticed because initially no defoliation occurred and the first nests were tiny. The causes of its mass reproduction during the last years are not clear, but the favourable weather conditions of the last decades and the lack of sufficient natural enemies definitely contributed to its enormous increase. It has to be admitted that the large number of recently planted oak stands played a major role in many parts of Brabant and Limburg. Because of their exposure and location on the higher sandy soils these oak stands are the ideal environment and food source for the processionary caterpillar. From this point of view it is important to change to mixed plantations in the future as much as possible.

As the surrounding arable land is intensively cultivated and the crops are often sprayed, only small natural fragments remain, where natural enemies can neither reproduce nor survive. Moreover, avenue trees provide a landscape with linear elements along which, the moths of *T. processionea* and can easily disperse. Initially, dispersal happens so rapid, that the natural enemies cannot keep in pace, but in due course, however, the species will be 'overtaken' by its predators. In the past this already happened in the Netherlands a few times before.

Nevertheless, for many years the species now has been a nuisance in Belgium, which make it very tricky to forecast its future development in the Netherlands. However, with respect to the development of the plague in the Reusel-Hilvarenbeek area, lack of food during the early summer of the coming year might become the species' worst enemy, resulting in a high mortality rate of the juveniles. In that case the remaining population maybe controlled effectively by an abundance of parasites. Therefore, it is likely that even the present population will not remain a problem in the years to come.

Final conclusions

For a long time *T. processionea* was known to be a very rare Notodontidae and in various collections in the Netherlands only some tens of dried specimens are present from the period in which the processionary caterpillar occurred in abundance. Lempke (1976) took it one step further and considered the species to be extinct in Belgium and The Netherlands. After the first reports on the processionary caterpillar in 1987 it was tried to keep its localities a secret in order to prevent collectors to catch all specimens. Afterward the species became the most common Notodontidae in parts of Belgium and the southernmost provinces of The Netherlands. Almost 5,000 moths were caught at light traps within a few hours in Hilvarenbeek on August 20, 1996 and two days afterwards almost 4,000!

Based on experiences in this country as well as abroad it is expected that the species will diminish to a very low level within a couple of years. It is not or hardly possible to take action during the initial colonisation process (phases zero and one) on the basis of present knowledge. There are hardly any nests so efficient control is almost impossible. At the start of phase two mechanical control is effective and can yield sufficient success in plantations with a tree height up to fifteen meters. Chemical control in order to prevent the caterpillars from becoming a nuisance should be well-considered, also in the interest of nature with its often complicated and very valuable ecosystems. However, many people living in the centres of the infested areas have lost their patience and they no longer believe that nature itself will solve the problem. Many owners and managers of oak stands therefore consider to use insecticides. Control with broadworking insecticides would be disastrous for many other insects, which together with their parasites and predators are part of the very complicated natural ecosystem of oak. It is expected that the plague can be managed sufficiently by means of a minimal use of selective crop protection compounds under nuisance conditions and at places with an increased risk to man and animal. However, rapid re-colonisation from untreated areas as Nature reserves may occur. Consequently, the combination of a monitoring programme and an adequate decision model is indispensable to keep the oak processionary caterpillar under control and - if necessary (start of phase two) - to act against it!

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