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Research Article

Spatial mapping of the common pistachio psylla, *Agonoscena pistaciae*: A case study in the Rafsanjan region, Iran

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Abstract: The common pistachio psylla *Agonoscena pistaciae* is a key pest of pistachio in Iran. A study was conducted to determine the spatial distribution of psylla nymphs and eggs in a 10 ha pistachio orchard in the Rafsanjan region, southeast of Iran. Three rows, each containing 33 trees (totally 99 trees), were randomly selected in the orchard based on a stratified sampling scheme. In each of the selected trees, three positions in the crown (top, middle and bottom) were considered. One leaf from each position as sampling unit (totally 297 samples) was clipped and number of nymphs and eggs were counted. Ordinary kriged maps were achieved for nymphs and eggs of the three positions using a variogram function. Results indicated the highest and lowest density of the nymphs occurred on the top and bottom positions of the crown, respectively. Eggs of the common pistachio psylla were laid mostly on the bottom of the pistachio crown.

Keywords: *Agonoscena pistaciae*, geostatistics, kriging, pistachio, Rafsanjan

Introduction

The common pistachio psylla, *Agonoscena pistaciae* Burckhardt and Lauterer (Hemiptera: Psyllidae) is a serious pest on pistachio in Iran. This species is widely distributed throughout the pistachio growing areas of Iran, especially in Rafsanjan. In autumn, the adult insects enter diapause under the loose bark on the trunks of pistachio trees, and in soil and under leaves where they overwinter. This pest has a multivoltine life cycle throughout Iran (Mehrnejad, 2003). This pest has two seasonal forms. The winter-form psyllids appear in early October and emigrate towards the overwintering shelters and attack pistachio trees in the late winter and early spring, feed on swollen buds, young leaves and shoots and establish the summer form generation. The insect lays her eggs mainly on the upper surface of the pistachio leaves, but egg laying on the petiole of tender leaves and young succulent plant shoots was observed as well (Mehrnejad 2003).

Spatial distribution is one of the most characteristic ecological properties of the species. Unlike rates of growth and reproduction, which often vary more between generations within a species than they do between species, spatial distribution yields characteristic parameters that segregate species. The spatial patterns of insects are no less specific (Taylor, 1984).

Historically, studies of insect's population biology have concentrated on changes through time, but patterns across spatial dimensions remain largely unexplored. Some studies have attempted to quantify spatial variation in populations with the use of indices of dispersion

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(Taylor, 1984) but these methods often fail to distinguish among different spatial patterns. The major impediments to research on spatial processes in insect ecology have thus been the lack of adequate analytical and data management tools. Recent development of two technologies has opened up new avenues for analyzing spatial patterns in insect populations: (i) geographical information systems (GIS) and (ii) geostatistics (Liebhold *et al*., 1993). Geostatistics is a branch of applied statistic that affords the opportunity to study spatial processes explicitly by recognizing the spatial variation at different scales (Cressie, 1993). It can quantify an unknown value, produce a map, validate sampling strategy, and so improve sampling (Oliver and Webster, 1991).

To improve pest management strategies, it is important to predict the abundance and distribution of the pest population (Trematerra *et al*., 2007). Accurate monitoring is therefore needed and that is why spatial analysis techniques, such as geostatistics, are increasingly being used in entomology (Liebhold *et al.*, 1993; Trematerra and Sciarretta, 2004).

The main purpose of this study is to determine the spatial distribution of nymphs and eggs of *Agonoscena pistaciae* in a pistachio orchard in the Rafsanjan region, Kerman province, Iran.

Materials and Methods

Site description

Experimental site is a pistachio orchard, approximately 10 ha, located between 30° 22' 36.5" and 30° 22' 52.5" N, and 55° 55' 55.7" and 55° 56' 10" E in the Rafsanjan region, Kerman province, southeast Iran (Fig. 1). Pistachio trees with average age of about 20 years were apart in rows by 1.5 and 3 m. The mean annual precipitation and temperature in the study area are 80.3 mm and 18.4 °C, respectively. The mean altitude of the area is 1450 m a.s.l.

Data collection

Three rows, each containing 33 trees (totally 99 trees), were randomly selected in the orchard based on a stratified sampling scheme (Fig. 1). On each of the selected trees, three positions in the crown (top, middle and bottom) were considered. One leaf from each position as sampling unit (totally 297 samples) was clipped and number of nymphs and eggs were counted.

The geographical position of each sampled tree was determined by a Global Positioning System (GPS).

Geostatistical analysis

Before applying the geostatistical tests, each variable was checked for normality, trend, and anisotropy (Goovaerts, 1997). The degree of spatial variability for each variable was then determined by geostatistical methods using variogram analysis, kriging, and autocorrelation (Trangmar *et al.*, 1985; Bailey and Gatrell, 1995; McBratney and Pringle, 1999).

An experimental variogram was determined for common pistachio psylla to ascertain the degree of spatial variability between neighboring observations according to the method described by Isaaks and Srivastava (1989):

$$\gamma_{(h)} = \frac{1}{2N_{(h)}} \sum_{i=1}^{N_{(h)}} [Z_{(x_i)} - Z_{(x_i+h)}]^2 \qquad (1)$$

Where $\gamma_{(h)}$ is the experimental semi-variance value at distance interval h; $Z_{(xi)}$ is the measured sample value at sample point x_i, in which there are data at x_i and x_{i+h}; and $N_{(h)}$ is the total number of sample pairs within the distance h.

Through analysis of the variogram, the best theoretical model (e.g., spherical, exponential, or Gaussian) and its parameters (nugget, sill, and range) were determined (Webster and Oliver, 2001; Li and Heap, 2008). In the present study, ordinary kriging (Goovaerts, 1997) was selected to create spatial distribution maps of the variables. Ordinary kriging is by far the most popular kind of kriging, and with good reason: it serves well in most situations with its assumptions easily satisfied (Oliver and Webster, 2015). It requires no other information than that plus the measurements and their geographic coordinates. It is also robust with regard to moderate departures from those assumptions, and therefore we focused on it.

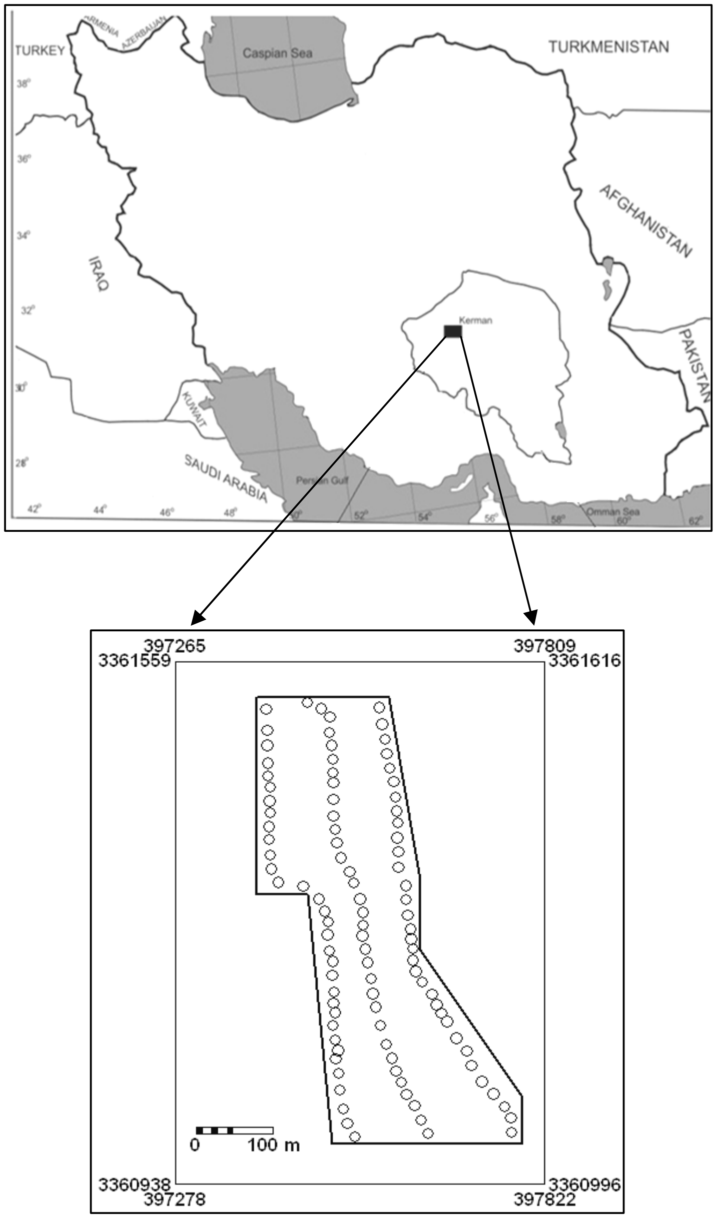

Figure 1 Location of the experimental orchard along with trees sampled in Rafsanjan area, Kerman province, Iran.

To check the validity of fitted models and to compare values estimated from the variogram models with actual values, some error measurements can be used. One of the most commonly used indices is RMSE, i.e. Root Mean Square Error (Li and Heap, 2008). RMSE indicates the absolute estimation errors and is calculated as follows:

$$RMSE = \sqrt{\frac{\sum (x' - x)^2}{n}} \qquad (2)$$

Where x is the observed value; x', the estimated value; and n, the number of observations.

Geostatistical analyses, cross-validation and kriging were conducted on measured and calculated variables using the VARIOWIN 2.2 software (Pannatier, 1996) and GEOEAS 1.2.1 (GEOEAS 1991), and contour maps were generated using Surfer 7.0 (Golden Software Inc. 1999).

Results and Discussion

Statistical description of the studied samples is given in Table 1. The results indicated significant differences in nymphs and eggs densities of the pest at different positions of the crown. The mean values in the Table 1 show the highest and lowest density of the psylla nymphs on the top and bottom positions of the crown, respectively. One of the fundamental ecological requirements of cold-blooded animals, including insects, is temperature and environmental condition for their survival. In addition, sufficient heat is needed to complete growth from birth to adulthood (Messenger, 1959; Messenger, 1969). Sun and shade environments place markedly different constraints on the photosynthetic performance of plants (Pearcy *et al*., 2005). Upper leaves are more effectively exposed to sunshine and therefore the upper region of the tree receives more sunlight and is made up of fresh leaves, twigs and branches. So, local changes in nutrient concentration among the leaves that are expected in turn to affect densities of the psylla nymphs. Moreover, in the upper parts of the trees the stylet of growing nymphs penetrates more easily into the leaf tissue and receives more food from the tree and more energy from sunlight.

Diurnal and seasonal changes in physical conditions through the canopy affect the physiological reactions of trees. Results of this study showed that the nymphs crowded at eastern and northern edges of orchard where borderline walls provided refuge against the wind. Andrewartha and Birch (1954) in study of climate's effects on *Thrips imagines* (Thysanoptera) expressed that weather condition is the only factor for controlling density of the trips. Some ecologists believe density-independent factors such as weather, including wind, control the insect's population (Andrewartha and Birch, 1954; Milne, 1957).

Results also indicated that eggs of the common pistachio psylla were laid mostly at the bottom of the pistachio crown (Table 2 and Fig. 3). Most of the trees have two types of leaves, i.e. sun leaves and shade leaves (Koike *et al*., 2001). Sun leaves are small, with small surface, which reduces the area of exposure to sun and wind. A shade leaf is large, with greater surface exposed to sun. These leaves receive indirect radiation because of shading by other leaves. Laying eggs on these leaves prevent eggs from desiccation.

High values of skewness, kurtosis and coefficient of variation (CV) indicated that data did not have normal distribution. Although normality is not a pre-requisite for kriging, it is a desirable property. Journel and Huijbregts (1978) stated that kriging would only generate the best absolute estimate if the random function fits a normal distribution. Thus, performing the logarithmic transformation provided both normality of the data and homoscedasticity of the variances.

The spatial dependence of nymphs and eggs density was modeled using analysis of semi-variance (Table 2 and Fig. 2). However, spatial dependencies were differing between both crown positions and developmental stages of the insect, as illustrated by the nugget, sill and range values (Table 2). Variograms of all variables, i.e., the nymphs and eggs of each crown position, were adjusted best to spherical and exponential models and ranged from 40 to 175 m (Table 2 and Fig. 2). Although the ranges were different, a sampling distance for nymphs equal to 298.2 m, for eggs equal to 275.2 m and for eggs + nymphs equal to 573.4 m are reasonable distances for study of the variables, i.e., the nymphs and eggs of each crown position, in the area. These distances could be used for decreasing the numbers of samples for monitoring of these variables in the future.

The nugget/sill (N/S) ratios as characteristics of the strength in spatial structure of the data ranged from 0.29 to 0.63 (Table 2). According to Cambardella *et al.* (1994) and Kravchenko (2003), this corresponds to a moderate spatial structure, that is 29 to 63 % of the data variability consisted of unexplainable, short distance, random variation. The N/S ratios of the variograms generally ranged from 0.01 to 1.0 (Cambardella and Karlen, 1999, Chang *et al*., 1999, Mueller *et al*., 2001). Most of the variograms having N/S ratios ranged from 0.1 to 0.6, is similar to our study.

The cross-validation statistic shows how well densities of nymphs and eggs can be estimated by application of the ordinary kriging method (Davis, 1987). RMSEs for all samples are nearly the same, although transformation slightly reduced RMSEs (Table 2) (Mueller *et al*., 2001).

It was concluded that pistachio psylla females tend to oviposit at bottom of pistachio crown probably due to enhanced egg survival; nevertheless, nymphs disperse upward to access higher quality younger leaves and sunlight.

Table 1 Descriptive statistics for nymphs and eggs densities of the common pistachio psylla in three positions of the crown.

Developmental stage	Min	Max	Mean	Median	Std. Deviation	CV (%)	Skewness	Kurtosis
Nymph (top)	4	315	57.5	36	62.2	108.2	1.7	3.1
Nymph (middle)	4	165	27.1	13	31.3	115.5	1.9	4.1
Nymph (bottom)	0	99	15.4	9	18.3	118.8	2.0	5.1
Egg (top)	0	561	28.4	15	73.4	258.5	6.3	42.1
Egg (middle)	0	169	11.5	7	22.7	197.4	5.2	30.1
Egg (bottom)	2	42	5.3	4	5.6	105.7	3.9	20.0

Table 2 Variogram models, interpolation parameters and cross validation statistics for nymphs and eggs densities of the common pistachio psylla on three strata of pistachio.

Developmental stage	Model	Nugget	Range (m)	Sill	Nugget/Sill	RMSE[1]
Nymph (top)	Spherical	0.086	58.0	0.220	0.39	0.576
Nymph (middle)	Spherical	0.113	66.1	0.191	0.59	0.560
Nymph (bottom)	Exponential	0.111	174.1	0.265	0.42	0.593
Egg (top)	Exponential	0.120	77.6	0.190	0.63	0.652
Egg (middle)	Exponential	0.039	40.1	0.134	0.29	0.531
Egg (bottom)	Exponential	0.046	157.5	0.146	0.31	0.574

[1] Root Mean Square Error.

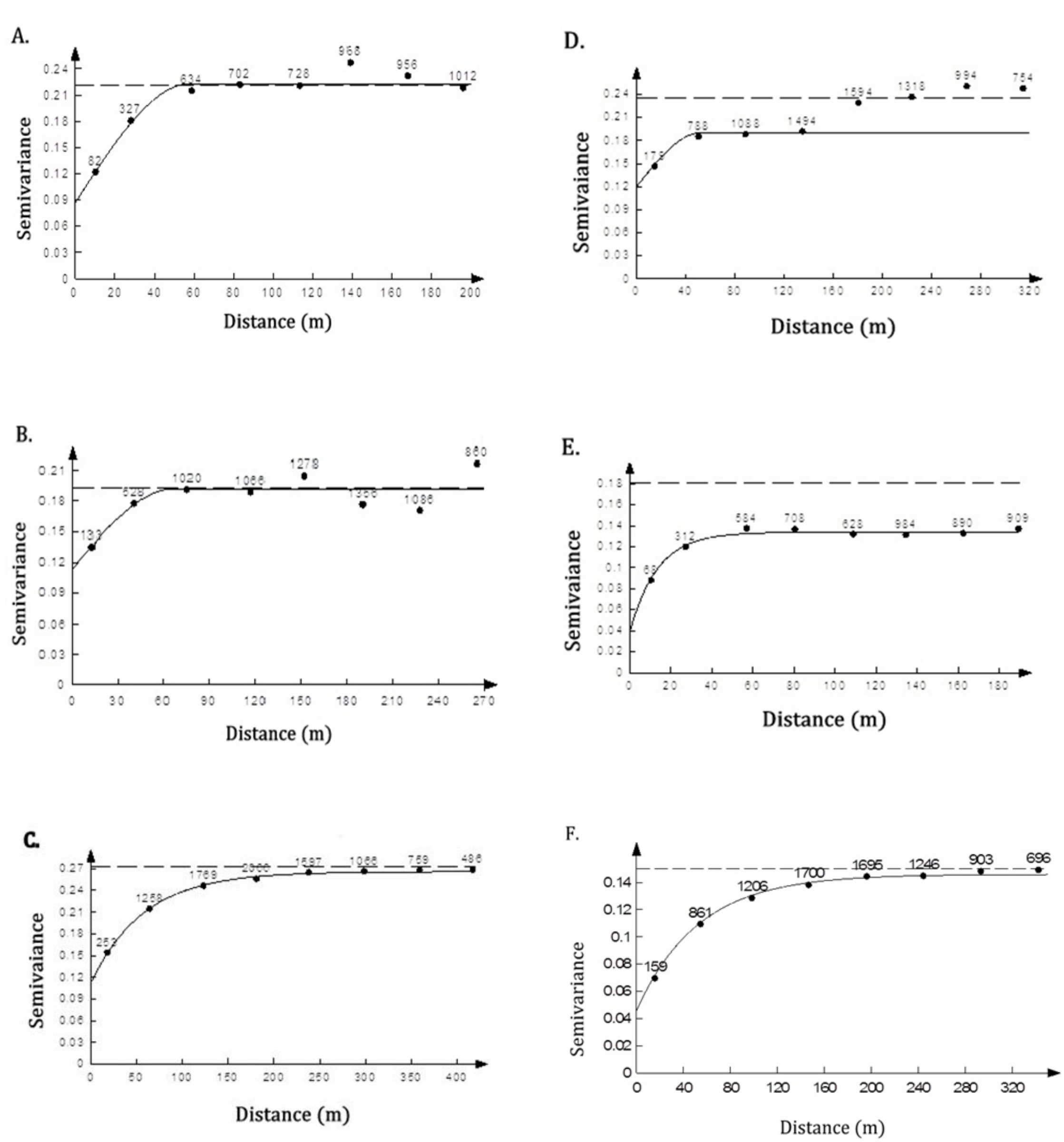

Figure 2 Variograms for nymphs and eggs densities of common pistachio psylla on three crown positions of pistachio trees. (A) Nymphs at the top of crown. (B) Nymphs of middle position. (C) Nymphs of bottom position. (D) Eggs of up position. (E) Eggs of middle position. (F) Eggs of bottom position.

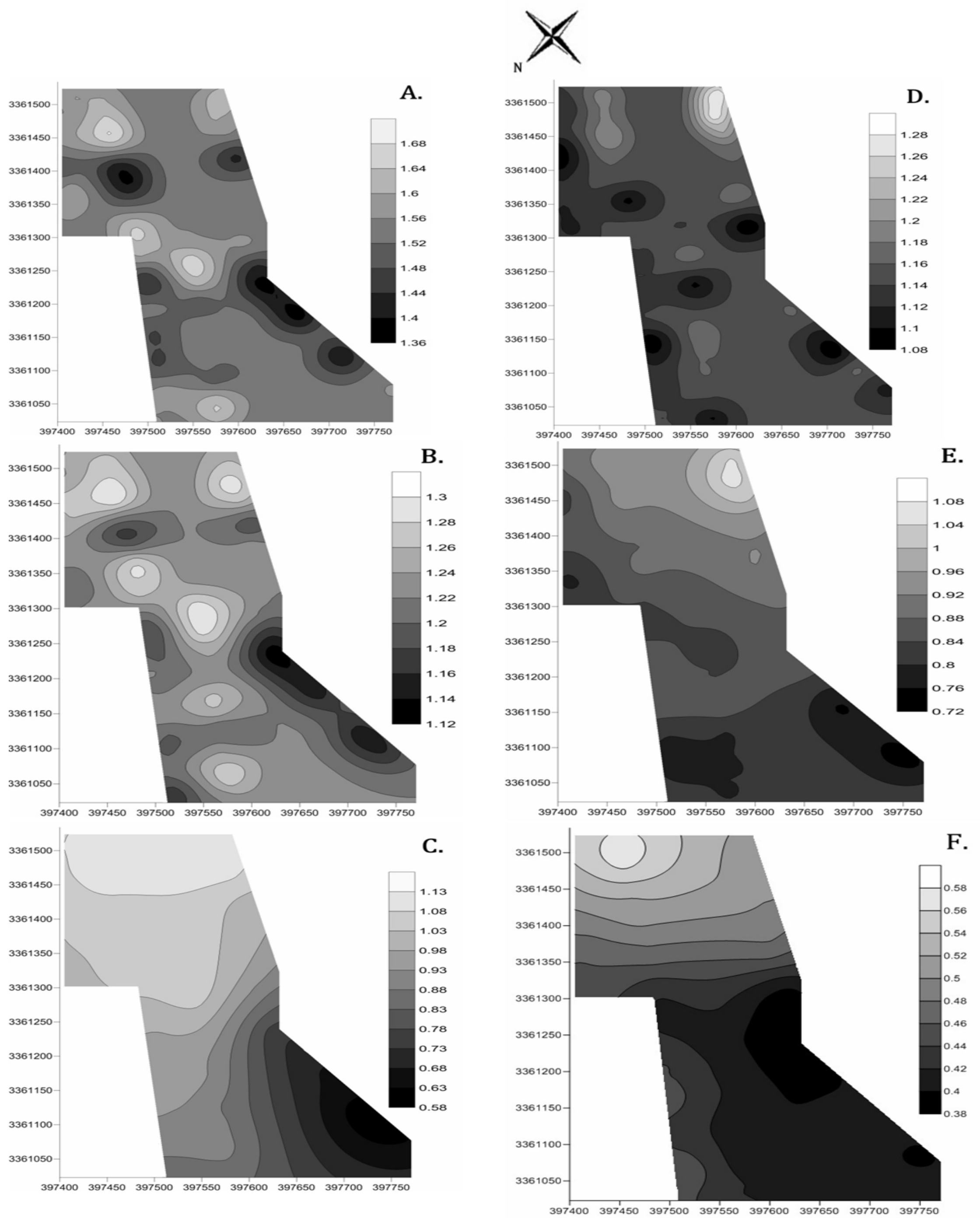

Figure 3 Kriging maps for nymphs and eggs densities of the common pistachio psylla on three crown positions of pistachio trees. (A) Nymphs at the top of crown. (B) Nymphs of middle position. (C) Nymphs of bottom position. (D) Eggs of up position. (E) Eggs of middle position. (F) Eggs of bottom position.

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پهنه‌بندی مکانی پسیل معمولی پسته، *Agonoscena pistaciae*: یک مطالعه موردی در منطقه رفسنجان، ایران

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چکیده: پسیل معمولی پسته *Agonoscena pistaciae* از آفات درجه اول و کلیدی پسته در ایران است. این مطالعه به‌منظور تعیین پراکنش مکانی پوره‌ها و تخم این آفت در یک باغ ۱۰ هکتاری در منطقه رفسنجان، در جنوب‌شرق ایران انجام شد. سه ردیف، هر کدام شامل ۳۳ درخت (در مجموع، ۹۹ درخت) به‌طور تصادفی و براساس یک الگوی نمونه‌برداری طبقه‌بندی‌شده انتخاب شد. در هر کدام از درخت‌های انتخاب شده، سه موقعیت مختلف در تاج هر درخت (بالا، وسط و پایین) انتخاب گردید. از هر موقعیت، یک برگ به‌عنوان واحد نمونه‌برداری (در مجموع، ۲۹۷ نمونه) جدا شد و تعداد پوره‌ها و تخم‌های روی آن شمرده شد. نقشه‌های کریجینگ معمولی با استفاده از تابع واریوگرام برای پوره‌ها و تخم‌های موجود در موقعیت‌های سه‌گانه مزبور ترسیم گردید. نتایج نشان داد که بیش‌ترین و کم‌ترین تراکم پوره به‌ترتیب در موقعیت‌های بالا و پایین تاج درخت وجود داشت. بیش‌ترین تراکم تخم پسیل معمولی پسته، عمدتاً در موقعیت پایین تاج درختان پسته مشاهده شد.

واژگان کلیدی: پسیل پسته، زمین آمار، کریجینگ، پسته، رفسنجان