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**Seasonal history of the Maritime Pine Bast Scale
Matsucoccus feytaudi Ducasse (Hemiptera: Matsucoccidae)
in Portugal**

Abstract - Seasonal history of members of the Matsucoccidae varies between a two-year cycle on the one hand and multivoltine development on the other; most of the investigated species display bivoltine development. Epidemic populations of *M. feytaudi* in the Mediterranean coast of France and Italy display univoltine development, with a male flight limited to few weeks in the early spring. Pheromone traps have revealed that in central Portugal males of *M. feytaudi* fly throughout the year. The question raised was whether the latter seasonal flight pattern implies multivoltine development of the Portuguese scale population or not. In order to address the question we compared the pattern of male flight with the occurrence of immature developmental stages of the scale. The main peak of male flight was observed in February and a smaller one in summer. This pattern coincides with the age structure of the immature stages of the scale. While the development of most of the nymphs does last about 10 months, a smaller portion completes the feeding cycle in about 5-6 months. It is suggested that due to the notable extension of the early spring oviposition period in the studied areas, the first egg masses that occur in December give rise to a second annual generation. The early first instar nymphs escape the aestivation, to which the major nymphs population is subject, by developing into second nymphal stage before daily average temperature reaches an upper threshold of 15 °C. It is suggested that high plasticity displayed by populations of both *M. feytaudi* and its host *Pinus pinaster* in the Iberian Peninsula allows the variation in both seasonal occurrence of the egg masses and rate of development of the nymphs, resulting in a non-uniform seasonal age structure. The outcome is two overlapping generations allowing male flight all year round.

Key words: plant-insect relationship, scale insects, pheromone traps.

INTRODUCTION

Approximately 30 species of modern bast scales of the genera *Matsucoccus* Cockerell and *Sonsaucoccus* Young (Hemiptera: Matsucoccidae) feed exclusively on pine, each species developing on one or a few hosts of a given subsection or section of the genus *Pinus* (e.g., Rieux, 1975; Ray, 1982; Liphshitz & Mendel, 1989). *M. pini* feeds only on pine species belonging to the *sylvestris* group (Rieux, 1975) and

M. macrocitrices on *P. strobus* (Kosztarab, 1996). Liphschitz & Mendel (1989) suggested that the development of *Matsucoccus* species on a particular pine species relates to scale's inability to trigger the defence system of the host while feeding. Data presented by Mendel (1992), Halevy (1995), and Mendel *et al.* (1997) suggest that host resistance, more than the natural enemy complex, is the key factor in the population dynamics of *M. josephi*. Resistance to the scale has probably been acquired through a long coevolution between *P. brutia brutia* and *M. josephi*. Lack of coevolution was suggested as the reason for the high susceptibility of *P. halepensis* and some subspecies of *P. brutia* to *M. josephi* and for the severe injuries produced by *M. matsumurae* when it was introduced, from Japan, in East Asia and the north-eastern USA and by *M. feytaudi* after being transferred from the Iberian peninsula or the Atlantic coast of France to the Mediterranean coasts of France, Italy and Tunisia (Mendel, 1998). The interaction with the host is surely a key factor on the biology of *Matsucoccus* and an important issue in order to understand population dynamics, geographical distribution, host range and aggressiveness of these scale insects.

Among the few studied members of the genus *Matsucoccus*, different modes of seasonal histories were revealed (e.g. Bodenheimer & Neumark, 1955; Ricux, 1975; Kosztarab 1996; Kosztarab & Kozár, 1988; Park 1991). Those living in the mild temperate zones, such as *M. matsumurae* and *M. pini*, are bivoltine. The populations overwinter as first instar nymph, resume activity early in the spring, mature a few weeks later and produce a second generation during summer (e.g. Cadahia, 1971; Park, 1991). In higher latitudes or further to the north the seasonal development is extended, with *Matsucoccus gallicolus* becoming univoltine, whereas *Matsucoccus macrocitrices* displays 2-year cycle (Kosztarab, 1996). In both cases, long overwintering occurs. On the other extreme, *M. josephi*, an east Mediterranean species (Mendel, 1998), displays a multivoltine behaviour, with up to 6-7 annual generations (Mendel *et al.*, 1997).

M. feytaudi is specific to maritime pine, *Pinus pinaster* Ait. Its distribution is therefore included in the range of its host, which occurs as fragmented populations in the western part of the Mediterranean basin. Western populations of the bast scale are endemic, whereas the eastern population was introduced in modern time, probably by humans (Burban *et al.*, 1999).

Both eastern and western populations of *M. feytaudi* have been considered univoltine (Cadahia & Montoya, 1968; Riom & Gerbinot, 1977; Covassi & Binazzi, 1992; Riom & Tacon, 1994). Adults occur early in the spring (February-March) while first instar nymphs appear about one month later. Two main periods of feeding activity occur. The first period occurs during early spring, when average temperatures are below the threshold 15°C. Higher temperatures induce aestivation on first instar nymphs. The second period starts in autumn with the drop of temperature. First instar nymphs complete development and turn into the second instar (Riom & Gerbinot, 1977).

Activation of traps baited with the female sex pheromone of *M. feytaudi* showed that in Portugal an almost all year round flight activity occurs. This pattern of behaviour

of the *M. feytaudi* males suggests that the Portuguese population of the scale is not univoltine (Carvalho *et al.*, 1997).

The objective of the present study has been therefore to investigate the reason behind the apparent unusual seasonal history of the bast scale in Portugal.

MATERIAL AND METHODS

Seasonal flight pattern of males

The seasonal flight pattern of males was monitored during three consecutive years using pheromone traps. Sticky delta traps baited with 400 mg racemic mixture of the *M. feytaudi* sex pheromone were placed in maritime pine stands.

In 1998, traps were placed in two areas, Sintra (38°47'N, 9°25'W, about 250 m above sea level) and Península de Setúbal (38°32'N, 9°8'W, about 30-35 m above sea level), respectively. The captures were examined every other week, and the baits were replaced once every two months. In 1999, traps were activated during the two main periods of flight activity February-April and July-August, in two stands, at Península de Setúbal and Marinha Grande (39°40'N, 8°55'W, about 50 m above sea level). In 2000, the trapping was carried out from February to July in two stands, at Península de Setúbal and Lousã (40°8'N, 1°4'W, about 700 m above sea level).

Sampling immature stages and adult females

Samplings of nymphs and females with ovisacs were conducted every other week, from February to July 2000, at the Península de Setúbal. The number of settled first (N_1), second (N_2) instar nymphs and females with ovisacs was estimated by examining 1 dm² of bark, on the stem section of the tree with highest probability of occurrence of the pine bast scale (Jactel *et al.*, 1996). Fifteen trees were sampled at random.

To confirm the presence of the summer generation of N_2 and adult females, the samplings were repeated in July 2001, on three pine stands: Península de Setúbal and in two stands at Marinha Grande (MGa and MGb), with 15, 18 and 11-12 years old trees, respectively. Current year exuviae were also counted to accumulate additional information about the occurrence of distinct summer and winter generations.

Fecundity, embryonic mortality and duration of the egg stage

Female fecundity, rate of development of the egg masses in the forest and embryonic mortality were estimated by sampling ovisacs in two pine stands, from March to May 2000.

Ovisacs were collected by using traps made of strips (4x32 cm in size) of grooved card (Kraft paper with grooves 2 mm in size) placed at half way up the stem, as suggested by Carle (1968). Traps were examined every other week. In the lab the cards were opened carefully and examined. Embryo mortality and hatching time were

examined by placing ovisacs in Petri dishes, surrounded by a vaseline ring at 24°C, 60%-80% RH and 12:12 LD. Emerged crawlers were counted and removed every other day. Non-hatched eggs were also counted.

Simulation of seasonal trends

To simulate the *M. feytaudi* seasonal trends a simple model was developed. The model was based on a 15 °C threshold temperature to trigger aestivation and on data collected in the studied regions.

RESULTS

Seasonal flight pattern of males

Male flight of *M. feytaudi* was almost continuous all year round, displaying two main peaks: a major one in winter and another one in summer (Fig. 1-3). Yet, the magnitude of the summer peaks as well as comparison with those of the winter varies largely depending on the specific stand.

Occurrence of immature stages and females with ovisacs on trees

Ovipositing females of *M. feytaudi* were observed as late as May (Fig. 4). In 1999 ovisacs were detected as early as in early December, suggesting that the oviposition period extends from December to May.

The significant number of N_2 recorded in July-August suggests that portion of the N_1 population escapes aestivation, forming about 4 months after hatching a distinct summer generation of the N_2 (Fig. 4). While the majority of N_1 population becomes

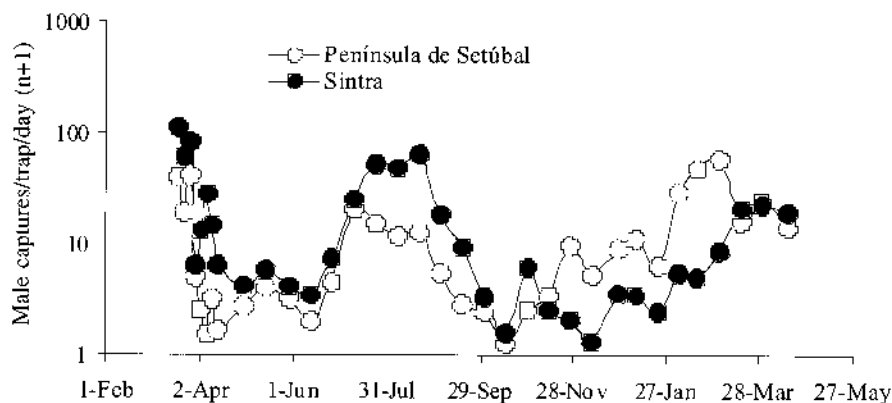


Fig. 1 - Flight pattern of *Matsucoccus feytaudi* males observed at Península de Setúbal and Sintra, in 1998/99.

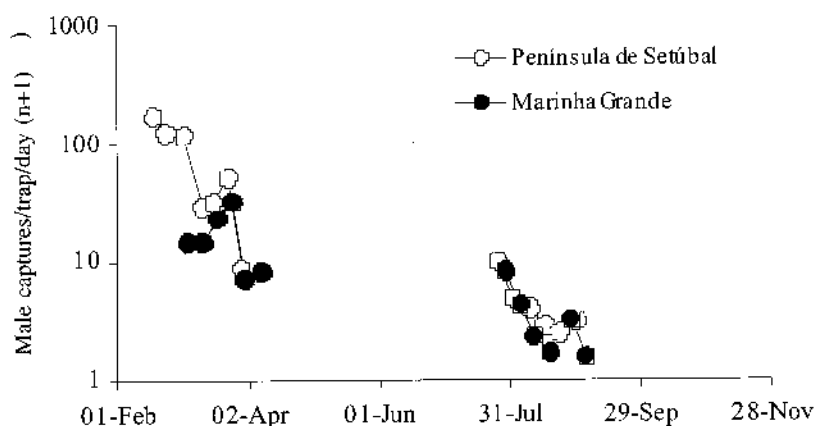


Fig. 2 - Flight pattern of *Matsucoccus feytaudi* males at Península de Setúbal and Marinha Grande, in 1999.

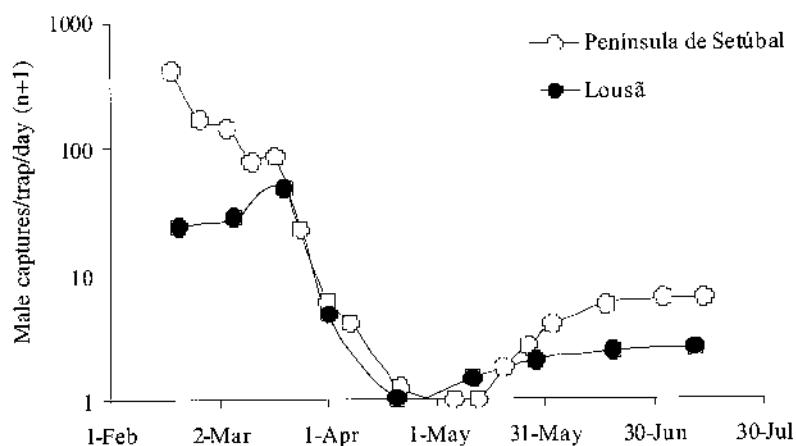


Fig. 3 - Flight pattern of *Matsucoccus feytaudi* males observed at Península de Setúbal and Lousã, in 2000.

noticeable three to four months after hatching. Hence, N_2 population displays a minor peak in summer and a major one in winter.

Further observations, carried out in July 2000 and 2001, strengthen the evidence of a summer generation (Table 1). The ratio between the sizes of summer and winter populations, estimated by fresh exuviae, suggests that the proportion of individuals in the population displaying a second generation is variable, ranging from about 1% up to 61%, in different stands and years, probably as a result of differences in

meteorological conditions. The differences in the size of each generation are consistent with differences in seasonal flight patterns of *M. feytaudi* males observed between stands.

Fecundity, embryonic mortality and duration of the egg stage

A large proportion of ovisacs in the traps was preyed, mostly by nymphs of coccinelids and *Elatophilus crassicornis*, reducing the number of intact ovisacs. The number of ovisacs sampled was higher in March, decreasing afterwards. The estimated fecundity in March (Table 2) differed significantly ($P < 0.05$) between stands. It was higher at Península de Setúbal, where a large density of the pine bast scale was also observed (Fig. 3). Significant differences ($P < 0.05$) were also registered between sampling periods within the stands.

Embryonic mortality of *M. feytaudi* varied from about 1 up to 11%, being significantly higher in ovisacs collected in May ($P < 0.05$) (Table 3). The duration of the egg development was reasonably constant, i.e., 21-25 days.

Simulation of seasonal trends

A simulation model was built based on the field and laboratory observations. In particular, our results indicate that: (i) duration of egg stage is about 1 month; (ii) duration of non-aestivated N_1 is 4 months; (iii) development of N_1 under aestivation lasts 7 months; (iv) duration of N_2 of the winter generation is about 3 months; (v) duration of N_2 of the summer generation is 1 month.

Average mortality of the immature stages (eggs, N_1 and N_2) due to predators and other factors is considered ranging from 60 to 80%.

To predict male captures the sex ratio used was 1:1 and is supposed that a pheromone trap captures males flying from the 12 nearest trees (i.e., about 100 m²).

Assuming a 15°C threshold temperature to trigger aestivation, two cases were simulated, one for a mild winter with daily average temperatures above 15°C occurring since March, and other with daily average temperatures below 15°C observed until early April. In the second case, the flight peak of males in summer is relatively higher than in the first case (Fig. 5). This result agrees with the field data indicating a more distinct summer flight activity of males, in comparison with the winter period, at higher elevations or northern latitude. In both cases, the pattern of flight activity of *M. feytaudi* given by the simulation model (Fig. 5) is consistent with field observations (Fig. 1 to 3). The overlapping of generations results in an almost constant presence of males all year round (Fig. 5).

DISCUSSION

The results suggest that the seasonal history of *M. feytaudi* in Portugal is the result of overlapping generations, instead the strait forward univoltine pattern reported for

Table 1 - Number of exuviae, second instar nymphs (N_2), females with ovisacs and male cocoons of *Matsucoccus feytaudi* sampled per dm^2 of bark at the middle of the tree trunk, in July-August.

Location	Year	Sampling trees	Exuviae* N_1+N_2	N_2	Females with ovisacs	Male cocoons	Ratio [(b+c+d)/a]·100
			(a)	(b)	(c)	(d)	
Península de Setúbal	2000	20	79	7	1	0	10.1
	2001	40	216	3	0	1	1.9
Marinha Grande a	2000	20	23	8	0	6	60.9
	2001	40	134	0	0	1	0.7
Marinha Grande b	2000	60	53	8	2	1	20.8
	2001	60	34	8	5	0	38.2

*for further explanations see text

Table 2 - Fecundity of *Matsucoccus feytaudi* females (mean \pm SE).

Location	Period					
	March		April		May	
	Eggs/ovisac	N*	Eggs/ovisac	n	Eggs/ovisac	n
Lousã	252.2 \pm 15.9	25	271.0 \pm 39.2	3	187.2 \pm 22.5	6
Península de Setúbal	325.7 \pm 26.2	22	—	—	—	—

*number of sampling trees

Table 3 - Embryonic mortality of *Matsucoccus feytaudi* (%) (mean \pm SE).

Location	March		May	
		n		n
Lousã	3.2 \pm 0.019	25	11.1 \pm 0.038	6
Península de Setúbal	1.3 \pm 0.002	22	—	—

Table 4 - Hatching time of *Matsucoccus feytaudi* (mean \pm SE).

Location	March		May	
	N° days	n	N° days	n
Lousã	20.8 \pm 0.46	25	24.6 \pm 0.65	6
Península de Setúbal	20.8 \pm 0.49	22	—	—

other regions. Our findings prove the occurrence of univoltine and bivoltine development of the scale in Portugal. Similar findings are expected in other areas of the Iberian Peninsula. The presence of different *Matsucoccus* stages in summer has also been observed recently in North Africa (H. Jactel, 2001 personal communication).

It is suggested that the major part of the population presents one annual generation,

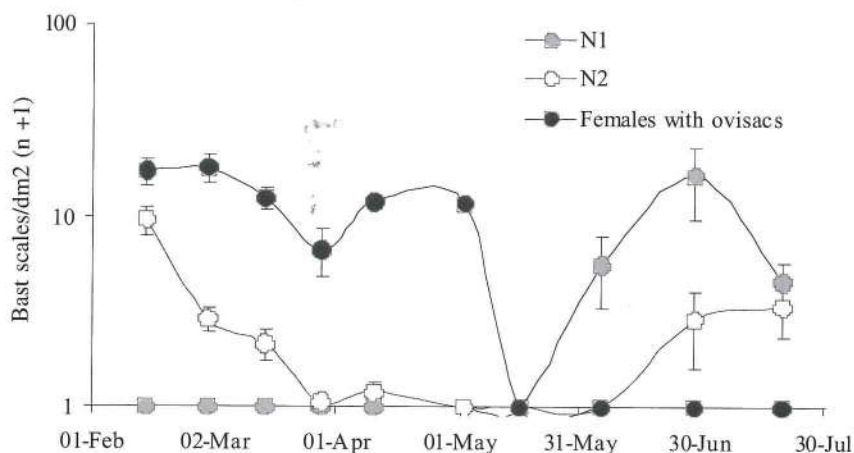


Fig. 4 - Number (mean \pm SE) of first and second instar nymphs (N_1 and N_2) and females with ovisacs per dm^2 of bark observed at Península de Setúbal, in 2000.

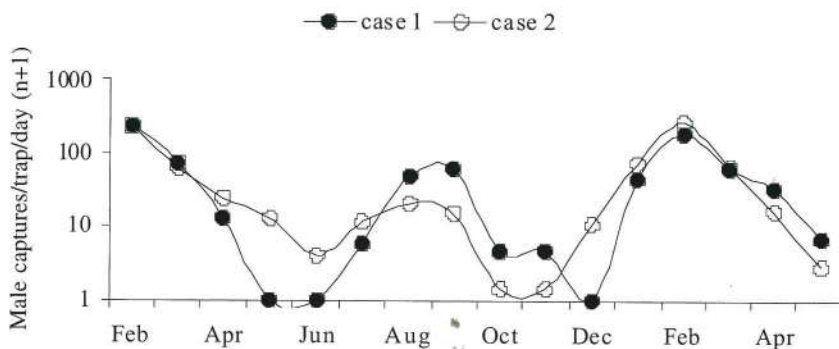


Fig. 5 - Simulated flight pattern of *Matsucoccus feytaudi* males, case 1: daily average temperatures above 15 °C are observed since March, case 2: daily average temperatures below 15 °C are observed until early April (see text for explanation).

with an aestivation of portion of N_1 population induced by temperature, as observed in other studies (e.g., Riom & Gerbinot, 1977). Furthermore, the fecundity, duration of the egg stage and duration of N_2 of the winter generation agree with the observations reported in France and Spain (Riom, 1979; Cadahia & Montoya, 1969) which are consistent with a principal univoltine character of the species.

The univoltine behaviour of *M. feytaudi* may be explained by an adaptation to seasonal trends on the host conditions. Studies based on fossil records of the pine and on its genetic structure indicate that *P. pinaster* survived the last glaciations sheltered in the warm enclave of the Iberian Peninsula (Figueiral, 1995; Salvador *et al.*, 2000).

Portugal or Spain had become then a secondary center of origin of *P. pinaster* which spread thereafter into the neighbouring countries. The endemic characteristics of *M. feytaudi* populations on the Iberian Peninsula and the geographical distribution of mtDNA diversity within the western lineage of the species is compatible with an Iberian *refugium* for the insect in association with its host (Burban *et al.*, 1999). In these particular conditions, *M. feytaudi* must have evolved to adapt its biology both to the Iberian climatic conditions and/or to the physiology of its host.

Mediterranean climate is characterised by mild winter, spring and autumn seasons and a dry summer. This may explain conformity to special seasonal trends on tree physiology and insect-host interaction. An increase of the phloem osmotic pressure associated with water stress, a possible decrease in N content associated with seasonal growth slowness (Kozłowski *et al.*, 1990), or the increase in secondary compounds, such as tannin and phenol compounds, could favour tree resistance and limiting the feeding activity of the scale during summer.

It is therefore suggested that aestivation of the maritime pine bast scale is an example of an adaptive behaviour to host physiological conditions, inducing the aestivation of the first instar nymphs. Seasonal changes in food quality or host resistance may account for low survival in summer. According to this assumption, temperature is probably the signal for *M. feytaudi* to undergo aestivation.

Yet, a rapid development from the N₂ stage to adults occurs due to the high autumn temperatures. In consequence, egg masses may be observed as early as December in the studied areas. Also, the genetic plasticity of the subpopulations (Burban *et al.*, 1999) may contribute for the extension of the egg laying period. Therefore a small portion of the N₁ population, of the early season occurring egg-masses may develop into N₂ before the increase of the daily average temperatures above 15°C. This may further give rise to a second generation, whose feeding period lasts about 5-6 months, while the development of the other individuals, constituting the main winter generation, lasts about 10 months. Thus, a main part of the population completes one generation yearly, while a minor part of the population is able to complete a second generation in about 14 months. The overlapping generations, as observed by an almost constant presence of adult males all year round, is support by the simulation results.

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