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Autor(en): **Gonzalez, Ramon / Campos, Mercedes**

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Spatial distribution of attacks by *Phloeotribus scarabaeoides* (Coleoptera: Scolytidae) in two olive grows in south of Spain

RAMON GONZALEZ & MERCEDES CAMPOS

Estation experimental del Zaidin (CSIC), U.E.I. Fitopatologia, c/Profesor Albareda 1, E-18008 Granada, SPAIN

The olive bark beetle, *Phloeotribus scarabaeoides* (BERN.), constitutes one of the principal insect pests in the present day olive culture. The study of the spatial distribution of attacks (feeding galleries) in the field was based upon the linear transect method in two olive groves near Granada (South Spain). The first area of sampling corresponds to a farm where the pruning wood is traditionally stored near the grove, whereas in the second one the leftover wood is removed to a distance from the olive crop during the pruning season. In each sampled area, the attacks of *P. scarabaeoides* were found 2.3 km and 3.5 km respectively from the centre of dispersion. Results revealed that there is a great influence of distance from the centre of dispersion on the level of attack, and the data fitted to an equation of the y=a+b/x type. A clear directional trend in the pattern of distribution of attacks has been observed. To interpret the results, the effect of environmental conditions such as temperature and relative humidity on the beetle activity, and wind speed and direction on the flight of the beetle offspring during the emergence period are discussed.

Keywords: *Phloeotribus scarabaeoides*, olive beetle, spatial distribution, Scolytidae, olive grove.

INTRODUCTION

The olive bark beetle (*Phloeotribus scarabaeoides* (BERNARD, 1788)) is considered as one of the main phytophages in present day olive culture (LIOTTA, 1981), causing direct and indirect damage on tree yield (JARRAYA, 1986).

In southern Spain this species only completes one generation per year (GONZALEZ, 1990), although for other regions 2 (BALACHOWSKY, 1949), 3 and even 4 (RUSSO, 1938; ARAMBOURG, 1984) generations have been reported, depending on the climate and availability of material for reproduction.

This insect always behaves as a secondary pest regardless of its population level. Reproduction mainly takes place in recently dead wood although it has occasionally been reported as taking place in living trunks or live tree branches in North Africa, weakened by drought or unsatisfactory pruning (ARAMBOURG, 1984).

In Spain, tree damage is caused by feeding periods by overwintering beetles before their dispersion flight, and by the newly emerging beetles throughout the summer (CORTES & RODRIGUEZ, 1978). The population increase of the olive beetle to epidemic levels is due to the abundance of material for reproduction made available by the annual olive pruning (from December to April). In spite of regulations laid down by the Ministry of Agriculture concerning the treatment of olive tree waste, branches, etc., these are often stored near the crop in an untreated state and become important centres of dispersion.

Distance from the focus of dispersion is a fundamental factor influencing density changes (WADLEY, 1944) in insect distribution. This phenomenon has been illustrated in the studies undertaken in different scolytid species such as *Hylesinus (= Leperisinus) varius* (F.) (LOZANO & CAMPOS, 1991), *Tomicus piniperda* (L.) (SAUVARD *et al.*, 1987) *Scolytus multistriatus* (MARSHAM), (COLLINS, 1938; WADLEY, 1944; ANDERBRANDT & SCHLYTER, 1987). Environmental conditions such as temperature, relative humidity, light intensity (CHARARAS, 1962) and wind speed and direction (SALOM & MCLEAN, 1989, 1990) constitute important factors on regulation of the dispersion of the bark beetles and therefore on the population distribution in the field.

As in other scolytid species such as *T. piniperda* (SAUVARD *et al.*, 1987), the existence of a feeding stage in the life cycle of *P. scarabaeoides* in young branches of the tree provides favourable conditions for a study of its spatial distribution. The main objectives of this study are: to determine the kind of distribution displayed by *P. scarabaeoides* in areas of the crop; to test the effect of the distance from the centre of dispersion on insect population in the trees and to identify early signs which will facilitate more accurate future studies of the influence of environmental variables on insect dispersion and colonization of the biotope.

MATERIAL AND METHODS

Description of the study area

Different areas dedicated to olive growing were explored in the Granada region (Spain) and two farms were chosen. At each of these, olive waste from pruning was handled in different ways.

Area A. This lies 20 kms to the North of Granada city between longitude 4403 and 4444 and latitude 4132 and 4129 U.T.M; it covers 371 ha of olive crops. Trees are between 50 and 80 years old, and the majority (approx. 80%) of the total (approx. 28500) are of the "picual" or "marteno" cultivar. The rest are mainly "hojiblanco". A large amount of the wood from the olive pruning is stored in the traditional way in the centre of the human population in the southern central region of the crop-growing area where it is stored for domestic use the following winter.

Area B. This lies 11 km South-West of Granada city between longitude 4340 and 4354 and latitude 4109 and 4110 U.T.M.. On this farm the leftover wood is removed to a distance from the olive crop during the pruning season (January-April) and therefore before the *P. scarabaeoides* attack has been completed (GONZALEZ, 1990). The nearest centre of human population is a farmhouse located 200 m from the plot. Other neighbouring farmhouses are 1900 m, 2400 m, and 1200 m from the plot. In contrast to area A these farmhouses do not store wood from the olive pruning, and the nearest dispersion centre is therefore 2900 m from the crop, in the village "La Malaha".

Sampling Method

Sampling was carried out in January and February of 1989 using the linear transect method. Within each transect, observation sites were at 100 m intervals and at each of these 4 neighbouring trees were sampled (distance between them < 15 m).

In area A, radial transects from the central urban nucleus were mapped (Fig. 1), which increased the intensity of the sampling near the dispersion centres. The direction of the transects and the number of observation sites in each one is illustrated in Tab. 1. A total of 384 trees were sampled.

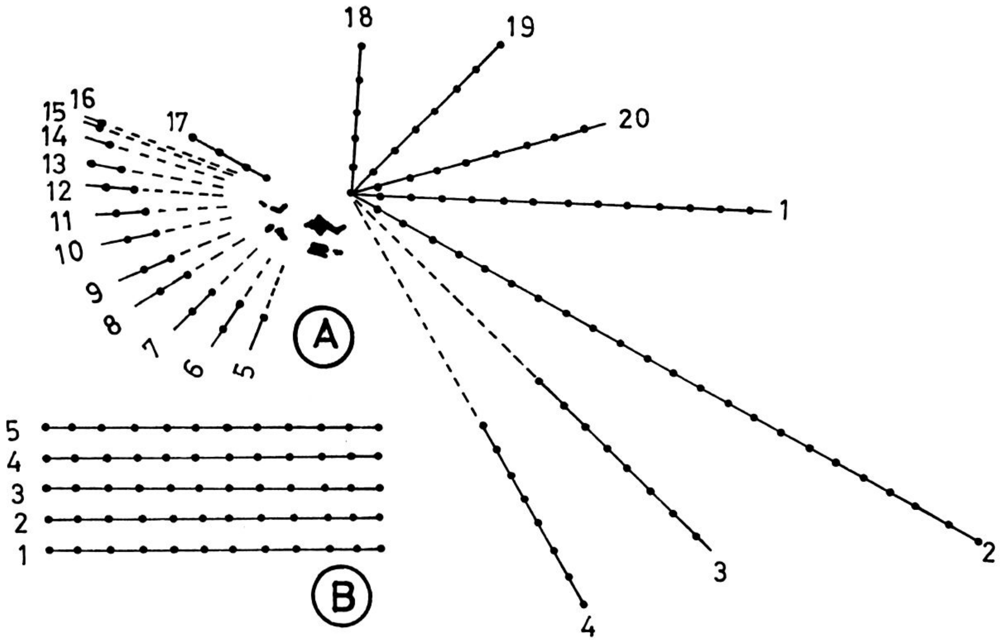

Fig. 1. Diagram of sampling sites in area A and B. Transects are represented by numbers and the sampling sites by black dots.

In area B, the absence of a centre of dispersion close to the olive groves together with the square shape of the plot, favoured sampling with parallel transects (Fig. 1), thus achieving homogeneous sampling throughout the crop. The distance between observation sites within a transect was 100 m, as in area A. There was a total of 5 transects with 12 observation sites in each and a total of 240 trees were sampled.

Tab. 1. Direction (angle with respect to the magnetic North) and number of sampling sites in the transects corresponding to area A.

Transects	Direction	No. of sites	Transects	Direction	No. of sites
1	10	14	11	186	2
2	40	23	12	195	2
3	56	10	13	200	2
4	72	8	14	207	1
5	121	1	15	211	1
6	133	2	16	214	1
7	145	2	17	220	4
8	157	2	18	285	5
9	166	2	19	323	7
10	177	2	20	352	8

The sampling procedure in the trees mainly focused on the higher area (h>2.5 m) in the northern sector where the greatest population density of scolytids was found (GONZALEZ, 1990). The terminal 35 cm of 10 randomly chosen branches between 1 and 3 years old were taken off each tree.

Total number of feeding galleries was counted in each branch, and the average density (feeding galleries/branch) was obtained at each sampling site (n=40); this was considered as an indicator of the extent of infestation.

Meteorological record

Meteorological data were obtained from the weather station nearest to the study area which is located at Granada airport (longitude 431 and latitude 411 U.T.M.) and belongs to the National Institute of Meteorology. It lies 10 km southwest of the southern boundary of area 1 and 4 km north of the northern boundary of area 2.

Data were collected for July and August since during this period more than 90% of the young adult *P. scarabaeoides* emerge from the pruned wood (GONZALEZ, 1990) and establish in the grove. The measurements of temperature (°C), relative air humidity (%), wind direction (angle with respect to magnetic north) and wind speed (m/s) were taken 5 times a day beginning at 9h, every 3 hours until 21h.

In order to illustrate graphically the changes of wind direction during the day, data collected at the same time were grouped. The different directions of the wind in the daily observations were represented by radial lines the lengths of which were proportional to the frequency of the wind direction in each. Since the minimum value accurately recordable by the anenometer was 1.5 m/s (5.41 km/h) all values of windspeed below this threshold were recorded as 1 m/s.

Statistical analysis

Gallery density data was first analyzed using the normality test based on the graphical representation of the accumulated frequencies. Chi-squared and Kolmogorov-Smirnov (K-S) tests were applied to compare the frequency distributions obtained with those in a normal distribution. Bartlett and Hartley tests were applied to test for homogeneity of variances within each group.

The difference in population within and between transects was determined by applying the Kruskal-Wallis analysis of variance by ranks.

One-way analysis of variance was used to determine significant differences between trees within each sampling site.

To determine directional influence of the beetle distribution, the density data from individual sampling sites obtained at equal distances from the centre of dispersion were considered.

Regression analysis was used to determine the function giving the best fitting, relating density values with distance from the scolytid's centre of dispersion.

Multiple comparison of means was carried out by first applying multiple range analysis in order to group the sampling sites according to similar population density values. After these statistical groups had been established we observed that some of the average density values were present in two groups. So as to avoid overlapping of contiguous groups, the intermediate categories confining similar densities were eliminated. Sampling sites whose means belonged to 2 groups were included in the group defined by the greater average density.

To determine whether the wind was randomly or significantly directed, data recorded at the same time of day were grouped together monthly and the frequency distributions were compared with a discrete uniform distribution using the Kolmogorov-Smirnov test. Two-way analysis of variance was applied to determine differences of wind speed from different months and different times of day.

RESULTS

Meteorological study

Both temperature and relative humidity varied greatly throughout the day. Temperatures between 18°C and 28°C were recorded at 9h in July with average values ranging from 23°C to 25°C. Maximum temperatures were recorded at 15h with values ranging from 25°C to 42°C and averages from 32°C to 35°C.

Relative air humidity values at 9h oscillated from 40% to 85% and average monthly values were between 60% and 70%. After this time and up to 15h relative humidity decreased greatly, with daily averages between 22% and 32% and minimum values between 7% (July 1987) and 18% (July 1988).

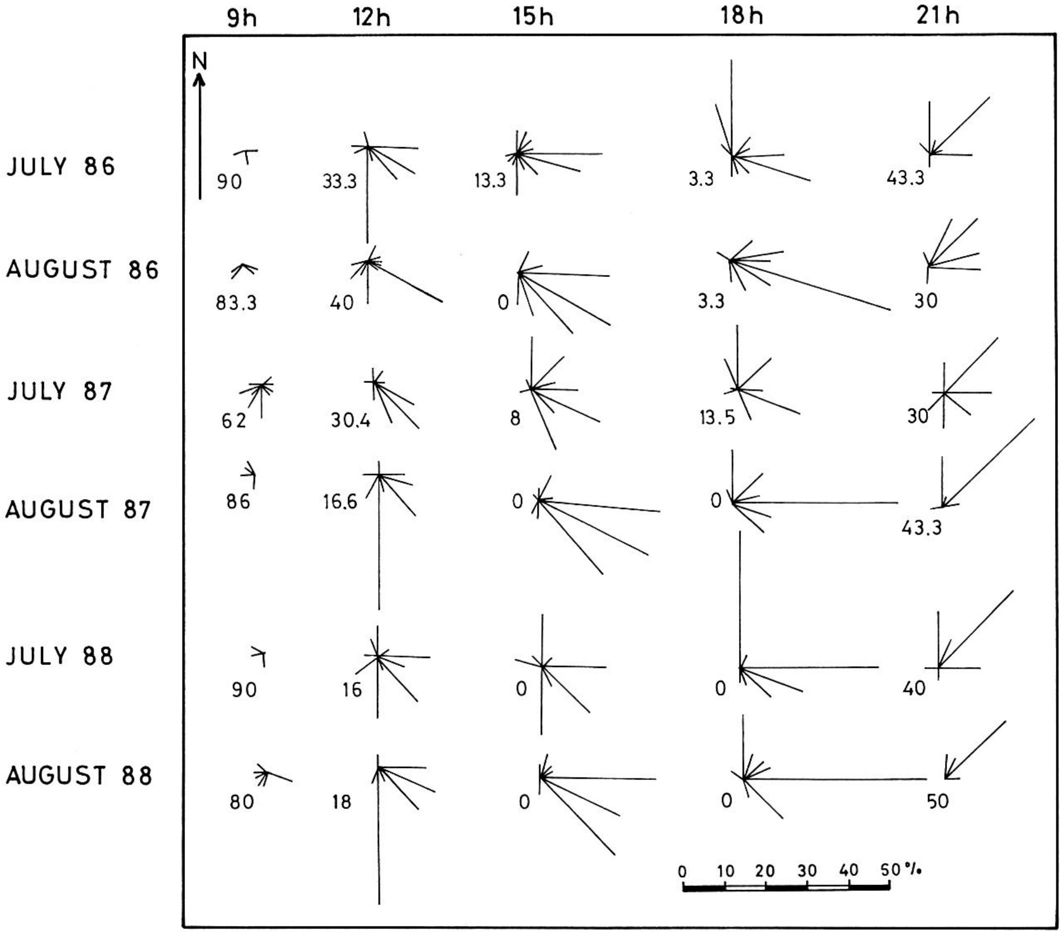

Fig. 2. Frequencies of the wind directions recorded throughout the day and grouped together to give monthly values. The number in the bottom left-hand angle represents the frequencies at which velocities lower than 1.5 m/s were observed.

A specific wind direction dominates at each hour of the day (K-S test, $p<0.001$). In the data recorded at 9h, N, NE and NNE were all equally dominant each making up 15% of the total with E reaching 10% (Fig. 2). At 12h, although northerly winds were still dominant (N in 21%) there was a change in the principal component towards the West (NNW in 10.8%, NW in 18.62% and WNW in 14.7%). Tendencies from the West were also observed at 15h and 18h with values of WNW (24.81%), W (18%) and NW (9.48%) at 15h, and at 18h NNW (25.35%), W (21.36%) and NW (11.11%). At 21h, a trend to the North-East was recorded at all sites, the dominant direction was towards the NE (31.20%) followed by N (15%) and E (13.4%).

Tab. 2. Mean values (±SD) of wind speed recorded at different times of day grouped together by months (data were collected for July and August since during this period more than 90% of the offspring of *P. scarabaeoides* emerge from the pruned wood).

Time (h)	Year	July		August	
		$\overline{X}$	SD	$\overline{X}$	SD
9		1.19	0.64	1.16	0.44
12	1	2.54	1.99	1.87	0.99
15	9	4.12	2.93	4.77	1.75
18	8	5.38	1.92	4.00	1.64
21	6	2.12	1.57	2.25	1.39
9		1.48	0.75	1.29	0.63
12	1	2.90	2.08	3.06	2.46
15	9	4.87	2.36	5.29	2.12
18	8	4.64	2.50	4.74	1.91
21	7	2.50	1.41	2.31	1.70
9		1.45	1.01	1.38	1.42
12	1	3.00	1.86	2.96	2.40
15	9	4.90	2.29	4.38	1.71
18	8	4.93	1.58	4.74	1.39
21	8	1.96	1.13	2.03	1.38

Wind speed varied greatly throughout the day. Tab. 2 shows average monthly wind speeds calculated from daily recordings. Speeds lower than 1.5 m/s were observed mostly at 9h and then at 21h (Fig. 2). No significant difference exist between the values observed in different months or years, although there was a difference at different times of the day (Two-ways ANOVA, $p<0.001$). No significant difference was found between the data recorded at 12h and 15h, however a significant difference among the data belonging to the rest of observations exist (multiple rank analysis, $p<0.05$). Winds were mildest in the morning ($\overline{X} = 1.32$ m/s, s.d. = 0.98 at 9h), after this time wind speed gradually increased until 15h-18h when maximum values were recorded ($\overline{X} = 4.75$ m/s, s.d. = 2.12 at 15h; $\overline{X} = 4.99$ m/s, s.d. = 2.03 at 18h). After 18h a significant decrease was recorded until $\overline{X} = 2.14$ m/s, s.d. = 1.25 at 21h.

Distribution of feeding galleries

Area A. The preliminary data analysis carried out in each transect reveals that the values of gallery density (gal./branch) do not fit a normal distribution (Chi-square test, $p<0.001$ for transects 1 to 4). On the other hand, density values within each site such as those within each tree do have a normal distribution (Chi-square test, $p>0.3$ for sites in transect 1).

Significant differences were found among the density values within transect only when number of sites exceeds 2 (Kruskal-Wallis test: $p<0.001$ for transects 1 to 4).

At the same distance from the centre of dispersion density values between different transects differ greatly, ($p<0.001$ for distances of 200 m, 300 m and 400 m). No significant differences between trees within one site were found, and most of sites showed values of F lower than 0.5 and $p > 0.5$.

Tab. 3. Levels of infestation of *P. scarabaeoides* corresponding to the different categories after multiple comparison of means ($p<0.05$) to data from sampling sites in area A. (To avoid overlapping sampling sites, whose means belonged to 2 groups, were included in the group defined by the greater average density).

Statistical categories	Density range (feeding galleries per sample)
a	< 0.7
b	0.71- 2.00
c	2.01- 5.00
d	5.01- 8.00
e	8.01-10.00
f	10.01-12.00
g	12.01-15.00

The distribution gradient was obtained by grouping together the sites with similar average density values to which multiple comparison was applied. Thirteen statistical categories were obtained, the seven main categories and their respective level of infestation are presented in Tab. 3.

Fig. 3 shows the result of superimposing the bands corresponding to the different categories on the map of the growing area. Examination of the figure reveals that the bands are arranged concentrically around a SW-NE axis (transect 2). This is the only direction where the maximum level of infestation is observed (category *g*), and which is maintained up to 600 m from the centre of dispersion. In this direction the level of infestation decreases more gradually, and category *a* extends to the NE boundary of the crop, 2.3 km from the centre of dispersion.

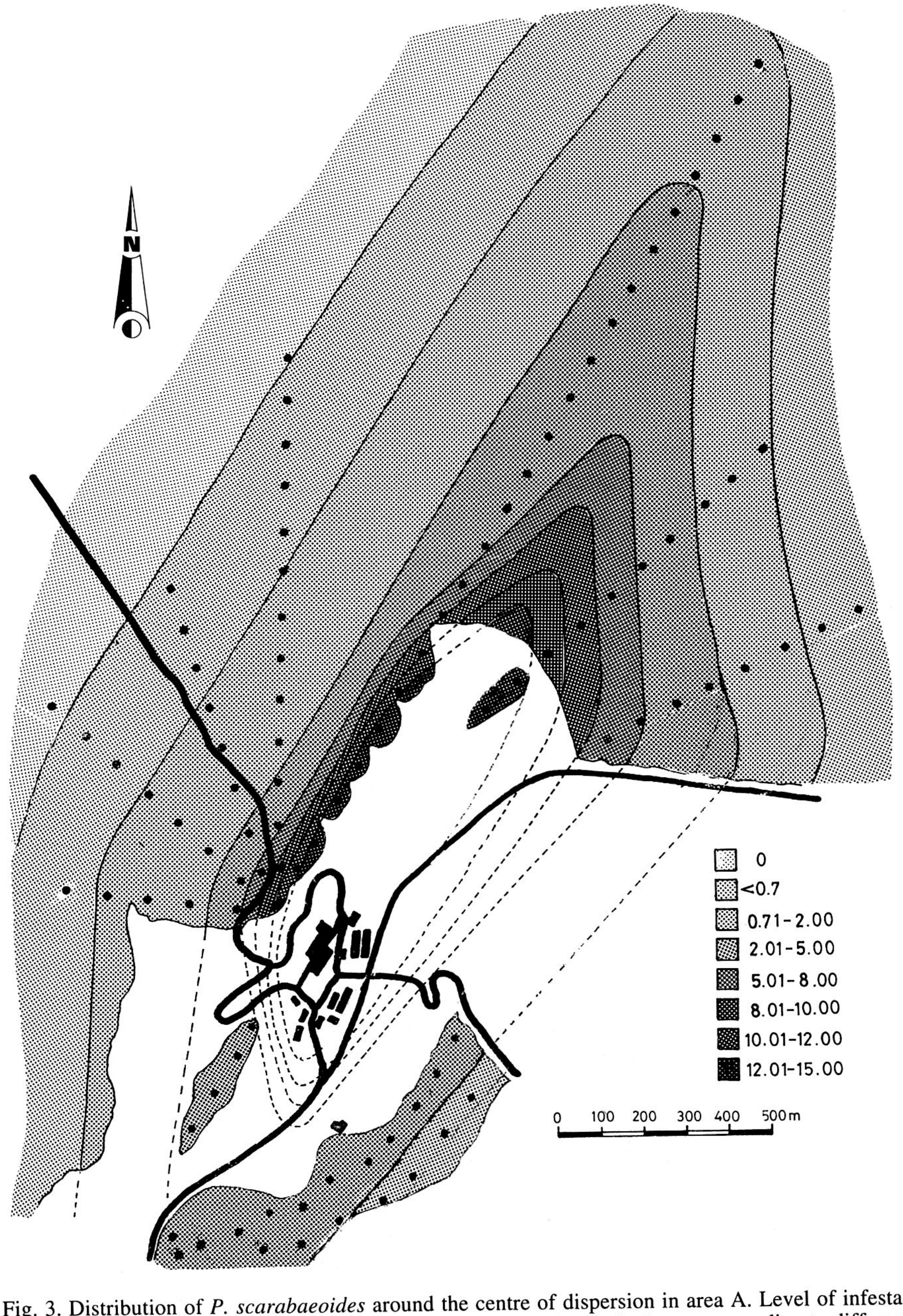

Fig. 3. Distribution of *P. scarabaeoides* around the centre of dispersion in area A. Level of infestation (average of feeding galleries per tree) is indicated by different shades corresponding to different categories described in the text.

On the other hand, the direction perpendicular to the axis (corresponding to transect 19), shows that maximum density decreases with increasing distance from the focus, and the feeding galleries are no longer observed less than 800 m from the focus.

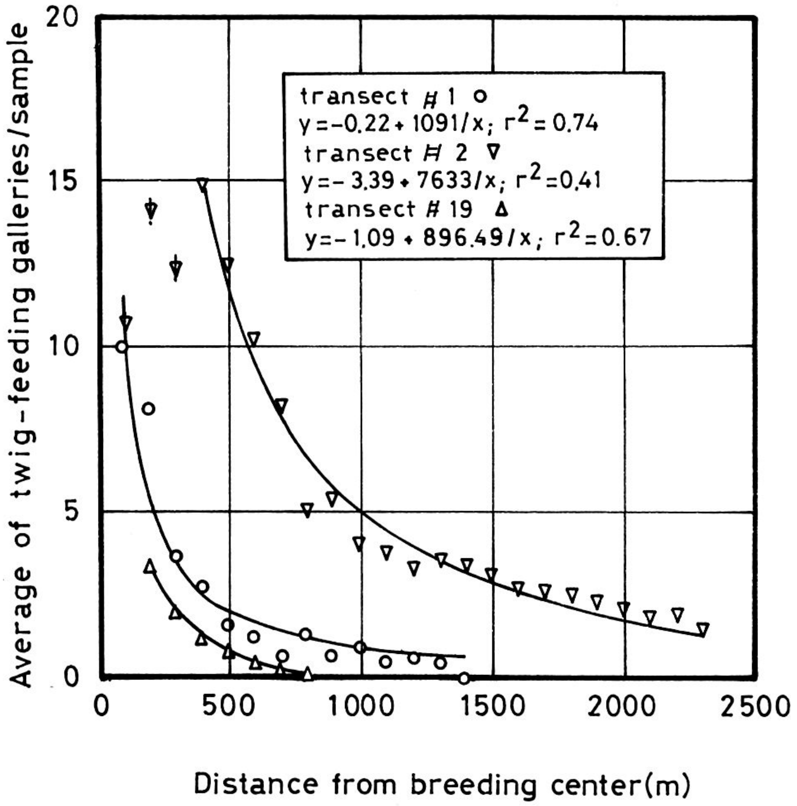

Fig. 4. Polynomial regression curves (y = b + a/x) relating density values (number of *P. scarabaeoides* feeding galleries per sample) and the distance from the centre of dispersion in the transects 1, 2 and 19 in area A. The triangles and the circles indicate the average value per site (values corresponding to sites <400 m from the focus in transect #2 have not been included in the regression).

The relationship between the density of feeding galleries and the distance from the centre of dispersion is shown in Fig. 4, where values corresponding to the three transects, 1, 2 and 19 with the greatest number of observation sites have been used. The data were fitted to the polynomial function type: y = b + a/x (Fig. 4).

Area B. Infestation levels observed in this area were all very low, ranging from 0.2 to 1.4 gal./branch. After the multiple comparison of means, the sites were grouped in the following three categories.

a: average density less than 0.3 gal./sample.

ab: average density between 0.3 and 0.9 gal./sample.

b: average density greater than 0.9 gal./sample.

The limit between categories *a* and *b* was approximately 0.6 gal./branch, a very similar value to that observed in area A. In general infestation level in the area

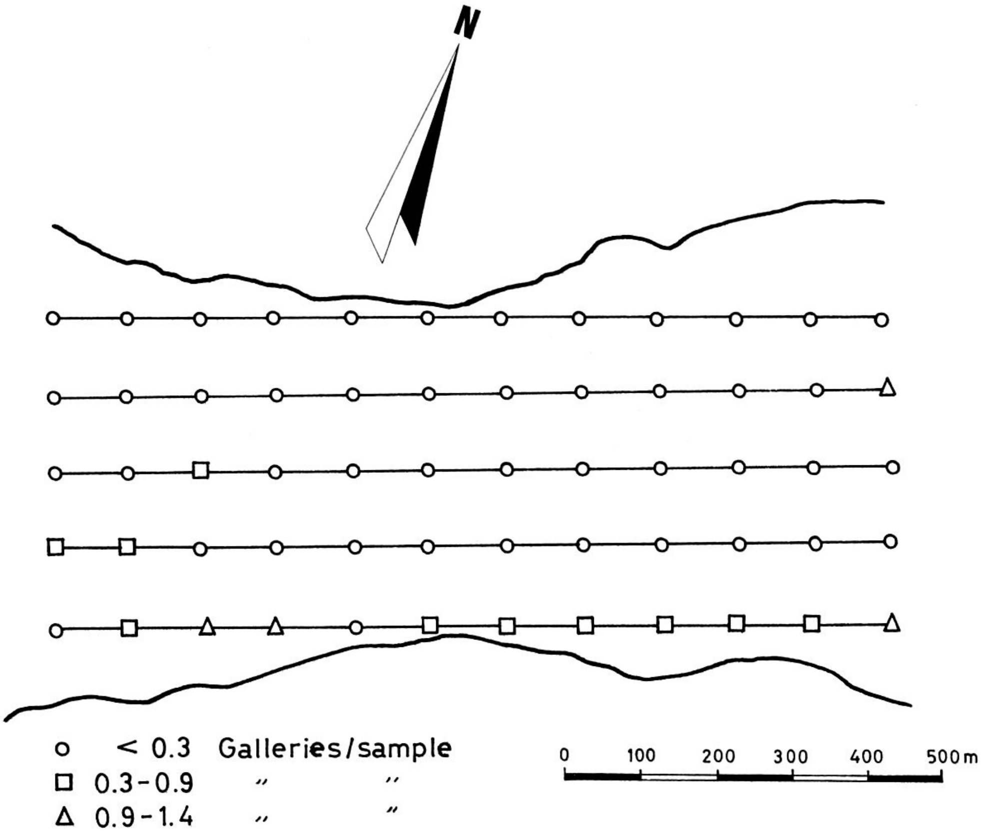

Fig. 5. Infestation levels of *P. scarabaeoides* (average number of galleries per sample) in sites corresponding to the different transects in area B.

was very uniform (Fig. 5) and at the majority of sites (70%) average values corresponded to category *a*.

Most of the sites revealing infestation levels *ab* and *b* were in transect 1 thus situated along the southern edge of the crop. In spite of this, examination of the results showed no statistically significant difference between transects (p=0.835). Therefore a clear trend of decreased infestation level in the tree with increasing distance from the centre of dispersion was not observed.

DISCUSSION

The results obtained for the two crop growing areas subjected to different conditions highly complement each other. Although an inverse relationship is found in area A between gallery density and the distance from the centre (d < 2.5 km) in area B infestation level in the trees seems to stabilize at distances from the centre greater than 2.5 km. According to the results, some beetles can colonize trees located at least up to 3.5 km from the focus, however we do not have accurate data to estimate the maximum distance in a single flight from the breeding center.

The influence of distance on decrease in infestation level has been observed in distribution studies carried out on other scolytid species such as *Tomicus piniperda* (Sauvard *et al.*, 1987), *Scolytus multistriatus* (Wadley, 1944; Ander-

BRANDT & SCHLYTER, 1987), *Leperisinus varius* (LOZANO & CAMPOS, 1991). In the former species, decrease in scolytid population density is produced very rapidly with increase in the distance from the centre of the focus of infestation, and data fits a potential equation. In the distribution studies on *S. multistriatus* (WADLEY, 1944) this decrease fits a logarithmic function and also indicates that no directional influence on the spatial distribution of the beetles occurs. Our results are in agreement with both these studies, since the infestation level decreases in a curvilinear manner, although *P. scarabaeoides* differs from these species in that its best fit is achieved with a polynomial function.

The main difference between our study and those undertaken on *S. multistriatus* lies in the existence of a directional influence on the spatial distribution of the population in the former. To interpret the directional trend we must also take into account environmental factors which influence the biological state of activity and suitable flight conditions (temperature, relative humidity, wind speed) as well as the influence of wind direction of the orientation of the flight. According to studies carried out by CHARARAS (1962) the insect activity is strongly dependent on temperature with the optimum between 18°C and 29°C. Dispersion flight takes place between 16°C and 18°C. The minimum temperature for dispersion flight in the olive bark beetle is 17°C (GONZALEZ, 1990); emergence of the young adults from the pruned wood, however, only occurs when the temperature is greater than 19°C. Along the emergence period this occurs from 9h and therefore the first emerging beetles to emerge during the day may begin their flight immediately after emergence. According to our own observations the majority of daily emergences of *P. scarabaeoides* take place between 12 and 16h, during which time interval the average daily temperature exceeds 30°C and relative air humidity decreases below 30%, which are not favourable conditions for dispersion of the beetles.

Wind speed may also strongly influence the beginning of scolytid flight. Average speeds are maximum (x=4.74 m/s) during the period of maximum *P. scarabaeoides* emergence (12h to 15h), and the insect take-off could become unfavourable because of the strong wind speed.

In addition to the temperature decrease below 30°C after 18h, wind speed also significantly decreases at this time, and relative humidity increases over 30%-40%. The dominant wind direction (SW - NE) coincides with the direction where the highest levels of population are found. This suggests that an important proportion of beetles could have a tendency to fly after 18h in a down-wind direction, however further research is needed in order to confirm this statement.

The hypothesis we put forward was consistent with the studies undertaken by SALOM & MCLEAN (1989) on *Trypodendron lineatum*, who indicated that at high wind speeds (>1.5 km/h) a directional trend down-wind in the insect flight was observed.

Both chemical and visual stimuli are involved in the landing response of scolytids (GIL *et al.*, 1985). According to our results, beetles tend to colonize the trees on the edge of the crop, thus explaining the higher population density there. On the other hand, the results from area A suggest that a population density regulation mechanism exists inside the tree. The existence of a band more than 500 m long in which density is independent of distance from the focus could be due to there being a maximum threshold population in the trees, above which the installation of newly emerged beetles would be inhibited. These would have to colonize less populated areas further away from the centre of dispersion. This hypothesis is in agreement with the studies of SAUVARD *et al.* (1987) on *Tomicus piniperda* in which these authors have reported the existence of a maximum population level tolerable for this scolytid.

CONCLUSIONS

Distance from the centre of dispersion is shown to be an important factor influencing population density changes in the spatial distribution of *P. scarabaeoides*. The decrease in density is curvilinear, and best fits a polynomial function of the $y = b + a/x$ type.

There is a directional trend in the spatial distribution in the cultivated area which may be caused by the dominant wind direction, since we would expect the insect to fly mainly down-wind when searching for a host tree.

In the direction where maximum dispersion occurs, the insects may cover distances of at least 3.5 km from the centre of dispersion. At this distance the infestation level in the trees begins to stabilize at a low level.

Knowledge of spatial variation in the insect population density will be necessary in order to investigate the relationship between infestation level and crop loss in different areas. These studies are being conducted presently which in turn will be of great use in determining the threshold population economically tolerable.

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RÉSUMÉ

Le neiroun, *Phloeotribus scarabaeoides* (BERN.), est considéré actuellement comme un des principaux insectes ravageurs de l'olivier. L'étude de la répartition spatiale de ses attaques (morsures nutriciales) dans la zone de culture a été réalisée a l'aide des transects linéaires sur deux sites de la province de Granada (Espagne). Dans le premier site, le bois de taille était traditionnellement stocké près de la zone de culture, tandis que dans le deuxième, le bois de taille était régulièrement écarté de l'olivier durant la saison.
Dans chacun des sites, les attaques de *P. scarabaeoides* ont été constatées jusqu'au 2.3 km et 3.5 km respectivement du centre d'infestation. Les résultats montrent que le niveau d'infestation dans les arbres est très influencé par la distance au centre de dispersion, et que la répartition des attaques autour du foyer suit une fonction du type: $y= a + b/x$.
On observe une tendance directionelle dans la distribution spatiale des attaques autour du foyer. Pour interpréter ces resultats, l'effet des conditions environnementales (variation journalière, température et humidite relative) sur l'activité des insectes, ainsi que de l'influence de la vitesse et la direction du vent durant la période d'émergence sur la direction du vol des scolytes sont discutés.

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