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Research Article

Geostatistical analysis of spatial distribution of *Therioaphis maculata* (Hemiptera: Aphididae) and coccinellid lady beetles (Coleoptera: Coccinellidae)

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Abstract: Understanding the spatial dynamics of insect distributions provides useful information about their ecological requirements and can also be used in site-specific pest management programs. Interactions between prey and predator are spatially and temporally dynamic and can be affected by several factors. In this study, geostatistics was used to characterize the spatial variability of spotted alfalfa aphid, *Therioaphis maculata* Buckton and coccinellid lady beetles in alfalfa fields. Global positioning and geographic information systems were used for spatial sampling and mapping the distribution pattern of these insects. This study was conducted in three alfalfa fields with areas of 7.3, 3.1 and 0.5 ha and two growing seasons, 2013 and 2014. The 0.5 ha field was divided into 10 × 10m grids and 3.1 and 7.3 ha fields were divided into 30 × 30m grids. Weekly sampling began when height of alfalfa plants reached about 15cm and was continued until the cuttings of alfalfa hay. For sampling, 40 and 10 stems were chosen randomly in 30 × 30m and 10 × 10m grids, respectively and shaken into a white pan three times. Aphids and coccinellids fallen in the pan were counted and recorded. Semivariance analysis indicated that distribution of *T. maculata* and coccinellids was aggregated in the fields. Comparison of the distribution maps of aphid and lady beetles indicated that there was an overlap between the maps, but they did not coincide completely. This study revealed that relationship between spotted alfalfa aphid and lady beetles was spatially dynamic. These results can be used in biological control and site-specific management programs of *T. maculata*.

Keywords: GIS, distribution map, kriging, prey-predator interactions

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Introduction

Alfalfa, *Medicago sativa* L., is an important forage crop in Iran and many other parts of the world. Similar to other crops, pests such as weevils, aphids and potato leafhopper can reduce alfalfa yield dramatically. Aphids are piercing-sucking insects and their feeding results in stunting, leaf curling and yellowing of the alfalfa plants. In addition, excretion of large amounts of honeydew, a food for sooty mold fungus, contaminates alfalfa plants and reduces its quality (Guerena and Sullivan, 2003). The spotted alfalfa aphid, *Therioaphis maculata* Buckten (Hemiptera: Aphididae) is an important pest that attacks alfalfa fields mainly in the second and third hay-cuttings (Khanjani, 2005).

Many biotic and abiotic factors can affect population dynamics of *T. maculata* in the alfalfa fields. The perennial nature of alfalfa creates a suitable habitat for many beneficial

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insects including pollinators and natural enemies of pests. These natural enemies can keep pest population levels down in alfalfa and adjacent fields (Guerena and Sullivan, 2003). Several predators including Coccinellidae, Syrphidae, Chrysopidae, Nabidae, and Anthocoridae families prey on aphids in alfalfa fields and play an important role in their population dynamics. Coccinellids are important and the most abundant predators of aphids in many agroecosystems including alfalfa fields (Elliott and Kieckhefer, 1990; Rakhshani *et al*., 2010). Conservation of these predators can help to reduce *T. maculata* population. Widespread use of chemical pesticides against different pests of alfalfa can reduce the populations of beneficial insects. Site-specific application of pesticides based on the spatio-temporal distributions of the pests and their natural enemies is one of the solutions suggested to reduce the use of chemicals and conserve beneficial insects in untreated refuges (Midgarden *et al*., 1997; Merrill *et al*., 2009).

Prey-predator interactions are not static but spatially and temporally dynamic (Park and Obrycki, 2004). Therefore, studying the spatial distribution of a pest and its predators is critical for understanding their ecological and behavioral characteristics, and can be used in pest biological and chemical controls. Spatial distribution is one of the most important ecological properties of species (Taylor, 1984) and has been studied by many researchers using non-spatial and spatial statistical techniques (Sciarretta *et al*., 2008; Reay-Jones, 2010; Karimzadeh *et al*., 2011; Rijal *et al*., 2014). Non-spatial statistics such as Taylor's power law, Iwao's regression and Greig-smith method have been used extensively to determine spatial distribution of insects, but the spatial locations of samples were not included in these methods. Therefore, these indices failed to distinguish among different spatial patterns (Taylor, 1984; Leibhold *et al*., 1993). Geostatistics is a set of statistical methods that uses both sample values and spatial information to characterize spatial patterns and predict the values of the variable at unsampled locations (Clark, 2001; Moral Garcia, 2006). In geostatistical surveys, areas such as field edges that are avoided as a source of bias in the traditional methods become primary areas to be explored. Also in this method, areas with low pest populations are as important as areas with high population density. These are advantages of geostatistics over traditional methods (Sciarretta and Trematerra, 2014). The sampling design and scale of the study in a geostatistical research depends on the previous information about the scales of spatial correlation of the target insect populations and the purpose of the study. If the research objective is to determine the distribution of a pest inside an orchard or arable field for optimizing control strategies or monitoring programs, a sampling point grid will be suitable to cover every part of the study area (McBratney *et al*., 1981; Sciarretta and Trematerra, 2014).

Generating distribution maps and comparing them in temporal sequences can be used to investigate the spatio-temporal synchrony and asynchrony of the predator and prey distributions. Currently available technologies such as global positioning system (GPS), geographic information system (GIS) and geostatistics have opened up new ways to characterize, analyze and map the insect distributions (Park and Obrycki, 2004; Moral Garcia, 2006). The objectives of this study were to determine the spatial distribution patterns of *T. maculata* and its coccinellid natural enemies in alfalfa fields and investigate their spatial synchrony using geostatistics and to compare the results of geostatistical analysis with the results of spatial analysis by distance indices (Shayestehmehr *et al*., 2017).

Materials and Methods

Study area

This study was conducted in two growing seasons, 2013 and 2014, and three alfalfa fields (0.5, 3.1 and 7.3 ha) located in the experimental farm of Faculty of Agriculture, University of Tabriz, Tabriz, Iran. Because there was no previous information about the scales of spatial correlation of *T. maculata* in alfalfa fields, the study was conducted at two different spatial scales. The 3.1 and 7.3 ha fields were divided

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into 30 × 30m and the 0.5 ha field was divided into 10 × 10m grids. Field borders and spatial locations of samples were georeferenced and saved in a hand-held GPS receiver (Model GPS-map 76CSx, Garmin, Olathe, Kansas, USA) in UTM coordinate system. There were 85 grids in 7.3 ha, 39 grids in 3.1 ha and 53 grids in 0.5 ha field, respectively.

Sampling

Weekly samplings began when alfalfa plants were about 15 cm in height and continued until the last hay cutting. Samplings were performed in the hours before noon to reduce sampling error. In 2013, 40 and 10 alfalfa stems were chosen randomly in 30 × 30m and 10 × 10m grids, respectively; and shaken into a white pan three times (Shayestehmehr *et al*., 2017). The aphids and coccinellids in the pan were counted and recorded (Summers *et al*., 2010). Aphid population increased in the 7.3 and 3.1 ha fields late in the growing season and made counting difficult and time consuming. In order to decrease the cost of sampling, the number of stems chosen was reduced to half.

In 2014, *T. maculata* was sampled as described previously. But the results of the previous year and literature review indicated that sweeping could be more appropriate for sampling of the coccinellids (Elliott and Michels, 1997; Schmidt *et al*., 2008). Therefore, five 180 sweeps in 30 × 30m grids and three 180 sweeps in 10 × 10m grids were considered as a sample unit and one sample unit was taken from each grid. The larvae and adults of coccinellids collected were counted and recorded.

Statistical analysis

Before autocorrelation analysis, the frequency distribution of the data was examined and the lognormal transformation was done for datasets to normalize distributions. Because the number of insects was zero in some samples, an offset value of one was added to all sample values before transformation. Variograms were used to quantify the degree of spatial correlation among samples and to determine distribution patterns of insects viz. aggregation, randomness and uniformity. The variogram is a plot of semivariance values of sample pairs against the separation distances (Farias *et al*., 2004). Semivariance was calculated using the following formula:

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

where, γ (***h***) is the experimental semivariance value at distance interval *h*, *h* is the distance between sample pairs or lag size, N (*h*) is the total number of sample pairs separated by *h*. $Z\,(\boldsymbol{x}_i)$ and $Z\,(\boldsymbol{x}_{i+h})$ are measured sample at points $\boldsymbol{x}_i$ and $\boldsymbol{x}_{i+h}$ (Vieira *et al*., 1983; Clark, 2001).

Because the empirical values of semivariance can fluctuate from point to point, a theoretical model must be fitted to the empirical variogram (Sciarretta and Trematerra, 2014). The residual sums of square (RSS) values were used to determine how well the model fits the points. Models with minimum RSS, were chosen. Range, sill and nugget are variogram parameters. Range is the distance at which the semivariance reaches its maximum value. Sill is the value of the semivariance at distance equal to the range. The nugget is the value of the semivariance when lag distance is zero. The nugget is composed of experimental errors and microscale variance that cannot be measured by the spacing of the sampling design (Brenner *et al*., 1998). Partial sill is the difference between sill and nugget. Spatial dependency was calculated by *k* parameter that can summarize the level of randomness and is defined as the ratio between the nugget and sill. Values of *k* below 0.8 indicate that the distribution is aggregated, as the *k* parameter approaches zero, the level of spatial dependency will become greater (Sciarretta and Trematerra, 2014). Geostatistical analyses were conducted using GS + 5.1.

Besides analyzing the spatial structures, another principal objective of a geostatistical analysis is to obtain estimates of variable values at unsampled locations (Moral Garcia, 2006). In this study, distribution maps were generated using the geostatistical interpolation method known as ordinary kriging in ArcGIS 9.3. Kriging provides estimates of the variable at unsampled locations based on the distance and spatial structure estimated (Leibhold *et al.*, 1993; Clark, 2001). Interpolated maps were used to visualize spatial distribution of spotted alfalfa aphid and lady beetles populations in the fields.

Spatial synchrony between spotted alfalfa aphid and lady beetles

The spatial correlation between spotted alfalfa aphid and lady beetles was determined using correlation analysis. The correlation coefficient near 1 indicates high positive association between two populations and the correlation coefficient near -1 indicates the high negative association between two populations.

Results

Geostatistical analysis

Based on the RSS values spherical, exponential, and Gaussian models were the best fitted models for empirical variograms of *T. maculata* and coccinellids in the large-scale study (Tables 1 and 2). Linear model fitted nine cases with no spatial structures. Any model could not be fitted for one dataset of lady beetles.

The *k* parameter values were < 0.8 in 21 cases of 23 datasets in large-scale study (Table 1) indicated that *T. maculata* were aggregated in 3.1 and 7.3 ha fields. Two species of lady beetles including *Coccinella septempunctata* Linnaeus and *Hippodamia variegata* (Goeze) were dominant in the alfalfa fields studied. Because populations of the lady beetles were low, all stages and species were pooled and analyzed together. The *k* parameter values of coccinellids were < 0.8 in 15 cases of 23 datasets (Table 2).

In the small-scale study, spherical, exponential, and Gaussian models best fitted empirical variograms too (Tables 3 and 4). Linear model fitted empirical variograms of four dates. The *k* parameter values indicated that both *T. maculata* and coccinellids had strong spatial structure and were aggregated in small-scale study.

Table 1 Geostatistical description of *Therioaphis maculata* in large-scale study.

Date of sampling	Field area (ha)	Model	Nugget	Sill	Range	*k*	RSS[1]
22 Jul 13	7.3 ha	Ex[2]	0.0	0.0	37.2	0.0	0.0
29 Jul 13	7.3 ha	Ex	0.0	0.1	45.6	0.0	0.0
05 Aug 13	7.3 ha	Sp[3]	0.1	0.4	225.4	0.3	0.0
17 Sep 13	7.3	Li[4]	57.6	63.4	324.7	0.9	569.0
25 Sep 13	7.3	Ex	45.3	90.6	753.2	0.5	1230.0
02 Oct 13	7.3	Ex	0.0	1.5	142.1	0.0	0.0
09 Oct 13	7.3	Ex	5.6	62.8	82.0	0.1	170.0
23 Jun 14	7.3	Ex	0.1	0.2	247.4	0.3	0.0
29 Jun 14	7.3	Sp	0.1	0.2	203.6	0.3	0.0
05 Jul 14	7.3	Ga[5]	2.6	7.0	202.7	0.4	0.3
11 Aug 14	7.3	Sp	0.1	0.4	186.3	0.1	0.0
18 Aug 14	7.3	Ga	13.3	56.7	376.0	0.2	25.4
24 Aug 14	7.3	Ex	0.0	0.2	35.5	0.0	0.0
26 Aug 13	3.1	Sp	0.1	1.1	107.9	0.1	0.0
13 Aug 13	3.1	Sp	0.1	40.8	79.9	0.0	13.3
08 Sep 13	3.1	Sp	7.2	202.3	154.6	0.0	550.0
19 Sep 13	3.1	Ex	0.0	1.7	26.9	0.0	0.1
10 Jul 14	3.1	Li	8.4	8.4	172.2	1.0	10.3
17 Jul 14	3.1	Ex	0.2	0.5	403.9	0.4	0.0
01 Sep 14	3.1	Ex	0.7	22.3	25.4	0.0	16.0
07 Sep 14	3.1	Sp	0.0	0.5	70.8	0.0	0.0
13 Sep 14	3.1	Sp	0.0	6.0	69.2	0.0	0.9
20 Sep 14	3.1	Ex	0.1	0.3	29.2	0.2	0.0

[1]: Residual sums of squares, [2]: Exponential model, [3]: Spherical model, [4]: Linear model, [5]: Gaussian model.

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Table 2 Geostatistical description of the coccinellid lady beetles in large-scale study.

Date of sampling	Field area (ha)	Model	Nugget	Sill	Range	*K*	RSS[1]
22 Jul 13	7.3	Ex[2]	0.0	0.0	703.1	0.5	0.0
29 Jul 13	7.3	Sp[3]	0.0	0.0	60.9	0.4	0.0
05 Aug 13	7.3	Ex	0.0	0.0	810.9	0.5	0.0
17 Sep 13	7.3	Ex	0.0	0.1	324.2	0.5	0.0
25 Sep 13	7.3	Sp	0.0	0.0	73.6	0.4	0.0
02 Oct 13	7.3	Sp	0.0	0.1	810.9	0.5	0.0
09 Oct 13	7.3	Ex	0.0	0.1	810.9	0.5	0.0
23 Jun 14	7.3	Ex	0.1	0.1	707.5	0.5	0.0
29 Jun 14	7.3	Li[4]	0.0	0.0	324.7	1.0	0.0
05 Jul 14	7.3	Li	0.1	0.1	324.7	1.0	0.0
11 Aug 14	7.3	Sp	0.1	0.1	810.9	0.5	0.0
18 Aug 14	7.3	Sp	0.1	0.2	773.6	0.5	0.0
24 Aug 14	7.3	Ex	0.1	0.2	810.9	0.5	0.0
26 Aug 13	3.1	Li	0.0	0.0	172.2	1.0	0.0
13 Aug 13	3.1	No	_	_	_	_	_
08 Sep 13	3.1	Li	0.0	0.0	172.2	1.0	0.0
19 Sep 13	3.1	Sp	0.0	0.1	86.4	0.1	0.0
10 Jul 14	3.1	Ex	0.0	0.4	408.2	0.1	0.0
17 Jul 14	3.1	Ga[5]	0.1	0.2	410.9	0.5	0.0
01 Sep 14	3.1	Li	0.1	0.1	167.9	1.0	0.0
07 Sep 14	3.1	Sp	0.0	0.2	80.4	0.1	0.0
13 Sep 14	3.1	Li	0.2	0.2	167.9	1.0	0.0
20 Sep 14	3.1	Li	0.1	0.1	167.9	1.0	0.0

[1]: Residual sums of squares, [2]: Exponential model, [3]: Spherical model, [4]: Linear model, [5]: Gaussian model.

Table 3 Geostatistical description of *Therioaphis maculata* in small-scale study.

Date of sampling	Model	Nugget	Sill	Range	*k*	RSS[1]
03 Jul 13	Ex[2]	0.0	0.1	40.0	0.2	0.0
09 Jul 13	Sp[3]	0.1	0.3	168.7	0.3	0.0
14 Jul 13	Ex	0.0	0.4	10.3	0.0	0.0
14 Aug 13	Ex	0.2	0.4	210.9	0.5	0.0
19 Aug 13	Li[4]	2.0	2.0	74.7	1.0	1.5
24 Aug 13	Sp	2.5	5.8	160.4	0.4	0.3
13 Oct 13	Sp	0.6	2.5	96.9	0.3	0.1
21 Oct 13	Ga[5]	0.1	1.1	210.9	0.1	0.0
30 Oct 13	Sp	0.3	2.7	68.5	0.1	0.4
11 Jul 14	Ga	1.5	6.0	83.7	0.3	0.8
15 Jul 14	Sp	0.3	2.3	79.1	0.1	0.0
21 Jul 14	Sp	0.7	2.0	69.2	0.4	0.1
27 Jul 14	Sp	0.0	0.5	60.7	0.0	0.0
03 Sep 14	Sp	1.7	14.5	77.0	0.1	1.6
09 Sep 14	Sp	0.9	0.3	168.6	0.3	0.0
14 Sep 14	Ga	2.6	12.2	78.2	0.2	4.0
21 Sep 14	Ga	0.1	0.6	172.2	0.1	0.0

[1]: Residual sums of squares, [2]: Exponential model, [3]: Spherical model, [4]: Linear model, [5]: Gaussian model.

Table 4 Geostatistical description of cocinellid lady beetles in small-scale study.

Date of sampling	Model	Nugget	Sill	Range	*k*	RSS[1]
09 Jul 13	Li	0.0	0.0	74.7	1.0	0.0
14 Jul 13	Ga	0.0	0.2	169.8	0.1	0.0
14 Aug 13	Ga	0.0	0.1	163.3	0.2	0.0
19 Aug 13	Sp[3]	0.0	0.1	160.0	0.5	0.0
24 Aug 13	Ex[2]	0.0	0.1	14.20	0.3	0.0
13 Oct 13	Ex	0.0	0.0	49.2	0.5	0.0
21 Oct 13	No	_	_	_	_	_
30 Oct 13	No	_	_	_	_	_
11 Jul 14	Ex	0.1	0.3	176.6	0.5	0.0
15 Jul 14	Li[4]	0.1	0.1	74.7	0.9	0.0
21 Jul 14	Li	0.1	0.1	74.7	1.0	0.0
27 Jul 14	Ga[5]	0.1	0.2	166.8	0.4	0.0
03 Sep 14	Li	0.1	0.1	74.7	1.0	0.0
09 Sep 14	Ex	0.1	0.3	210.9	0.5	0.0
14 Sep 14	Ga	0.1	0.7	162.7	0.2	0.0
21 Sep 14	Ex	0.1	0.3	189.2	0.5	0.0

[1]: Residual sums of squares, [2]: Exponential model, [3]: Spherical model, [4]: Linear model, [5]: Gaussian model.

Spatial synchrony between spotted alfalfa aphid and lady beetles

Correlation analysis indicated that spatial correlation between spotted alfalfa aphid and lady beetles in the fields was dynamic (r = 0.02-0.445 in 7.3 ha, 0.008-0.487 in 3.1 ha and 0.0007-0.381 in 0.5 ha). The distribution maps also indicated that spotted alfalfa aphid and lady beetles distributions did not always coincide well in space in both large-scale and small-scale (Figs. 1-3).

Discussion

The results of geostatistical analyses indicated that like many other insects, *T. maculata* and lady beetles had aggregated distribution pattern in the space in some sampling dates. These results are consistent with the results of Fievet *et al.* (2007), Tomanovic *et al.* (2008) and Rijal *et al.* (2014). They reported aggregated spatial distribution pattern of *Sitobion avenae* F., cereal aphids and *Vitacea polistiformis* (Harris), respectively. These results also confirmed the results of spatial analysis by distance indices (Shayestehmehr *et al.*, 2017). Aggregated distribution of spotted alfalfa aphid could be explained by quality of host plant, reproduction behavior and climatic conditions. Spatial distribution of lady beetles can be affected by their tendency to prey patches in the fields. Prey-density dependence does not explain all the spatial distribution of a predator. Therefore, there may be factors other than prey abundance that would explain predator aggregations in agroecosystems. Factors such as aphids, reproductive behavior or climatic conditions could affect the spatial distribution of lady beetles.

As seen in the results, nugget was not zero in some variograms. A zero nugget of variogram indicates a strong spatial autocorrelation and confidence in data of sampling. The presence of nonzero nuggets reflects two sources of variability: the spatial dependency at a scale smaller than the minimum lag distance and the sampling error (Karimzadeh *et al.*, 2011; Sciarretta and Trematerra, 2014). Because of large number of samples, sampling error could not be the major reason; and probably spatial dependency at small scales caused nonzero nuggets.

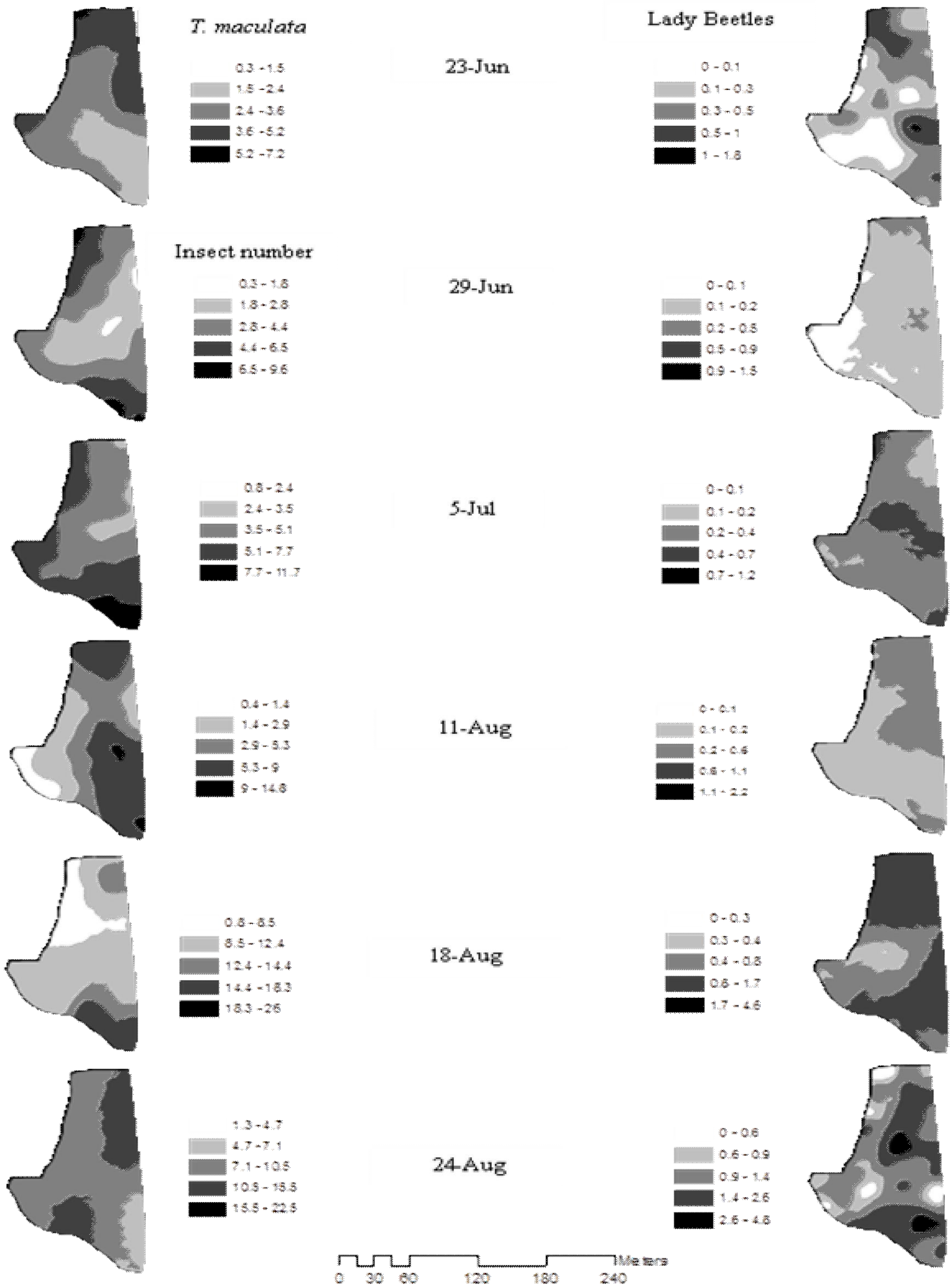

Figure 1 Exemplary distribution maps of spotted alfalfa aphid *Therioaphis maculata* and coccinellid lady beetles in the 7.3 ha field in 2014.

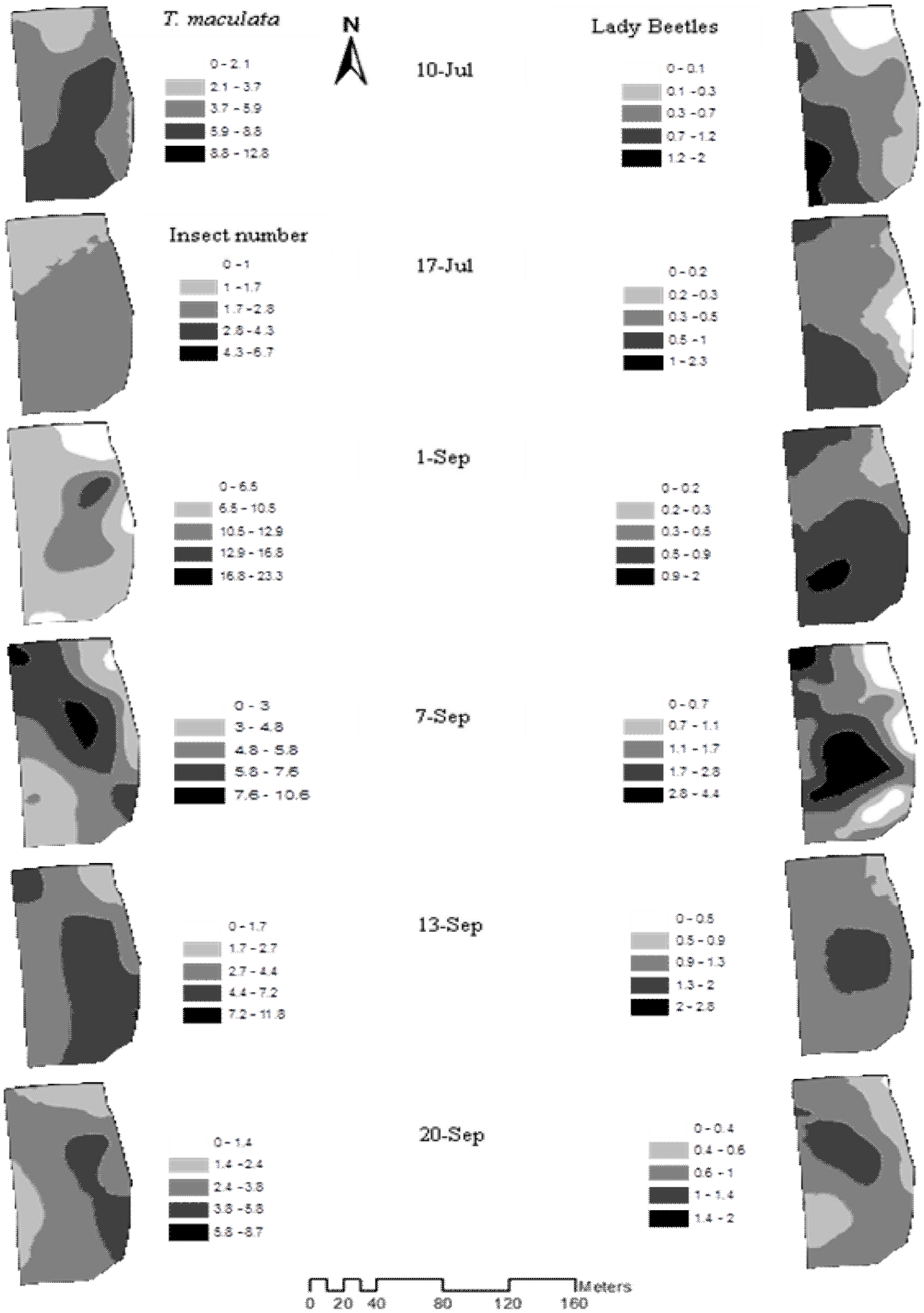

Figure 2 Exemplary distribution maps of spotted alfalfa aphid *Therioaphis maculata* and coccinellid lady beetles in the 3.1 ha field in 2014.

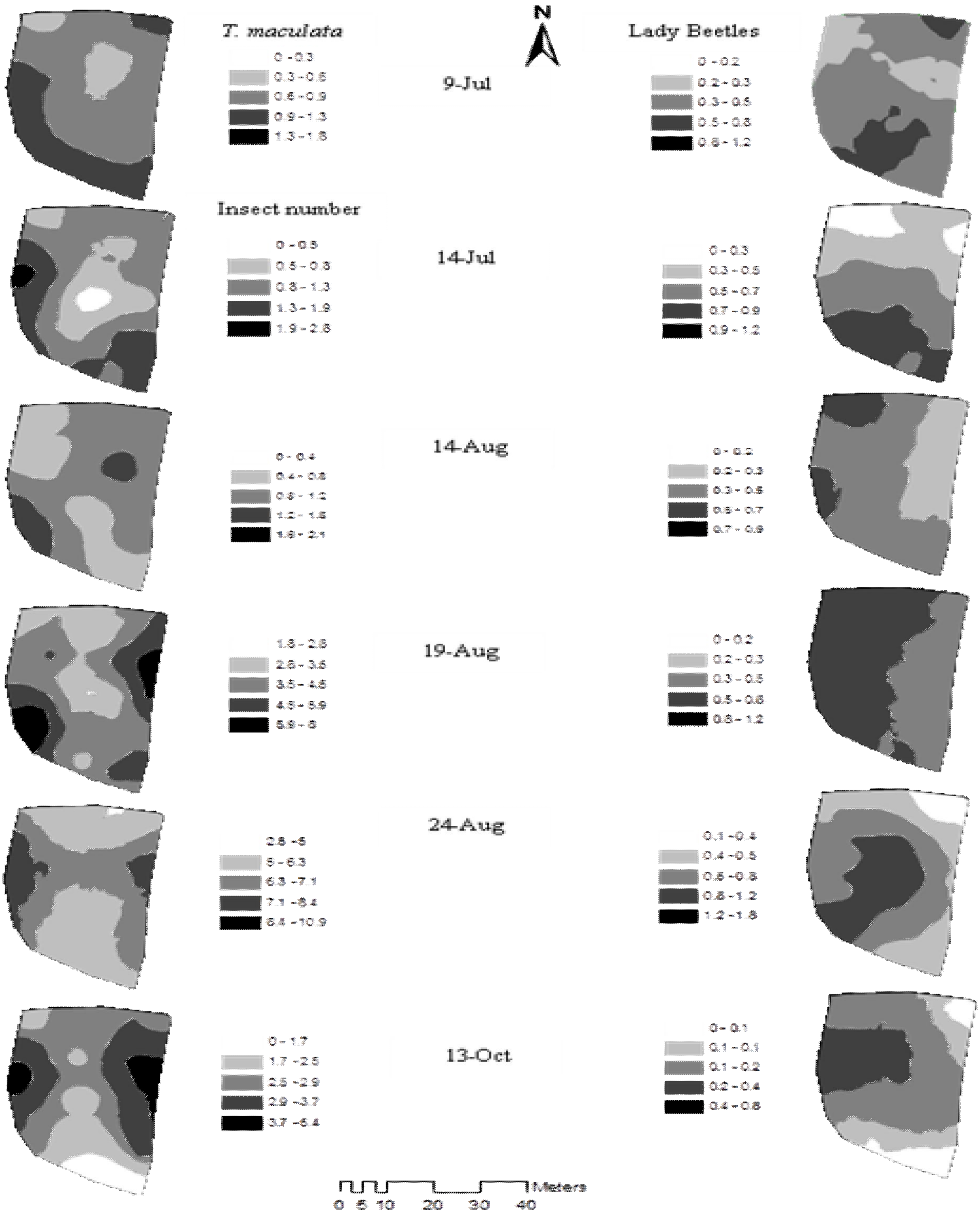

Figure 3 Exemplary distribution maps of spotted alfalfa aphid *Therioaphis maculata* and coccinellid lady beetles in the 0.5 ha field in 2013.

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Another objective of this study was to determine the spatial correlation between spotted alfalfa aphid and lady beetles in studied fields. The maps generated in this study indicated that spatial distribution pattern of the aphid and coccinellids did not always coincide well in the space. The results of this study also indicated that the spatial distribution patterns of spotted alfalfa aphid and lady beetles were not similar for all sampling dates (Tables 1-4) and their spatial synchrony was dynamic throughout the growing season in the studied fields (Figs. 1-3). Park and Obrycki (2004) also indicated that distribution of lady beetles did not always coincide with distribution of corn leaf aphids in corn fields. Their study also documented dynamic relationships in time and space between lady beetles and corn leaf aphids throughout the growing season.

Several factors can influence the spatial synchrony between lady beetles and spotted alfalfa aphid in the field. According to the data obtained during two years of the study, coccinellid population density was low in the fields studied. It could be one of the factors affecting the spatial coincidence of coccinellids and *T. maculata*. Other factors such as hay-cutting, availability of alternative food sources for coccinellids, presence of other natural enemies, prey density, environmental factors such as agronomic, edaphic and geographic can also influence the probability of spatial synchrony of spotted alfalfa aphid and lady beetles in the alfalfa fields (Richards and Harper 1978, Harper *et al.*, 1990; Schaber *et al.*, 1990; Park and Obrycki, 2004).

For insect pests, information on the spatial distribution of populations can be used for site-specific application of pesticides and conservation of natural enemies. The spatial distribution pattern can also be used to determine where and when to sample to obtain representative population estimates. Furthermore the success of biological control depends on spatio-temporal overlapping of populations of pests and their natural enemies (Park and Obrycki 2004). Therefore it is necessary to examine whether the distribution of predators varied in relation to densities of their prey over time and place. These considerations emphasize the importance of field studies in ecology and the need for methods that use the spatial information in ecological count data. Comparing the results of geostatistical analysis and spatial analysis by distance indices (SADIE) revealed that both geostatistics and SADIE can be used to investigate the spatial distribution pattern of insect populations and support pest management programs.

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تجزیه زمین‌آماری پراکنش مکانی شته خالدار یونجه *Therioaphis maculata* (Hemiptera: Aphididae) و کفشدوزک‌های خانواده Coccinellidae

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چکیده: بررسی پویایی مکانی پراکنش حشرات، اطلاعات مفیدی در مورد نیازهای بوم‌شناختی آنها فراهم کرده و می‌تواند در برنامه‌های مدیریت مکان ویژه آفات مورد استفاده قرار گیرد. رابطه شکار و شکارگر از لحاظ مکانی و زمانی پویا بوده و می‌تواند به وسیله عوامل مختلف تحت تأثیر قرار گیرد. در این پژوهش پویایی مکانی شته‌ی خالدار یونجه، *Therioaphis maculata* Buckton و دشمنان طبیعی آن از خانواده Coccinellidae با استفاده از زمین‌آمار، سامانه موقعیت‌یابی جهانی (GPS) و سامانه اطلاعات جغرافیایی (GIS) مورد مطالعه قرار گرفت. از GPS برای اندازه‌گیری مساحت مزارع و تعیین موقعیت مکانی نمونه‌ها، از زمین‌آمار برای تعیین میزان وابستگی مکانی داده‌ها و به‌دست آوردن الگوی پراکنش مکانی حشرات و از GIS برای تهیه نقشه پراکنش آفت و دشمنان طبیعی آن استفاده شد. این بررسی طی دو سال در سه مزرعه یونجه به مساحت‌های ۰/۵، ۳/۱ و ۷/۳ هکتار و در دو مقیاس انجام شد. مزارع ۳/۱ و ۷/۳ هکتاری به شبکه‌های ۳۰ × ۳۰ متر و مزرعه ۰/۵ هکتاری به شبکه‌های ۱۰ × ۱۰ متر تقسیم شدند. نمونه‌برداری‌های هفتگی در هر چین، با رسیدن ارتفاع بوته‌ها به حدود ۱۵ سانتی‌متر شروع و تا برداشت چین‌ها ادامه داشت. برای نمونه‌برداری از شته‌ها و کفشدوزک‌ها، به‌ترتیب ۴۰ و ۱۰ ساقه در شبکه‌های ۳۰ × ۳۰ متر و ۱۰ × ۱۰ متر انتخاب شده و داخل یک تشت سفید سه بار تکان داده شدند. سپس شته‌ها و کفشدوزک‌های افتاده داخل تشت شمارش و ثبت شدند. نتایج تجزیه زمین‌آماری نشان داد که شته خالدار یونجه و کفشدوزک‌ها در مزارع مورد مطالعه الگوی مکانی تجمعی داشتند. هم‌چنین مقایسه نقشه‌های پراکنش نشان داد که رابطه شته خالدار یونجه و کفشدوزک‌ها در مزارع مورد مطالعه از لحاظ مکانی پویا بود. از این نتایج و نقشه‌ها می‌توان در افزایش کارآیی عوامل کنترل زیستی، انجام سمپاشی‌های مکان-ویژه علیه شته خالدار یونجه و در کل مدیریت مؤثر و کارآمد این آفت در مزارع یونجه استفاده کرد.

واژگان کلیدی: سامانه اطلاعات جغرافیایی، نقشه پراکنش، کریجینگ، رابطه شکار-شکارگر

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