J. Agr. Sci. Tech. (2022) Vol. 24(1): 107-122

Bioecology and Spatial Distribution of the Pistachio Leafhopper, *Idiocerus stali* Fieber (Hemiptera: Cicadellidae) in Pistachio Orchards

A. Jamshidi[1*], H. A. Vahedi[1], A. A. Zamani[1], and B. Farhadi Bansooleh[2]

ABSTRACT

Worldwide, Iran is the first producer of pistachio, which is one of the most economically important agricultural products for this country. *Idiocerus stali* Fieber (Hemiptera: Cicadellidae) is one of the most important pests of this plant. Adults and nymphs pest feed on leaf tissues and fruit clusters, and they cause damage by sucking the sap. This pest has one generation per year. In this research, population fluctuations of the pistachio leafhopper associated to the temperature and humidity changes and its spatial distribution, using both statistical and geostatistical methods were studied in 2018-2019. The spatial distribution of all life stages in both years was cumulative according to Iwao model, whereas considering Taylor's power law model it was cumulative in 2018 and random in 2019. Considering coefficients' values, both models of Taylor's power law (R^2= 0.93) and Iwao model (R^2= 0.92) are appropriate for estimating the type of spatial distribution for this pest, however, Taylor model showed a better data fitting. Concerning geostatistics models, Kriging interpolation method was more accurate than Inverse Distance Weighting (IDW) and it was used to produce pest distribution maps. The movement process of adults, nymphs, and the sites of laying areas per week was precisely determined. Hence, contamination *foci* can be identified and used to apply appropriate management methods at the right time at a low cost.

Keywords: Geostatistics, IPM, Iwao model, Kriging, Taylor's power law.

INTRODUCTION

Pistachio (*Pistacia vera* L., Anacardiaceae) is one of the indigenous products in Iran with the highest export and economic value (Abrishami, 1994). Currently, Iran is the first largest pistachio producer with 551307 tons per year (FAO, 2018). The pistachio leafhopper, *Idiocerus stali* Fieber (Hemiptera: Cicadellidae) is one of the important pests of pistachio trees which reduces pistachio production by feeding on the sap, making the tree weak and susceptible to attack by other pests and diseases.

Adult overwintering leafhopper are the same color as pistachio tree bark and females lay one or two eggs after the growth of tree buds, under the bark of petiole or the tail of cluster. This species has four nymphal instars and one generation per year, and 70-100 eggs per adult are laid (Zenouzi, 1958).

Another study was conducted on *I. stali* biology in Qazvin Province. The results indicated that the emergence of overwintering adults occurred from the second week of April, and hatching begins

[1] Department of Plant Protection, College of Agriculture, Razi University, Kermanshah, Islamic Republic of Iran.
[2] Department of Water Engineering, College of Agriculture, Razi University, Kermanshah, Islamic Republic of Iran.
*Corresponding author; e-mail: jamshidi.ar@razi.ac.ir

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

in the third week of April. The emergence of nymphs occurred since mid-May and the emergence of new generation leafhopper since mid-June. The average damage to each cluster was 79.1% (Jalilvand and Kashanizadeh, 2013).

In Greece, it was reported that high populations of the pistachio leafhopper cause the burning of young clusters and atrophy of leaves (Mourikis *et al*., 1998).

Another study conducted on pistachio pests in Turkey stated that overwintering adults of *I. stali* were observed from the first week of March until the buds were opened, especially on sunny days. Nymphs appeared from the second week of May, and they increased in number until the end of May. Adult appeared on the first week of June (Yanik and Yucel, 2001).

Due to the significance of this pest on pistachio trees and the fact that very little information about this pest is presently available, it is essential to study its different biological and ecological aspects. In this research, field biology and population fluctuations as well as the spatial distribution pattern of pistachio leafhopper were investigated using classical and geostatistical methods.

MATERIALS AND METHODS

This research was done in the 18-hectare pistachio garden of the Faculty of Agriculture, Razi University of Kermanshah (34˚ 19’ 30.24’’ N - 47˚ 05’ 55.71’’ E and 1,200 meters above sea level) from 2018 to 2019. The distance between trees was five meters. Sampling of leafhopper population was investigated from 4 March to 4 November in 2018 and from 3 March to 3 November in 2019. To investigate pistachio leafhopper's life cycle, 60 branches about 20 cm long containing several leafhopper's eggs were selected and enclosed by a net and checked every day, and the life span of the pest was recorded.

To investigate the population fluctuations of pistachio leafhopper, different pest life stages were regularly sampled every week. In 2018, 50 pistachio trees were selected with a regular arrangement in five rows out of 10. One branch was selected on each tree at two heights of 1.5, and 2.5 m above the ground in four main directions, and its tip (the last 20 cm) was carefully examined, and the number of eggs, nymphs, and adults were counted and recorded. All four branches in the four major geographical directions at every elevation were considered as a single sampling unit. The selected 20 cm shoots were marked, and the same shoots were examined weekly. In 2019, 50 pistachio trees were randomly selected: on each tree, four 20 cm long branches were marked, and the number of eggs, nymphs, and adults were counted and recorded.

Geographical coordinates (latitude and longitude due to UTM) of 50 trees selected in 2018 and 2019 were provided using GPS for drawing Kriging and IDW maps. The extracted information was prepared as an Excel file to be able to transfer to ArcGIS software after measuring the pest density and determining the location's geographical coordinates.

Taylor and Iwao's regressions were used to determine the pest's spatial distribution pattern at different life stages.

Regarding Taylor power law, there is a relation between the population variance (S^2) and the average population density ($\bar{x}$).

$$S^2 = a\,\bar{x}^b \qquad (1)$$

To convert the above equation to a linear relationship and calculate the coefficients (a) and (b), the sides of Equation (1) are multiplied by logarithm, and the following equation is obtained:

$$\mathrm{Log}\,(s^2) = \log(a) + b\,\log(\bar{x}) \qquad (2)$$

Where, a: Width from an origin, which depends on sample size, and b: The line slope is an indicator of population distribution type.

The values smaller, equal, and larger than the slope of the line show, respectively, uniform, random, and cumulative distributions (Arlando and Torres, 2005).

Iwao index is a regression relationship between Lloyd's mean crowding (m*) and the mean of the population ($\bar{x}$) calculated as the following equation.

$$\bar{x}\beta + m^* = \alpha \quad (3)$$

$$m^* = \bar{x} + \left(\frac{s^2}{\bar{x}}\right) - 1 \quad (4)$$

In these equations, α represents the population's tendency to accumulate (if positive) or repulsion among individuals (if negative), and β represents population distribution type. Significant differences between regression line slope shaving b= 1 (Taylor) and β= 1 (Iwao index) were calculated with statistic *t*, equation (5) is Obtained.

$$t = \frac{|slope - 1|}{SE_{slope}} \quad (5)$$

The value of the calculated *t* was compared with *t* value on the tables according to the degrees of freedom (n-2). If the magnitude of the value of calculated *t* is larger than *t* in the table, the difference between Taylor and Iwao indices will be important, and the spatial distribution of pest will be cumulative. If the difference with the number one is not important, the distribution is random type (Feng and Nowierski, 1992).

The semi-variogram is used to describe the spatial relationship of a regionalized variable (e.g. population density of a pest) at different locations. The semi-variogram (γ) equation is as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2$$

(6)

In this equation, z (x_i) is a measured sample point at x_i, z (x_i + h) is a measured sample at point x+h, and N(h) is the number of pairs separated by lag h. Each calculated value of semi- variogram along with their value h indicates a point in the coordinates of γ–h. The experimental semi- variogram is obtained by fitting a model to these points (Madani, 1994).

The ratio *DD* (Degree of Dependence)= $\frac{c}{(c_\circ + c)}$ is a value used to classify the spatial dependence of variables, where, $c_\circ$ is nugget and *c* is partial sill. If this ratio is less than 25%, the spatial dependence of variable is weak, whereas if it is from 25 to 75%, its spatial dependence is moderate, and if it is greater than 75%, its spatial dependence is strong (Isaaks and Srivastava, 1989).

All models provided by the software were used to calculate variograms. In variogram analysis, the model type and values of nugget, range, and partial sill were determined. The ordinary Kriging method was used for spatial interpolation and Location map (12 lags were selected; the amount of lag size at each sampling date was different due to the different numbers of insects per date). Kriging is a moving average weight, that is an interpolation technique of a variable in non-sampled areas utilizing variable values at adjacent points and weights determined by variogram model (λi) (Webster and Oliver, 2000).

$$Z^*_{x_\circ} = \sum_{i=1}^{n} \lambda_i Z_{(xi)} \quad (7)$$

In this equation $Z^*_{x_\circ}$ is the value estimated at point $x_\circ$, $Z_{(xi)}$ is the actual value of sample at points x_i, n the number of observations which are in the neighborhood of the point we want to estimate, and λ_i is the statistical weight to sample $Z_{(xi)}$ adjacent to point $x_\circ$ assigned.

IDW method is one of the interpolation methods in which points close to a measured point are given more weight than points farther away. Unlike kriging, this method does not follow the assumptions about the spatial relation among data (no variogram). It solely relies on the assumption that points closer to estimation point are more similar to farther points. In this study, an IDW with a power 2 was chosen (Webster and Oliver, 2000).

The cross-validation method was used to evaluate the efficiency of interpolation methods. The Root Mean Square Error

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

(RMSE) was considered for assessment models. Finally, population density maps of different life stages of pistachio leafhopper were drawn by using ArcGIS 10.6 version.

RESULTS

Field Biology of *Idiocerus stali*

This pest is overwintering as an adult, under the bark and fissure of pistachio trees. Overwintering adults were gray in color, and in early March, with the warming of the weather, left overwintering places and started walking on the branches of pistachio trees. They fed standing on buds, dropping sap. The first egg laid was observed in late March. Females create holes using their ovipositor in petioles, fruit tails, or cluster tails, and in each hole, one or two eggs were placed diagonally. Then, the eggs were covered with secretions that became black during the time, and laying locations were identifiable as black dots. The eggs were oval, milky in color and 0.8±0.07 mm in length (30 eggs were measured with a ruler below the binocular). The average laying period was two and a half months. Embryonic development took from 15 to 20 days. Four nymphal ages were observed. After hatching, the first nymphs appeared, and they fed on fruits, tail clusters, and petioles, and by producing honeydew, making clusters and leaves sticky. When they had completed their growing period, they went back to leaves and molted. The second instar nymphs appeared in late April, third instar nymphs emerged in early May, and the fourth instar nymphs appeared in late May, and like the first nymphs, fed on tail clusters and petioles and they molted in the lower page of leaves. The growth period of pistachio nymphs was 60 days on average, and the duration of the first, second, third, and fourth instar were 7.48±0.11, 12.22±0.24, 12.43±0.21 and 12.62±0.12 days, respectively. After the last molt, adult summer forms appeared in the late May, and then they moved to overwintering places.

Population Fluctuations of *Idiocerus stali*

In 2018, the first instar nymphs peaked on 20 May with a mean population of 12.16±1.82 {mean per sampling unit [all four branches (the last 20 cm) in four major geographical directions in every elevation on each tree were considered as a single sampling unit]± standard error} and the second instar nymphs reached their peak with an average population of 17.26±2.04 on 27 May (Figure 1). The peak of the third instar nymphs with a mean population of 25.74±3.5 was on 3 June, and the fourth nymphs with a mean population of 14.88±1.58 reached their peak on10 June. Egg peak date was 22 April, with a mean population of 64.04±17.58 and adults reached a peak on 1 July with a mean population of 22.86± 1.6.

In 2019, population peaks for nymphs from the first to the fourth instar were 9.52±1.71, 16.62±1.7, 23.22±3.27, and 9.58±1.57, respectively, and occurred on 26 May, 2, 9, and 16 Jun, respectively. Eggs reached their peak on 28 April with mean population of 26.1±4.64, and adults on 7 July with a mean population of 20.28±1.9. (Figure 2)

Relationship between Temperature and Humidity with Population Fluctuation

In 2018, there was an important relationship between temperature changes and the adult population fluctuation, which was a direct relation (Figure 1). There was no important relationship among the population fluctuations of the other life stages and whole immature *I. stali* and temperature changes. There was an important direct relation among humidity changes and egg population fluctuations, 1st instar, 2nd instar, and whole immature stages. There was an important and inverse relation among humidity changes and adults population fluctuations. Population fluctuations in nymphs with age three and four had no important relation with humidity changes.

In 2019, there was an important relation and inverse between temperature changes

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

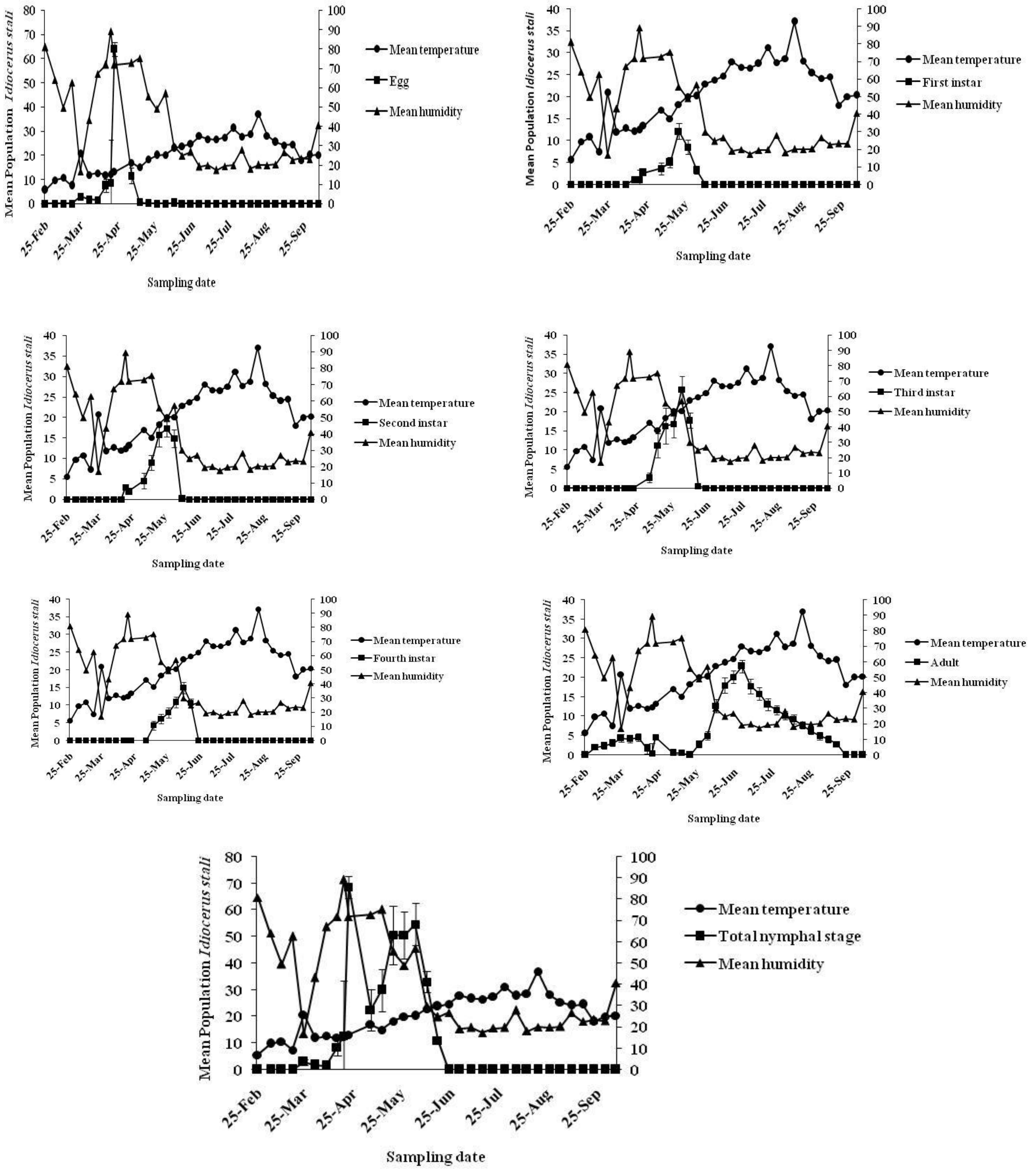


Figure 1. The curve of average population fluctuations of total life stages *Idiocerus stali* and the average temperature and humidity during different days of sampling in 2018.

Table 1. Taylor's power law regression parameters for mean of the different life stages of *Idiocerus stali* in 2018 and 2019.

Life stages	Year	*Intercept±SE*	*b±SE*	$t_b(d_f)$	t_{table} $\alpha = 0.05$	R^2	P_{value}	Spatial distribution
Egg	2018	1.098±0.121 (0.827- 1.368)	1.546±0.145 (1.223- 1.870)	1.363(10)	2.228	0.918	0**	Cumulative
	2019	0.857±0.042 (0.763- 0.951)	1.535±0.053 (1.416- 1.654)	0.396(9)	2.262	0.989	0**	Cumulative
1st Instar	2018	1.219±0.231 (0.655- 1.784)	1.032±0.359 (0.153- 1.910)	0.089(6)	2.447	0.579	0.028*	Random
	2019	0.902±0.070 (0.731- 1.073)	1.280±0.110 (1.011- 1.549)	3.508(6)	2.447	0.957	0**	Cumulative
2nd Instar	2018	1.108±0.121 (0.811- 1.404)	1.143±0.136 (0.810- 1.476)	0.626(6)	2.447	0.921	0**	Random
	2019	0.998±0.111 (0.727- 1.269)	1.046±0.133 (0.720- 1.372)	0.315(6)	2.447	0.911	0**	Random
3rd Instar	2018	1.243±0.208 (0.709- 1.777)	1.203±0.195 (0.701- 1.705)	0.685(5)	2.571	0.883	0.002**	Random
	2019	0.709±0.068 (0.534- 0.885)	1.405±0.072 (1.221- 1.589)	4.410(5)	2.571	0.987	0**	Cumulative
4th Instar	2018	1.810±0.212 (1.223- 2.398)	0.201±0.225 (-0.422- 0.825)	8.112(4)	2.776	0.167	0.421ns	-
	2019	0.841±0.126 (0.518- 1.165)	1.189±0.154 (0.793- 1.584)	1.503(5)	2.571	0.922	0.001**	Random
adult	2018	1.067±0.104 (0.854- 1.280)	0.872±0.127 (0.611- 1.134)	0.396(27)	2.052	0.634	0**	Random
	2019	0.865±0.049 (0.765- 0.965)	1.144±0.071 (0.999- 1.289)	0.772(29)	2.045	0.923	0**	Cumulative
Total nymphal stages	2018	1.048±0.274 (-0.416- 1.681)	1.382±0.215 (0.886- 1.878)	1.036(8)	2.306	0.837	0**	Random
	2019	0.874±0.132 (0.576- 1.172)	1.237±0.110 (0.988- 1.486)	1.205(9)	2.262	0.933	0**	Random
Total life stages	2018	0.431±0.168 (0.086- 0.775)	1.677±0.149 (1.370- 1.983)	1.837(27)	2.052	0.823	0**	Cumulative
	2019	0.954±0.146 (0.654- 1.253)	1.203±0.146 (0.905- 1.501)	0.444(29)	2.045	0.701	0**	Random

ns: No significant difference, *: Significant difference at the level of 0.05, **: Significant difference at the level of 0.01.

and egg and adult population fluctuations (Figure 2), whereas no important relationship was detected concerning nymphs. Also, there was an important inverse relationship between humidity changes and adult population fluctuation, whereas this was not observed for other life stages.

Spatial Distribution Studied by Using Classical Statistics

To identify this pest's spatial distribution pattern utilizing classical statistics, two regression methods of Taylor power law and Iwao index were applied. The results are presented in Tables 1 and 2.

Regarding the values of coefficients, both models are appropriate for estimating the type of pest spatial distribution, however, Taylor model showed a better data fitting than Iwao index. In addition, Taylor model is a good model for identifying spatial distribution patterns that are not affected by small environmental fluctuations and sample size (Croft *et al*., 1976; Nestel *et al*., 1995).

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

Table 2. Iwao's regression parameters for mean of the different life stages of *Idiocerus stali* in 2018 and 2019.

Life stages	Year	$\pm SE\alpha$	$\pm Se\beta$	$t_b(d_f)$	t_{table} α= 0.05	R^2	P_{value}	Spatial distribution
Egg	2018	7.990±1.924 (3.702- 12.278)	4.639±0.110 (4.415- 4.864)	0.605(10)	2.228	0.995	0**	Cumulative
	2019	6.886±2.416 (1.419- 12.352)	2.407±0.220 (1.910- 2.904)	0.396(9)	2.262	0.930	0**	Cumulative
1st Instar	2018	29.837±17.803 (-13.725- 73.398)	-0.415±3.012 (-7.784- 6.953)	0.046(6)	2.447	0.003	0.895 ns	-
	2019	7.805±1.658 (3.748- 11.862)	1.686±0.317 (0.910- 2.462)	0.293(6)	2.447	0.824	0.002 **	Random
2nd Instar	2018	15.904±7.045 (1.333- 33.142)	1.164±0.672 (-0.480- 2.808)	0.013(6)	2.447	0.333	0.134 ns	-
	2019	10.407±2.412 (4.506- 16.309)	0.976±0.264 (0.329- 1.622)	0.006(6)	2.447	0.694	0.010 **	Random
3rd Instar	2018	25.296±15.170 (-13.700- 64.292)	1.445±0.987 (-1.092- 3.981)	0.021(5)	2.571	0.300	0.203 ns	-
	2019	4.130±1.338 (0.692- 7.568)	1.678±0.101 (1.420- 1.937)	0.318(5)	2.571	0.982	0**	Cumulative
4th Instar	2018	22.099±3.011 (13.738- 30.460)	-0.149±0.309 (-1.006- 0.708)	0.436(4)	2.776	0.054	0.655 ns	-
	2019	7.067±2.319 (1.107- 13.027)	1.278±0.292 (0.528- 2.028)	0.095(5)	2.571	0.793	0.007 **	Random
adult	2018	15.945±4.102 (7.529- 24.362)	0.470±0.421 (-0.394- 1.334)	0.044(27)	2.052	0.044	0.274 ns	-
	2019	7.059±1.015 (4.983- 9.136)	1.144±0.135 (0.867- 1.420)	0.035(29)	2.045	0.711	0**	Random
Total nymphal stages	2018	26.679±14.723 (-7.273- 60.631)	1.609±0.459 (0.551- 2.667)	0.020(8)	2.306	0.605	0.008 **	Random
	2019	11.032±3.057 (4.118- 17.947)	1.143±0.107 (0.900- 1.386)	0.021(9)	2.262	0.926	0**	Random
Total life stages	2018	-8.419±10.226 (-29.401- 12.564)	2.984±0.377 (2.210- 3.759)	0.051(27)	2.052	0.698	0**	Cumulative
	2019	9.606±2.575 (4.340- 14.873)	1.281±0.113 (1.049- 1.512)	0.026(29)	2.045	0.815	0**	Cumulative

ns: No significant difference, *: Significant difference at the level of 0.05, **: Significant difference at the level of 0.01.

Spatial Distribution Studied by Using Geostatistics Methods

To select the most appropriate interpolation method, the best semi-variogram function should be selected to fit the data. The results for all life stages of leafhopper are presented in Table 3 for 2018 and in Table 4 for 2019. For each sampling date, the best semi-variogram model of all models offered by ArcGIS is identified, and its associated geostatistical description was provided. After selecting the appropriate semi-variogram functions, Kriging interpolation methods and IDW tested the RMSE of these two methods

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

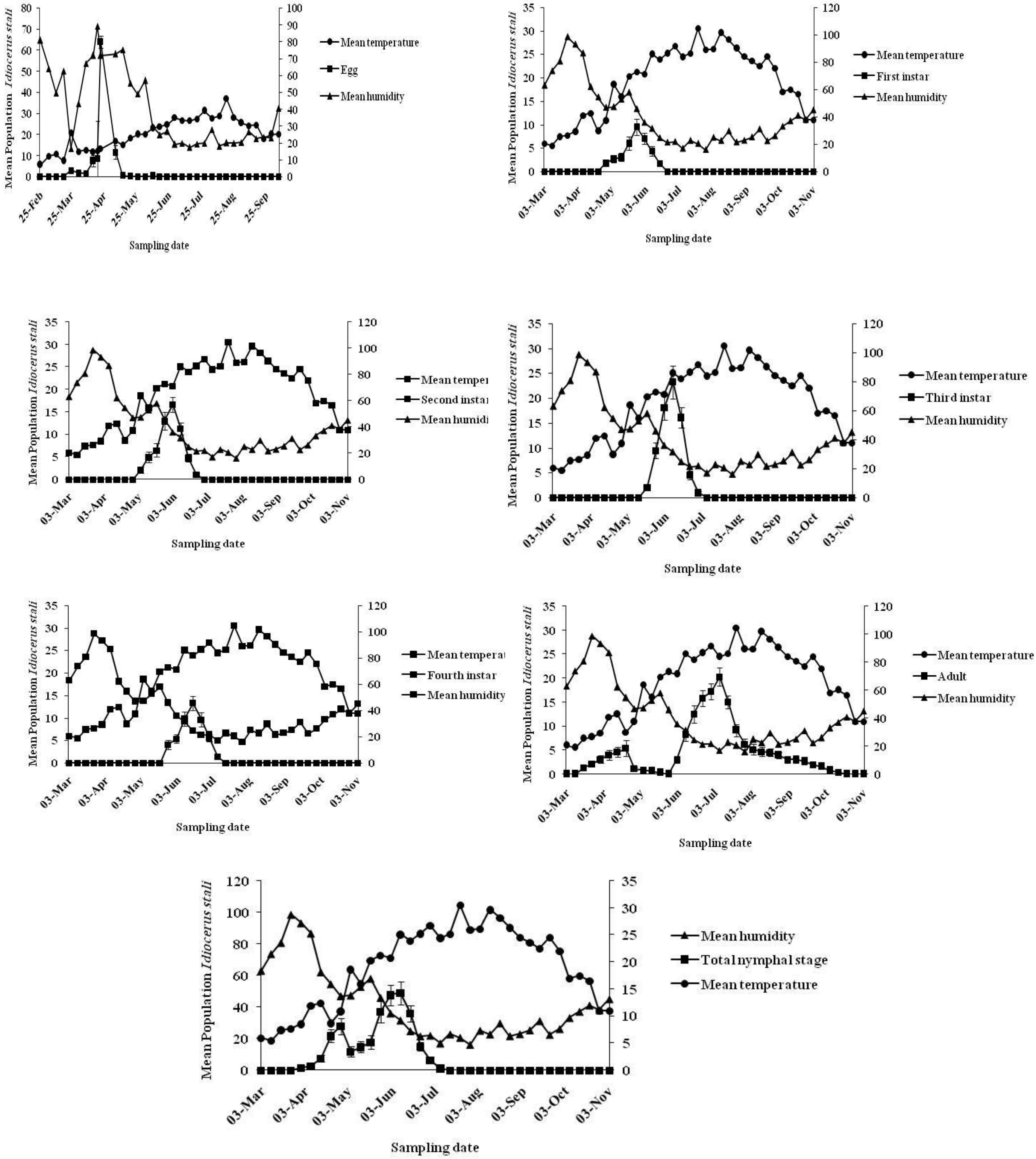


Figure 2. The curve of average population fluctuations of total life stages *Idiocerus stali* and the average temperature and humidity during different days of sampling in 2019.

Table 3. Geostatistical description of the best semi-variogram model of total life stages of *Idiocerus stali* by using ordinary Kriging method during different days of sampling in 2018.[a]

Sampling date	Variogram model	Nugget	Partial sill	Range major	DD (%)	RMSE
25-Feb	Circular	16.13	4.82	31.66	23.01	4.57
04-Mar	Gaussian	32.48	2.42	31.92	6.94	6.02
11-Mar	Pure nugget effect	25.05	0	21.98	0	5.18
18-Mar	Pure nugget effect	99.15	0	31.66	0	9.57
25-Mar	Pure nugget effect	99.28	0	17.37	0	10.47
01-Apr	J-Bessel	44.62	25.32	10.00	36.20	7.60
08-Apr	Pure nugget effect	448.89	0	9.84	0	21.63
15-Apr	Hole Effect	9417.37	4863.12	14.07	34.05	139.83
22-Apr	Pure nugget effect	431.71	0	9.00	0	21.41
19-Apr	Hole Effect	604.23	1526.83	31.92	71.65	40.12
06-May	Hole Effect	1161.62	859.21	10.25	42.52	46.24
13-May	Circular	3991.55	299.06	11.67	6.97	68.97
20-May	J-Bessel	0	1865.91	4.41	100	50.64
27-May	Gaussian	1911.32	711.88	30.90	27.14	46.24
03-Jun	Gaussian	775.16	473.30	26.27	37.91	29.96
10-Jun	Hole Effect	254.48	88.44	27.81	25.79	16.91
17-Jun	Hole Effect	93.19	36.05	14.18	27.89	9.77
24-Jun	Pure nugget effect	127.15	0	17.09	0	11.56
01-Jul	Pure nugget effect	168.88	0	13.29	0	13.04
08-Jul	Stable	0	132.65	8.57	100	11.49
15-Jul	Pure nugget effect	112.07	0	21.98	0	10.80
22-Jul	Pure nugget effect	66.96	0	13.18	0	8.67
29-Jul	Hole Effect	0	55.55	4	100	7.61
05-Aug	Pure nugget effect	58.38	0	11.96	0	8.07
12-Aug	Pure nugget effect	36.38	0	9.92	0	6.14
19-Aug	Pure nugget effect	31.35	0	15.38	0	5.64
26-Aug	Pure nugget effect	47.95	0	12.06	0	7.31
02-Sep	Pure nugget effect	44.76	0	14.18	0	6.43
09-Sep	J-Bessel	20.24	0.93	9.92	4.38	4.60

[a] DD: Degree of Dependence, RMSE: Root-Mean-Square Error.

obtained for each sampling date. Any method with the least value for this criterion has the highest accuracy. Due to the values obtained, Kriging method was found to be more accurate than IDW method in both years, except for one case. Hence, distribution maps obtained by Kriging method are presented in Figure 3.

Due to RMSE values, Hole Effect and J-Bessel models showed the best fit for spatially dependent data, whereas non-spatial dependent data fitted to pure nugget effect variograms. Pure nugget effect is called a condition where there is no spatial structure in the data (Liebhold *et al*., 1993).

According to Figure 3, on 17-March, the spatial distribution of insects was cumulative and the geostatistical results fitted the pest population at this date with Hole Effect model which indicated the cumulative distribution every week. The Degree of Dependence (DD) was zero, and the spatial distribution was random. Also, these synergies were found in maps of other stages. According to the map guide, the most colorful spots are the locations most infected with pistachio leafhopper in the garden.

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

Table 4. Geostatistical description of the best semi-variogram model of total life stages of *Idiocerus stali* by using ordinary Kriging method during different days of sampling in 2019.[a]

Sampling date	Variogram model	Nugget	Partial sill	Range major	DD (%)	RMSE
17-Mar	Hole Effect	10.74	0.04	95.88	0.39	3.14
24-Mar	Pure nugget effect	16.97	0	246.97	0	4.28
31-Mar	Pure nugget effect	48.55	0	154.29	0	7.23
07-Apr	J-Bessel	0	105.67	0.02	100	9.51
14-Apr	Pure nugget effect	368.72	0	207.43	0	20.16
21-Apr	Circular	1145.91	8.86	74.00	0.77	33.41
28-Apr	Pure nugget effect	1299.75	0	210.75	0	38.39
05-May	Pure nugget effect	470.67	0	164.39	0	22.09
12-May	Pure nugget effect	524.76	0	75.58	0	23.69
19-May	Pure nugget effect	480.73	0	54.46	0	22.41
26-May	J-Bessel	0	930.97	21.25	100	31.35
02-Jun	Pure nugget effect	729.24	0	155.93	0	27.16
09-Jun	Hole Effect	684.98	464.94	55.04	40.43	32.01
16-Jun	Gaussian	1074.68	98.92	246.97	8.43	30.01
23-Jun	Gaussian	205.76	84.17	210.75	29.03	15.39
30-Jun	J-Bessel	157.97	35.82	55.04	18.49	13.03
07-Jul	Pure nugget effect	197.25	0	135.90	0	14.03
14-Jul	Pure nugget effect	96.3٧	0	124.22	0	10.37
21-Jul	Gaussian	83.29	1.86	237.99	2.19	9.73
28-Jul	J-Bessel	21.98	38.95	24.78	63.92	8.19
04-Aug	Pentaspherical	54.72	1.33	64.16	2.37	7.72
11-Aug	Gaussian	39.62	12.34	210.75	23.75	6.65
18-Aug	Pure nugget effect	31.49	0	38.02	0	5.68
25-Aug	K-Bessel	21.76	1.11	64.49	4.86	4.82
01-Sep	Hole Effect	4.18	25.46	24.39	85.89	5.35
08-Sep	J-Bessel	14.99	20.57	20.05	57.84	5.85
15-Sep	Pure nugget effect	20.58	0	129.59	0	4.57
22-Sep	Pure nugget effect	15.91	0	143.28	0	4.13
29-Sep	Pure nugget effect	8.91	0	79.26	0	3.03
06-Oct	Pure nugget effect	4.69	0	115.97	0	2.12
13-Oct	Pure nugget effect	0.77	0	246.97	0	0.92

[a] DD: Degree of Dependence, RMSE: Root-Mean-Square Error.

DISCUSSION

In this research, four nymphal instars were observed for *I. stali*, which is in accord with Jalilvand and Kashanizadeh (2013). Zenouzi (1958) also stated four nymphal instars, whereas in another research three nymphal instars were observed (Behdad, 1984).The reason for this difference can be attributed to weather conditions or differences in nutrition quality.

In Behdad's (1984) studies, the life stage duration of the first, second, and third instar were from 7 to 9 days, from 10 to 15 days, and from 12 to 15 days, respectively, which corresponds to the times recorded in the present study.

The average population of different life stages of this pest was higher in 2018 than in 2019: this can be attributed to the application of pesticides in 2019 (Confidor® 0.4 per thousand), which reduced pest population. No spraying was done in the study area in 2018. Moreover, the emergence of overwintering adults started two weeks earlier in 2018 (4 March, against 17 March in 2019). The reason for this difference might be high rainfall in March

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

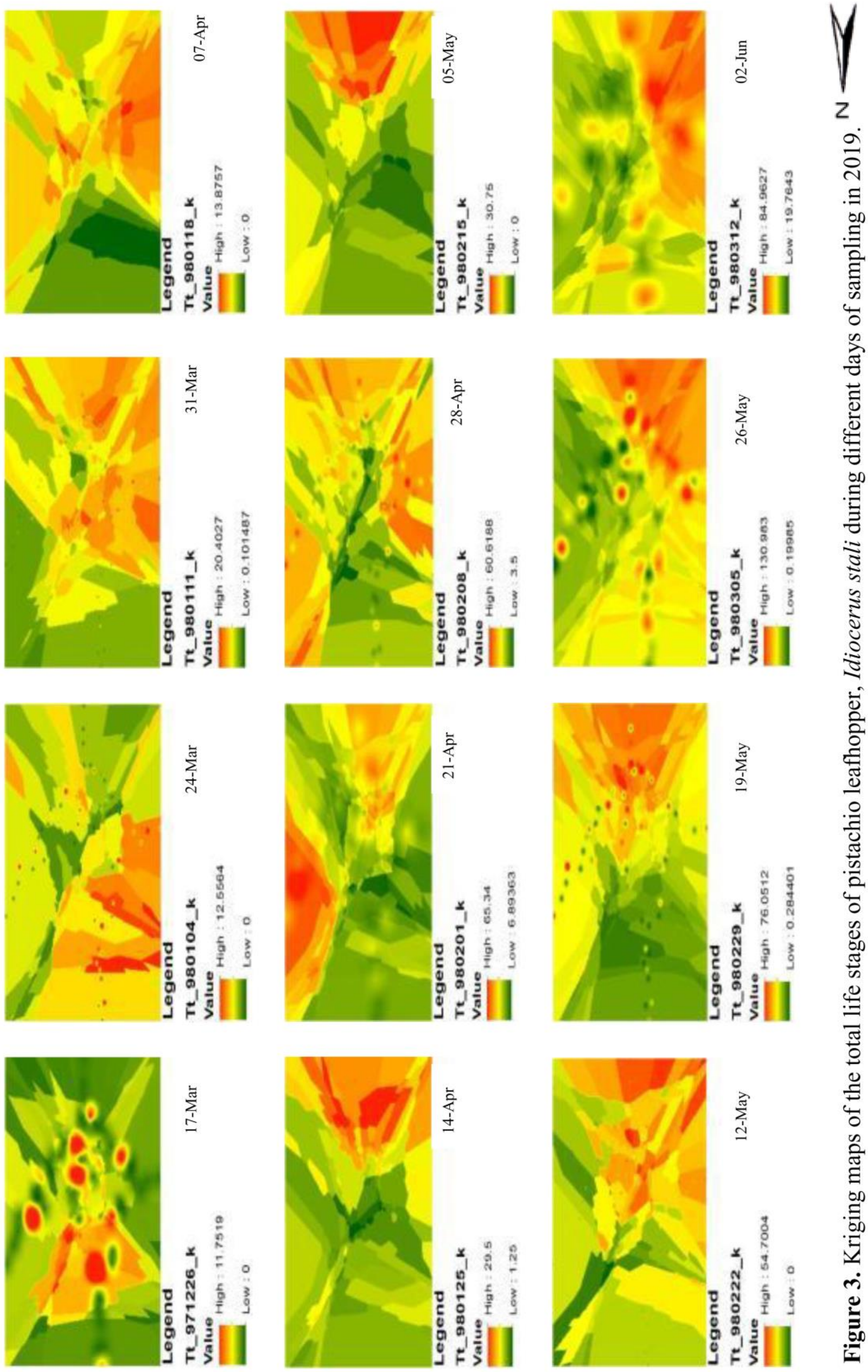


Figure 3. Kriging maps of the total life stages of pistachio leafhopper, *Idiocerus stali* during different days of sampling in 2019.

Figure 3 continued…

Continued of figure 3…

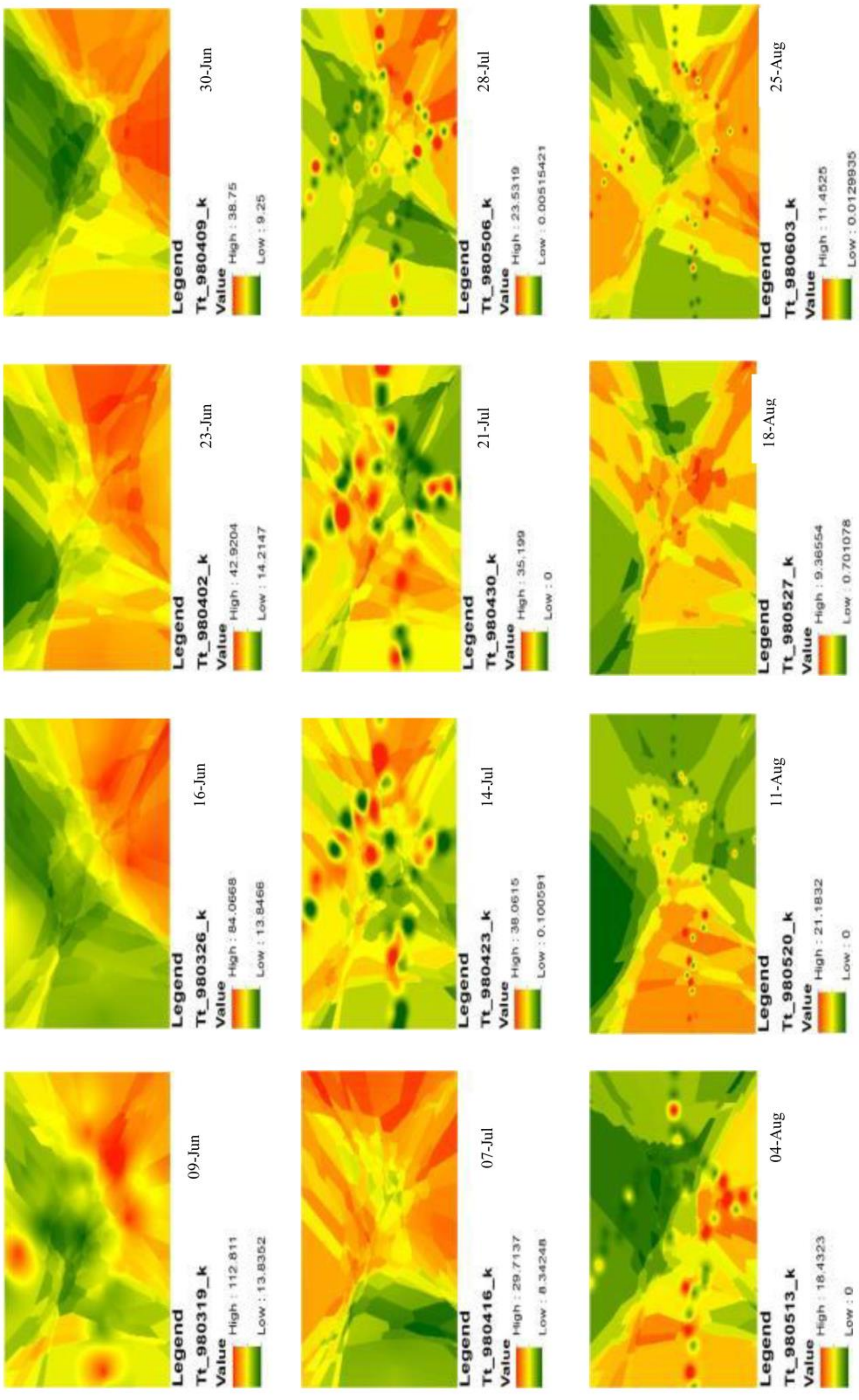
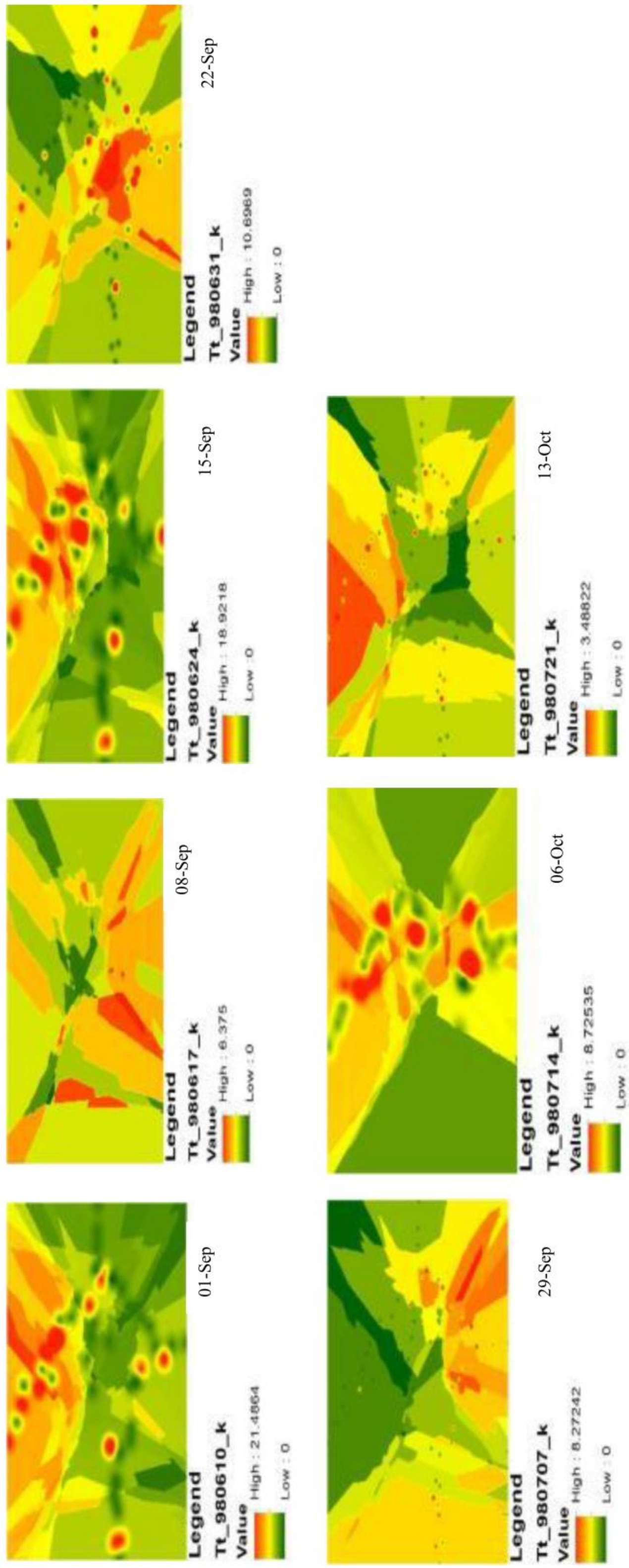


Figure 3 continued…

Continued of Figure 3…



2019, which caused leafhoppers to leave their overwintering places later.

According to Yanik and Yucel's (2001) findings in Birecik region in Turkey, overwintering adults appeared in garden during the first week of March, but adults were also observed in summer form on 1 June, consistent with our findings. The reason can be the similar weather conditions in the two regions.

According to the results, the range of semi-variogram was different from 4 to 247 m and DD (Degree of Dependence) was from 0 to 100% (Table 3). In geostatistics, higher range values are more useful in pest management. In sampling the pest's population, the distance between samples can be increased up to 75% of the range value (Hassani Pak, 1997). For example, if the range value is 100 m, we can collect the samples at a distance of 75 m from each other. Therefore, in a region with a specified area, as the range value increases, fewer samples are required to estimate the population density of a pest. In other words, the range of semi-variogram plays an important role in determining the distance between samples.

Iwao index was not important for adults and all nymphs in 2018, and it could not detect the spatial distribution of these steps. In Taylor's power law method, the egg stage's spatial distribution and the sum of all life stages were recognized as cumulative, and the rest of stages as random. In 2019, in Iwao method, the eggs' spatial distribution, third instar nymphs, and sum of whole life stages were recognized cumulative and the remaining stages as random. In Taylor's power law method, the spatial distribution of eggs, the first and third nymphs and adults, appointed cumulative, and the rest of stages were random. However, according to geostatistical methods, the spatial distributions of all stages were generally random. However, the spatial distribution per week was determined precisely. Geostatistics is one of the most accurate methods of estimation; it examines many factors like distance among points, anisotropy, and spatial variability. An advantage of geostatistics is a careful survey for spatial distribution and locations of different life stages of a pest and identification of contaminated places. Different methods of pest control can be accurately performed at low cost. The results showed that Kriging method was highly accurate for estimating population density of this pest in non-data points.

For better management of pests, predicting its abundance and population distribution is very important (Trematerra *et al*., 2007). Therefore, it requires careful monitoring, and that is why spatial analysis methods, like geostatistics, are widely used in entomology (Liebhold *et al.,* 1993, Trematerra and Sciarretta, 2004). Following the classical statistics, the indices usually focus on the distribution of sample abundance and measure the relation of sample variance with its mean, but they ignore insects' spatial location, which itself produces undesirable effects; for example, these indices usually cannot distinguish among different spatial patterns (Hurlbert, 1990). Their interpretation of spatial pattern largely depends on the size of sample units (Sawyer, 1989). As a result, the methods depend on samples' geographical location for investigating their spatial location. Geostatistical techniques are a good alternative. Taylor and Iwao indicators can only provide a distribution coefficient for the whole season, and the sampling dates cannot be separated by them (Southwood and Henderson, 2000).The locations of whole life stages, laying, and movement of leafhopper adults and nymphs were precisely determined each week. Therefore, it is possible to identify contamination *foci* and take over appropriate management measures in the right time at low cost.

The present study shows the superiority of geostatistical methods over classical statistical methods in line with reducing the pesticide consumption and site specific integrated pest management. The geostatistical method shows the places where the pest has more accumulation, and

[DOR: 20.1001.1.16807073.2022.24.1.7.7]

by spraying in that particular place, we can avoid excessive consumption of pesticides; as a result, we cause less damage to the environment.

REFERENCES

1. Abrishami, M. H. 1994. *Persian Pistachio, a Comprehensive History*. University Publication Center, Iran, 669 pp.
2. Arlando, P. S. and Torres, L. M. 2005. Spatial Distribution and Sampling of *Thaumetopoea pityocampa* (Lep.: Thaumetopoeidae) Populations on Pinus Pinstar. *For. Ecol. Manag.*,**210:** 1-7.
3. Behdad, A. 1984. Pests of Iranian Fruit Trees. Bina Pub, Isfahan Printed, Iran, 743 pp.
4. Croft, B. A., Welch, S. M. and Dover, M. J. 1976. Dispersion Statistics and Sample Size Estimates for Populations of the Mite Species, *Panonychus ulmi* and *Amblyseius fallacis* on Apple. *Environ. Entomol.*, **5(2):** 227-233.
5. FAO. 2018. *Food and Agricultural Commodities Production*. Available in: http://www.fao.org/faostat/en/#data/QC.
6. Feng, M. G. and Nowierski, R. M. 1992. Spatial Distribution and Sampling Plans for Four Species Cereal Aphid (Hom,: Aphididae) Infesting Spring Wheat in Southwestern Idaho. *J. Econ. Entomol.*, **85:** 830-837.
7. Hassani Pak, A. A. 1997. *Geostatistics* . Tehran University Press. 314 PP.
8. Hurlbert, S. H. 1990. Spatial Distribution of the Montane Unicorn. *Oikos*,**58:** 257-271.
9. Isaaks, E. H. and Srivastava, R. M. 1989. An Introduction to Applied Geostatistics. Oxford University Press,New York.USA, 592 PP.
10. Jalilvand, N. and Kashanizadeh, S. 2013. Study on the Biology of *Idiocerus stali* Qazvin Climate. *Bull. Agr. Natur. Resour. Res.*, **15:** 22-30.
11. Liebhold, A. M., Rossi, R. E. and Kemp, W. P. 1993. Geostatistics and Geographic Information Systems in Applied Insect Ecology. *Annu. Rev. Entomol.*, **38:** 303-327.
12. Madani, H. 1994. *Fundamentals of Geostatistics*. First Edition, Amir Kabir University of Technology, Tafresh Branch, Iran, 668 PP.
13. Mourikis, P. A., Sourgianni, A. T. and Chitzanidis, A. 1998. Pistachio Nut Insect Pests and Means of Control in Greece. II International Symposium Pistachio and Almonds, *Acta Hortic.*, **470:** 604-611.
14. Nestel, D., Cohen, H., Saphir, N., Klein, M. and Mendel, Z. 1995. Spatial Distribution of Scale Insects: Comparative Study Using Taylor’s Power Law. *Environ. Entomol.*, **24(3):** 506-512.
15. Sawyer, A. J. 1989. Inconstancy of Taylor's b: Simulated Sampling with Different Quadrat Sizes and Spatial Distributions. *Res. Popul. Ecol.*, **31:** 11-24.
16. Southwood, T. R. E. and Henderson, P. A. 2000. *Ecological Methods.* 3rd Edition Blackwell Science, Oxford.
17. Trematerra, P., Gentile, P., Brunetti, A., Collins, L. E. and Chambers, J. 2007. Spatio-Temporal Analysis of Trapcatches of *Tribolium confusum* du Val in a Semolinamill, with a Comparison of Female and Male Distributions. *J. Stor. Prod. Res.*, **43:** 315-322.
18. Trematerra, P. and Sciarretta, A. 2004. Spatial Distribution of Some Beetles Infesting a Feed Mill with Spatio-Temporal Dynamics of *Oryzaephiluss urinamensis*, *Tribolium castaneum* and *Tribolium confusum*. *J. Stor. Prod. Res.*, **40:** 363-377.
19. Webster, R. and Oliver, M. A. 2000. *Geostatistics for Environmental Scientists*. ISBN: 0-41-96553-7, Wiley Press, 271 PP.
20. Yanik, E. and Yucel, A. 2001. The Pistachio (*P. vera* L.) Pests, Their Population Development and Damage State in Sanliurfa Province. In: “*XI GREMPA Seminar on Pistachios and Almonds*”, (Ed.): Ak, B. E., CIHEAM, Zaragoza, PP. 301-309.
21. Zenouzi, H. 1958. Pistachio Leafhopper and Way of Its Controling. *Iran Agr. Promot. Org.*, **34:** 14.

بیواکولوژی و توزیع فضایی زنجرک پسته، *Idiocerus stali* Fieber (Hem.: Cicadellidae) در باغات پسته

آ. جمشیدی، ح. ا. واحدی ، ع. ا. زمانی و ب. فرهادی بانسوله

چکیده

پسته از مهم‌ترین و اقتصادی‌ترین محصولات کشاورزی ایران و محصولی صادراتی و ارز آور است. ایران اولین تولید کننده پسته است. زنجرک *Idiocerus stali* Fieber (Hem., Cicadellidae)، یکی از مهم‌ترین آفات این محصول است. حشرات کامل و پوره‌های این زنجرک از بافت برگ و خوشه میوه پسته تغذیه کرده و با مکیدن شیره پرورده خسارت وارد می‌کنند. بیواکولوژی این آفت مطالعه شد و مشخص شد که یک نسل در سال دارد. در این پژوهش نوسانات جمعیت زنجرک پسته در ارتباط با تغییرات درجه حرارت و رطوبت مطالعه شد. توزیع فضایی مجموع مراحل زیستی بر اساس مدل آیوائو در هر دو سال از نوع تجمعی بود و بر اساس مدل قانون توان تیلور در سال ۱۳۹۷ از نوع تجمعی، اما در سال ۱۳۹۸ از نوع تصادفی بود. با توجه به مقادیر ضرایب تبئین، هر دو مدل مدل قانون قدرت تیلور ($R2 = 0.93$) و مدل آیوائو ($R2 = 0.92$) برای تخمین نوع توزیع فضایی آفت مناسب هستند و مدل تیلور در مقایسه با مدل آیوائو همبستگی بیشتری با داده‌ها داشته و بهتر از شاخص تیلور داده‌ها را برازش می‌کند. همچنین پراکنش فضایی زنجرک پسته با استفاده از زمین آمار هم بررسی شد. بر اساس نتایج روش کریجینگ در مقایسه با روش Inverse Distance Weighting (IDW) دقت بالاتری داشت و نقشه های پراکنش آفت با استفاده از این روش تهیه شد. روند حرکت حشرات کامل و پوره‌ها و هم‌چنین محل‌های تخم‌گذاری در هر هفته دقیقاً مشخص شد و به این ترتیب می‌توان کانون‌های آلودگی را شناسایی و اقدامات مدیریتی مناسب را در زمان مناسب و با هزینه کم انجام داد.

[DOR: 20.1001.1.16807073.2022.24.1.7.7]