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Is insecticide spraying a viable and cost-efficient management practice to control pine processionary moth in Mediterranean woodlands?

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ABSTRACT

Insect pests are a major threat to many forests worldwide, from boreal to tropical forest ecosystems. Some pests exhibit periodical outbreaks, after which their populations often crash as a result of natural biological control. To offset such outbreaks, several management techniques are used, including aerial spraying of insecticides. The question remains whether pest decline following an outbreak is the result of management practices or a natural consequence of the insect's population cycle. In this study, we assessed the performance of aerial spraying of insecticides on pine woodland stands to control pine processionary moth *Thaumetopoea pityocampa* (PPM) outbreaks in southern Spain. To achieve this, we compared the degree to which a forest stand recovers from defoliation from one year of severe damage by PPM to the following year (infestation index) in stands that were treated (i.e. subjected to aerial spraying) and untreated using a 4-years database from the Regional Environmental Council. The results revealed a significant similar recovery from infestation after a PPM outbreak of both sprayed and non sprayed pine woodland stands, for the four most representative pine species (black, Aleppo, maritime, and stone pine). It is concluded that insecticide spraying cannot be considered a prevention for outbreaks if it is applied once the outbreak explodes. Management practices that can help control PPM outbreaks include promoting spatial heterogeneity at the landscape level, fostering biodiversity in pine plantations, and reinforcing parasitoid insect and predatory bird populations that negatively affect the PPM. This study illustrates how simple sampling designs and statistical tests can be useful decision-making tools and can help improve the environmental viability and cost-efficiency of forest management practices.

1. Introduction

Herbivorous insects are integral components of forest dynamics, in which they play important roles (Dajoz, 2000). However, populations may occasionally grow rapidly into damaging proportions (Berryman, 2002). Such sporadic outbreaks can have catastrophic impacts on forests and trees, leading to the complete destruction of large areas of natural and/or planted forests, and considerable economic losses in some cases. In Europe, a number of insect species have achieved pest status over the last half century, since forestry plantations have become more important. One such pest is the pine processionary moth (*Thaumetopoea pityocampa*, Lepidoptera: Notodontidae; henceforth PPM; EPPO/CABI 1997). PPM is one of the most destructive pests in Mediterranean countries, where it attacks different pine species, some of which have been widely used in massive afforestations (Dajoz, 2000). In the last few decades, the area affected by PPM outbreaks in Europe has expanded northwards and upwards in the mountains, and the pest is now affecting higher altitude and latitude areas where it used to be absent (Hódar and Zamora, 2004; Battisti et al., 2005). This has resulted in high attack rates in areas hardly affected by this insect in the past (Battisti et al., 2005). Thus, the application of control methods for aggressive pests such as PPM is a key issue in Mediterranean forestry.

Foliage feeding insects often exhibit periodical outbreaks (Berryman, 2002). In the particular case of PPM, Robinet (2006) proved the existence of a roughly 6-year periodicity by long-term monitoring of nests in France, and similar results were obtained in southern Spain (Hódar and Zamora, 2009) and Italy (Battisti et al., 1998). This cycle, however, is not regular and may vary as much as from three to ten years (see Geri and Miller, 1985). To control PPM outbreaks, several management techniques have been used to date, including manual cutting and burning of nests, pheromone traps/mating disruption systems, and lethal mixtures of chemical and biological insecticides. Of these, aerial spraying of pine forests

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with insecticides is the most widely used option in most Mediterranean countries and has proved successful in preventing the pest multiplying, with apparently limited environmental effects (Sanchis et al., 1990; Battisti et al., 1998; Demolin and Martin, 1998; Dajoz, 2000). These insecticides target larval stages and are thus applied in late summer or early autumn provided that an outbreak of PPM has been detected during the previous winter. Given the proved efficacy of such treatment (Sanchis et al., 1990; Battisti et al., 1998; Demolin and Martin, 1998), aerial spraying of insecticides is thus expected to result in lower PPM incidence during the following winter. Application of insecticides is however implemented at a time when the moth's population is expected to crash as a result of natural biological control (predators–parasitoids, host plant, or both; Berryman, 2002). It follows to question whether PPM decline following aerial spraying of insecticides is a result of management practices or a natural consequence of the insect's population cycle. Despite of the simplicity of this reasoning, no attempt to answer this question has been done during the last two decades of control pest management practices in European forests and plantations. In this study, we assessed the performance of insecticide spraying by comparing the response of heavily infested stands that were either treated (with insecticide) or untreated. Our hypothesis is that, if PPM is effectively controlled by biological agents, we will find no differences in the response of heavily infested woodlands subjected to aerial spraying and untreated stands. Given the current range expansion and intensified virulence of PPM in Europe (Battisti et al., 2005), the implementation of tools that assess the effectiveness of pest management control practices are invaluable for forest management. The integration of forest management practices and scientific evidence is essential in order to ensure that the most environmentally sound and cost-efficient management practices are implemented.

2. Methods

2.1. Study area

The study area is the region of Andalusia (southern Spain). This area covers around 87,300 km^2 (ca. the size of Austria) and includes a wide variety of habitats, from lowlands and meadows on the western side to tall mountains (well above 3000 m.a.s.l.) in the east. Around 44,000 km^2 are forested, of which 19% are covered by both natural (1%) and afforested pine woodlands, mostly monocultures (99%) (Consejería de Medio Ambiente – Junta de Andalucía, 2003). In order to monitor PPM outbreaks, the Regional Environmental Council created a network of pine woodland stands scattered throughout the region (Carrasco et al., 2000). Five main pine species, black (*Pinus nigra*), Aleppo (*P. halepensis*), maritime (*P. pinaster*), stone (*P. pinea*), and Scots (*P. sylvestris*), represent the bulk of pine woodlands. Overall, there are 4389 pine woodland stands: 614 black pine, 1434 Aleppo pine, 657 maritime pine, 1137 stone pine, and 316 Scots pine, covering around 730,000 ha.

2.2. Life cycle of the PPM

In the adult phase, the PPM is a short lived moth which emerges in summer (June–August) and flies at night. The male moth is attracted to the female moth by pheromones that she emits. They will mate and a single female can then lay up to 300 tiny eggs which she attaches in a mass to a pine needle. Around one month later these eggs hatch into minute caterpillars. Caterpillars eat pine needles by night and build white silky nests on the tip of pine branches to take advantage of the sun's heat. These appear during the winter and a single pine tree may have many. This period of night time eating occurs during the winter months (October–March). At the end of the winter (March–April), the caterpillars leave the nest to burrow into the soil. The colony follows a leader, nose to tail, in a long procession. While searching out a pupation site, they may travel a distance of 30 or so metres to find soft soil to burrow into. Once underground they change into pupae and they will lay dormant until the summer months.

2.3. Data collection

At the end of every winter (February–April), trained rangers evaluate the degree of infestation in marked pine stands, according to six categories: 0 = no infestation, 1 = scattered nests, scant defoliation, 2 = defoliation and nests visible from the stand border, 3 = strong defoliation and numerous nests at the stand border, some defoliation in the center of the stand, 4 = very heavy defoliation both at the border and center of stands, and 5 = massive defoliation, almost no foliage remaining (Montoya and Hernández, 1991; Hódar and Zamora, 2004). Pine stands are surveyed by several hundred forest rangers from the Regional Forest Council each year. The application of treatments to control PPM outbreaks only occurs when a forest stand has a degree of infestation $\geq$3. Application of insecticides in earlier infestation stages is not practical because many woodland stands experience low levels of infestation that are not necessarily followed by a population outbreak. On the other hand, not all forest stands with a degree of infestation $\geq$3 are necessarily treated (Table 1), as for instance pine woodlands included in protected areas, which in general are not sprayed. Aerial ultra-light volume (ULV) spraying of insecticides (henceforth referred to as spraying) is the most frequent treatment, and it was applied to 96% of treated forest stands during the study period (Table 1). The main insecticide used to control PPM was diflubenzuron in a dose of 45 g diluted in 3 l of oil per hectare (DIMILIN 45 ULV) (Carrasco, 2008).

We used these data on the incidence of defoliation by PPM for the period 2002–2005. Although there is a climatic component that makes some years more prone to PPM infestation at a regional scale (Hódar and Zamora, 2009), we can assume that, in general terms, the PPM in each woodland stand follow its own cycle. Since our study focuses only on stands in later stages of infestation (which are those that are potential candidates for aerial spraying), there is no need to have information on earlier stages of the full 6-year cycle.

2.4. Data analysis

To compare the effects of spraying vs. no management of forest stands, we created a response variable, *PPM infestation index*, that reflects the degree to which a forest stand recovers from defoliation from one year of severe damage by PPM (degree of infestation $\geq$3) to the following year.

$$\text{PPM infestation index} = \text{degree of infestation}_{t+1} - \text{degree of infestation}_{t}$$

Since the highest infestation value considered is 5, the *PPM infestation index* may vary between −5 and 5, where negative values indicate some recovery from PPM infestation as compared to the previous year, and positive values indicate an increase in the degree of infestation by PPM.

We first compared the *PPM infestation index* in woodland stands that were subjected to spraying vs. those non-sprayed provided they had suffered a degree of infestation $\geq$3 during any of the years within the study period for each of the pine species. Of the five main pine species, only the first four were considered for this study since data for Scots pine were insufficient. The total number of stands subjected to spraying vs. no spraying was 14 vs. 256 for black pine,