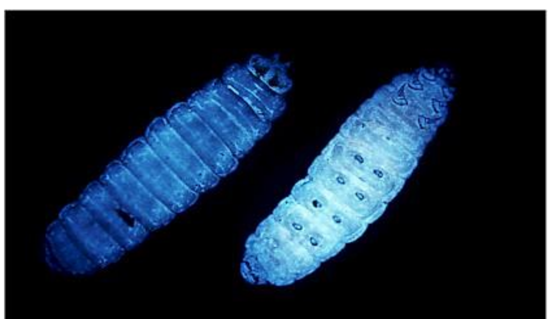
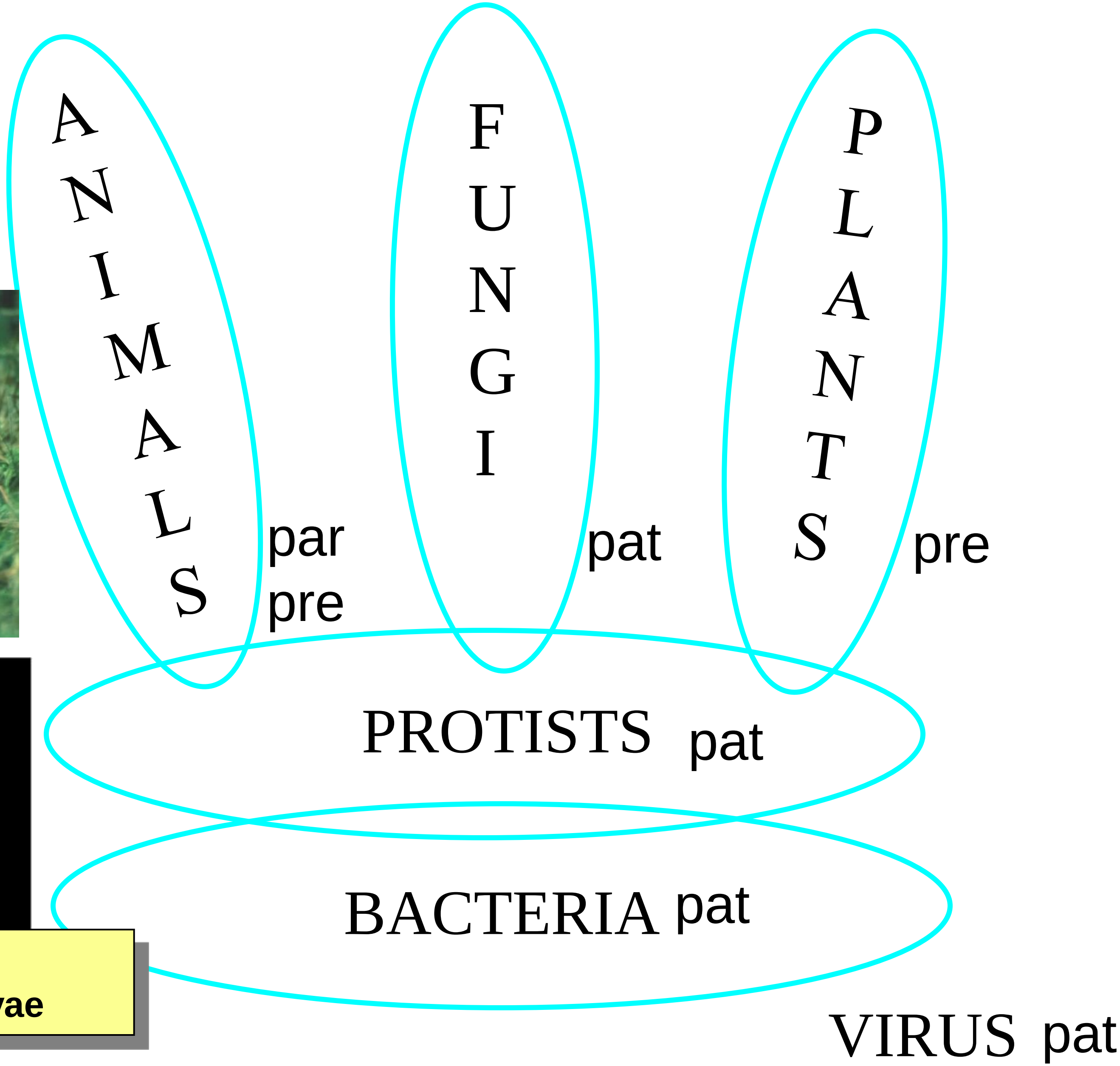
| | |
|---|---|
| **Course contents:** | **1. Insect abundance and distribution: species-area relationships. Diversity of forest insects in relation to tree species, feeding guilds, and to the history of forest stands. Invasive species in forestry: definitions, concepts, and applications.**<br><br>**2. Classification of the outbreaks and related examples. Population dynamics: demographic growth versus mortality. Population cycles in different types of forest ecosystems.**<br><br>**3. Ecological factors affecting the populations of forest insects. Effects of climate and temperature, including climate change. Mechanisms of resistance developed by the host plants and adaptations of the insects. Role of natural enemies in population regulation.**<br><br>**4. Principles of integrated pest managements based on the knowledge of the insect ecology. Prevention, direct and indirect control, economic assessment of costs and benefits of IPM in forestry.** |

# Natural enemies: predators, parasitoids, pathogens



**Fluorescent *Photorhabdus* bacteria inside *Galleria* larvae**



# Population regulation in nature

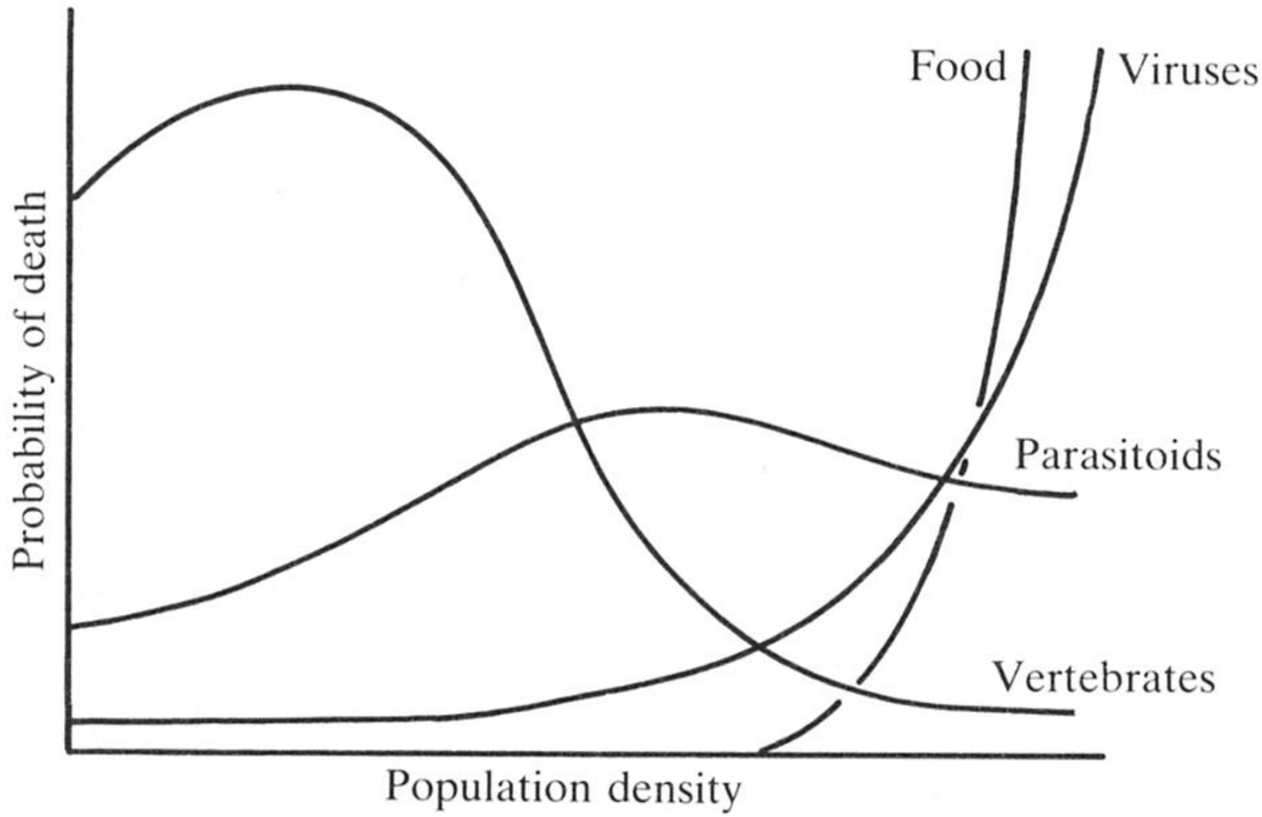



FIG. 7.1. The effect of population density of *Lymantria dispar* on the probability of death from vertebrate predators, insect parasitoids, viral pathogens, and food shortage (from Berryman *et al*. 1987, after Campbell 1975).

## Gypsy moth and processionary moth examples (slides 10-19 and 36-42 of section 2)

- **Enemy richness**
- **Mortality factors**
- **Sequential action**
- **Competition**
- **Density dependence**
- **Allee effect**

# Enemy richness in the oak processionary moth

**Table 2.4** List of insect parasitoids of developmental stages of *T. processionea*, with an indication of their activity in Rumania

| Stage | Parasitoid species | Maximum mortality (%) |
|---|---|---|
| Egg | *Anastatus bifasciatus* (Hym., Eupelmidae) | 15 |
| | *Ooencyrtus masii* (Hym., Encyrtidae) | |
| | *Pleurotropis pyrgo* (Hym., Eulophidae) | |
| | *Trichogramma embryophagum* (Hym., Trichogrammatidae) | |
| Larva/pupa | *Blondelia nigripes* (Dipt., Tachinidae) | |
| | *Carcelia processioneae* (Dipt., Tachinidae) | 51 |
| | *Compsilura concinnata* (Dipt., Tachinidae) | 38 |
| | *Eucarcelia excisa* (Dipt., Tachinidae) | |
| | *Masicera cuculliae* (Dipt., Tachinidae) | |
| | *Pales pavida* (Dipt., Tachinidae) | |
| | *Phorocera agilis* (Dipt., Tachinidae) | |
| | *Phorocera assimilis* (Dipt., Tachinidae) | |
| | *Phryxe semicaudata* (Dipt., Tachinidae) | |
| | *Phryxe vulgaris* (Dipt., Tachinidae) | |
| | *Winthemia speciosa* (Dipt., Tachinidae) | |
| | *Zenillia dolosa* (Dipt., Tachinidae) | |
| | *Zenillia libatrix* (Dipt., Tachinidae) | |
| | *Apanteles ruficrus* (Hym. Braconidae) | |
| | *Meteorus spp*. (Hym. Braconidae) | 13 |
| | *Rogas geniculator* (Hym. Braconidae) | |
| | *Pteromalus puparum* (Hym., Chalcididae) | |
| | *Angitia vestigialis* (Hym. Ichneumonidae) | |
| | *Cubocephalus germari* (Hym. Ichneumonidae) | |
| | *Phobocampe pulchella* (Hym. Ichneumonidae) | |
| | *Pimpla spp*. (Hym. Ichneumonidae) | |
| | *Schizoloma amictum* (Hym. Ichneumonidae) | |
| | *Theronia atalantae* (Hym. Ichneumonidae) | |

# Enemy richness in the pine processionary moth

**Table 2.1** List of insect parasitoids of developmental stages of *T. pityocampa*. Periods of activity and maximum values or estimates of the mortality rate based on 20 years of observations in Algeria (1983–2003) in various forest types are also given (Zamoum et al. 2006). No parasitoids are known for the adult stage

| Stage | Parasitoid species | Period of activity (month) | Maximum mortality (%) |
|---|---|---|---|
| Egg | *Baryscapus servadeii* (Hym., Eulophidae) | VI–IX | 20 |
| | *Ooencyrtus pityocampae* (Hym., Encyrtidae) | IV–VI and VII–X | 8 |
| | *Anastatus bifasciatus* (Hym., Eupelmidae) | VI and IX | 0.5 |
| | *Trichogramma embryophagum* (Hym., Trichogrammatidae) | V–VI and VII | 0.1 |
| | *Pediobius bruchicida* (Hym., Eulophidae) | III and IV | 0.03 |
| | *Eupelmus (Macroneura) seculata* (Hym., Eulophidae) | V–VI–VII | 0.1 |
| | *Eupelmus (Macroneura)* sp. (Hym., Eulophidae) | V–VI–VII | 1 |
| | *Eupelmus (Macroneura) vesicularis* (Hym., Eulophidae) | Not available | Not available |
| Larva | *Phryxe caudata* (Dipt., Tachinidae) | IX–X and II–III–IV | 10 |
| | *Compsilura concinnata* (Dipt., Tachinidae) | IV–V | 7 |
| | *Exorista segregata* (Dipt., Tachinidae) | IV | 5 |
| | *Erigorgus femorator* (Hym., Ichneumonidae) | I–II–III | 17 |
| | *Cotesia vestalis* (Hym., Braconidae) | IX–X–XI | 4 |
| | *Pteromalus chrysos* (Hym., Chalcididae) | IV | Not available |
| | *Dibrachys lignicola* (Hym., Chalcididae) | IV | Not available |
| Pupa | *Villa brunnea* (Dipt., Bombyliidae) | VIII–IX | 35 |
| | *Coelichneumon rudis* (Hym., Ichneumonidae) | V–VI | 5 |
| | *Conomorium pityocampae* (Hym., Pteromalidae) | VI–VI | 0.1 |

**Table 2.2** List of predators of developmental stages of *T. pityocampa*. Periods of activity and estimates of the mortality rate based on 20 years of observations in Algeria (1983–2003) in various forest types are also given (Zamoum et al. 2006)

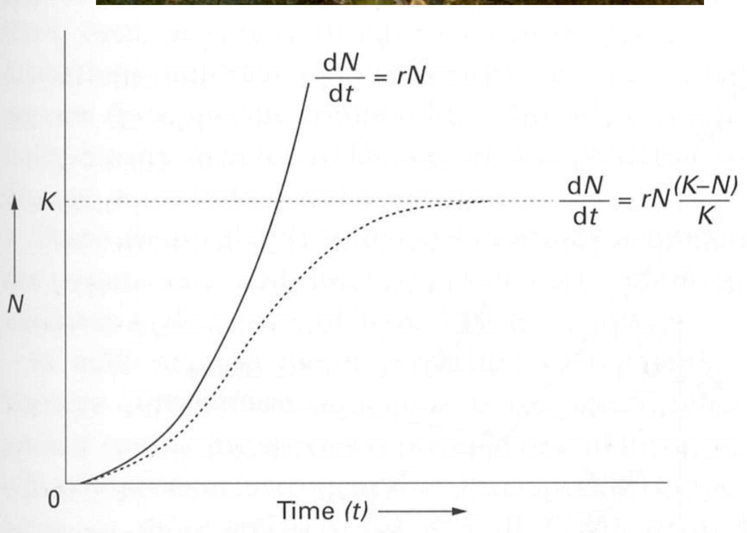
| Stage | Species | Period of activity (month) | Mortality |
|---|---|---|---|
| Egg | Orthoptera | VIII | Medium |
| Larva | *Xanthandrus comtus* (Dipt., Syrphide) | X–XI | Medium |
| | *Scolopendra* sp. (Myriapoda) | IV–VII | Low |
| | *Sphodromantis* sp. (Mantidae) | IX | Low |
| | *Coccinella septempunctata* (Coccinellidae) | IX–X | Low |
| | *Formica rufa* (Hym. Formicidae) | Not available | Not available |
| | *Linepithema humile* (Hym., Formicidae) | Not available | Not available |
| | *Calosoma sycophanta* (Col. Carabidae) | Not available | Not available |
| | *Parus spp.* (Paridae) | III–IV | Low |
| Pupa | *Upupa epops* (Aves, Upupidae) | V–VI | Low |
| | *Sus scrofa* (Mammalia, Suidae) | Not available | Not available |
| Adult | *Vespa germanica* (Hym., Vespidae) | VII–IX | Low |
| | *Crematogaster scutellaris* (Hym., Formicidae) | VII–IX | Low |
| | *Leptothorax recedens* (Hym., Formicidae) | VII–IX | Low |
| | *Paraechinus* sp. (Erinaceidae) | VI–IX | Medium |

**Table 2.3** List of pathogens of developmental stages of *T. pityocampa*. Estimates of the mortality rate based on 20 years of observations in Algeria (1983–2003) in various forest types are also given (Zamoum et al. 2006)

| Stage | Species | Mortality |
|---|---|---|
| Egg | Unidentified fungus | Low |
| Larva | *Smithiavirus pityocampae* (Virus) | up to 80 % |
| | *Borrelina pityocampae* (Virus) | up to 80 % |
| | *Clostridium* sp. (Bacteria) | Low |
| | *Beauveria bassiana* (Fungus) | 5–20 % |
| | Nematode | Not available |
| Pupa | *Beauveria bassiana* (Fungus) | 5–20 % |
| | *Poecilomyces fumoso-roseus* (Fungus) | Low |
| | *Metarrhizium anisopliae* (Fungus) | Low |
| | *Verticillium* sp. (Fungus) | Low |

$N_t = \lambda N_o$ unlimited growth, $\lambda$ per capita growth rate

| | |
|---|---|
| Initial population size | = 20 |
| Number of females | = 10 |
| Fecundity (average) | = 150 |
| Next generation | = 10 × 150 |
| | = 1500 |
| Abiotic mortality | = 89% |
| Survival | = 11% |
| | = 1500 × 0.11 |
| | = 165 |
| Per capita rate of increase, $\lambda$ | $= N_{t+1}/N_t$ |
| | = 165/20 |
| | = 8.25 |
| Population size in 35 years | $= \lambda^{35} \times N_0$ |
| | $= 8^{35} \times 20$ |
| | = 811 000 000 000 000 000 000 000 000 000 000 moths |




Verhulst's logistic function

K carrying capacity

# Lotka & Volterra competition model

$$\frac{dN_1}{dt} = r_1 N_1 \left[ \frac{(K_1 - N_1 - \alpha N_2)}{K_1} \right]$$

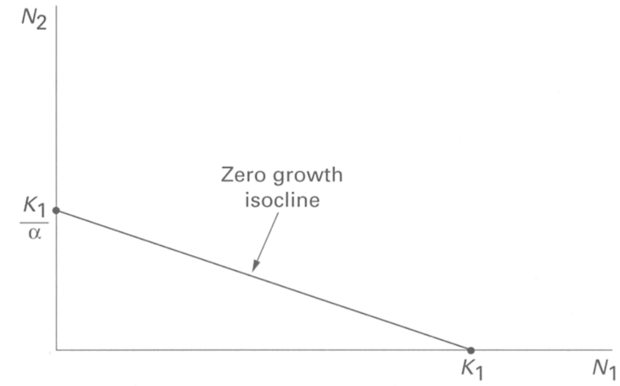
and

$$\frac{dN_2}{dt} = r_2 N_2 \left[ \frac{(K_2 - N_2 - \beta N_1)}{K_2} \right].$$

se dN/dt = 0

$N_1 = K_1 - \alpha N_2$

$N_2 = K_2 - \beta N_1$




# Biological control types

**Table 7.2.** *The ways in which natural enemies may be used in biological control programmes against insects* (*see text*)

| Host or prey | Natural enemy | |
|---|---|---|
| | Introduced | Native |
| Introduced | Classical biological control | Fortuitous control |
| Native | Fortuitous control<br>From related hosts<br>'Adaptation importation' | Augmentation<br>Conservation<br>Inundation<br>Intra-areal transfer |

# Economic threshold and enemy release

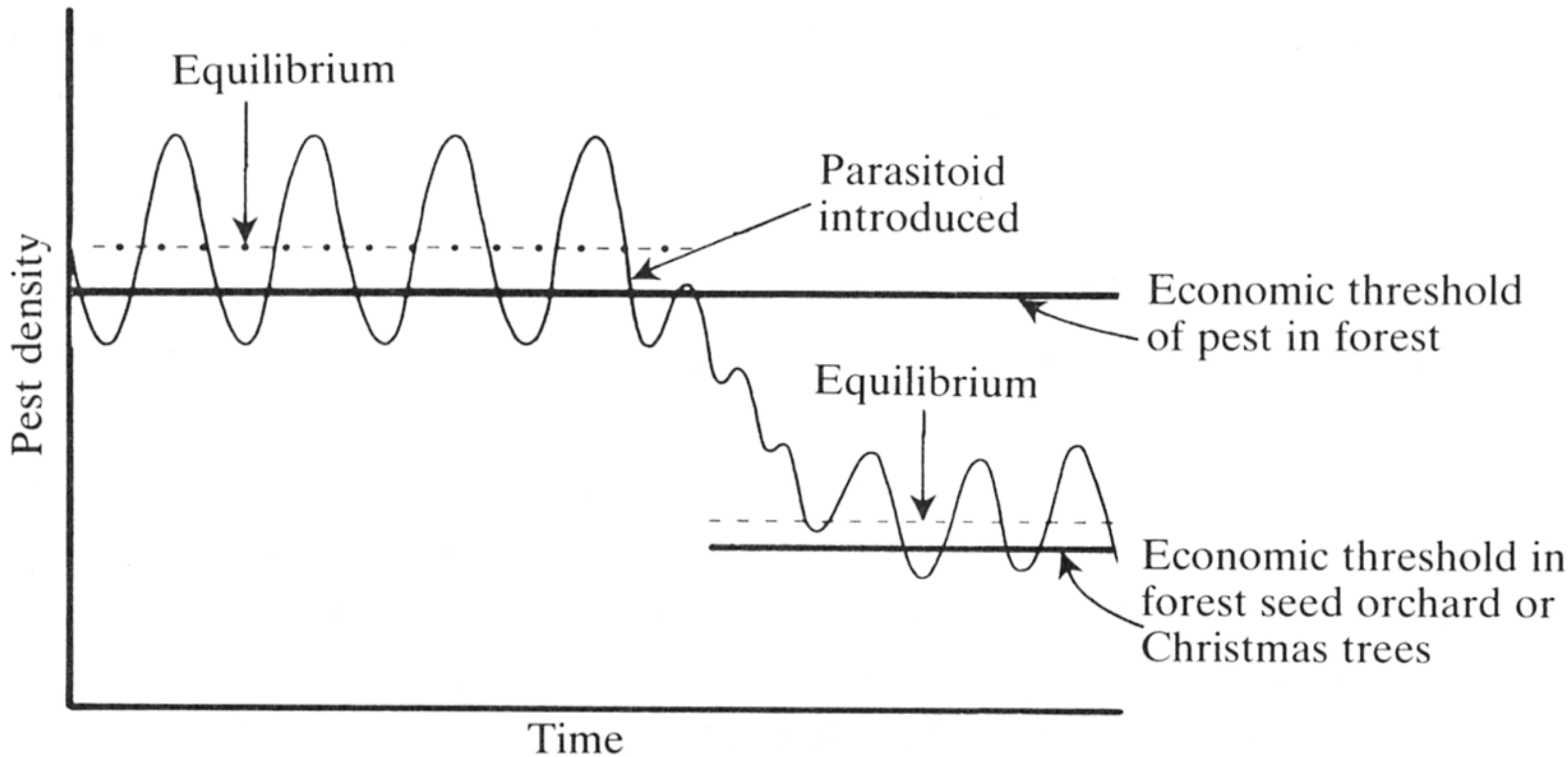



FIG. 7.2. A hypothetical example of biological control in relation to the economic threshold in a forest and in specialized forest crops. Control is achieved in the forest but not in the other crops where the economic threshold is lower (after Smith and van den Bosch 1967).

# A case study: the natural enemies of the pine processionary moth *Thaumetopoea pityocampa*

Egg parasitoids: 3 major + 5 minor species
Egg predators: many occasional

Larval parasitoids: 1 major + 4 minor species
Larval predators: many insects, birds and mammals (hairs!)

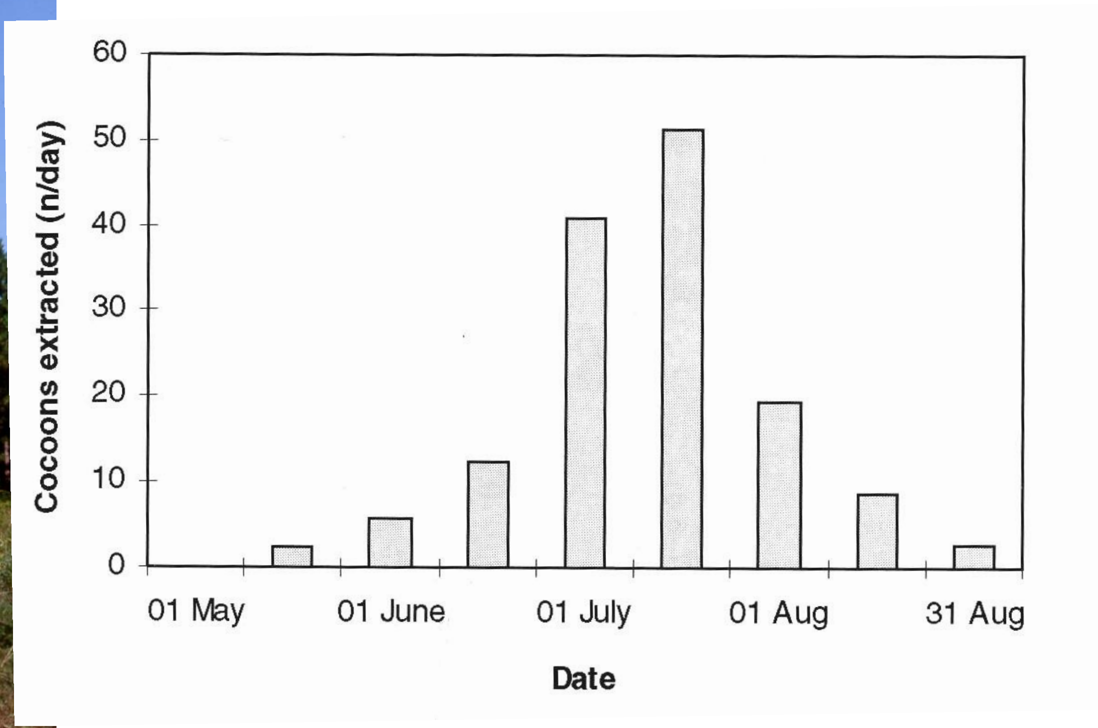
Pupal parasitoids: 1 major + 3 minor species
Pupal predators: 1 major and many occasional

Pathogens of larvae and pupae: 2 major and many occasional

Adult moth: many occasional (birds and mammals)

Experiment of manipulation of the access to predation: the hoopoe Upupa epops and the pine processionary moth Thaumetopoea pityocampa

Pupation site



Cocoons extracted

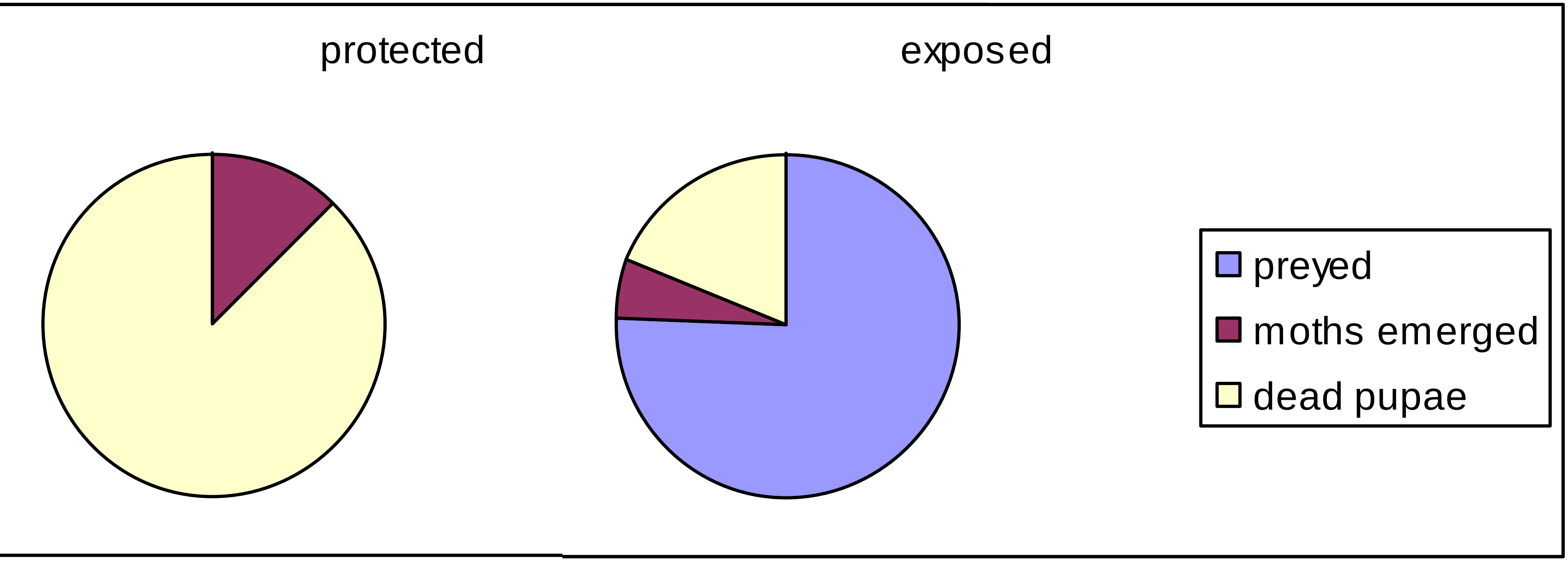
Hoopoe preying on pupae

Holes in soil

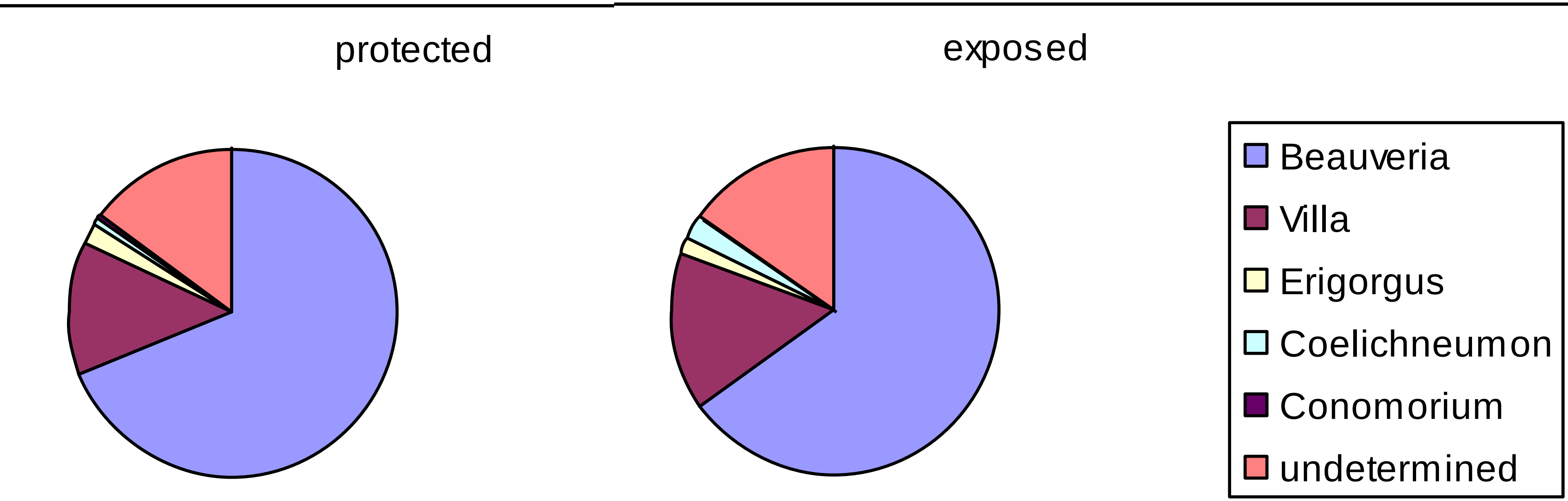
- 20 sites protected from birds and 20 sites exposed

- counting emerging moths

- counting dead pupae



# Mortality factors of pupae: fungi, insect parasitoids, insect predators



# Microbial control

**Virus: nuclear polyedrosis virus (NPV)**

**Bacteria: Bacillus thuringiensis kurstaki (BTK)**

**Fungi: Beauveria bassiana**

**Nematodes: Steinernema spp.**

# Microbial control by Btk

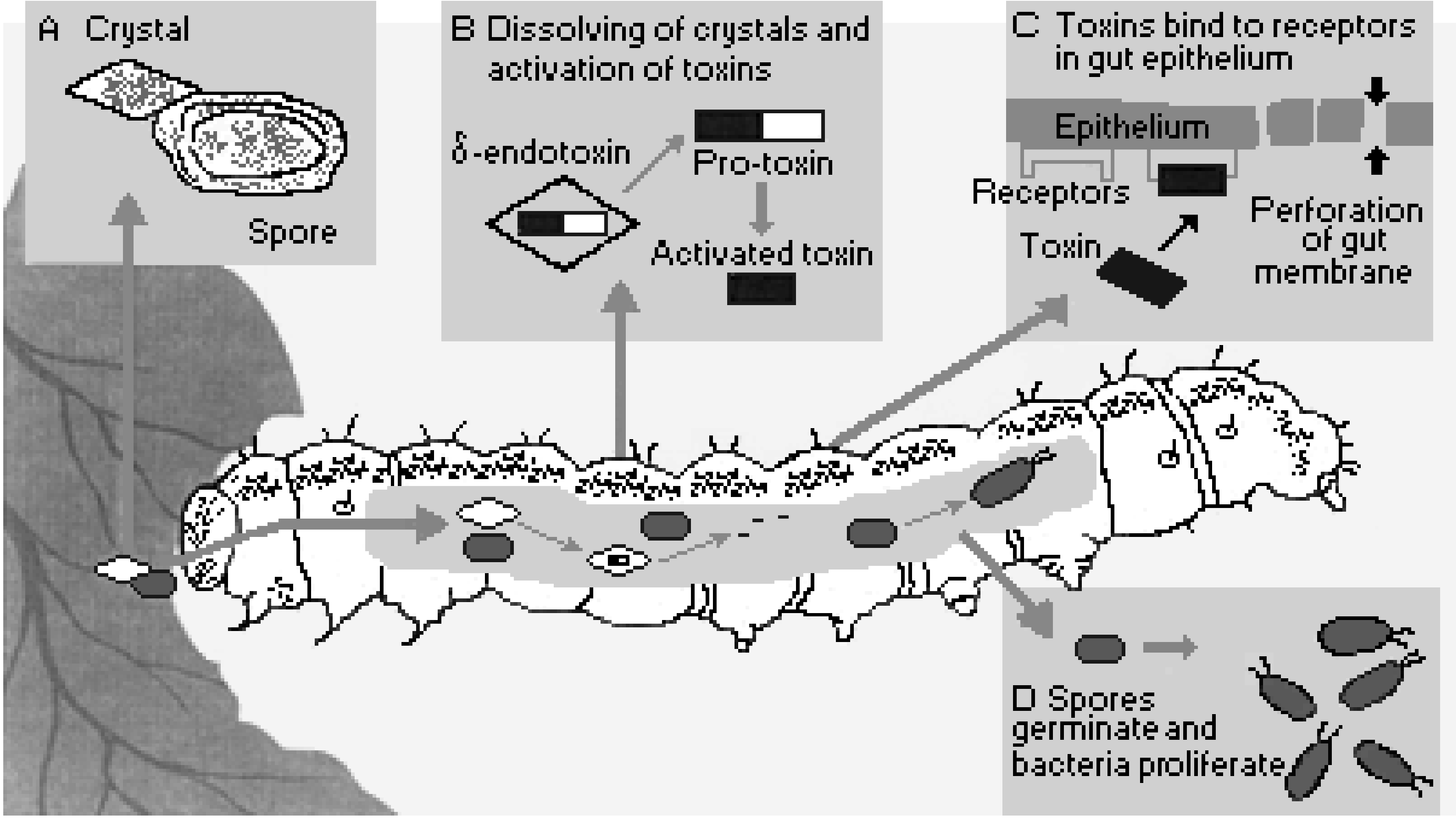



Fig. 1. Mechanism of toxicity of Bt

# Examples of microbial control by Btk

Lymantria dispar – Sardinia cork oak stands:

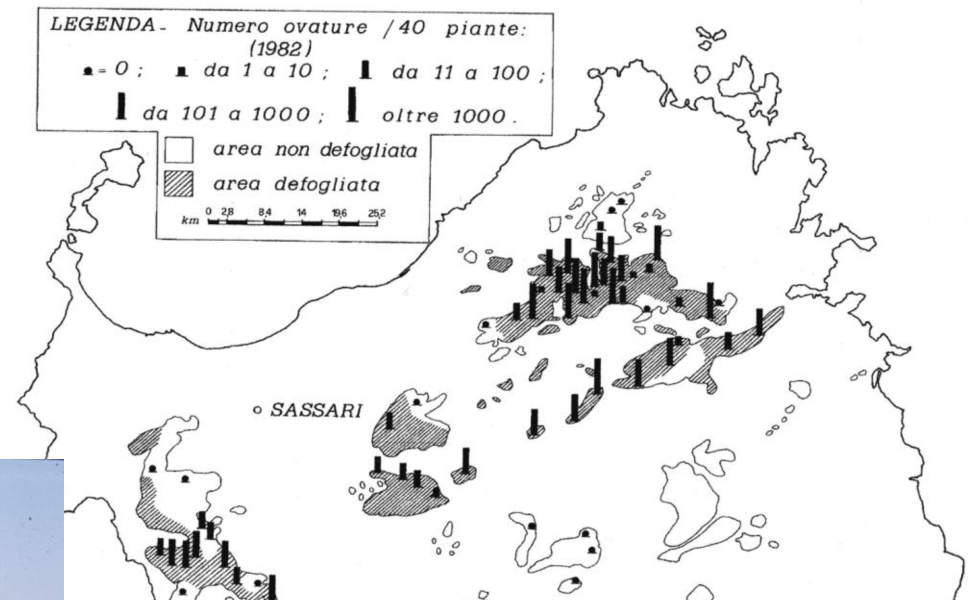
3000 - 14000 ha/year

Thaumetopoea pityocampa in pine stands:

500 – 1200 ha/year

# Use of Btk against Lymantria in Sardinia (from Luciano et al. 2002)

Monitoring by assessment of egg density: threshold 100 egg masses / 40 trees

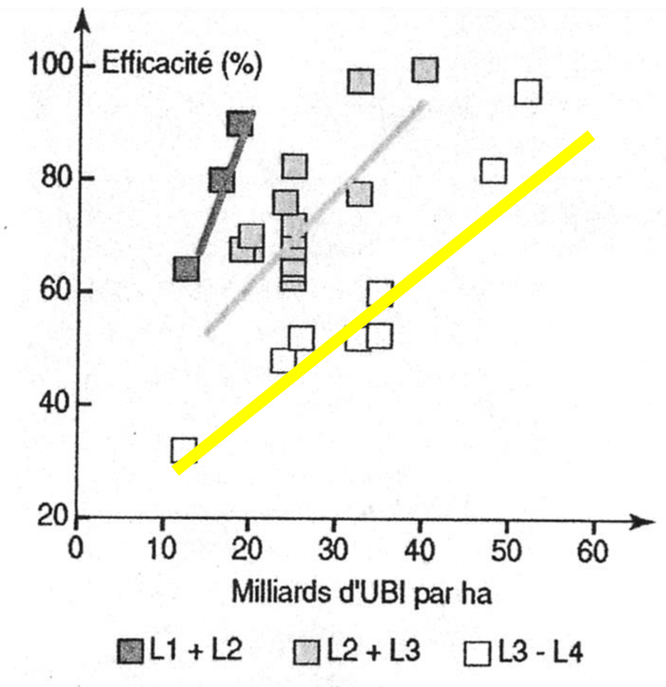



ULV (Ultra Low Volume) spraying from helicopter

# Egg masses of Lymantria dispar on cork oak

## Commercial products and dosage of Btk

The most commonly used in Europe is Foray, based on Btk strains producing different types of toxins, mainly cry 1A. Registration in Italy: Foray 48B (12 miliardi BIU/litro -Biological International Unit), dose 2 - 4 litre/ha.




Calculation of dose-mortality relationship in T. pityocampa, different larval age (Martin & Mazet, 2001)

## The situation in Italy

- **Sprayed areas (see document Foray 48B)**

- **Limitations**

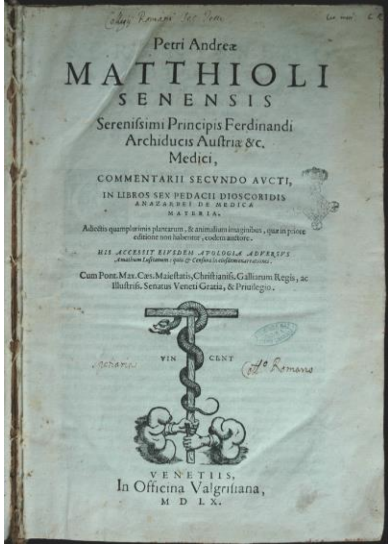
- **Cost/benefit**

- **Risks**

# Biocontrol of the processionary moth

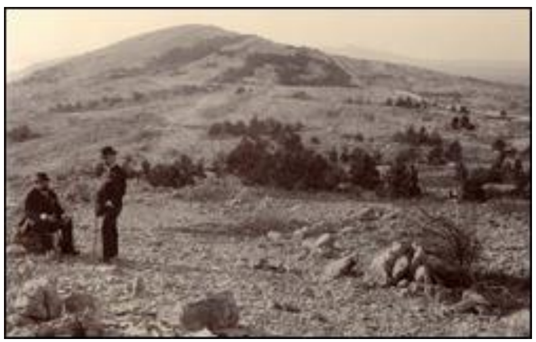
## A case study in the Venosta/Vinschau Valley (Northern Italy)

1568

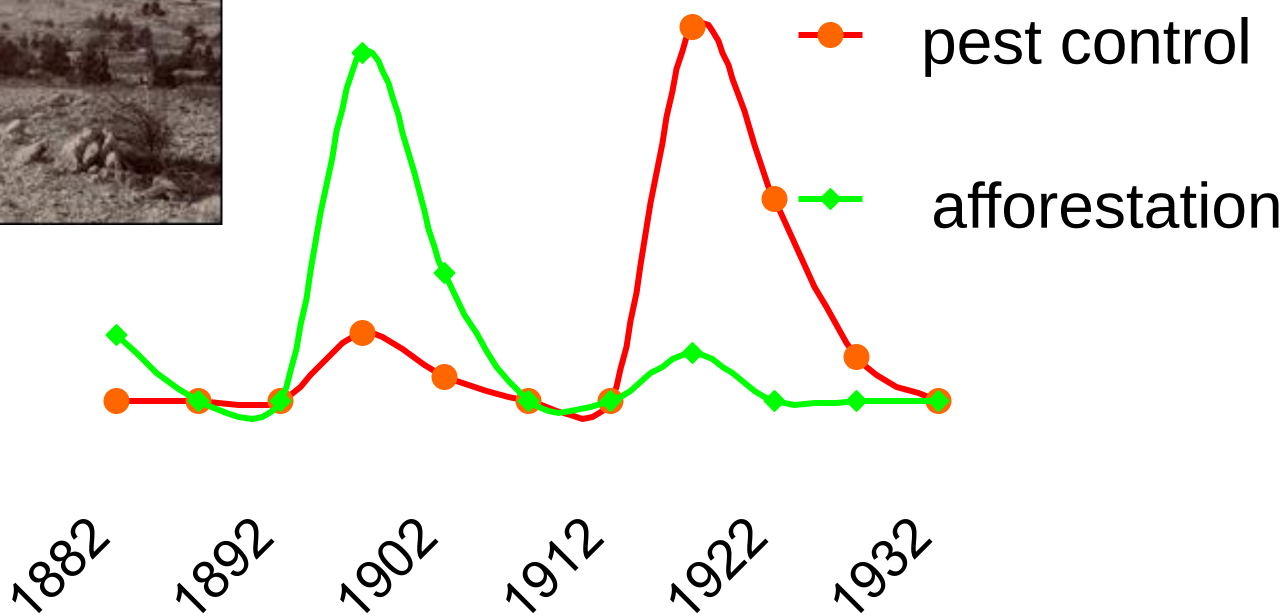




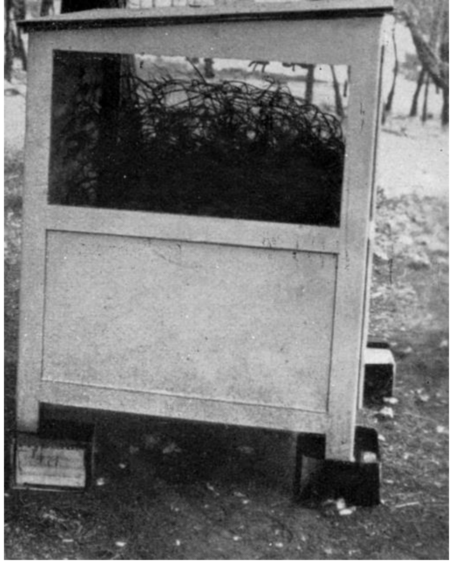
1897

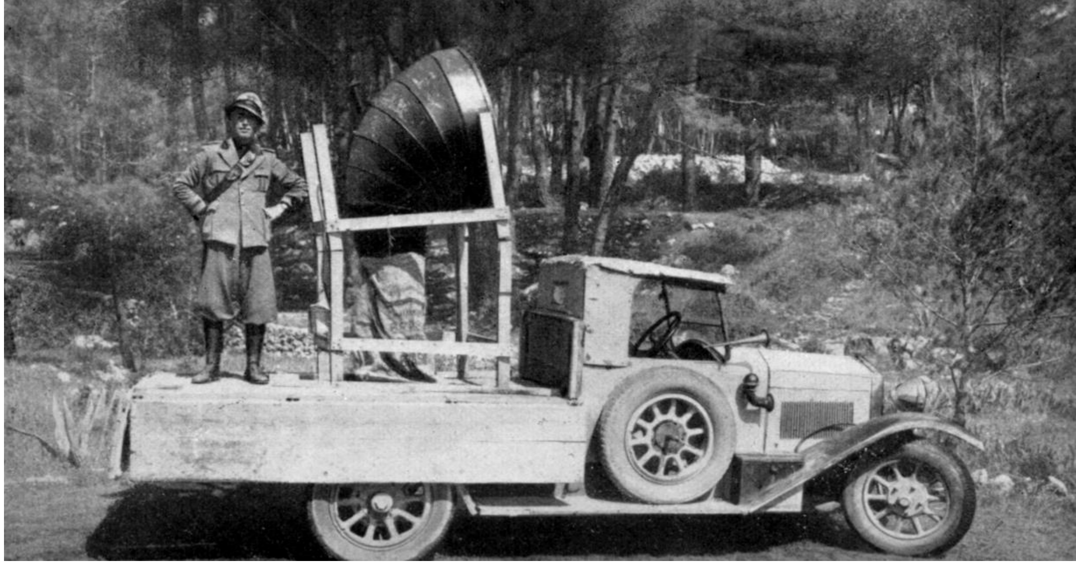


Pine processionary moth



1937





1969

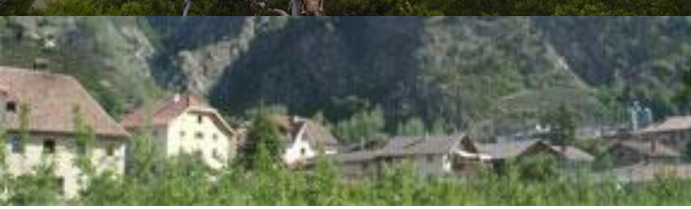
# Main questions

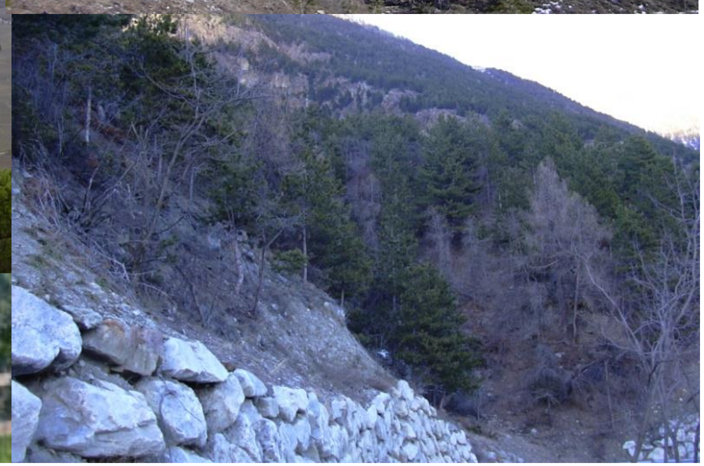
1. Are strategies of Integrated Pest Management in pine forests sustainable from the financial and social point of views?

2. Does financial/social sustainability change if we take into account the possible effects of climate change and to what extent ?

# Val Venosta/Vinschgau, Northern Italy





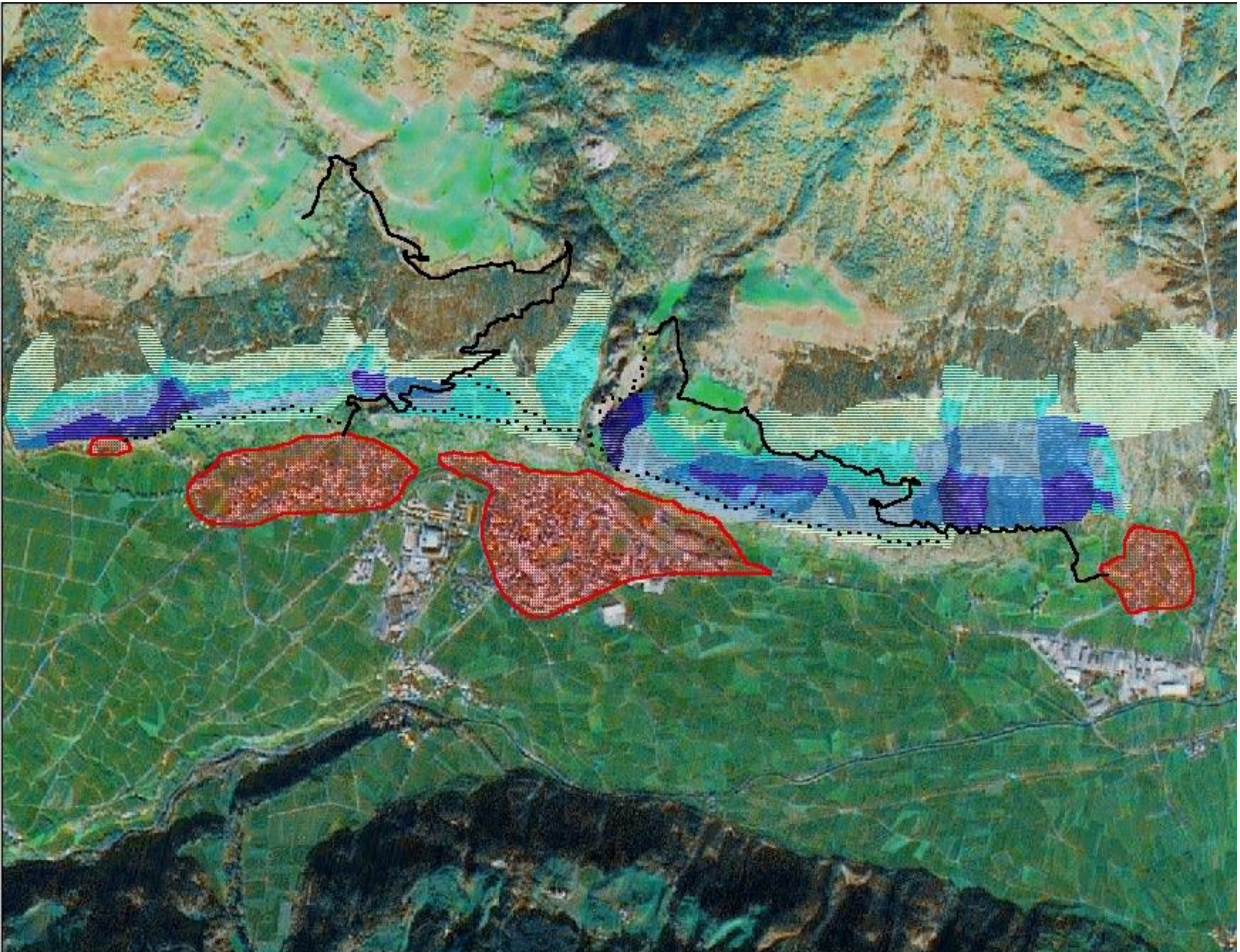


- <u>Total area</u>: 940 ha of Pine forests aged around 60-70
- none or very scarce importance for timber production
- planted with the main purpose of preventing soil erosion
- today important for tourism and landscape

- From 1958 to 1995 nests were collected from tree using shears, then burned.

- From 1995 to 1998 nothing was done.
- Since 1999 the Forest Service has regularly carried out pest control using Btk sprayed by an helicopter.
- Everything is recorded: area treated and costs.

# Area treated with Btk 1999 - 2007



Btk treatment

Relation-ship with human activity

# Items considered in Cost-Benefit Analysis

## Financial sustainability

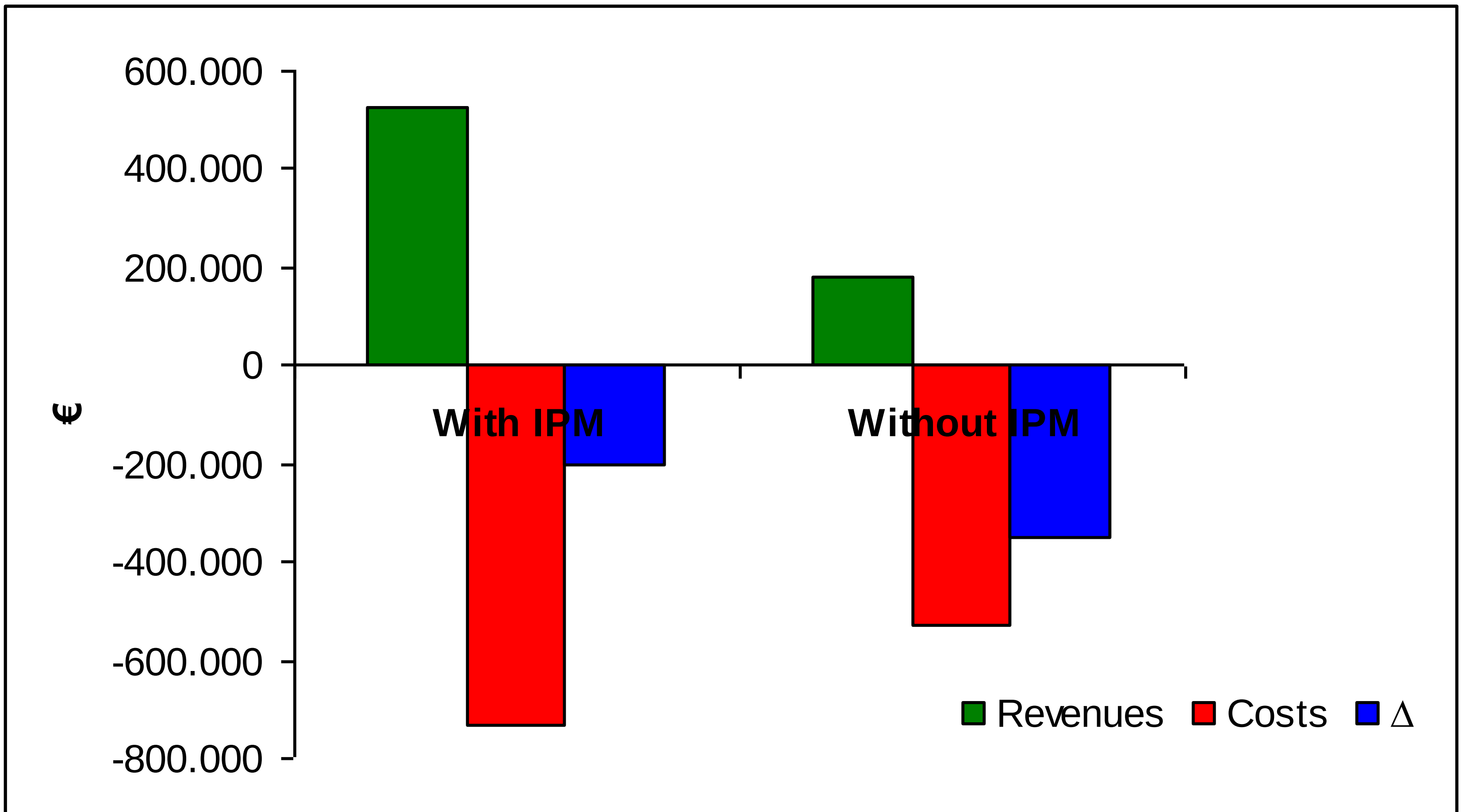
- Market revenues
  - Timber sold through thinnings
  - Maintenance of estate value

- Market costs
  - Forest management costs
  - Btk treatment costs

**Alternatives compared under financial sustainability**

- With IPM - the situation with the investment, Btk treatments
- Without – the situation without the investment

Time-span of the analysis 15 years, discount rate 2%



# Items considered in Cost-Benefit Analysis

## Financial sustainability

- Market revenues
  - Timber sold through thinnings
  - Maintenance of estate value
- Market costs
  - Forest management costs
  - Btk treatment costs

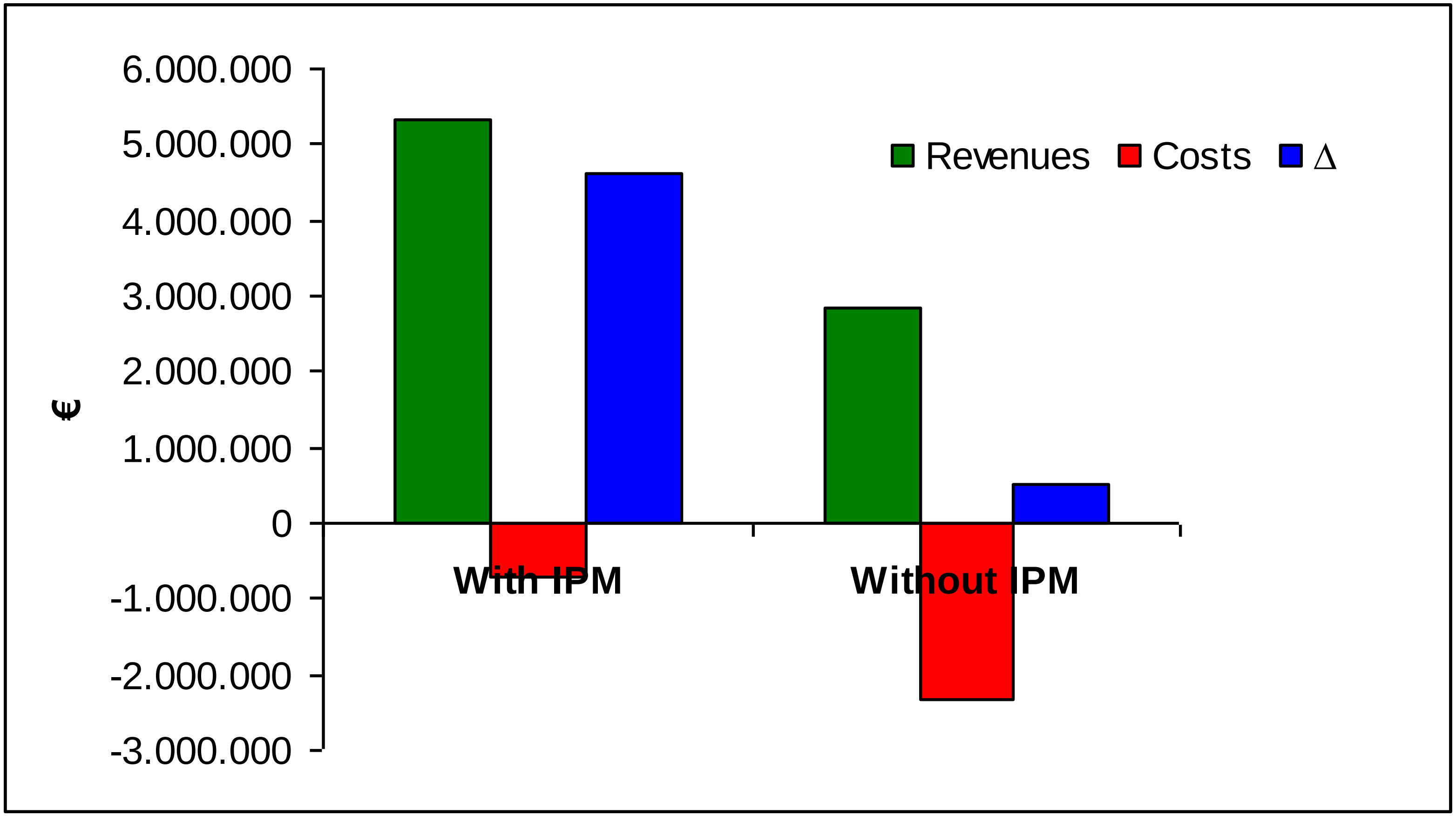
## Social sustainability

- Social benefits
  - Hydrogeological protection
  - Carbon fixation
  - Recreational and landscape values
- Social costs
  - Risks to human health caused by larvae

**Alternatives compared under financial and social sust.**

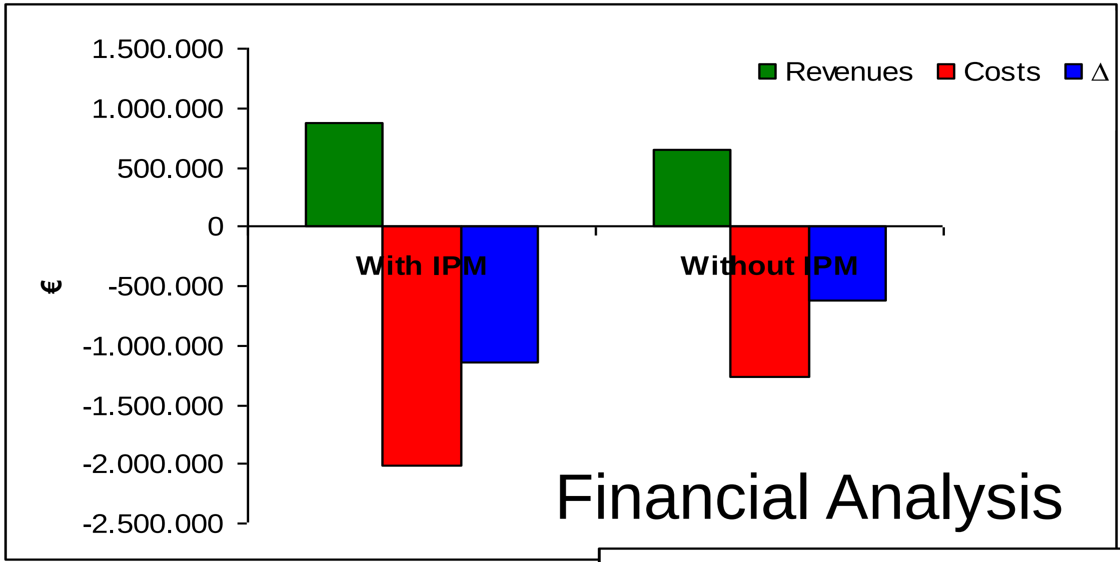
- With IPM - the situation with the investment, Btk treatments
- Without – the situation without the investment

Time-span of the analysis 15 years, discount rate 2%

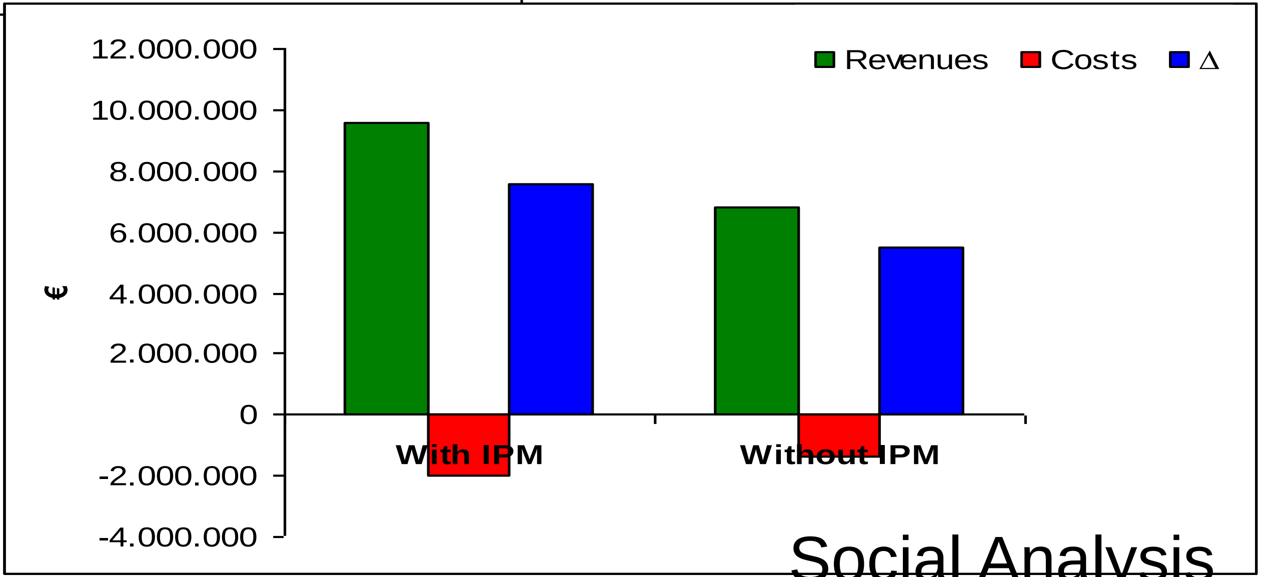


# Alternatives compared under climate change scenario

The temperature increase of 1°C in the future will imply the expansion of both pine forest and processionary moth




Financial Analysis




Social Analysis

# Conclusions

- with respect to the ‘business as usual’ situation, it appears that the increase of the pine area and of the area attacked by pine moth will be more costly to treat and therefore not financially sustainable
- there is a need of new cost-effective treatment systems
- pest control is always justified from the social point of view