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Optimization of *Agriotes sordidus* monitoring in northern Italy rural landscape, using a spatial approach

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Abstract

A spatial analysis of *Agriotes sordidus* (Illiger) (Coleoptera Elateridae) was carried out on data collected by means of pheromone traps in a farm of 500 hectares in northern Italy. The main objective of the paper was to analyse the spatial distribution of this economic pest, in order to optimise the monitoring; another aim was to understanding the spatial patterns of this insect in relation to the geographic and agronomic management of the site investigated. Spatial distribution was studied by means of geostatistical analysis of the total number of captured individuals per year (variable *Sum*) and the peak of population density (variable *Peak*). Data were analysed using the total of traps and reduced datasets by means of re-sampling simulations. The semi-variograms showed that adults of *A. sordidus* exhibited a strong aggregative pattern in the investigated area, confirming previous preliminary studies. Kriging contour maps were used to describe spatial aggregation of *A. sordidus*. Cross-validation analysis demonstrated that the simulations with 50% of the total of traps produced maps with a good concordance between estimated and measured values, with the caution to maintain a uniform distribution of the sample points within the monitored area. Simulations by means of geostatistics were suitable to optimise the monitoring in order to obtain a compromise between precision and feasibility. This study provided an interpretation of the spatial dynamics of *A. sordidus* adults on meso-scale, leading to an estimation of the risk-zones for pest damage. Further studies are needed in order to understand the role of a number of agronomic variables on the populations of *A. sordidus*, to design zones of different risk of infestation and to optimize the monitoring and management of this economic pest in northern Italy.

Key words: Coleoptera Elateridae, *Agriotes sordidus*, pheromone traps, sampling, spatial distribution, geostatistics, kriging.

Introduction

Among click beetles (Coleoptera Elateridae), some species like *Agriotes sordidus* (Illiger), *Agriotes litigiosus* (Rossi) and *Agriotes brevis* Candeze are considered economic pests in northern Italy. These insect pests can cause economic damages to many vegetable and arable crops, including potato, sugar beet, corn, tomato, onion, watermelon, melon (Curto and Ferrari, 1999; Furlan *et al*., 2000). Many factors, including the high costs related to the larval samplings and the lack of economic thresholds, contribute to make problematic the management of these pests. For this reason control methods in many cases are carried out without following basic IPM criteria, thus leading to a non-rational management of insecticide soil applications (Furlan *et al*., 1997). It was demonstrated that sequential sampling based on stop lines was a suitable method to standardise the monitoring *Agriotes* larvae by means of soil sampler (Furlan and Burgio, 1999). Nevertheless, soil sampling technique has not been adopted by farmer of northern Italy because it proved to be too much time-consuming (Ferrari *et al*., 2002). In alternative, baited traps with germinating seeds (Doane *et al*., 1975; Chabert and Blot, 1992; Williams *et al*., 1992) can be used, but this method in northern Italy conditions showed to be suitable only for certain specific risk situations. A sampling method of *Agriotes* spp. populations based on pheromone traps showed to be a promising method in the monitoring of adult populations (Furlan *et al*., 2001; Ferrari *et al*., 2002). An application of this method in a large scale context in Italian rural landscapes is in progress, even if an economic threshold based on adult catches has not been defined.

Many authors pointed out that the development of a rational pest-management sampling must be based on a detailed knowledge of spatial aspects of an insect species (Nyrop and Binns, 1991). For these reasons a great deal of efforts has been invested in characterizing spatial patterns of insect populations. Geostatistics, a family of statistics that describe correlations through space and/or time, are used for quantifying and modelling spatial correlation at a spectrum of spatial scales and interpolating between sample points (Matheron, 1965; Liebhold *et al*., 1993). Another approach based on distance indices (SADIE) (Perry, 1995; Thomas *et al*., 2001; Perry *et al*., 2002; Holland *et al*., 2004) has been used in order to model the spatial patterns of organisms. Spatial analysis of entomological data seems to be particularly useful to understand distribution of insects at broad scales. Theoretical advances and simulation models have shown that the spatial dynamics of invertebrates in fragmented farmland ecosystems is a major factor in population and metapopulation processes (Thomas *et al*., 2001). Spatial sampling plan is an important part of IPM when decision making in pest control is based on spatial distribution of pests (Park and Tollefson, 2006). Spatial analysis in applied entomology could be used to identify zones of different risk, optimizing pest management (Blackshaw and Vernon, 2006). For these reasons spatial analysis could represent a valid tool within the area wide pest management (Beckler *et al*., 2005). Nevertheless the current fashion to apply geostatistical techniques to the spatial pattern in ecology and entomology requires, by some authors, great caution (Perry, 1997). An overview on spatial aspects and problems in experimental design for ecology and agriculture is offered by Perry (1997) and practical guidelines for selecting statistical methods for quantifying spatial pattern in ecological data can be found in Perry *et al*. (2002).

Elateridae species, for their peculiar life-cycle, seem to be particularly suitable to applications of spatial analysis because adult captures by pheromone traps may provide a potential predictive estimation of the infestation risk in the area infested by larvae in the following years. A correlation analysis between adult catches and following larval infestations is in progress (unpublished data); field data have demonstrated in some circumstances such relationship even if a statistical model is not still available. Spatial analysis of Elateridae was carried in previous studies at different scales (Williams *et al*., 1992; Blackshaw and Vernon, 2006; Toepfer *et al*., 2007). In particular, a preliminary GIS-based approach in Northern Italy showed to be suitable to provide information on the spatial distribution patterns of *Agriotes* spp. populations by means of pheromone traps (Burgio *et al*., 2005). In the present paper a further analysis of a 2-year monitoring of *A. sordidus* by means of spatially referenced pheromone traps is reported. This species was chosen for its economic importance in northern Italy.

Objective of the present paper was to optimise the monitoring of *A. sordidus*, improving the knowledge on the spatial distribution of this species in relation to the geographic and cultural features of the site investigated. A specific aim was to apply a re-sampling methodology based on geostatistic analysis to optimize the monitoring, thus expanding a first preliminary analysis (Burgio *et al*., 2005). In particular, simulations based on GIS were employed in order to evaluate the optimal number of traps to set in a heterogeneous farm, and to find a compromise between precision and feasibility.

Materials and methods

Study area

Research was carried out in 2002 and 2003 seasons, in Brancole-Coop Sorgeva farm, an organic farm of 500 ha located in Ferrara province (northern Italy), an area characterised by clayey soil. The prevalent crops in this rural landscape are alfalfa, corn, soybean and tomato. The crops cultivated in the farm were wheat, alfalfa, pea, tomato in 2002, and wheat, corn, alfalfa, tomato, bean, sunflower in 2003 (figure 1).

Sampling

YATLOR-funnel traps were used to monitor *A. sordidus* adults, in order to cover all the cropped area. Pheromone traps baited with the specific pheromone for *A. sordidus* (Furlan *et al*., 2001; Tóth *et al*., 2002) were set, for a total of 114 traps. The pheromone used in the research was geranyl-hexanoate that in previous studies demonstrated to attract very effectively *A. sordidus*. Pheromones were provided by Prof. M. Tóth (Hungarian Academy of Sciences, Budapest). All the pheromone traps were spatially referenced using a GPS system (Trimble$^{®}$). In areas potentially suitable to higher captures (i.e. more susceptible crops, presence of border effects like field margins, and influence of previous crops on Elateridae infestations) a higher number of traps was set, following the principles of the stratified sampling.

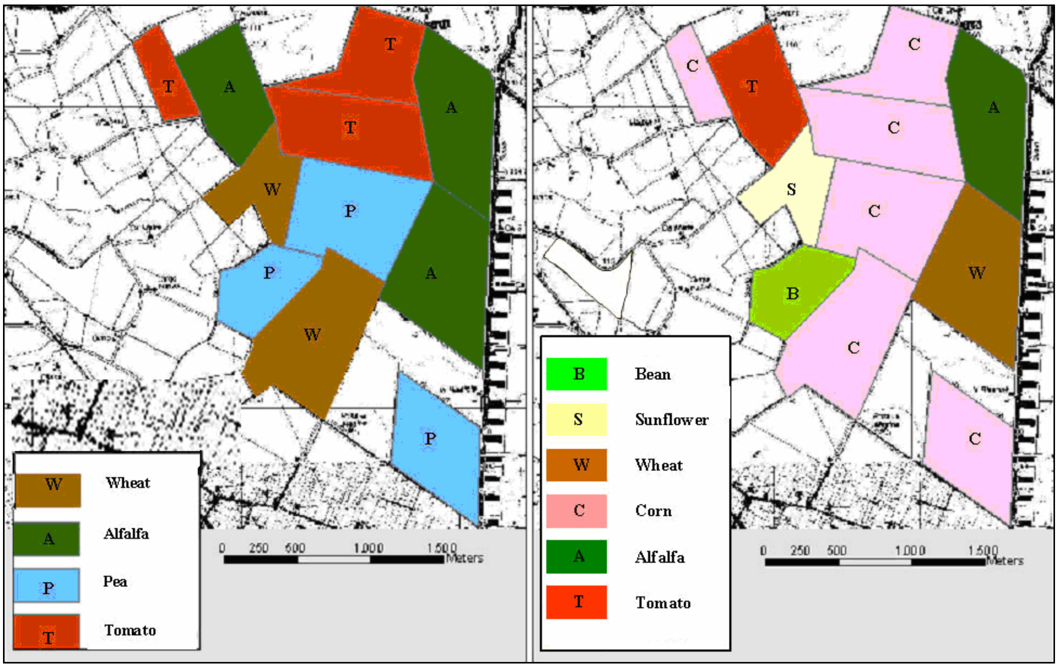

Figure 1. Map of study area and cropping in 2002 (left) and 2003 (right) seasons.

The adult samplings were carried out between April and August in 2002 and 2003 seasons. Click beetle populations were counted every 30-40 days, by collecting adults in each trap; the specimens were identified to species level and sexed in laboratory.

Data analysis

Geostatistic analysis was carried out using Arcview 8.2 ESRI, by calculation of variograms (semi-variograms) and ordinary kriging. Variograms are a plot of the γ (h) as a function of distance *h* (or *lag*) (Liebhold *et al.*, 1993):

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

where $\gamma\,(h)$ is the estimated semi-variance for lag *h*, and N (*h*) is the number of pairs of point separated by *h*. Variograms were calculated on the adult catches in the different sampling dates and on the total of adult catches in a season, using a spherical model (lag numbers = 12; lag distance = 277 m). The distance at the which the variogram values level off is know as the *range*, that designates the average distance within which the samples remain correlated spatially. The variogram value at which the model appears to intercept the ordinate is know as the *nugget* (C_0), defined the pure random variation, or white noise, including the sampling error (Liebhold et al., 1993). If a variogram displays a levelling-off behaviour, then the variogram value at which the plotted points level off is known as the *sill* that is usually equivalent to the traditional sampling variance. *Sill* includes two components, *partial sill* (or spatial structural variance, C) and nugget effect (C_0). The best semi-variogram model was selected by interpreting the model outputs, including: i) a visual identification of model by interpreting the *range*, nugget (C_0), *partial sill* (C) and *sill* ($C_0 + C$); ii) calculating the highest proportion of variability, $C/(C + C_0)$, in other words the proportion of sample variance that is explained by the spatial structure variance (Rossi *et al.*, 1993; see also Toepfer *et al.*, 2007, for a practical example concerning western corn rootworm sampling).

Ordinary kriging, an interpolation technique that predicts the value of the variable in the non-sampled points generating contour maps, was used in order to describe the spatial aggregation of *A. sordidus* captures. Semi-variogram and related kriging were computed in "anisotropy" that takes in account different spatial relationships in different directions.

Data of *A. sordidus* were analysed using the total of traps (100% of data set) and three reduced data set (75%, 50% and 25% of traps). The data set reduction was employed using simulations based on a "random stratified criterion" (Sharov, 2009). The simulations were obtained by dividing the monitoring area (500 hectares) in sub-areas (strata) of 1 hectare, in which two points per stratum were selected for the 75% data set reduction, one point per stratum was selected for the 50% reduction and one point per two adjacent strata was selected for the 25% data set reduction. The principle of the "random stratified criterion" (Sharov, 2009) was applied in order to maintain a uniform density of traps in the whole sampling area, avoiding biased estimates of the captures in some strata. The reduction of the data set generated, for each criterion of simulation, two sub-samples: a "training set" based on the selected points and used for geostatistic analysis, and a "test-set", based on the excluded points and used for the validation of the maps.

The variables analysed by semi-variogram and ordinary kriging in each data set were: the total of catches in each year (*Sum*) and the peak of density of the captures in each year (*Peak*). The goodness of maps calculated on the total data set and the reduced data set were estimated by means of cross-validation analysis (Arcview 8.2 ESRI). For each map the mean prediction error (MPE) was calculated, by the average of the differences between the predicted and measured (sampled) values; this parameter is considered a simple indicator of the predictability of a map (for example low values of MPE are associated to good predictability of a map).

Results

The results of the semivariogram analysis calculated on the whole data set (100% of traps, corresponding to 114 traps) and on the reduced data set (75%, 50% and 25% of data set) are shown in table 1. Semivariograms, fitted by spherical model, showed in all the cases a good correlation between experimental data and models, indicating a clumped distribution of the adult captures. The *nugget* (called also white noise, Sharov, 2009) represents two, often co-occurring source of variability. A source derives from spatial variability at a scale smaller than the minimum lag distance; the other genesis of a *nugget* is experimental error (Liebhold *et al.*, 1993). Semi-variograms were strongly affected by directions and for this reason they were computed in anisotropy. For variable *Peak*, major range (maximum distance at which variability is observed) showed values of 2499 and 2887m in 2002 and 2003 season, respectively. Major range of variable *Sum* was 1624 and 2544m in 2002 and 2003, respectively.

Ordinary kriging was used to draw the contour plots of the adult captures of *A. sordidus*, calculated on the total of traps (100% of data set) (figure 2) and on the reduced data set (figures 3-4). In table 2 the mean predicted error and the results of the crossvalidation analysis are shown. Correlation coefficients (r) of the cross-validation analysis calculated on the 100% of data set ranged between 0.52 and 0.78, indicating a significant ($P < 0.05$) linear correlation between predicted and estimated values (table 2). Cross-validation analysis (table 2) showed for all the data set reductions a good concordance between data estimated and data predicted, in both the year, for both the variables *Peak* and *Sum*.

The simulation with reduced data set produces kriging maps with a good concordance between estimated and calculated values (tables 1-2 and figures 2-4). Only maps obtained with the simulations with 75 and 50% of data set are shown. The spatial distribution of *A. sordidus* simulated with 75 and 50% of the data showed a

Table 1. Results of semi-variogram analysis of the captures of *A. sordidus* in 2002 and 2003. The variables analysed are the maximum of the captures in each year (*Peak*) and the total of catches in each year (*Sum*). Semi-variogram analysis was carried out on the whole data set (100% of traps) and on three reduced data set (75, 50 and 25% of traps). See materials and method for details.

Year	Variable	Data set (%)	Mean	*Nugget* (C_0)	Partial *sill* (C)	$C/(C+C_0)$	Major range (m)	Minor range (m)	Direction (°)
2002	Peak	100	185.79	446.83	46829.00	0.99	2499.70	1256.00	2.90
		75	210.41	818.54	56309.00	0.99	2397.00	1358.00	357.30
		50	206.55	0.00	53969.00	1.00	2303.00	1360.00	6.50
		25	207.88	0.00	45201.00	1.00	2338.30	121.90	2.30
	Sum	100	420.12	76699.00	77957.00	0.50	1624.60	742.90	279.80
		75	394.98	40062.00	120120.00	0.75	1704.30	793.75	277.30
		50	395.09	46711.00	103520.00	0.69	1672.70	682.65	282.50
		25	403.36	0.00	165900.00	1.00	1201.10	583.16	81.50
2003	Peak	100	451.50	63174.00	79216.00	0.56	2887.80	1418.70	283.20
		75	466.17	57525.00	101230.00	0.64	3201.40	1727.10	281.20
		50	479.34	50769.00	145010.00	0.74	3173.80	1934.30	280.20
		25	525.33	90599.00	193530.00	0.68	2750.30	2299.90	86.00
	Sum	100	657.40	85961.00	106730.00	0.55	2544.80	1357.20	53.90
		75	682.51	95518.00	121520.00	0.56	2707.00	1679.90	69.20
		50	683.30	85741.00	161960.00	0.65	3145.40	1813.10	78.70
		25	714.85	129570.00	181480.00	0.58	2750.30	2028.00	60.80

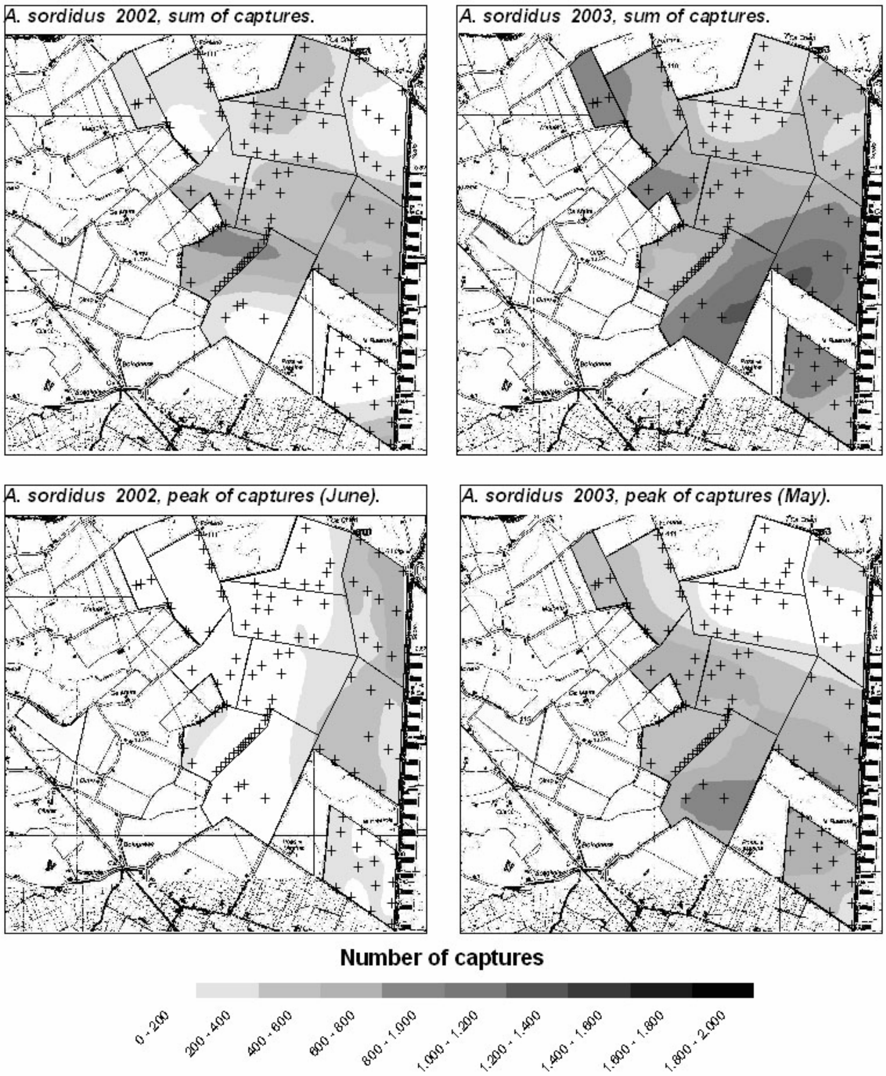

Figure 2. Contour plots of *A. sordidus* captures in 2002 and 2003, including the spatial analysis of the sum of captures (top) and the spatial analysis of the peak on infestation (bottom). Ordinary kriging was calculated on the total of traps (100% of data set).

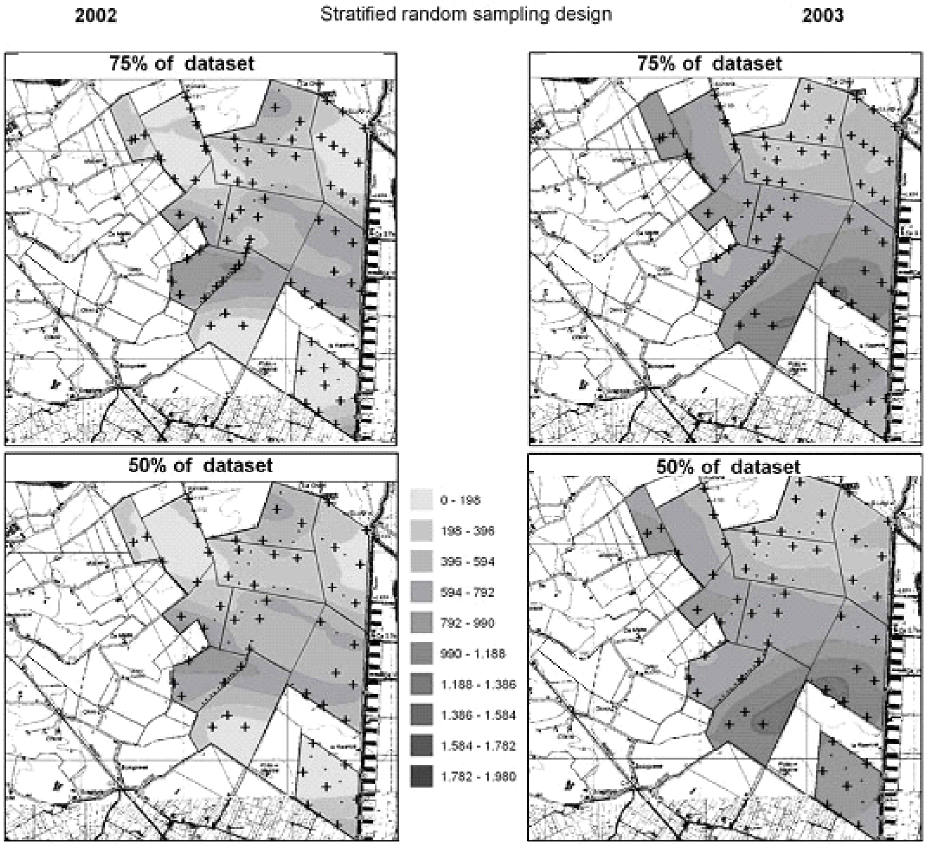

Figure 3. Contour plots of *A. sordidus* populations, calculated on the sum of captures in 2002 and 2003. Ordinary kriging was calculated on the 75% (top) and 50% (bottom) of data set.

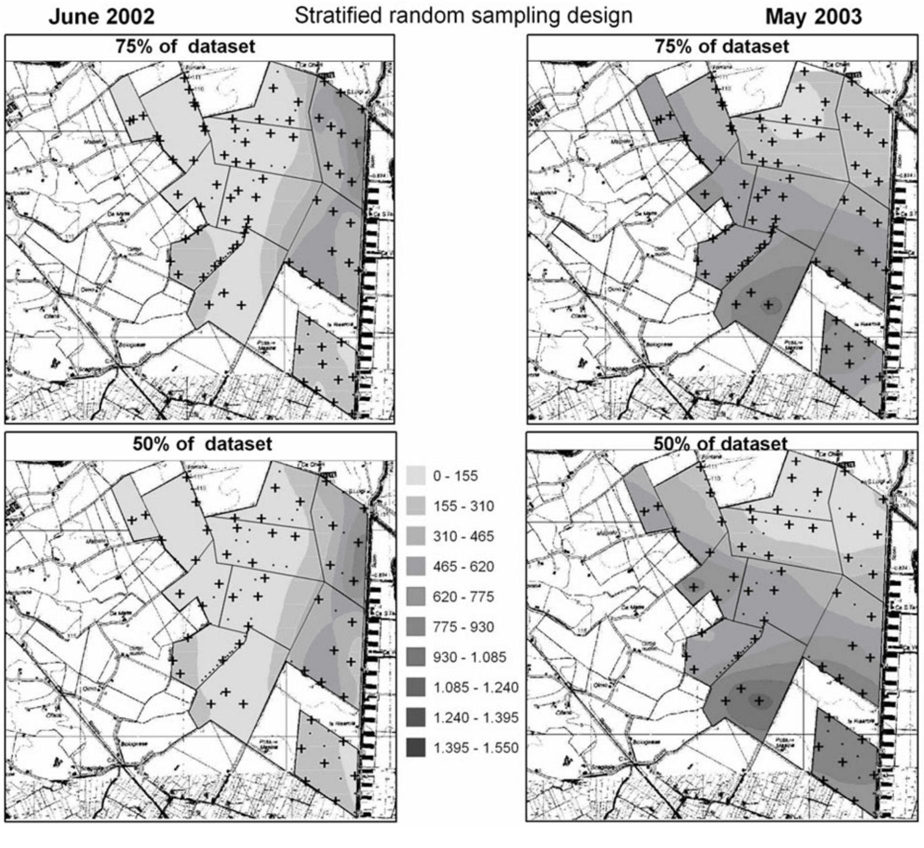

Figure 4. Contour plots of *A. sordidus* populations, calculated on the peak of captures in 2002 and 2003. Ordinary kriging was calculated on the 75% (top) and 50% (bottom) of data set.

Table 2. Results of cross-validation analysis of *A. sordidus* in 2002 and 2003. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

Year	Variable	Data set (%)	MPE	r	P
2002	Peak	100	−2.46	0.78	***
		75	−2.89	0.8	***
		50	−0.79	0.86	***
		25	−12.11	0.85	***
	Sum	100	1.32	0.61	***
		75	−6.10	0.67	***
		50	0.87	0.44	**
		25	−28.62	0.64	***
2003	Peak	100	2.40	0.58	***
		75	2.12	0.58	***
		50	3.68	0.65	***
		25	0.11	0.59	**
	Sum	100	0.21	0.52	***
		75	0.39	0.5	***
		50	7.96	0.54	***
		25	−12.58	0.43	*

Table 3. Correlations of mean prediction error (MPE) against the different data set reductions (100, 75, 50 and 25% of traps).

Variable	Correlation	R	P
Peak	MPE *vs* data set reductions	0.38	0.34
Sum	MPE *vs* data set reductions	0.17	0.67

good concordance with the maps calculated using the whole data (100% of data set). The spatial pattern showed a good representation of data also reducing the data set until 75% of the data set, with the important caution to maintain a uniform distribution of the sample points (traps) within the monitored area. The mean prediction error (MPE) from cross-validation analysis was used in order to evaluate the goodness of the kriging maps obtained by means of the data-set reduction. The MPEs from cross-validation showed no statistical correlation against the data-set reductions (variable Peak: $P = 0.34$, $r = 0.38$; variable Sum: $P = 0.12$, $r = 0.59$) (table 3), showing that errors did not increase according to the reduction of the sample size. In particular, MPE showed a very limited range of variation in the simulation with 100%, 75% and 50% of data set, even if this parameter showed a consistent increase for the maps originated with 25% of data set (table 2). For example, for the maps obtained with 25% of data set (variable sum), MPE was 28.6 and -12.6 in 2002 and 2003, respectively, while it showed lower values for data-set with 75 and 50% of data (table 2).

Representation of the spatial distribution of *A. sordidus* adults can be reached using a data set reduction until 50% of the original data, in other words using a total of 57 instead of 114 traps in the area considered (500 hectares). In the simulations based on data set reduction, in some cases (i.e. 2003 data and 2002 *Peak* data) the ratio $C/(C + C_0)$, increased in function of the data set reduction (Tab. 1). In particular, it is worth noting that $C/(C + C_0)$ showed highest values for 75 and 50% of the data set, in comparing with 100% of data set. This trend was probably due to a reduction of samples characterised by high auto-correlation values, leading to a better estimation of spatial structure and a consequent reduction of the nugget effect (white noise) (table 1).

Contour maps calculated by ordinary kriging provided a descriptive analysis of the spatial pattern of *A. sordidus* in the macro-area investigated. In 2002 *A. sordidus* occurred in large patches mainly on alfalfa, while in 2003 mainly on sunflower and tomato (figure 5). *A. sordidus* populations showed higher patches mainly in the south-eastern area of the farm (figure 2). Besides an aggregated distribution at farm scale, contour plots showed also an evident intra-crop clumped distribution, a phenomenon particularly evident on alfalfa, corn and wheat.

The distribution pattern of this Elateridae species was affected by local factors, the nature of which for the moment can not be proved but only conceivable; we assume that crops and soil characteristics could have an influence on spatial dynamic of this pest. Similarly, the adult captured in the current season in an area can be consider an indicator of potential infestation in the following years, even if a statistical correlation is not still available. This adult monitoring, interfaced with the susceptibility of the crops which will be cultivated in the same area, will generate an estimation of the risk of larval attack. The adult infestations registered in 2002 and 2003 did not resulted in an economic damage, thus confirming the result of previous experiences in northern Italy (Curto and Ferrari, 1999; Furlan and Burgio, 1999; Furlan *et al.*, 2000; Ferrari *et al.*, 2002).

Discussion and conclusions

A number of studies on spatial aggregation of Elateridae larvae were carried out using classical approaches, including descriptions of frequency distributions of counts or relationships between means and variances (Yates and Finney, 1942; Seal *et al.*, 1992; Furlan and Burgio, 1999). These approaches permitted to define the kind of

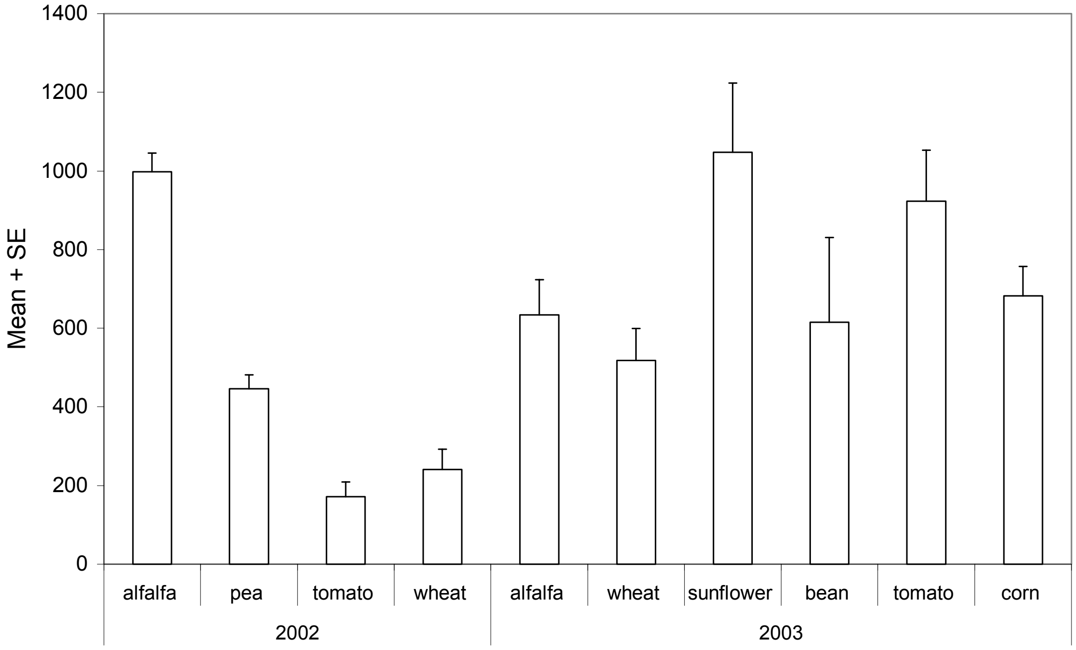

Figure 5. Mean number of *A. sordidus* per trap captured in 2002 and 2003 seasons.

spatial aggregation (i.e. random or aggregated) and to calculate optimum sample size required for economic management of wireworms. A major constraint of these methods is that they generally make little or no use of spatial information, in other words do not represent true spatial analysis. A geostatistical description of the spatial distribution of *Limonius californicus* (Mannerheim) wireworms (Elateridae) was carried out by Williams *et al.* (1992): the spatial structure was described by the spherical model, indicating an aggregated spatial arrangement. Moreover, the authors stated that a stratified "hexagonal" pattern was better than random sampling. A comparison between geostatistical analysis and two traditional methods of assessing spatial dispersion illustrated the additional information yielded by geostatistics (Williams *et al.*, 1992).

In our study, *A. sordidus* caught by pheromone traps showed a strongly aggregated pattern. Alfalfa, wheat and corn showed large patches of adult population. Besides this general trend, it was also observed a strong clumped distribution of adult populations within-crop. This phenomenon could depend by many reasons, including the influence of previous crops, differences in soil type and border effects determined by factors external to the farm. As pointed out by Blackshaw and Vernon (2006) in a study on Elateridae using SADIE analysis obtained by pheromone traps, the catches can derive from both local density and activity, but they are also influenced by the sensitivity of the lure. For this reason the interpretation of trap data could be, in some instances, problematic. For example the spatial pattern could be affected by the radius of attractiveness of the baited traps, thus influencing the distribution maps. Preliminary experiments demonstrated that the effective radius of attractiveness of the traps used in our research was about 20 meters (Lifrieri, 2001; Furlan, unpublished data). For this reason it is unlikely that the active attractiveness of the lures have significantly influenced the distribution of the pest in the large-scale farm (500 ha) of our study. In the study of Blackshaw and Vernon (2006), the spatial patterns of two Elateridae species, *Agriotes lineatus* (L.) and *Agriotes obscurus* (L.), were similarly highly aggregated and clustered at the landscape scale; also, for both species, a spatio-temporal stability at the landscape scale was evident. In a study of Toepfer *et al.* (2007) on small-scale maize field, larvae of *Agriotes ustulatus* (Schaller) were clustered in 75% of cases and their distributions were mainly determined by vegetation cover.

In our study, very large patches of adult population were observed in the eastern part of the farm, indicating the presence of factors that did affect adult catches. A GIS analysis showed that the mentioned area is besides a chicken breeding, separated from the farm by a channel margin with a dense plant population. The presence of these local factors could have influenced the adult aggregation of Elateridae, leading to higher catches rates in the traps close to the eastern area. In particular the weeds infesting the channel margin (including high population of *Phragmites* spp.) should have created a foraging area suitable for high aggregations of Elateridae adults. On the other hand, the presence of an animal breeding close to the channel should have determined higher concentration of organic matter in the border of the farm, leading to high susceptibility to Elateridae infestations, but this conclusion is only hypothetical because a detailed agronomic study of the soil was not carried out.

In a fragmented rural landscape the monitoring of Elateridae should take into account the heterogeneous pattern of adult population. For example in a wide rural farm characterised by different crops and soil structure, a stratified sampling program should be suggested, by division of the total area in sub-areas characterised by different crops, and potential factors affecting adult dynamics, like content of organic matter and the previous crops (i.e. meadows and alfalfa). Field studies showed that organic matter influenced the larval infestation of *A. sordidus*, thus affecting local populations (Furlan *et al.*, 2000). For this reason, in case of organic soil a more intense and precise monitoring should be suggested, because this kind of soil is suitable for larval infestations. Also, it was demonstrated for *A. sordidus* (Furlan *et al.*, 2004) that local adult populations are linked to agronomic and climatic condition of one and/or two years before.

Sampling program of Elateridae on a large-scale it should be important to analyse the potential factor affecting infestations and to provide to plan a more accurate and precise monitoring in the area potentially characterised by higher risk of infestation. The simulations calculated with different numbers of traps demonstrated that the reduction of the data set until 50% (corresponding to the density of 1 trap/ 8.7 hectares) generated a good representation of the spatial dynamic of *A. sordidus.* The maps calculated with only 25% of the traps generated maps with similar spatial structure of the other cases but characterised by higher mean predicted errors. The sample size simulated by our geostatistics analysis should be validated for technical purposes, in order to assess the validity of the method. Moreover, the variogram analysis could be useful in order to plan the monitoring grid of the pest, in order for example to avoid auto-correlation of data. For a better comprehension of the spatial dynamics of *A. sordidus* at larger scale (i.e. province or region) further study are necessary in order to explain the distribution pattern of the pest at such scales.

As evinced by other studies, there still remains the difficult issue of relating adult male catches to larval distribution (Blackshaw and Vernon, 2006). Unfortunately, in our region and in northern Italy, an economic threshold for Elateridae populations is not yet available. Nevertheless, research in northern Italy on a relationship between adult catches and damage is still in progress (Furlan, unpublished data). Preliminary empirical data collected in our region seems to demonstrate that the captures registered in our study did not result in an economic damage for subsequent crops (tomato and corn).

Considering the difficulties in the sampling of *A. sordidus*, pheromone traps could be an effective tool to standardise and optimize the monitoring of the pest at large-scale. Elateridae species, for their peculiar lifecycle, seem to be particularly suitable to applications of spatial analysis because adult captures by pheromone traps could provide a prediction of the risk in the subsequent years for the investigated crops. Our present data, confirmed by further studies (Burgio *et al.*, 2005; Blackshaw and Vernon, 2006), show that geostatistics could be an effective tool to study the distribution of Elateridae populations, in order to provide a precise pest management of these pest, by means of the identification of extensive zones at different risk of infestation and, consequently, susceptible of different pest management.

Further studies should analyse in detail the influence of soil type, soil texture, previous crops and climatic condition against adult caught and crop damages. Combining a geostatistic analysis of agronomic characteristics of soil, and climatic condition of the area investigated, with adult distribution pattern, it should be possible to drawn the risk-areas on a predetermined scale of investigation (for example a province) and to provide to a more precise monitoring and management of Elateridae on large rural areas (i.e. provinces) characterised by Elateridae populations.

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References

BECKLER A. A., FRENCH B. W., CHANDLER L. D., 2005.- Using GIS in areawide pest management: a case study in South Dakota.- *Transactions in GIS*, 9 (2): 109-127.

BLACKSHAW R. P., VERNON R. S., 2006.- Spatiotemporal stability of two beetle populations in non-farmed habitats in an agricultural landscape.- *Journal of Applied Ecology*, 43: 680-689.

BURGIO G., FERRARI R., RAGAGLINI G., PETACCHI R., POZZATI M., REGGIANI A., FURLAN L., GALASSI T., 2005.- Analisi spaziale delle popolazioni di *Agriotes sordidus* Illiger e *Agriotes litigiosus* Rossi (Coleoptera Elateridae) mediante geostatistica e GIS: primi risultati di un'indagine eseguita in Emilia-Romagna.- *Informatore Fitopatologico*, 55 (4): 45-50.

CHABERT A., BLOT Y., 1992.- Estimation des populations larvaires de taupins par un piège attractif.- *Phytoma*, 436: 26-30.

CURTO G., FERRARI R., 1999.- Elateridi e altri insetti terricoli. Le specie presenti in Emilia-Romagna.- *Il Divulgatore*, 22 (7): 1-63.

DOANE J. F., LEE W., KLINGER J., WESTCOTT N. D., 1975.- The orientation response of *Ctenicera destructor* and other wireworms (Coleoptera: Elateridae) to germinating grain and to carbon dioxide.- *Canadian Entomologist*, 107: 1233-1252.

FERRARI R., BORIANI L., FURLAN L., MAINI S., 2002.- Monitoraggio e prevenzione per combattere gli elateridi.- *Agricoltura*, 30 (4): 55-57.

FURLAN L., BURGIO G., 1999.- Distribuzione spaziale e campionamento di *Agriotes ustulatus* Schäller, *A. brevis* Candeze, *A. sordidus* Illiger (Coleoptera Elateridae) in Nord Italia.- *Bollettino dell'Istituto di Entomologia "Guido Grandi" della Università degli Studi di Bologna*, 53: 29-38.

FURLAN L., TÓTH M., UJVARY I., 1997.- The suitability of sex pheromone traps for implementing IPM strategies against *Agriotes* populations (Coleoptera: Elateridae), pp. 173-182. In: *Proceedings of XIX IWGO Conference*, Guimaraes, August 30 - September 5, 1997.

FURLAN L., CURTO G., FERRARI R., BORIANI L., BOURLOT G., TURCHI A., 2000.- Le specie di elateridi dannose alle colture agrarie nella Pianura Padana.- *Informatore Fitopatologico*, 50 (5): 53-59.

FURLAN L., TÓTH M., YATSININ V., UJVARY I., 2001.- The project to implement IPM strategies against *Agriotes* species in Europe: what has been done and what is still to be done, pp. 252-262. In: *Proceedings of XXI IWGO Conference*, Legnaro, Italy, 27 October - 3 November, 2001.

FURLAN L., GAROFANO N., TÓTH M., 2004.- Biologia comparata di *Agriotes sordidus* Illiger nel Nord e Centro sud d'Italia.- *Informatore fitopatologico*, 54 (11): 32-37.

HOLLAND J. M., WINDER L., WOOLLEY C., ALEXANDER C. J., PERRY J. N., 2004.- The spatial dynamics of crops and ground active predatory arthropods and their aphid prey in winter wheat.- *Bulletin of Entomological Research*, 94: 419-431.

LIEHBOLD A., ROSSI R. E., KEMP W. P., 1993.- Geostatistics and geographic information systems in applied insect ecology.- *Annual Review of Entomology*, 38: 303-327.

LIFRIERI L., 2001.- Valutazione della capacità attrattiva del feromone sessuale su *Agriotes litigiosus* Rossi (Coleoptera Elateridae). 101 pp. *Thesis*, Facoltà di Agraria, Alma Mater Studiorum Università di Bologna, Italy.

MATHERON G., 1965.- *Les variables régionalisées et leur estimation*.- Masson, Paris, France.

NYROP J. P., BINNS M., 1991.- Quantitative methods for designing and analysing sampling programs for use in pest management, pp. 67-132. In: *Handbook of pest management agriculture* (PIMENTEL D., Ed.) Volume 2.- CRC Press, Boca Raton, USA.

PARK Y. L., TOLLEFSON J. J., 2006.- Development and economic evaluation of spatial sampling plans for corn rootworm *Diabrotica* spp. (Col., Chrysomelidae) adults.- *Journal of Applied Entomology*, 130 (6-7): 337-342.

PERRY J. N., 1995.- Spatial analysis by distance indices.- *Journal of Animal Ecology*, 64: 303-314.

PERRY J. N., 1997.- Statistical aspects of field experiments, pp. 171-201. In: *Methods in ecological & agricultural entomology* (DENT D. R, WALTON M. P., Eds).- CAB International, Wallingford, UK.

PERRY J. N., LIEBHOLD A. M., ROSENBERG M. S., DUNGAN J., MIRITI M., JACOMULSKA A., CITRON-POUSTY S., 2002.- Illustration and guidelines for selecting statistical methods for quantifying spatial pattern in ecological data.- *Ecography*, 25: 578-600.

ROSSI R. E., BORTH P. W., TOLLEFSON J. J., 1993.- Stochastic simulation for characterizing ecological spatial patterns and appraising risk.- *Ecological Applications*, 3: 719-735.

SEAL S. R., MCSORLEY R., CHALFANT R. B., 1992.- Seasonal abundance and spatial distribution of wireworm (Coleoptera: Elateridae) in Georgia sweet potato fields.- *Journal of Economic Entomology*, 85 (5): 1802-1808.

SHAROV A. A., 2009.- *Quantitative population ecology*.- Department of Entomology, Virginia Tech, Blacksburg, USA. [online] URL: http://home.comcast.net/~sharov/PopEcol/

THOMAS C. F. G., PARKINSON L., GRIFFITHS G. J. K., FERNANDEZ GARCIA A., MARSHALL E. J. P., 2001.- Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats.- *Journal of Applied Ecology*, 38: 100-116.

TOEPFER S., ELLSBURY M. M., ESCHEN R., KUHLMANN U., 2007.- Spatial clustering *of Diabrotica virgifera virgifera* and *Agriotes ustulatus* in small-scale maize fields without topographic relief drift.- *Entomologia Experimentalis et Applicata*, 124: 61-75.

TÓTH M., FURLAN L., SZARUKAN I., UJVARY I., 2002.- Geranyl hexanoate attracting males of click beetles *Agriotes rufipalpis* Brullè and *A. sordidus* Illiger (Coleoptera: Elateridae).- *Journal of Applied Entomology*, 126: 1-3.

WILLIAMS LIVY III, SCHOTZKO D. J., MCCAFFREY J. P., 1992.- Geostatistical description of the spatial distribution of *Limonius californicus* (Coleoptera: Elateridae) wireworms in the Northwestern United States, with comments on sampling.- *Environmental Entomology*, 21: 983-995.

YATES F., FINNEY D. J., 1942.- Statistical problems in field sampling for wireworms.- *Annals of Applied Biology*, 29: 156-167.

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