CROP PROTECTION

Spatio-Temporal Analysis of Insect Pests Infesting a Paddy Rice Storage Facility

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Análise Espacial e Temporal de Insetos-Praga em Estrutura Armazenadora de Arroz

RESUMO - O trabalho relata a ditribuição temporal e espacial da fauna entomológica coletada em um armazém com arroz em casca durante dois anos, dando ênfase às espécies mais abundantes. O experimento, utilizando 19 armadilhas tipo gaiola foi realizado em Massaranduba, SC, de novembro de 1997 a outubro de 1999. Durante as coletas, *Sitophilus oryzae* (L.), considerada praga primária foi coletada em maior número (28.542 espécimes); outras pragas primárias como *Rhyzopertha dominica* (Fabricius) (3.931 espécimes) ou pragas secundárias como *Cryptolestes ferrugineus* (Stephens) (4.075 espeécimes) e *Oryzaephilus surinamensis* (L.) (1.069 espécimes) também tiveram grande ocorrência. Várias espécies mostraram variações na distribuição e dependendo do inseto-praga e do ano, todas as áreas foram infestadas. As populações de insetos estavam presentes tanto nas áreas de recebimento como nos silos, em um ou nos dois anos. Analisando as diferentes distribuições, as várias áreas de armazenamento de arroz apresentaram diferentes propensões de infestação de insetos, com os silos do sudoeste e a moega, que foram as áreas que apresentaram maior infestação. Além disso, as variações entre o primeiro e segundo ano mostraram acentuada redução do total da população de insetos no segundo ano, mas em diferentes locais, dependendo das espécies consideradas. Tais resultados provavelmente se devem às medidas de limpeza adotadas dentro e fora dos silos e na área de processamento, incluindo a aplicação de inseticida na estrutura.

PALAVRAS-CHAVE: Arroz armazenado, *Sitophilus oryzae*, fauna entomológica

ABSTRACT - The study describes the temporal and spatial distribution of the insect fauna collected in a paddy rice storage facility over two years, with major emphasis on the most abundant pests. The experiment, using 19 food-bait traps, was carried out in the county of Massaranduba, State of Santa Catarina, Brazil, from November 1997 to October 1999. During the whole survey, *Sitophilus oryzae* (L.), a primary pest associated to stored cereals, was the most abundant species in the storage facility (28,542 specimens captured). Other beetles were collected in remarkable numbers, both primary pests, such as *Rhyzopertha dominica* (Fabricius) (3,931 specimens), and secondary pests, such as *Cryptolestes ferrugineus* (Stephens) (4,075 specimens) and *Oryzaephilus surinamesis* (L.) (1,069 specimens). In general, various species showed very variable distribution and, depending on pest and year, all parts of the facility appeared infested. Pest populations were present both in processing area and in silos, at least in one of the two years survey. Analyzing different distributions, the various zones of the rice facility appeared to have different propensity to insect infestations, with the south-eastern silos and the grain pit with the conveyor belt as the most frequently infested. Moreover, variations between the 1st and 2nd year survey showed a strong decrease of total population numbers in the 2nd year, but in different ways, depending on the species considered. Such a result was probably due to the cleaning measures accomplished inside and outside the silos and in the processing area, including application of insecticide on the structure.

KEY WORDS: Stored rice, *Sitophilus oryzae*, insect entomológica

Insects associated with raw rice and processed food cause quantitative and qualitative losses. Infestations can occur just prior to harvest, during storage in a variety of structures such as cribs and metal or concrete bins, and in-transit in a variety of carriers. Stored-product insects are often found in warehouses, food-handling establishments, and retail grocery and pet stores. These insects can also breed in purchased food packages or food residues in a consumer's pantry, and may contaminate other food products stored in the pantry. Therefore, preventing economic losses caused by stored-product pests is important from the farmer's field to consumer's table.

Several tools are available for managing insects associated with raw grains and processed food. Effective use of pesticides and alternatives requires a thoroughout understanding of the pest ecology, the application of chemicals only when pest populations exceed acceptable levels, and an evaluation of risks, costs and benefits. Regarding this, the Integrated Pest Management (IPM) concept emphasizes the integration of disciplines and control measures including biological enemies, cultural management, sanitation, proper temperature utilization and pesticides into a total management system aimed at the prevention of pests from reaching damaging levels. The development of IPM programs has been considered by the food industry for both raw and processed commodities (Hagstrum & Flinn 1996). The food industry will need to use IPM programs more extensively in the future to satisfy the increasing demands of consumers and regulatory agencies for reduction of pesticide use.

Crucial factors for IPM in stored-products include understanding factors that regulate systems, monitoring insect populations, maintaining good records and using this information to make sound management decisions. New tools have been developed for detecting insects in stored-products, estimating insect population growth, and administering fumigants as well as natural methods of insect control such as grain temperature manipulation. Existing or potential new technologies to detect the presence of insects and estimate insect population levels include pheromone traps, sampling devices, acoustic sampling methods and chemical tests which detect live or dead insects through the presence of enzymes (Trematerra 2002). Computer-assisted decision support systems have also been developed which estimate insect population growth and spatial distribution of insects as a function of the environmental factors (Trematerra & Sciarretta 2002).

The introduction of spatial analysis in applied entomology opened new possibilities to study and manage the spatial distributions of stored-product pests (Arbogast *et al.* 1998, Brenner *et al.* 1998). In the data analysis, algorithms as variograms are used to estimate a pest population density at locations not sampled and the so-obtained spatial distributions are represented graphically by means of interpolated maps. This analysis can provide crucial information to improve the monitoring and precision targeting control methods and has been recently used in flour-mills, feed-mills, warehouses and commodity facilities, against several moth and beetle pests (Arbogast & Mankin 1999, Arbogast *et al.* 2002, Campbell *et al.* 2002, Trematerra & Sciarretta 2002).

Our research had the objective to describe the temporal and spatial distribution of main pests trapped in paddy rice storage facilities over two years collection, with major emphasis on spatio-temporal dynamics of most abundant pests, focusing on the effectiveness of the cleaning and other pest control measures adopted during the monitoring period.

Material and Methods

Study Area. The experiment was installed in a paddy rice storage facility in the county of Massaranduba, State of Santa Catarina, Brazil, from November 1997 to October 1999. The structure was constituted by 10 metal silos and a processing area formed by several sheds connected to one another (Fig. 1). The silos were grouped in two areas and each group was connected to a single bucket elevator: silos A-D were located in the north-western corner and silos E-J were positioned in the south side of the facility; both silos received rice with peel from outside, from different farms.

Processing area, closed to silos, was located in the eastern side of the facility; it was composed by several rooms where the rice was processed.

Traps and Data Collection. Nineteen food-baited cage traps, made according to the Throne & Cline (1991) model and adapted by Pereira (1999), were used during the monitoring period.

The bait was a mixture of one part of wheat germ, two parts of broken corn kernels, two parts of whole corn kernels and two of rice kernels, previously sifted to remove strange matters and frozen to eliminate possible insect infestation (Paula *et al.* 2002). The food mixture was placed on the bottom of the cage and removed every fifteen days to count the insect captured.

Traps were placed at the beginning of November 1997 and checks were conducted fortnightly until the end of October 1998 (1st year survey); after a one-month stop, monitoring began again until the end of October 1999 (2nd year survey).

Data Analysis. Principal Component Analysis (PCA) was carried out from annual trap catches (n), using SPSS version 8.0.0 (SPSS Inc., Chicago, Illinois, USA). A test of Shapiro-Wilk for Normal distribution and Skewness was performed and non-normal characteristics were removed transforming row data in $\ln(n+1)$. Variables were positioned, after Varimax rotation, in the space of the first two principal components.

Spatial analysis was carried out using Surfer version 8.02 (Golden software, Golden, Colorado, USA) with x, y representing the coordinates of the trap position in the building (expressed in meters), and z the trap catch counts. By interpolating z values, surfer produces a dense grid of values. The interpolation algorithm used was linear kriging with zero nugget. The interpolation grid obtained is used to produce a contour map, which shows the configuration of the surface by means of isolines representing equal

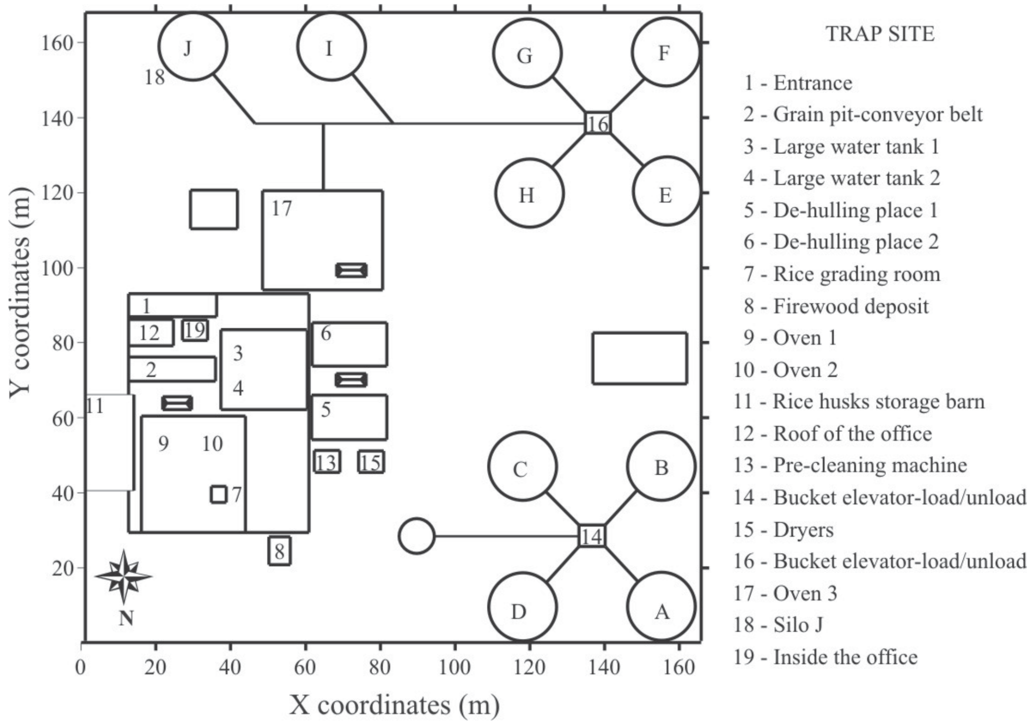

Fig. 1. Plan of the paddy rice storage facility. Capital letters indicate silos site; *x*,*y* axis are expressed in meters.

z-values. A base map showing the plan of paddy rice storage facility, with the same coordinate system, was placed on top of the contour map.

A normalized *z* variable is obtained by converting annual sum of trap catches in catch probability by means of a derived indicator, following Brenner *et al.* (1998). This procedure enables to focus the areas with important insect densities by minimizing the effect of an unusual trap count and by leaving out low-density zones. The trap counts were sorted in descending order and expressed as proportions of the pooled annual counts. An indicator score of "1" was given to all traps with catches that exceeded a critical proportion, that we set at around 85% (cumulative frequency distribution); a score of "0" was given to the remaining traps. The interpolation of scores yields a contour map with isolines ranging from 0 to 1.

Results

A total of 45,612 insects were captured in the cage traps, belonging to the orders Dermaptera, Hemiptera, Lepidoptera, Coleoptera and Hymenoptera. The Coleoptera species prevailed, with: *Sitophilus oryzae* L. (72.3% of specimens trapped), *Cryptolestes ferrugineus* (Stephens) (8.9%), *Rhyzopertha dominica* (Fabricius) (8.6%), *Oryzaephilus surinamensis* (L.) (2.3%), *Tribolium castaneum* (Herbst) (1.3%), and *Gnatocerus cornutus* (Fabricius) (0.9%); species in other coleopteran families and of other orders represented 5.6% of total specimens trapped. The list of insects collected is reported in Paula *et al.* (2002).

During the 1st year (November 1997-October 1998), a total of 28,542 insects were captured. Most abundant species was *S. oryzae* (20,124 specimens), followed by *R. dominica* (3,403), *C. ferrugineus* (1,813), *Carpophilus* spp. (1,034), *O. surinamensis* (1,007), *Ephestia* spp. (388), *T. castaneum* (275), and *G. cornutus* (86).

During the 2nd year (November 1998-October 1999), 17,070 insects were collected. Most abundant species was *S. oryzae* (12,866 specimens), followed by *C. ferrugineus* (2,262), *R. dominica* (528), *Carpophilus* spp. (416), *G. cornutus* (338), *T. castaneum* (317), *Ephestia* spp. (77), and *O. surinamensis* (62).

Ordination Analysis. PCA was calculated, for both years of survey, using the annual catch data of the eight most abundant pests populations: *Carpophilus* spp., *C. ferrugineus, Ephestia* spp., *G. cornutus, O. surinamesis, R. dominica*, *S. oryzae* and *T. castaneum*.

Results showed a clear structure of components extracted, with variance explained by the first two components of 54% in the 1st year and 55% in the 2nd year. Positions of the insects inside the two principal component space showed a marked separation of *R. dominica* and *S. oryzae* (considered primary pests) from other species *Carpophilus* spp., *C. ferrugineus*, *Ephestia* spp., *G. cornutus*, *O. surinamesis* and *T. castaneum* (considered secondary pests) (Fig. 2). *O. surinamensis* occupied an isolated position in the plot, while the other species resulted closer, especially in the 2nd year. Among them, secondary pests with a preference for moldy substrates (i.e., *C. ferrugineus* in both years and *Carpophilus* spp. in the 2nd year) appeared more isolated.

Moreover, for each species, PCA analysis was computed ordinating the annual catch data of traps. Results indicated

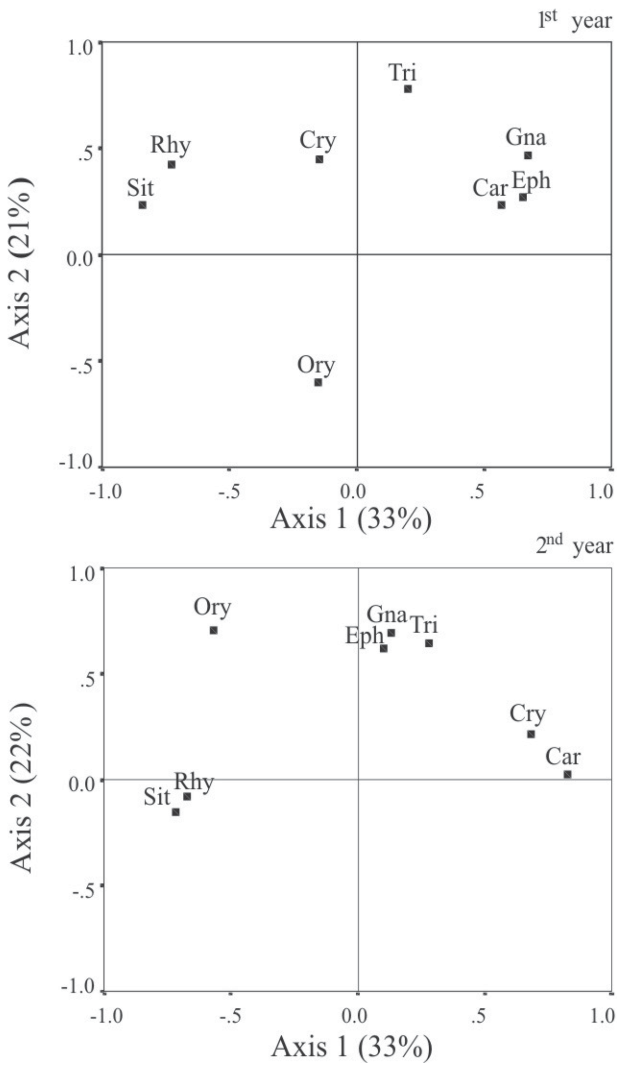

Fig. 2. Ordination of eight most abundant pests in the space of the first two principal components (axes 1 and 2). Species are identified by the first three letters of the genus name. The number in parenthesis represents the percentage of variance explained by the correspondent axis.

a complex structure with 7-8 extracted components with eigenvalues >1, and a variance explained by the first two components always under 50%. Disposition of the traps in the space of the first two factors did not suggest any clear ordination; a differentiation of some silo traps from the others was obtained in the case of *Carpophilus* spp., *O. surinamensis*, *R. dominica* and *S. oryzae*.

Spatial Distribution of Main Pests. Indicator variables were calculated, for both year of survey, using the annual catch data of the eight most abundant pests populations. Spatial distributions for the 1st and 2nd year is depicted in Fig. 3.

Analyzing different distributions, the various zones of the rice facility appeared to have different propensity to insect infestations.

Around silos I-J, only for *Carpophilus* and *Ephestia* species, high infestations were not found. In the case of *G. cornutus*, *O. surinamensis* and *T. confusum* (in 2nd year), and *C. ferrugineus*, *R. dominica* and *S. oryzae* (in both years), populations had high density, in some cases the highest of the facility, frequently connected to those located at the entrance of the processing area. Silos A-D and silos E-H resulted less frequently infested than silos I-J, but high density foci in these zones were detected for many species, particularly in the case of *S. oryzae*.

Grain pit with the conveyor belt were recorded almost always infested, except for O. *surinamensis* (1st year), *G. cornutus* (1st year) and *Carpophilus* spp. (both years). The same situation resulted also in the de-hulling places 1 and 2, where high infestations, often connected with various nearby sites, were observed, particularly in the place 2 with *G. cornutus* and *T. castaneum* (1st year), *C. ferrugineus*, *O. surinamensis*, *R. dominica* and *S. oryzae* (both years).

The pre-cleaning machine and the nearby dryers represented a focus of infestation in several cases (*C. ferrugineus* and *S. oryzae* during the 1st year; *Ephestia* spp. during the 2nd year; *Carpophilus* spp., *G. cornutus* and *T. castaneum* in both years), usually connected each other or with neighbouring areas. Among the three ovens present in the facility, oven 1 resulted more infested respect others (*Carpophilus* spp. and *T. castaneum* in the 1st year; *Carpophilus* spp., *O. surinamensis* and *S. oryzae* in 2nd year), maybe due to the proximity of the grain pit. Near the large water tanks 1 and 2, foci were observed only in the cases of *Ephestia* spp., *R. dominica* and *S. oryzae*, usually linked to the grain pit or de-hulling place infestations. Other sites, such as the rice husks storage barn, the rice grading room, the firewood deposit and the office, were rarely found infested.

Spatio-Temporal Dynamics of Main Pests. When monthly trap catches were high enough, the monthly sums of trap catches were calculated and used as the *z* variable to compare the spatio-temporal dynamic.

The monthly temporal contour maps of *Carpophilus* spp., *C. ferrugineus*, *O. surinamensis*, *R. dominica* and *S. oryzae* were built and reported in Fig. 4; instead for *Ephestia* spp., *G. cornutus* and *T. castaneum*, low catches did not allow the construction of monthly maps.

High presence of *Carpophilus* spp. was detected from December 1997 to May 1998 and in March-April 1999 (Fig. 4). Contour maps were built from 1 November 1997 to 1 July 1998 and from 5 February to 2 June 1999 (Fig. 5). Location of infestations during the 1st year changed from a month to another, but always bounded to small parts of the processing area or around silos A-D. In 1999, a single main focus was observed around the pre-cleaning machine in March and April maps.

The highest number of *C. ferrugineus* occurred in November-December 1997 and April-May 1998 during the 1st year surveyed, while during the 2nd year numbers were very low, except for April (Fig. 4). Monthly contour maps were depicted from 1 November 1997 to 1 July 1998 and from 4 March to 30 June 1999 (Fig. 6). Spatio-temporal distribution from November 1997 to February 1998 showed a distribution of populations mainly in the processing zone,

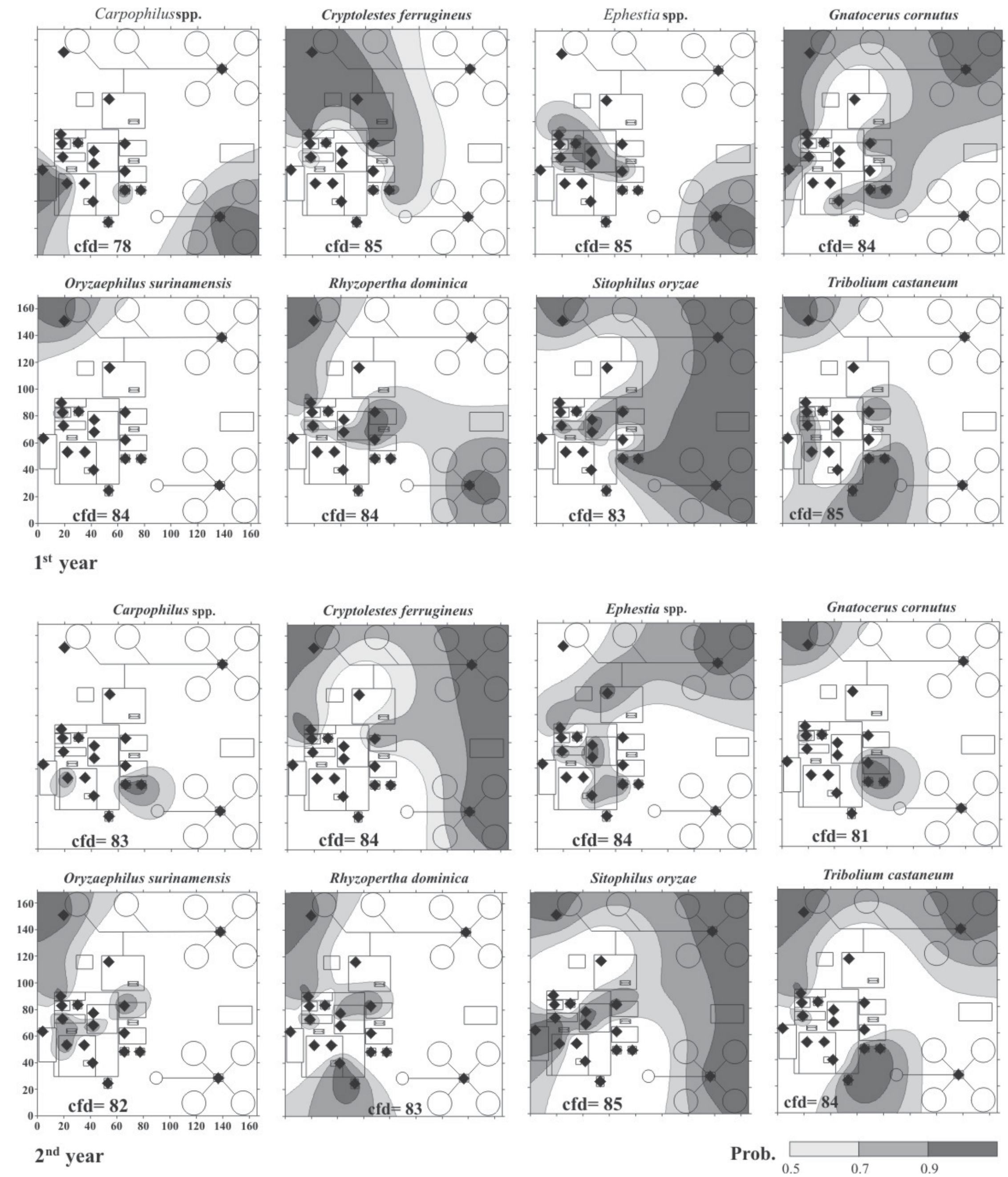

Fig. 3. Probability contour lines, obtained by converting the annual trap catches, showing spatial distribution for *Carpophilus* spp., *C. ferrugineus*, *Ephestia* spp., *G. cornutus*, *O. surinamesis*, *R. dominica*, *S. oryzae* and *T. castaneum* in the paddy rice storage facility. Cumulative frequency distribution (cfd), expressed as percentage, for each species is given. Probability levels (Prob.) are indicated in the scale. Contours are not showed for low density areas, with cfd < 0.5; *x,y* axis are expressed in meters.

but with a variable location of foci (oven 3, entrance, grain pit with the conveyor belt). Afterwards, distribution strongly reduced in this area, while increased in the zone of silo J, to became stable in that location. In 1999, a strong infestation around silos E-G was limited to the month of April; other foci were observed in the entrance and in the de-hulling place 1.

O. surinamensis was detected mainly in the period of April-August 1998; during the 2nd year, catches were very low (Fig. 4). Spatio-temporal distribution was depicted from 20 February to 22 October 1998 (Fig. 7). A stable locus was detected near the silo J during all the time. Weak loci during August and September were in the grain pit with the conveyor belt, in the de-hulling place 2 and on the roof of the office.

R. dominica populations were high during all months of the 1st year, with the maximum in November-December 1997 and again in October 1998; in the 2nd year, infestation

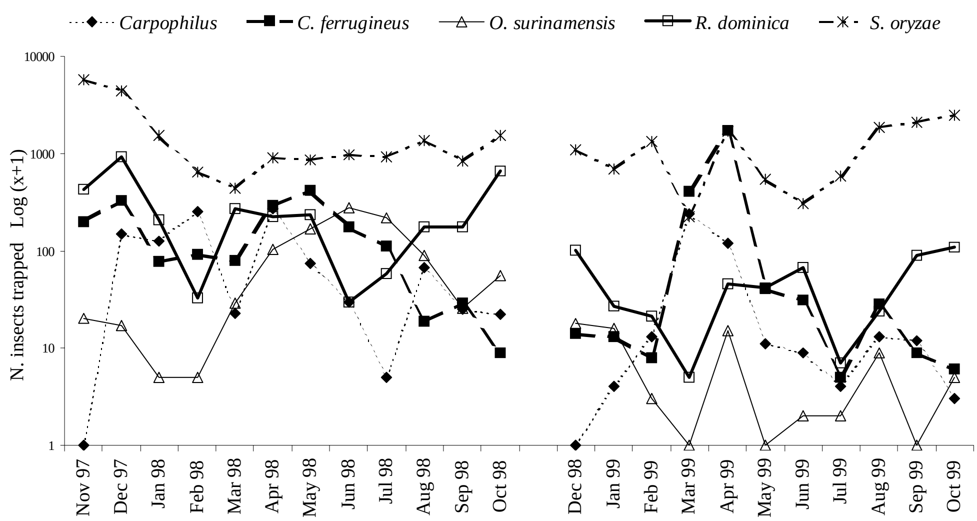

Fig. 4. Temporal dynamic pattern of captures of *Carpophilus* spp., *C. ferrugineus*, *O. surinamensis*, *R. dominica* and *S. oryzae*, in the paddy rice storage facility.

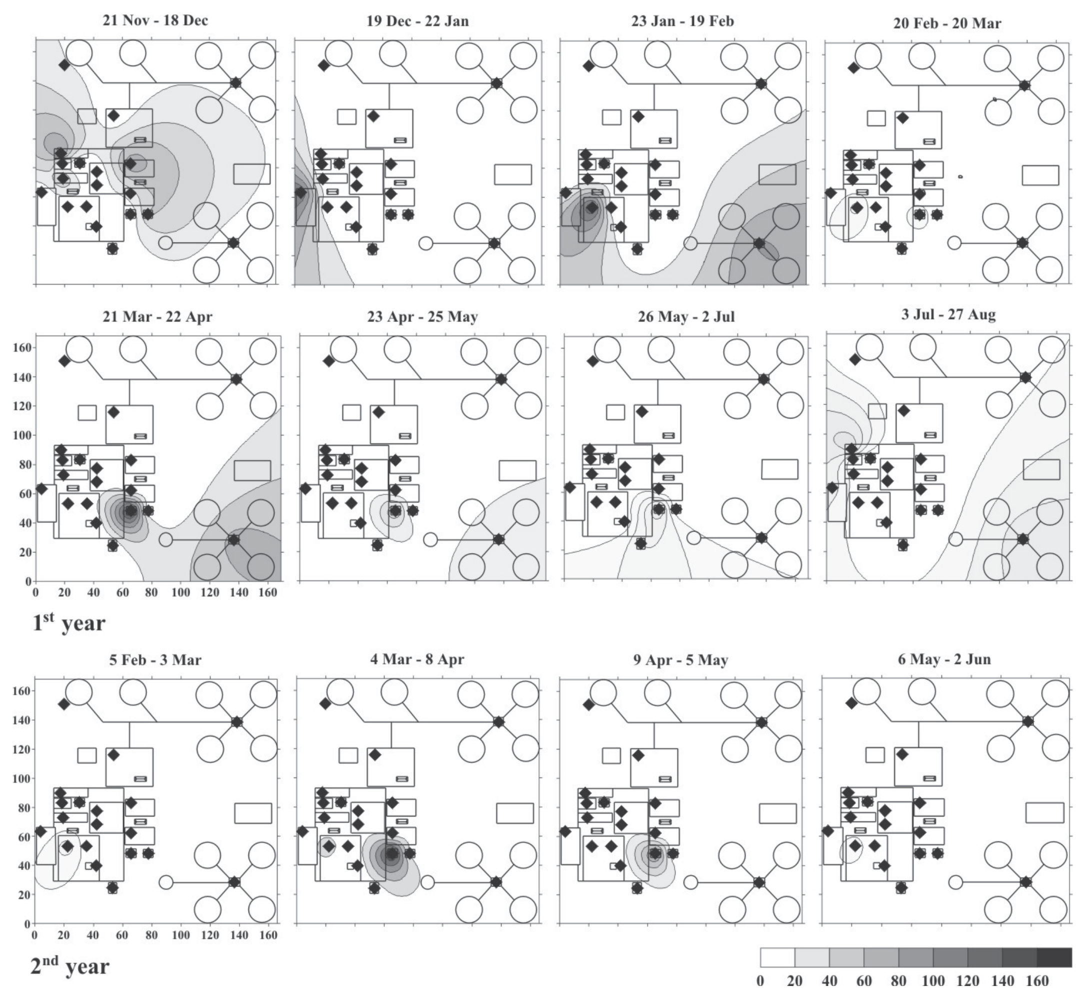

Fig. 5. Spatial distribution of *Carpophilus* spp. in the paddy rice storage facility, during the I year survey (21 November - 27 August) and the II year survey (5 February - 2 June). Scale indicating the number of insects captured is depicted. *x*,*y* axis are expressed in meters.

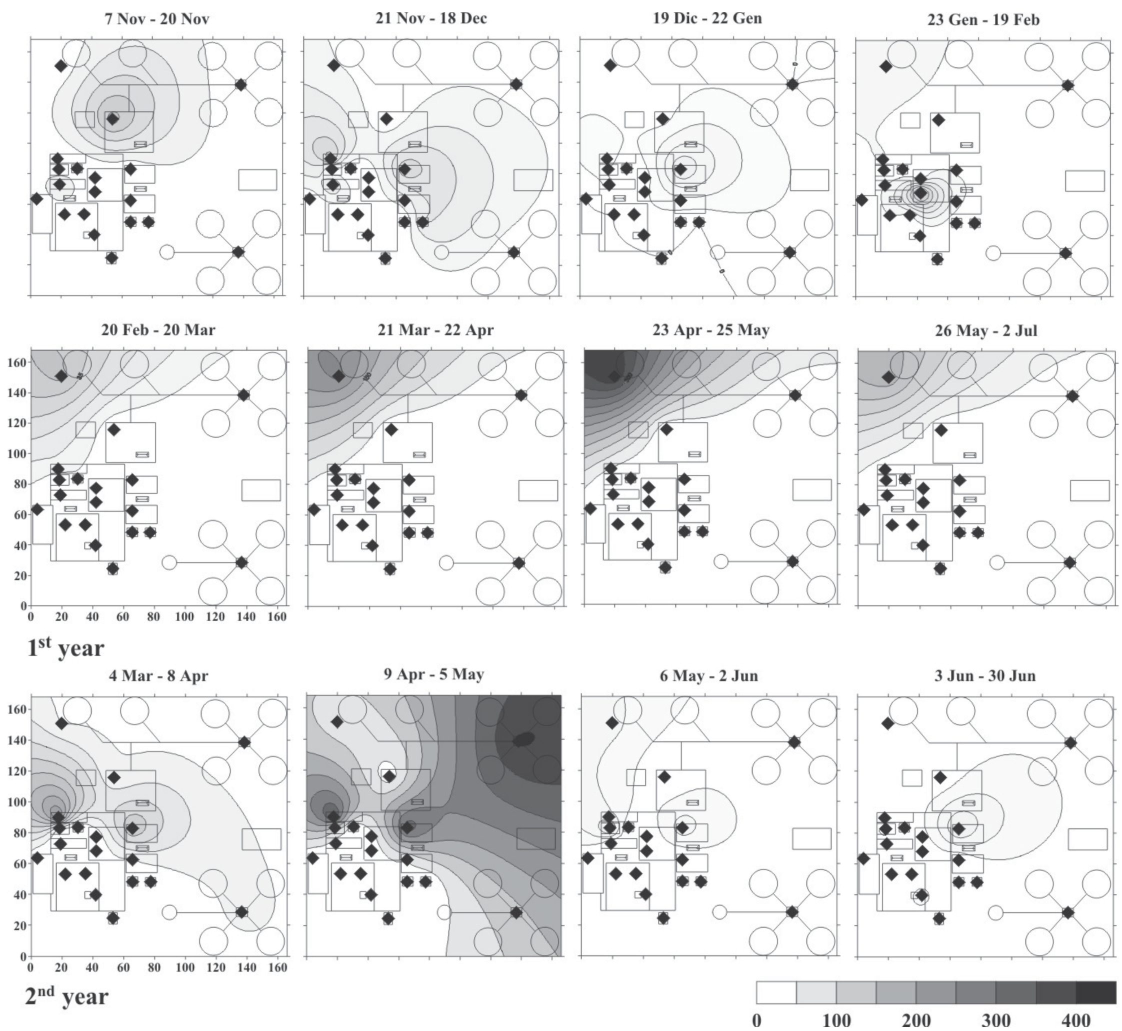

Fig. 6. Spatial distribution of *C. ferrugineus* in the paddy rice storage facility, during the I year survey (7 November - 2 July) and the II year survey (4 March - 30 June). Scale indicating the number of insects captured is depicted. *x*,*y* axis are expressed in meters.

decreased to lower levels (Fig. 4). Spatio-temporal dynamic is shown by monthly contour maps for the 1st year (Fig. 8). At the beginning of the survey (November 1997), infestations were located in the area of silos A-D, in the grain pit with the conveyor belt and in the de-hulling place 2. From the end of January, distribution changed and the infestations remained near the silo J, while in the processing area no catches were detected. In August, spatial location of *R. dominica* changed again, disappearing from silos area and having locus foci again in the processing area (near the entrance, in the grain pit with the conveyor belt and in the de-hulling place 2).

S. oryzae had very high presence during all the monitoring period. In the 1st year, maximum was in November and December 1997; in the 2nd year, catches increased during the last months of the monitoring (August-October 1999) (Fig. 4). Contour maps of the 1st year showed different trends in the various areas of the paddy rice storage facility (Fig. 9). At the beginning of the survey, hot spots were around silos E-H, near the dryers and the grain pit with the conveyor belt. In following months, distribution changed radically: new foci appeared in the processing area, near the water tanks and the pre-cleaning machine, instead the infestation near silos E-H disappeared quickly. From the end of March, catches in the processing area decreased, while new infestations grew in the silos area (silos A-D and J). Distribution changed from July onward and the infestations remained limited in several zones of the processing area. During the 2nd year (Fig. 9), important presence of *S. oryzae* was detected in the silos area only in April and July (silos A-D), while a stable hot spot was located in the grain pit with the conveyor belt.

Discussion

Spatial distribution of insects in the food industry is significantly affected by various factors, such as food availability, processing practices, temperature conditions in different areas and interaction among species; such factors are responsible for the spatio-temporal dynamics of pests, as well as for the population abundance levels (Hagstrum *et al.* 1996).

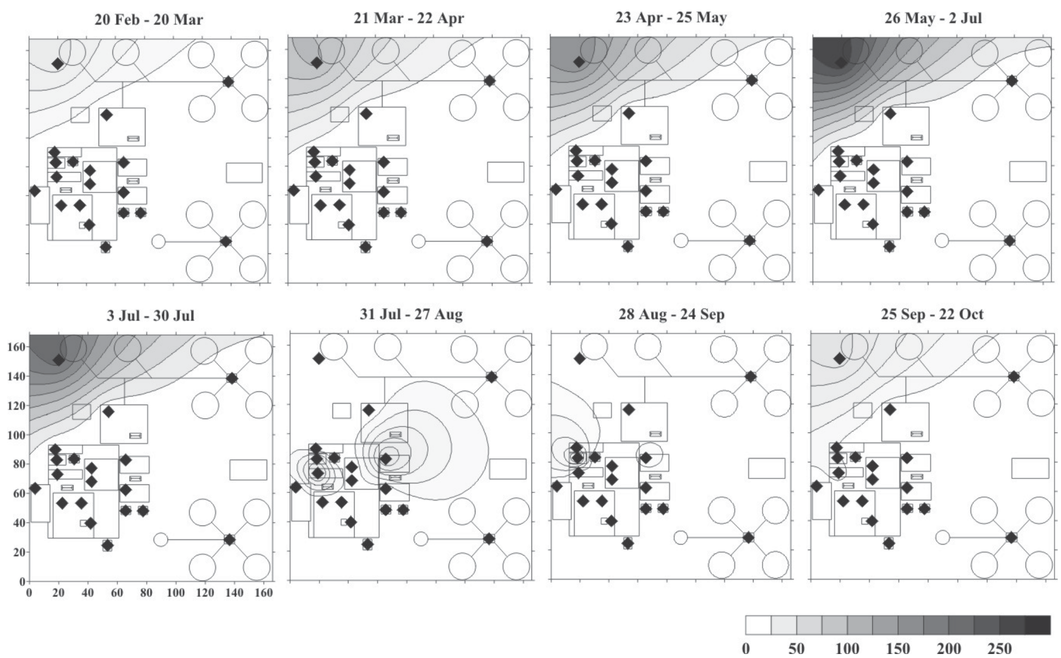

Fig. 7. Spatial distribution of *O. surinamensis* in the paddy rice storage facility, during the I year survey (20 February - 22 October). Scale indicating the number of insects captured is depicted. *x,y* axis are expressed in meters.

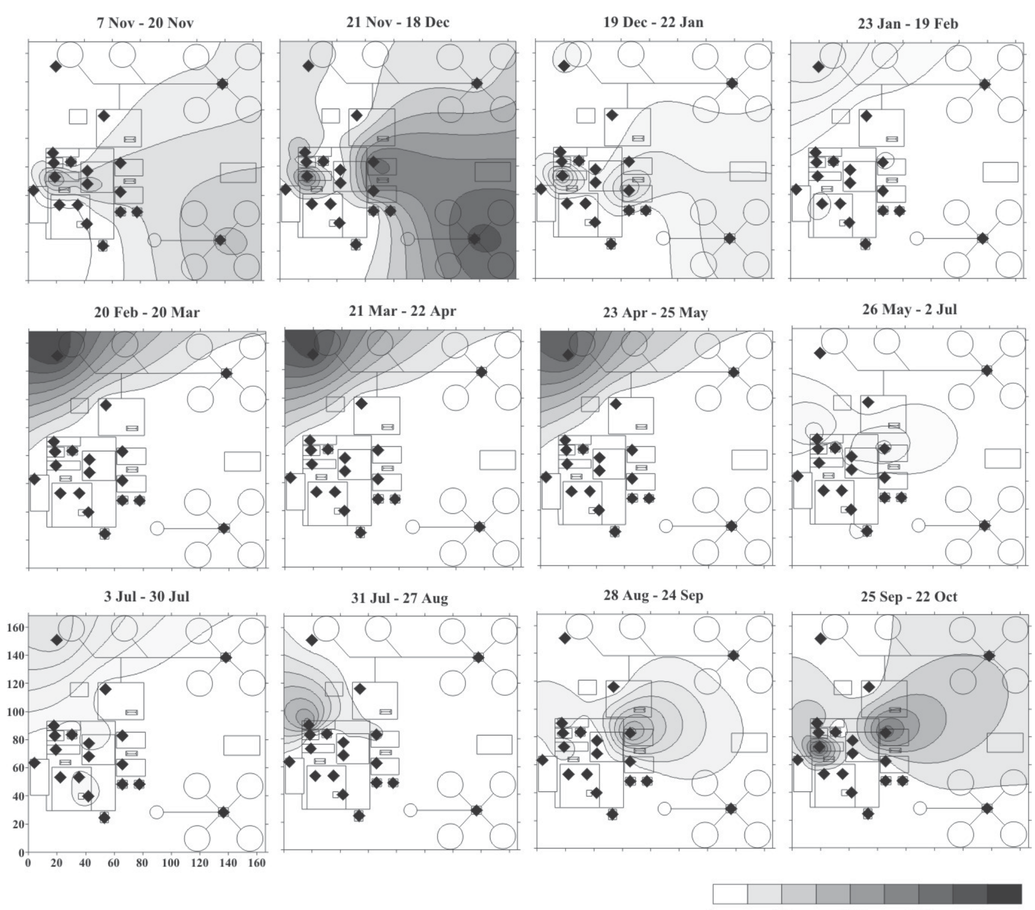

Fig. 8. Spatial distribution of *R. dominica* in the paddy rice storage facility, during the I year survey (7 November - 22 October). Scale indicating the number of insects captured is depicted. *x,y* axis are expressed in meters.

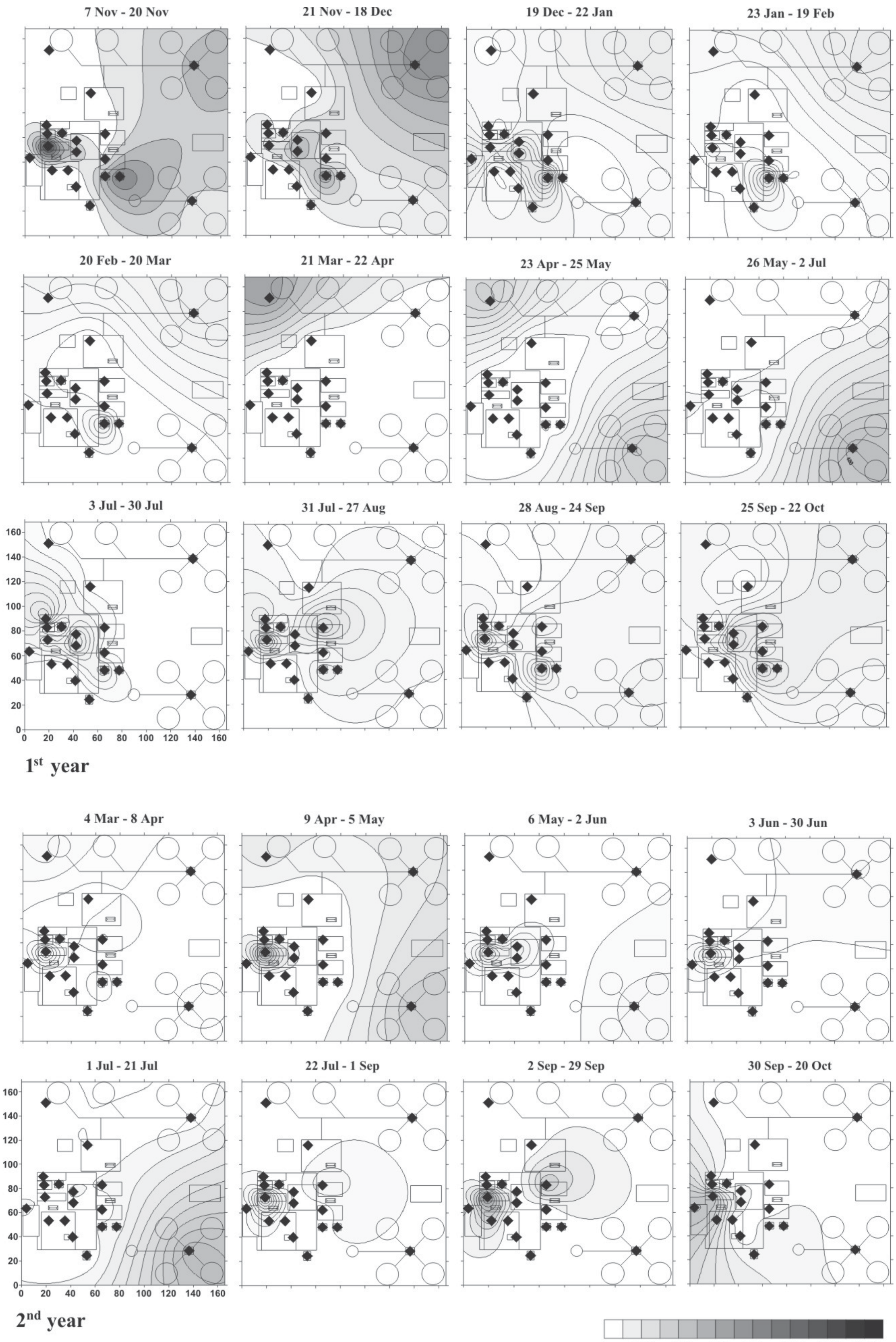

Fig. 9. Spatial distribution of *S. oryzae* in the paddy rice storage facility, during the I year survey (7 November - 22 October) and the II year survey (4 March - 20 October). Scale indicating the number of insects captured is depicted. *x,y* axis are expressed in meters.

In the paddy rice storage facility, the various species showed very variable distribution and, depending on the pest and year, all parts of the structure appeared infested, both in processing areas and in silos areas, at least in one of the two years survey. Large extension of distribution in silos area has to be interpreted as an interpolation effect since few traps were deployed there.

Results of PCA analysis suggested that the food preference is the most important factor that influences the distribution of the different species. Primary pests (*S. oryzae* and *R. dominica*) were well established in silos and entrances, where they can find intact kernels for their development. Secondary pests showed more variegate distributions, depending not only on debris and mould presence, but also on interaction between various species. This is the case of *T. castaneum* and *G. cornutus*, that have similar ecological requirements: spatial distribution of *T. castaneum* during the 1st year is similar to that of *G. cornutus* in the 2nd year, and vice versa. Other pests with scarse population and circumscribed distribution, such as *O. surinamensis*, are probably limited in time and space by the competition with other secondary species.

Areas with maximum level and frequency of infestations were those with abundance of alimentary resources, i.e. zones where rise stocks are introduced in the facility, sorted and stored (entrance, grain pit with the conveyor belt, silos) and where debris and dusts are produced by the processing of rice (de-hulling places, pre-cleaning machine and dryers).

In such areas, at the beginning of the survey, no control measures were used and residues of old bags and garbage were spread in the processing area; moreover, the rice was not homogenous because it was received from many different farms, and in different times. Basic cleaning measures were adopted inside and outside the storage facilities as soon as the results of the first survey were obtained. The sanitation measures included simple operations such as the elimination of piles of old sacks, garbage and other materials and the cleaning of floors, machineries and silos before filling, as well as insecticide application on the silo walls.

The efficacy of these measures can be evaluated with a comparison between the 1st and the 2nd year surveys, that showed a strong falling of population numbers in the 2nd year. Such a result was obtained because, before the beginning of the new crop storage, cleaning measures were accomplished inside and outside the silos and in the processing area, including application of insecticide on the structure.

Nevertheless variations in number and in spatial distribution were not uniform, but changed in some unexpected ways. As for *S. oryzae* numbers decreased of 36% in the 2nd year, but spatial distribution did not shrank, with a reduction in the zone of the pre-cleaning machine and the dryers, interested by constant curative practices, and an augmentation in the rice husks storage room and oven 1, probably shelter sites. Regarding *C. ferrugineus*, numbers increased in the 2nd year, and spatial distribution in part changed, appearing in the area of silos A-H. Also *G. cornutus* and *T. castaneum* populations grew in the 2nd year, but, in the first case spatial distribution resulted narrower, whereas in the second case a new hot spot appeared around silos E-H. Decreasing of population corresponded, for *Carpophilus* spp. and *R. dominica*, to a reduction in infestation extent, while for *Ephestia* spp. and *O. surinamensis*, to an enlargement of distribution.

The changes of spatial distributions are probably strongly influenced by the pest management practices; in fact, species submitted to a pressure due to the curative intervention adjust to new surroundings, maintaining low level population in less treated zones. To obtain an in-depth effect of measures, also shelter sites, that represent hidden infestation foci ready to quickly re-colonize the remaining sites of the structure, should be identified and monitored.

Spatial analysis allows locating these persistent infestation foci that can determine a new spreading of infestation. By using the spatial maps built monthly, monitoring practices can be directed with a high degree of precision, allowing the early detection of pests in shelter sites, before they move to infest the grain mass in other areas of the facility or inside the silos, and help to make the most efficient and cost effective decision about handling and control strategies.

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