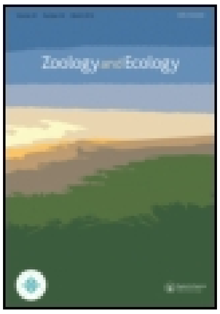

Zoology and Ecology

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tzec20

Spatial distribution of small white butterfly Pieris rapae (L.) in the cauliflower fields of Tehran

Gholamhosein Hasanshahi [a] , Fatemeh Jahan [a] , Habib Abbasipour [a] , Jaber Karimi [a] & Alireza Askarianzadeh [a]

[a] Faculty of Agricultural Sciences, Department of Plant Protection , Shahed University , Tehran , Iran

Published online: 05 Sep 2013.

To cite this article: Zoology and Ecology (2013): Spatial distribution of small white butterfly Pieris rapae (L.) in the cauliflower fields of Tehran, Zoology and Ecology

To link to this article: http://dx.doi.org/10.1080/21658005.2013.834656

Zoology and Ecology, 2013
http://dx.doi.org/10.1080/21658005.2013.834656

Taylor & Francis
Taylor & Francis Group

Spatial distribution of small white butterfly *Pieris rapae* (L.) in the cauliflower fields of Tehran

Gholamhosein Hasanshahi, Fatemeh Jahan, Habib Abbasipour*, Jaber Karimi and Alireza Askarianzadeh

Faculty of Agricultural Sciences, Department of Plant Protection, Shahed University, Tehran, Iran

(*Received 15 March 2013; accepted 6 August 2013*)

One of the most basic information to understand insect population dynamics is the pattern of their spatial distribution. This study was conducted on spatial distribution of the small white butterfly, *Pieris rapae* (Lepidoptera: Pieridae), in the cauliflower fields in the south of Tehran from late May until October 2011. Each cauliflower plant was presumed to be a sampling unit. The pattern of spatial distribution was determined for each development stage of *P. rapae* by using regression models (Taylor's power law and Iwao's patchiness regression). The results indicated that the spatial distribution pattern was clumped for all life stages of *P. rapae*. In Taylor's and Iwao's models, the slopes of regression lines were more than one for all life stages. Also, population fluctuations of different stages of this pest were high during the season. The spatial distribution pattern can be used to improve the sampling programme, estimate the exact population density and to plan and perform integrated management of the small white butterfly.

Vabzdžių populiacijų dinamikos supratimui erdvinės struktūros tyrimai yra labai svarbūs. Teherano pietinėje dalyje nuo 2011 m. gegužės pabaigos iki spalio mėnesio žiedinių kopūstų laukuose buvo tiriama ropinio baltuko *Pieris rapae* (Lepidoptera: Pieridae) populiacijos erdvinė struktūra. Visose šio kenkėjo vystymosi stadijose erdvinė struktūra buvo nustatoma naudojant Teiloro laipsninės regresijos modelį ir Iwao regresiją. Visoms *P. rapae* vystymosi stadijoms buvo būdinga grupinė erdvinė struktūra. Pagal Teiloro ir Iwao modelius regresinių linijų nuolydis visoms *P. rapae* vystymosi stadijoms buvo didesnis už vienetą. Taip pat nustatyti dideli gausumo sezoniniai pokyčiai visose šio kenkėjo vystymosi stadijose. Ropinio baltuko erdvinės struktūros žinojimas leidžia tobulinti mėginių rinkimo programas, apskaičiuoti tikslų populiacijos tankumą ir planuoti bei vykdyti integruotą populiacijos valdymą.

Keywords: *Pieris rapae*; spatial distribution; Taylor's and Iwao's methods; cauliflower

Introduction

The cauliflower, *Brassica oleracea* L. var. *botrytis*, is one of the plants of Brassicaceae family (Cruciferae). In the countries with moderate weather for cultivation, this plant can be grown throughout the year (Macharia, Lohr, and Groote 2005). An area under cultivation of this plant is about 200–300 ha in Tehran (Karimi 1992). Many pests, including *Pieris rapae* (Linnaeus, 1758), *Plutella xylostella* L., *Brevicoryne brassicae* (L.), *Myzus persicae* Sulzer., *Lipaphis erysimi* Kaltenbach., *Bagrada hilaris* Burmeister and *Pieris brassicae* attack plants of the Cruciferae family (Adane-Kassa and Abate 1995; Nyambo and Pekke 1995; Oduor, Lohr, and Seif 1996; Ooi 1980). A research conducted by Forster and Hommes (1991) showed that pest damage due to *P. xylostella*, *P. rapae*, *P. brassicae* and *Mamestra brassicae* caused 6, 45, 71 and 40% reduction in yield, respectively. The small white butterfly because of its overeating larvae can cause irreparable damage to cruciferous plants. The larvae of *P. rapae* damage cruciferous crops by chewing leaves, hearts and curds. Young larvae hatch on the outer leaves and feed on them superficially leaving the upper leaf surface intact. Older larvae make holes in the leaves and are more likely to eat through small veins; they also damage the outer leaves of the hearts of cabbages or the curd of broccoli or cauliflowers. They often bore into the centre of the head and damage the edible portion of the plant. Heavily infested plants become ragged and stunted, but no webbing occurs. The presence of masses of wet greenish-brown excrements deep among leaves is indicative of this pest. In large infestations with *P. rapae,* the plant may be reduced to a partial or complete skeleton, in which all the leaf tissue except the veins has been eaten (Metcalf and Flint 1962). This pest was observed for the first time in Quebec City (east of Canada) in 1860 and in Iran in 1938. Now it is reported from all parts of Iran. Natural enemies are the influencing factors on the population density of the small white butterfly (Lim 1986). The absence of parasitoids, especially larval parasitoids in the cauliflower fields, is one of the factors that lead to high densities of *P. rapae* (Lim 1986). The studies on the parasitic insect fauna of the small white butterfly in different regions have great importance for the control of this pest (Aliyev 1999). Eggs and larvae of *P. rapae* are attacked by a number of predators, including Carabidae beetles, lacewing, spiders and beetles of the family Staphylinidae, and a number of parasitoids such as *Cotesia glomerata* and *Pteromalus puparum*

*Corresponding author. Email: Abasipour@shahed.ac.ir

(Jun, Gong-yin, and Cui 2004; Pfiffner et al. 2009; Sato and Ohsaki 2004). Unfortunately, excessive use of pesticides for pest control did not produce satisfactory results and reduced the efficiency of these parasitoids (Costea, Mustata, and Lozan 2002). Pest and parasitoid interactions are difficult to understand in field conditions. With the knowledge of pest dispersion, some of the reasons about population changes and also cognition of biological characteristics of species could be realised (Poole 1974). Examination of the spatial distribution pattern for a pest and its reaction to natural enemies provides considerable knowledge of interactions between them and has an effective role in integrated pest management. A pattern of distribution results from interactions between the population and its surrounding environment. The knowledge of spatial distribution in the environment makes more information to describe population dynamics of pests (Pedigo and Zeiss 1996). More knowledge of spatial distribution of pests and their natural enemies helps to understand better the behaviour and population size of insects and natural enemies. Also, it gives more different information about the impact of environmental factors on population fluctuations of pests and parasitoids (Radjabi 2003; Sahragard and Heidari 2001). Several distribution patterns for populations have been observed, and the most common are (a) homogeneous, or uniform, or regular, or positive binomial, (b) random, (c) contagious (clumped), or negative binomial and (d) geometric. These distribution patterns often provide appropriate models for four possible (regular $m > S^2$, random $m = S^2$, contagious $m < S^2$, geometric $m + m^2 = S^2$) relations between variance and arithmetic mean in a population (Young and Young 1998). The objective of this study was to elucidate spatial distribution of the small white butterfly, *P. rapae*, by using Taylor's and Iwao's models.

Materials and methods

Sampling

The sampling started after planting cauliflowers in the research station of the Shahed University in the south of Tehran in late June and continued until early November 2011. In this study, cauliflower plants were assumed to be the sampling units. One-hundred-hectare cauliflower fields in the south of Tehran were randomly selected, and the sampling was done on the plots of 1000 m in diameter with about 10 m intervals every 14 days. All individuals of different development stages were counted on each plant and then were recorded. For sampling of eggs, three leaves of each plant were randomly selected and the number of eggs on the underside of leaves was counted. Due to the presence of dust on the surface of leaves, the counting of eggs was not possible. For calculating the number of eggs in every plant, the mean number of eggs on the three leaves was multiplied by the total number of leaves per plant.

Spatial distribution pattern of the small white butterfly, ratio of variance to mean (z)

The index of distribution is a suitable and the simplest test to assess the distribution pattern of organisms. If the ratio of variance to mean is not significantly different from one, population distribution is random, and if it is more or less than one, then distribution will be cumulative or uniform, respectively. In rare cases of random distribution, the ratio of variance to mean is equal exactly to one. So, deviation from one can also be tested with the calculated index of dispersion (I_D) (Elliott 1979):

$$I_D = x = \frac{S^2(n-1)}{\bar{x}},$$

where I_D = index of dispersion, S^2 = variance value, $\bar{x}$ = average value.

If the number of samples is high, the following equation is used:

$$Z = \sqrt{2x^2} - \sqrt{2(\upsilon - 1)},$$

where υ = degrees of freedom ($n-1$).

Random distribution: if the calculated I_D was between χ ($\alpha = 0.05$ and 0.95 or $\alpha = 0.01$ and 0.99; df $= n-1$).

Taylor's power law

In 1961, Taylor for the first time showed that in most animals there is a linear relationship between the mean and the variance of population density that is performed in cumulative, random and uniform distribution (Taylor 1961). For determining the spatial distribution of the small white butterfly, the logarithm of variance and mean data in each time was taken and then the regression line between the logarithm of variance and mean values of *a* and *b* in different dates was calculated (Taylor, Lindquest, and Shipp 1998):

$$\log x^2 = \log a + b \log \bar{x},$$

where b = slope of the regression line, a = y-axis intercept of the regression line.

Due to the slope of the regression line (b), if this value is equal to one, then it is random distribution, and if it is more or less than one, then it will be cumulative or uniform distribution, respectively. To calculate the significance of amounts of b with the number of one, the following formula is used:

$$t = \frac{|b-1|}{\mathrm{SE}_b}.$$

If the calculated t-value is smaller than the t-value given in the table with df = $n-1$, zero assumption is accepted and spatial distribution pattern ($b=1$) will be random. Otherwise, on the basis of the numerical value of the slope of the regression line (b), the type of spatial distribution will be determined.

Iwao' s patchiness regression

In this method, the linear regression resulting from relationship between Lloyd's index of mean crowding (x^*) and the mean population density is in different time:

$$x^* = \beta\bar{x} + \alpha.$$

In this regard, α is the base density index and β is the density of the accumulation coefficient. In cases where β is larger, equal or smaller than one, distribution is cumulative, random or uniform, respectively (Southwood and Henderson 2000). In case where the slope of the regression line (β) is close to one, like in Taylor's regression method, statistical tests must be done to review significant differences with one:

$$T_c = \frac{|\beta - 1|}{SE_\beta}.$$

If the calculated t-value is smaller than the t-table value with df = $n-1$, zero assumption is accepted and the spatial distribution pattern ($\beta=1$) will be random. Otherwise, on the basis of the numerical value of the slope of the regression line (β), the type of spatial distribution will be determined. Lloyd's index of mean crowding (x^*) is calculated using the following formula:

$$x^* = \bar{x} + \left(\frac{S^2}{\bar{x}} - 1\right).$$

Statistics

For determining spatial distribution, the logarithm of variance and mean data in each time was taken and then the regression line between the logarithm of variance and mean was calculated by the SPSS statistical program. The graphs were designed using the Microsoft Excel program. Also, all models were analysed using the SPSS statistical program (SPSS 2004).

Table 1. Density (number of insects per plant) of different stages of the small white butterfly, *P. rapae*, in cauliflower fields in the south of Tehran.

Stages	Mean ± SE
Egg	24.52 ± 4.20
1st larval instar	0.70 ± 0.19
2nd larval instar	0.77 ± 0.18
3rd larval instar	0.91 ± 0.20
4th larval instar	0.67 ± 0.17
5th larval instar	0.17 ± 0.05
Total larva	3.05 ± 0.72
Pupa	2.26 ± 0.59
Total	29.84 ± 5.46

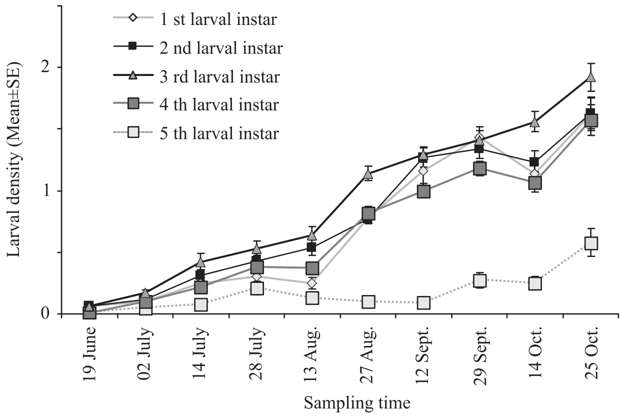

Figure 1. The mean of the larval density (±SE) of the small white butterfly, *P. rapae*, in the cauliflower fields of the south of Tehran.

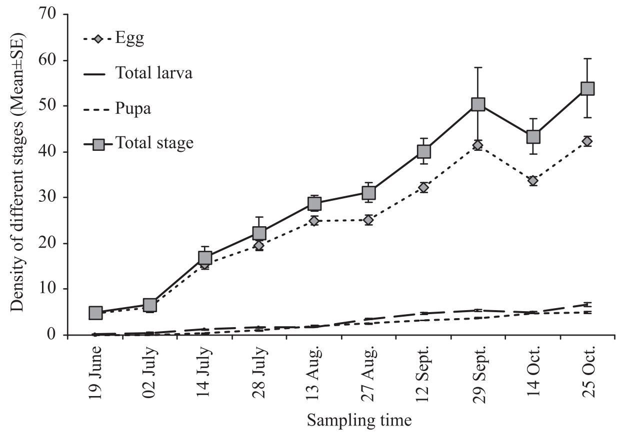

Figure 2. The mean of population density of different growth stages of the small white butterfly, *P. rapae*, in the cauliflower fields of the south of Tehran.

Results

Density of P. rapae

The mean density of the small white butterfly of different stages (egg, larva and pupa) and of all stages in total is given in Table 1. Also, fluctuations of the density of different stages of the small white butterfly are shown in Figures 1 and 2. Higher density was observed in October. As shown in Figures 1 and 2, with time increasing and with the season coming to the end the density of larvae of different stages increased. The highest and the lowest density of larvae were observed for the 3rd larval instars and 5th larval instars, respectively. Also, the density of larvae was higher than the density of pupae.

Table 2. Fitting of the variance to mean index of spatial distribution of the small white butterfly, *P. rapae*, in different sampling times.

Sampling time	Index	Egg	1st instar	2nd instar	3rd instar	4th instar	5th instar	Total larva	Pupa	Total
19 June	I_D	1298.08	96.00	96.00	97.00	99.00	0.00	88.00	98.00	1266.01
	S^2/x_{avg}	13.11	0.97	0.97	0.98	1.00	0.00	0.89	0.99	12.79
	Dispersion type*	Con.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Con.
2 July	I_D	1648.89	95.00	94.00	92.00	94.00	95.00	103.33	94.00	1504.00
	S^2/x_{avg}	16.66	0.96	0.95	0.93	0.95	0.96	1.04	0.95	15.19
	Dispersion type	Con.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Con.
14 July	I_D	5068.24	100.00	109.33	129.71	114.36	92.00	192.15	81.00	4492.08
	S^2/x_{avg}	51.19	1.01	1.10	1.31	1.16	0.93	1.94	0.82	45.37
	Dispersion type	Con.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Con.
28 July	I_D	6784.94	83.00	103.36	83.39	86.29	136.14	165.51	152.18	6208.10
	S^2/x_{avg}	68.53	0.84	1.04	0.84	0.87	1.38	1.67	1.54	62.71
	Dispersion type	Con.	Rnd.	Rnd.	Rnd.	Rnd.	Con.	Con.	Con.	Con.
13 Aug.	I_D	2877.71	120.00	108.44	98.86	99.00	133.15	163.00	164.13	2428.14
	S^2/x_{avg}	29.07	1.21	1.10	1.00	1.00	1.34	1.65	1.66	24.53
	Dispersion type	Con.	Rnd.	Rnd.	Rnd.	Rnd.	Rnd.	Con.	Con.	Con.
27 Aug.	I_D	3341.20	117.77	102.38	150.73	107.00	90.00	147.12	138.68	3124.10
	S^2/x_{avg}	33.75	1.19	1.03	1.52	1.08	0.91	1.49	1.40	31.56
	Dispersion type	Con.	Rnd.	Rnd.	Con.	Rnd.	Rnd.	Con.	Con.	Con.
12 Sept.	I_D	4833.72	230.45	142.36	101.29	110.00	113.22	283.86	78.34	4315.56
	S^2/x_{avg}	48.83	2.33	1.44	1.02	1.11	1.14	2.87	0.79	43.59
	Dispersion type	Con.	Con.	Con.	Rnd.	Rnd.	Rnd.	Con.	Rnd.	Con.
29 Sept.	I_D	14858.00	148.26	104.71	113.18	93.15	147.07	223.34	119.14	13843.79
	S^2/x_{avg}	150.08	1.50	1.06	1.14	0.94	1.49	2.26	1.20	139.84
	Dispersion type	Con.	Con.	Rnd.	Rnd.	Rnd.	Con.	Con.	Rnd.	Con.
14 Oct.	I_D	6528.90	121.36	169.00	131.35	140.80	115.00	257.34	192.90	5726.70
	S^2/x_{avg}	65.95	1.23	1.71	1.33	1.42	1.16	2.60	1.95	57.85
	Dispersion type	Con.	Rnd.	Rnd.	Rnd.	Con.	Rnd.	Con.	Con.	Con.
25 Oct.	I_D	10153.64	204.95	151.77	143.58	175.64	210.97	329.18	175.13	9057.54
	S^2/x_{avg}	102.56	2.07	1.53	1.45	1.77	2.13	3.33	1.77	91.49
	Dispersion type	Con.	Con.	Con.	Con.	Con.	Con.	Con.	Con.	Con.

Notes: *Con. = contagious, Rnd. = random, S = variance, x_{avg} = mean.

Table 3. Spatial distribution parameters of the small white butterfly, *P. rapae*, based on Taylor's method.

Parameter	Egg	1st instar	2nd instar	3rd instar	4th instar	5th instar	Total larva	Pupa	Total
B	1.77	1.48	1.39	1.40	1.24	−0.005	1.74	1.42	2.19
SE_β	0.04	0.06	0.08	0.08	0.06	0.009	0.07	0.11	0.26
T	19.25	8.00	4.87	5.00	4.00	−111.67	10.57	3.81	4.57
Spatial distribution	Con.*	Con.	Con.	Con.	Con.	Con.	Con.	Con.	Con.

Note: *Con. = contagious.

Table 4. Spatial distribution parameters of different stages of the small white butterfly, *P. rapae*, based on Iwao's method.

Parameters	Egg	1st instar	2nd instar	3rd instar	4th instar	5th instar	Total larva	Pupa	Total
B	4.64	3.07	2.58	2.53	2.47	3.06	2.60	3.74	3.10
SE_β	0.32	0.21	0.36	0.18	0.14	0.28	0.14	1.16	0.22
T	11.37	9.85	4.38	8.50	10.50	7.35	7.57	2.36	9.54
Spatial distribution	Con.*	Con.	Con.	Con.	Con.	Con.	Con.	Con.	Con.

Note: *Con. = contagious.

Index of dispersion of the small white butterfly

According to Table 2, the population distribution of small white butterfly eggs was cumulative during the season. In the beginning of the season, different stages of larva were in random distribution, and such trend continued until 27 August. After that, the distribution of the population was cumulative, and this trend continued until the end of the season. The spatial distribution of the total of growth stages of the pest was obtained as cumulative during the season. One reason for this is that the mean of the egg population was higher than the mean of other growth stages. The population distribution of small white butterfly pupae was random, and such trend continued until 14 July, and after that it was variable to the end of the season.

Spatial pattern of **P. rapae** *based on Taylor's power law*

The calculated *t*-value and *t*-table value (2.35) were compared and it was observed that in all developmental stages of the pest, the calculated *t*-value was larger than the *t*-table value. So, zero assumption based on the random spatial distribution of different developmental stages of the pest could be rejected. As β coefficients for all developmental stages of the pest separately and in total were greater than one, it can be concluded that population was characterised by cumulative distribution (Table 3).

Spatial pattern of **P. rapae** *based on Iwao's model*

The *t*-value calculated for all developmental stages of the small white butterfly was larger than the *t*-table value. Because, β coefficient in all developmental stages of the pest was greater than one, so it can be concluded that all developmental stages of *P. rapae* based on the method of Iwao were characterised by cumulative distribution (Table 4).

Discussion

Sampling gives us comprehensive information about the presence or absence of pest outbreaks or non-outbreaks, their migration, feeding, reproduction, mortality, age structure, population growth, density and distribution, as well as information for analysing and determining their control (Isaaks and Srivastava 1989; Pedigo 1994). Also, *estimating the population density* of pests can provide detailed information about potential damage to plants and agricultural products (Hasanshahi, Askarianzadeh, et al. 2012).

Responses among individuals of a pest population are difficult to understand in field conditions. With this information some of reasons behind population changes and also cognition of behavioural characteristics of species could be realised (Poole 1974). If the foundation of an effective pest management programme is the understanding of pest ecology and behaviour, then this understanding must be at an appropriate spatial and temporal scale for the pest species and the environment. This is because the structure of the landscape mosaic in which an organism lives influences ecological processes such as population dynamics, movement patterns and spatial distribution.

The type of spatial distribution of pests provides considerable knowledge of interactions among individuals of a population, which can have an effective role in control of pests. A pattern of distribution is a result of interaction between all individuals of the population and its habitat. Also, spatial distribution provides important information to researchers in the description and knowledge of populations and, overall, in evaluating pest dynamism (Pedigo and Zeiss 1996). Hasanshahi, Yazdanpanah, et al. (2012) calculated the density of eggs, larvae and pupae of the cabbage white butterfly and their results showed that the number of eggs, larvae and pupae were 1.29, 2.06 and 0.72 (per plant), respectively. In our study, the density of eggs, larvae and pupae obtained was 24.52, 3.05 and 2.62 per plant, respectively.

In our study, the population distribution of small white butterfly eggs was cumulative during the season. Since the small white butterfly usually lays its eggs in groups, it could be one of the reasons for cumulative distribution of eggs.

It seems that most larvae of the small white butterfly, *P. rapae*, feed on the middle leaves, and only part of them are deployed on the upper and lower leaves. Larvae usually pupate in the same place and on the middle leaves. Also, most larvae are on the lower surface of leaves where they eat and pupate. In general, according to all mentioned parameters, the pattern of distribution for the small white butterfly is contagious or clump. This type of behaviour and distribution is recorded for several species of Lepidoptera and many insects (Geiger and Daane 2001; Hamilton and Hepworth 2004; Ifoulis and Savopoulou-Soultani 2006). The spatial pattern can be changed due to changes in the density or movement of larvae from one plant to another and away from the place of eggs (Pedigo and Buntin 1994). The density of small white butterflies increased towards the end of the season, so its peak was observed at the end of the season and was due to weather conditions (Hasanshahi, Yazdanpanah, et al. 2012). This can explain the distribution type of the pest and its change from random to cumulative during the season. Different researches confirm that the density of serious pests of cauliflower, including the diamondback moth, *P. xylostella*, and *B. brassicae*, increased in Tehran and the highest density was observed at harvest time (Hasanshahi 2012; Hasanshahi, Abbasipour, et al. 2012; Hasanshahi, Askarianzadeh, et al. 2012; Jahan 2012). Based on the studies by Doosti et al. (2012), egg density of the small white butterfly was 18–19 eggs per plant. Also, larval density of this pest was 0.4–2.99 larvae per plant, and pupa density was 0.19–0.87 pupae per plant. Hasanshahi (2012) obtained the spatial distribution pattern of all life stages of the diamondback moth, *P. xylostella*, and its parasitoids using regression models of Taylor's power law and Iwao's patchiness regression. In Taylor's and Iwao's models, the slopes of regression for all life stages were more than one. But based on both models, the spatial distribution pattern of parasitoids of *P. xylostella* was uniform, and the slopes of regression for all parasitoids were less than one.

More knowledge of spatial distribution of pests and their natural enemies helps to understand better the behaviour and population size of insects and natural enemies. Also, it gives more different information about the impact of environmental factors on population fluctuations of pests and parasitoids (Radjabi 2003; Sahragard and Heidari 2001). According to a study by Chua and Lim (1979), the spatial distribution of *P. xylostella* was uniform for all developmental stages of the pest. In other studies, the spatial distribution of immature stages of the diamondback moth was obtained to be cumulative (Sivapragasma, Yosiaki, and Tetsuo 1985). Although the spatial pattern is specific for each species (Taylor 1984), this parameter is influenced by the patterns of behaviour, environment, host plants, etc. (Sedaratian et al. 2010).

Conclusion

In this study, the spatial distribution pattern of the small white butterfly, *P. rapae*, was found, which can be used in sampling programmes, in estimating the accurate population density of this pest, and in its management. In our study, the density of *P. rapae* was the highest at the end of the season (25 October). Therefore, we must have a plan to reduce pest population at the end of the season.

Acknowledgement

This work was supported by Faculty of Agricultural Sciences, Shahed University, Tehran, Iran.

References

Adane-Kassa, T. A., and T. Abate. 1995. "Experience in Biological Control of Insect Pests in Ethiopia: A Review. Integrating Biological Control and Host Plant Resistance." *Proceedings of a CTA/IAR/IIBC Seminar, Addis Ababa, Ethiopia*: 20.

Aliyev, A. A. O. 1999. "Fauna of the Subfamily Ichneumoninae (Hymenoptera, Ichneumonidae) of Azerbaijan with New Records." *Turkish Journal of Zoology* 23: 1–12.

Chua, T. H., and B. H. Lim. 1979. "Distribution Pattern of Diamondback Moth, *Plutella xylostella* (L.) (Lep.: Plutellidae) on Choy-sum Plants." *Zeitschrift fur angewandte Entomologie* 88: 170–175.

Costea, G., G. H. Mustata, and A. Lozan. 2002. "Role of Braconidae (Hymenoptera) in Limitation of Lepidoptera Cabbage Pest's Populations in Romania." In *Parasitic Wasps: Evolution, Systematic, Biodiversity and Biological Control*, edited by G. Melika and C. Thuroczy, 391–395. Budapest: Agroinform.

Doosti, Z., G. H. Hasanshahi, H. Abbasipour, F. Jahan, and A. Askarianzadeh. 2012. "Seasonal Population Fluctuations of the Cabbage White Butterfly, *Pieris rapae* (L.) (Lep.: Pieridae) in Cauliflower Fields of the South of Tehran." *20th Iranian Plant Protection Congress*: 671. Shiraz University.

Elliott, J. M. 1979. "Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates." *Freshwater Biological Association, Scientific Publication* 25: 1–157.

Forster, R., and M. Hommes. 1991. "Supervised Control of Lepidopterous Pests in White Cabbage." *Bulletin OILB SROP* 15 (4): 127–137.

Geiger, C. A., and K. M. Daane. 2001. "Seasonal Movement and Distribution of the Grape Mealy Bug (Hom.: Pseudococcidae): Developing a Sampling Program for San Joaquin Valley Vineyards." *Journal of Economic Entomology* 94: 291–301.

Hamilton, A. J., and G. Hepworth. 2004. "Accounting for Cluster Sampling in Constructing Enumerative Sequential Sampling Plans." *Journal of Economic Entomology* 97: 1132–1136.

Hasanshahi, G. 2012. "Natural Parasitism of the Diamondback Moth, *Plutella xylostella* (L.) (Lep.: Plutellidae) in the Cauliflower Fields of the South of Tehran." MSc thesis, Shahed University, Iran (in Persian with English Abstract).

Hasanshahi, G., H. Abbasipour, A. Askarianzadeh, F. Jahan, and J. Karimi. 2012. "Seasonal Population Fluctuations of the Diamondback Moth, *Plutella xylostella* (L.) (Lep.: Plutellidae) on Different Cauliflower Cultivars." *Archives of Phytopathology and Plant Protection* 46 (10): 1136–1149. http://dx.doi.org/10.1080/03235408.2012.760897.

Hasanshahi, G., A. Askarianzadeh, A. M. Naji, F. Jahan, and M. Salehi Tabar. 2012. "Evolution of Quantitative Damage Diamondback Moth, *Plutella xylostella* (Lep.: Plutellidae) on Canola, *Brassica napus* L. in Tehran Region." *The National Conference of Environment and Plant Production* 1: 27–31.

Hasanshahi, G., A. Yazdanpanah, Z. Dusty, A. Askarianzadeh, H. Abbasipour, and J. Karimi. 2012. "Population Density of the Cabbage White Butterfly, *Pieris rapae* (L.) (Lep.: Pieridae) on Different Cultivars of Cauliflower in the South of Tehran." *International Conference on Environment and Plant Production*: 54–58.

Ifoulis, A. A., and M. Savopoulou-Soultani. 2006. "Use of Geostatistical Analysis to Characterize the Spatial Distribution of Lobesia Botrana (Lepidoptera: Tortricidae) Larvae in Northern Greece." *Environmental Entomology* 35 (2): 497–506.

Isaaks, E. H., and R. M. Srivastava. 1989. *An Introduction to Applied Geostatistics*. New York: Oxford University Press.

Jahan, F. 2012. "Comparison of Different Cauliflower Cultivars on Population and Biological Parameters of *Brevicoryne brassicae* (L.) (Hom.: Aphididae) in South of Tehran." MSc thesis, Shahed University, Iran (in Persian with English Abstract).

Jun, C., Y. Gong-Yin, and H. Cui. 2004. "Parasitism of *Pieris rapae* (Lep.: Pieridae) by a Pupal Endoparasitoid, *Pteromalus puparum* (Hymenoptera: Pteromalidae): Effects of Parasitisation and Venom on Host Hemocytes." *Journal of Insect Physiology* 50: 315–322.

Karimi, J. 1992. "Study on Biology of *Pieris rapae* L. (Lep.: Pieridae) and Ability of *Bacillus thuringiensis* Subsp. *kurstaki* on Biological Control." MSc thesis, Tarbiat Moddarres University, Iran (in Persian with English Abstract).

Lim, G. S. 1986. "Biological Control of Diamondback Moth." In *Proceedings of the 1st International Workshop, Shanhua, Taiwan*, edited by N. T. Talekar and T. D. Griggs, 159–171. Tainan: Diamondback Moth Management.

Macharia, I., B. Lohr, and H. De Groote. 2005. "Assessing the Potential Impact of Biological Control of *Plutella xylostella* (Diamondback Moth) in Cabbage Production in Kenya." *Crop Protection* 24: 981–989.

Metcalf, C., and W. P. Flint. 1962. *Destructive and Useful Insect, Their Habits and Control*. 3rd ed. New York: McGraw-Hill.

Nyambo B., and A. Pekke. 1995. *Brassica Planning Workshop for East and Southern Africa Region, Lilongwe-Malawi*, May 15–18. GTZ-IPM Horticulture Nairobi.

Oduor, G. I., B. Lohr, and A. A. Seif. 1996. "Seasonality of Major Cabbage Pests and Incidence of their Natural Enemies in Central Kenya." *Proceedings of the 3rd International Workshop of Diamondback Moth, Kuala Lumpur, Malaysia*: 37–42.

Ooi, P. A. C. 1980. "Laboratory Studies of *Diadegma cerophagous* (Hym.: Ichneumonidae), a Parasite Introduced to Control *Plutella xylostella* (Lep.: Hyponomeutidae) in Malaysia." *Entomophaga* 25 (3): 249–259.

Pedigo, L. P. 1994. "Introduction to Sampling Arthropod Population." In *Handbook of Sampling Methods for Arthropods in Agriculture*, edited by L. P. Pedigo and G. D. Buntin, Vol. 689, 1–11. Boca Raton, FL: CRC Press.

Pedigo, L. P., and G. D. Buntin. 1994. *Handbook of Sampling Methods for Arthropods in Agriculture*. Boca Raton, FL: CRC Press.

Pedigo, L. P., and M. R. Zeiss. 1996. *Analyses in Insect Ecology and Management*. Ames: Iowa State University Press.

Pfiffner, L., H. Luka, C. Schlatter, A. Juen, and M. Traugott. 2009. "Impact of Wild Flower Strips on Biological Control of Cabbage Lepidopterans." *Agriculture, Ecosystems and Environment* 129: 310–314.

Poole, R. W. 1974. *An Introduction to Quantitative Ecology*. New York: McGraw-Hill Kogakusha.

Radjabi, Gh. 2003. *Insect Ecology Applied and Considering the Conditions of Iran*. Tehran: Agricultural Research and Education Organization (in Persian).

Sahragard, A., and R. Heidari. 2001. "Biology and Spatial Distribution of Rose Sawfly (Hym.: Argidae) in Guilan." *Journal of Entomological Society of Iran* 21 (2): 25–37.

Sato, Y., and N. Ohsaki. 2004. "Response of the Wasp (*Cotesia glomerata*) to Larvae of the Large White Butterfly (*Pieris brassicae*)." *Ecological Research* 19: 445–449.

Sedaratian, A., Y. Fathipour, A. A. Talebi, and S. Farahani. 2010. "Population Density and Spatial Distribution Pattern of *Thrips tabaci* (Thysanoptera: Thripidae) on Different Soybean Varieties." *Journal of Agriculture, Science and Technology* 12: 275–288.

Sivapragasma, A., I. Yosiaki, and S. Tetsuo. 1985. "Spatial Distribution of the Diamondback Moth, *Plutella xylostella* L. on Cabbage." *Japanese Journal of Applied Entomology and Zoology* 29: 8101–8104.

Southwood, T. R. E., and P. A. Henderson. 2000. *Ecological Methods*. 2nd ed. Oxford: Blackwell Science.

Taylor, L. R. 1961. "Aggregation, Variance and the Mean." *Nature* (Lond.) 189: 732–735.

Taylor, L. R. 1984. "Assessing and Interpreting the Spatial Distribution of Insect Populations." *Annual Review of Entomology* 29: 321–357.

Taylor, R. A. J., R. K. Lindquest, and J. L. Shipp. 1998. "Variation and Consistency in Spatial Distribution as Measured by Taylor's Power Law." *Environmental Entomology* 27: 191–201.

Young, J. L., and J. H. Young. 1998. *Statistical Ecology*. Boston, MA: Kluwer Academic.