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Towards a sylvicultural method of pest control for *Matsucoccus feytaudi* Ducasse, the Maritime pine bast scale (Hemiptera: Margarodidae)

Abstract - *Matsucoccus feytaudi* Ducasse, a specific pest of Maritime pine (*Pinus pinaster)* is spreading to the eastern part of its natural host area (south-eastern France, Corsica and northern Italy) where it has caused severe outbreaks. Due to the fact that no direct control method is available, studies have focussed on preventive sylvicultural practices to reduce the damage at the stand level. Combining both population estimates and symptom occurrences, it was shown that both bark thickness and tree vigour are positively correlated with tree resistance. These results were used to identify the most resistant trees at the stand level developing a bi-dimensional threshold approach. The model was tested in stands where those that appear to be most susceptible trees were removed so as to reduce the host availability and slow epidemic development of the pest. Two years after the thinning, the population increase was significantly slow down in the treated plots as compared to the untreated plots. Further field tests are required to evaluate the long-term effect of selective thinning for the management of *M. feytaudi*.

Key words: *Matsucoccus feytaudi*, *Pinus pinaster*, tree resistance, pest control, sanitary thinning

INTRODUCTION

The maritime pine bast scale, *Matsucoccus feytaudi* Ducasse, a pest specific of *Pinus pinaster*, has recently caused severe outbreaks in the eastern part of its natural host area (south-eastern France, Corsica and northern Italy). The scale insect killed 120 000 ha of pine forest in Southeast of France in the 1960s (Riom, 1994). Considerable damage has been caused in Ligury and North of Tuscany with the spread of the scale to Italy (Covassi & Binazzi, 1992). In Corsica, where this study was conducted, the presence of the insect was recorded for the first time in 1994 (Jactel *et al.*, 1998). In North Corsica the infested area covers an area of 1000 km^2 expending every year at a rate of 5 km per annum. The first symptoms of pine decline were observed in 1997 (Jactel *et al.,* 1998) and tree mortality is now noticed in stands located in the originally infested area, which indicates that the population dynamics have reached the epidemic phase. The scale is threatening more than 27 000 ha of *Pinus pinaster* forest in Corsica, some of the stands being part of the UNESCO World Patrimony. Control of scale insects with insecticides has proved ineffective due to their waxy body covering and cryptic behaviour. The need therefore exists to develop new effective methods of management of *M. feytaudi*, both inexpensive and environmentally friendly.

This study represents a first attempt to develop a sylvicultural method of Maritime pine scale management based on sanitary thinning, i.e. removal of the trees most susceptible to *M. feytaudi* from the stand. The main objective has been to reduce the suitable host availability and thereby prevent the epidemic development of the pest at the stand level, ultimately reducing the amount of damage.

The study was conducted in 3 stages. First we investigated anatomic and dendrometric characteristics related to tree resistance that could be used by foresters. Then, we tested these characters as forecasting parameters in order to identify the more sensitive trees in Maritime pine stands. Finally, we used those characters to differentiate between susceptible and resistant trees in a field test in order to assess the effectiveness of this management the following 2 years.

MATERIAL AND METHODS

Characters of the Maritime pine tree resistance to M. feytaudi

In the summer of 1998, characteristics in 62 pine trees, 18 to 22-year-old, were studied in 2 stands located within the originally infested area (Pineto and Asco forests), probably since 1994 where the trees already exhibited symptoms of decline. The bark (i.e. rhytidome) thickness was measured with a handled bark gauge and a caliper square. Ten measurements were taken all around the stem, at the stem section where the highest larvae numbers are usually found (Jactel *et al.,* 1996); the maximum value was recorded. The tree vigour was evaluated using a height growth index (HGI) before *M. feytaudi* infestation, i.e. before 1994, as a constitutive resistance trait. The HGI was computed as the ratio between the length of the 1993 internode and the total length of the 5 internodes from 1989 to 1993. The higher the index value the more vigorous the tree was in 1993; a low value indicating a relative slowing down of tree growth. The internode lengths were measured with a telescopic height pole.

In order to estimate the tree infestation level, we evaluated the density of larvae at the modal height of their distribution (Jactel *et al.,* 1996), by counting the number of 2^{nd}-instar exuviae per square dm. In order to estimate the tree susceptibility to *M. feytaudi*, we combined two factors: density of larvae and occurrence of decline symptoms. Regarding larval density, the trees were split into two classes, separated by a threshold value of ten larvae per sq. dm, because no decline symptoms had been observed in trees with less than 10 larvae per sq. dm. Concerning the decline symptoms, the trees were split into a class with no symptom and in a class with resin flow on the stem bark and/or crown yellowing and/or mortality.

Determination of susceptible trees at the stand level

In order to evaluate the reliability of the bark thickness and the height growth index as predictors of the tree susceptibility, we monitored the evolution of the larval density and the appearance of strong decline symptoms, i.e. crown yellowing or tree mortality, in the same 62 trees, from 1998 to 2001. We investigated the feasibility of determining threshold values by using a two-dimensional graphic resolution.

The sanitary thinning field test

The selective thinning in which trees susceptible to *M. feytaudi* were removed was tested in two plots located in the same area, of the Pineto forest. The first plot was an uneven-aged pure stand of *P. pinaster*, 30 to 50-year-old, with a density ranging from 2000 to 2500 trees/ha. The second plot was an even-aged pure stand of *P. pinaster*, 8-year-old, with an average density of 500 to 1500 trees/ha. Three experimental subplots of 40 trees were delimited in each stand. In the first subplot, trees were thinned by the forest manager according to current practices, i.e. reducing by a fifth the initial tree density in the older stand and by half in the younger stand. In the second subplot, we implemented the sanitary thinning. We reduced the initial tree density by two thirds, only preserving trees with the thickest bark or the highest growth index values. The third subplot was the control, subjected to no intervention. The thinning was conducted in 1999. The sanitary status of the 169 remaining trees was monitored from 1999 to 2001, using six notes combining the density of larvae and the occurrence of symptoms: 0 (uninfected), 1 (larval density$<2/dm^2$, no symptom), 2 (larval density$<10/dm^2$, no symptom), 3 (larval density$>10/dm^2$, no symptom), 4 (larval density$>10/dm^2$, resin flow on the stem bark), 5 (larval density$>10/dm^2$, resin flow outside the stem bark and reddish crown), 6 (dead tree).

RESULTS

Characters of the Maritime pine tree resistance to M. feytaudi

In order to analyse the correlation between maximum bark thickness and density of larvae per tree we sorted the 62 trees according to the bark thickness and divided them among 15 classes of 4-5 trees. The mean density of larvae per class significantly decreased with the mean bark thickness per class ($Y = \exp(-1.84X+4)$; $R^2 = 0.62$; F $= 21.49$; $P < 0.005$) according to an exponential model (figure 1). As shown in figure 2, trees with a low *M. feytaudi* infestation level (larval density < 10 per dm_) exhibited a significantly higher mean bark thickness than highly infested trees (*t* test: T = -2.19;

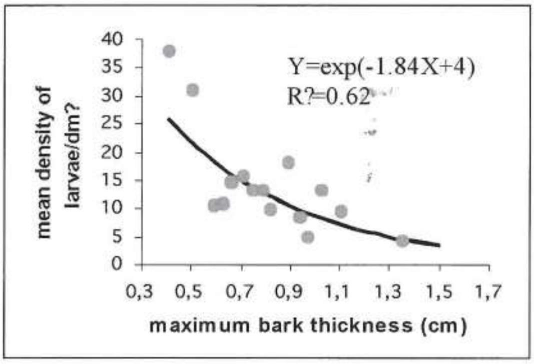

Fig. 1
Correlation between density of *Matsucoccus feytaudi* larvae per dm^2 and mean maximum bark thickness per class of bark thickness.

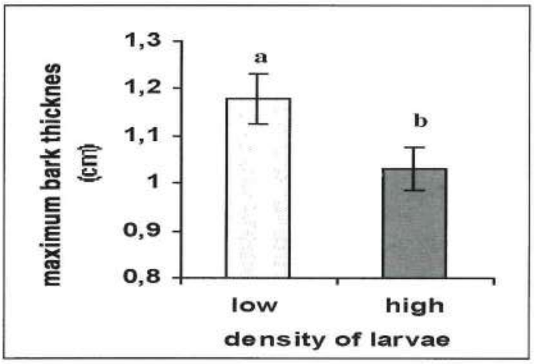

Fig. 2
Mean maximum bark thickness of Maritime pine trees as related to low (< 10 per dm^2) and high (>=10 per dm^2) density of larvae of *Matsucoccus feytaudi*.
(Bars with different letters indicate significantly different means, *t* test, $\alpha = 5\%$)

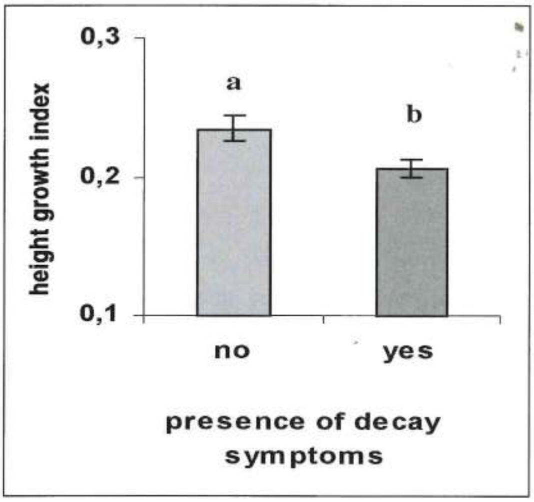

Fig. 3
Mean height growth index for Maritime pine trees with decline symptoms and trees without decline symptoms.
(Bars with different letters indicate significantly different means, *t* test, $\alpha = 5\%$)

$P = 0.033$). No significant differences were observed between the mean bark thickness of trees with and without decline symptoms (*t* test: T = 1.87; $P = 0.069$).

In order to analyse the correlation between the height growth index and density of larvae per tree we sorted out the 62 trees according to the HGI values and subdivided them into 15 classes of 4-5 trees. There was no significant correlation between mean HGI value per class and mean larval density per class. No significant differences were observed between mean HGI values of low and high-infested trees. Meanwhile the mean HGI value of declining trees was significantly lower than the mean HGI value of trees exhibiting no symptoms (*t* test: T = 2.56; $P = 0.013$) (figure 3).

Discriminating susceptible trees at the stand level

Figure 4 shows the distribution of the 62 sampled trees along two axes: maximum bark thickness and height growth index identifying trees with and without strong

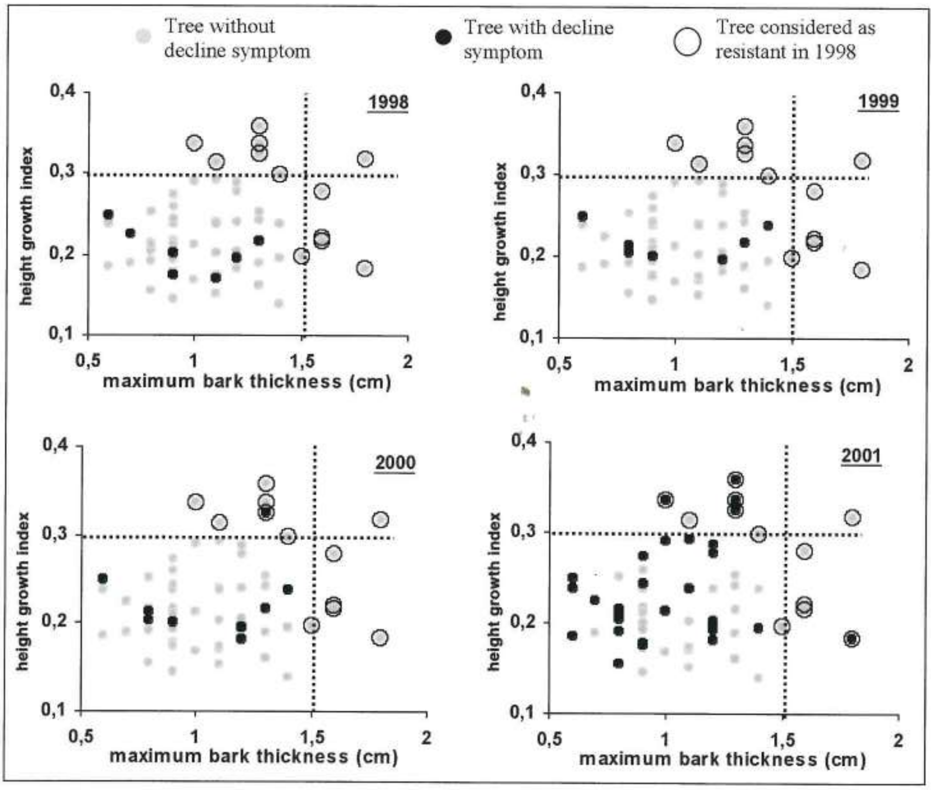

Fig. 4 - Evolution of infestation and decline symptoms of 62 Maritime pine trees to *Matsucoccus feytaudi* at the stand level from 1998 to 2001.

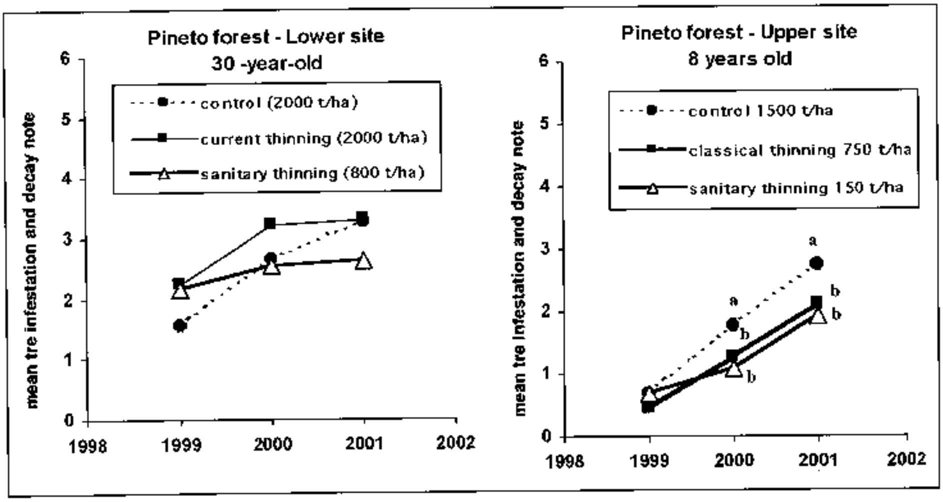

Fig. 5 - Evolution of the note of *M. feytaudi* infestation in Maritime pine stands according to the thinning treatment, from 1999 to 2001.
(Means with the same letters for the same year are not significantly different, Scheffe's multiple range test, a = 5%)

decline symptoms. According to the 1998 spatial pattern, we proposed two threshold values for tree resistance to *M. feytaudi*: 0.3 for HGI and 1.5 cm for maximum bark thickness. Twelve trees, almost 20% of the sample, were located in the graph beyond those two thresholds and considered as resistant (figure 4).
Among the 12 potential resistant trees, none in 1999 and only one in 2000 exhibited new decline symptoms. Their HGI was equal or slightly higher than the threshold value. In 2001, four more potentially resistant trees began to decline (figure 4). Three of them had one of the thinnest barks in the potentially resistant tree cluster and the other the lowest HGI value.

The sanitary thinning field test

Two years after the treatments, pine trees in the thinned subplot were in a better shape than in the other two subplots in the 30-year-old stand and than the control subplot in the 8-year–old stand (figure 5). In 2001, the mean notes of sanitary status were in respect of the older stand 2.6, 3.3 and 3.3 in the sanitary thinned, normally thinned and control subplot respectively likewise in respect of the younger stand 1.9, 2.1 and 2.7 in the sanitary thinned, currently thinned and control subplot respectively. In the latter stand, we found a significant difference between the mean note of sanitary status in the control subplot and in the other two in 2000 ($F = 6.54$, $P = 0.022$) and in 2001 ($F = 6.51$, $P = 0.023$). Moreover, the decline seems to have been slowed in the sanitary thinned subplots. Values of the slopes of the linear regression of the infestation against years after the thinning were the lowest in sanitary thinned plots in respect of both old and young stands. Values for the older stand were, 0.23, 0.54 and 0.86 in the sanitary thinned, routinely thinned and control subplot respectively. In the younger stand they were 0.61, 0.82 and 1.02 in the sanitary thinned, routinely thinned and control subplot respectively.

DISCUSSION

Characters of P. pinaster *resistance to* M. feytaudi

Density of the *M. feytaudi* larvae in Maritime pine trees significantly decreases with the increasing of bark thickness. Additional data indicated that the density of deep bark cracks, at the bottom of which the phloem is accessible, was also negatively correlated with the bark thickness. Comparing the susceptibility of several *P. pinaster* provenances, Schvester and Ughetto (1986) related larval density to bark structure. Similar studies of *Cryptococcus fagisuga* Lindinger (Lonsdale, 1983) and *Matsucoccus matsumurae* (Kuwana) (McClure, 1985) consistently indicated that bark structure was a physical basis for host resistance. Tree infestation by *M. feytaudi* is caused by the successful settling of the crawlers which colonise deep bark cracks on the trunk (Riom, 1977; Carle, 1973). Outer bark would then prevent tree colonisation; as a physical barrier, provided that it would be sufficiently thick and poorly cracked to reduce the probability of successful settlements by the first instar. Bark thickness could then be considered as a host non acceptance trait in the Russel's classification of plant resistance mechanisms (1978). The reduction of suitable host availability resulting from selective thinning could therefore have a dramatic effect on pine scale population dynamics.

During the experiments, tree vigour did not affect the level of *M. feytaudi* infestation but only the occurrence of decline symptoms. Likewise, weakened *Pinus tabulaeformis* are more damaged by *M. matsumurae* (Zhao & Li, 1989). However, no significant correlation was found between tree growth and number of larvae. Vigorous trees might be more tolerant to high densities of larvae. Many studies, particularly on bark beetles, have shown that water or nutrient stressed trees are more prone to pest attack (Lieutier & Levieux, 1985). They can not mobilise the energy required to synthesise the secondary metabolites involved in defence reactions. As observed in *Fagus sylvatica* infection by *C. fagisuga* (Gora *et al.*, 1996; Dubeler *et al.*, 1997), while introducing its stylet and releasing saliva in the phloem, *M. feytaudi* larval destroy cells thereby initiating a defence reaction of the tree (Carle, 1973). Resin is neo-synthesised in the phloem tissue that can flow in the bark cracks and resin droplets often cover the stem of highly infested trees. In weakened trees, the synthesis of large amount of resin may result in a physiological stress, leading to crown decline and a higher susceptibility to attacks by secondary pest insects such as weevils and scolytids. Accordingly, the selective thinning of trees that exhibit a low vigour index could disrupt the regular pest succession which usually leads to tree mortality in *M. feytaudi* outbreaks (Carle, 1968).

Discriminating susceptible trees at the stand level

During the first three years of the monitoring, the prediction of tree resistance based on bark thickness and tree vigour proved to be quite reliable. Only one of twelve potentially resistant trees exhibited symptoms of decline. However, in 2001, we observed an increase in the number of predicted resistant trees turning susceptible. In the same period, we observed a general increase the damage in the area (DSF, 2000) that could have resulted from the start of an epidemic outbreak. Increasing damage may be due to unfavourable climatic conditions in 2001 that had led to a general weakening of the trees and consequently a higher number of declining infested trees. Anyway, it must be emphasised that most of the potentially resistant trees that failed to overcome the scale infestation were those with the thinnest bark, i.e. mainly selected according to the vigour criterion. In order to improve the tree selection efficiency it could be of great interest to rely on both criteria, i.e. bark thickness and vigour rather than bark thickness or vigour, also to give a higher relative weight to the bark structure. For instance, selecting trees with maximum bark thickness higher than 1.3 cm and HGI higher than 0.2 would have provided in 2001 a set of six resistant trees and caused no failure.

However, the main drawbacks of the method are the high rate of selection (remaining 10-20% of potentially resistant trees), and the lack of absolute thresholds, requiring their adjustment to each stand condition and structure. The application of the method for sanitary thinning would then require a great number of measurements and would result in a very low tree density. Further studies are needed to develop an effective selection method adjusted to the foresters' constraints.

The sanitary thinning field test

The results of the field test indicated a positive effect of the sanitary thinning in terms of damage reduction and slowing down of decline. This seems to be consistent with the use of bark thickness as the main criterion for predicting tree resistance to *M. feytaudi*.

However, owing to it being based on a high rate of tree selection, the sanitary thinning also resulted in a high reduction of tree density. In the 30-year-old plot, the control and current thinning subplots had the same tree density after the treatment and they showed the same level of infestation in 2001, when the sanitary thinning subplot had a lower tree density and a lower infestation level. Likewise, in the 8-year-old plot, the note of sanitary status consistently decreased with the tree density in the subplots. Water and nutrient supply were improved by reducing tree density, and thereby was increased their vigour. The beneficial effect of the sanitary thinning may be related either to the reduction of suitable host availability or to the increase of tree tolerance to higher levels of infestation. In order to evaluate independently the real effect of a selection based on the criterion of bark thickness, we would need to compare the changes in *M. feytaudi* infestation in plots resulting from a current and a sanitary thinning of a similar tree density after the thinning.

CONCLUSION

Several experiments have already been conducted to identify pine species provenances resistant to *M. feytaudi* (Schvester & Ughetto, 1986; Harfouche *et al.*, 1995; Fusaro, 1997), *M. josephi* (Mendel, 1998), and *M. matsumurae* (Li *et al.*, 1997). Such long-term studies can provide suitable material for reforestation but are not adequate to prevent the development of great damage in newly infested forests. Preliminary, promising results indicate that a preventive thinning of the more sensitive trees i.e. those with the thinnest stem bark and the lowest height growth index, may reduce the level of Maritime pine tree infestation by *M. feytaudi*.

However further observations are needed to verify whether the damage has been reduced or only delayed in the thinned plots and to really separate the effect of sanitary thinning from the consequence of the tree density reduction. Finally the method has to be validated at the stand level and more user-friendly techniques for identifying resistant trees have to be found in order to suit with the foresters' requirements.

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