# Improved Methods for Survey of Carabid Beetles (Coleoptera: Carabidae) Using Pitfall Trapping and Spatial Autocorrelation Techniques[1]

Ya-hui Hu, Jie Dong, Xiao-xia Liu, Qing-wen Zhang[2], and Zhang-wu Zhao[2]

Hunan Plant Protection Institute, Changsha, 410125 China; Department of Entomology, College of Agronomy and Biotechnology, China Agricultural University, Beijing 100094 China.

J. Entomol. Sci. 46(1): 30-39 (January 2011)

**Abstract** Ground beetles (Coleoptera: Carabidae) inhabiting a peach orchard were collected using pitfall traps placed adjacent to plastic barriers that were perpendicular to each other and crossed each other at their midpoints. Each array of traps contained 5 traps with 1 at the midpoint of each barrier and the other 4 at the ends of each plastic barrier. The trap located at the center of each array captured about 40% of the total beetles trapped by each array, thus suggesting that a single trap located at the center of the array could be a more efficient means of sampling. Using spatial autocorrelation techniques, the range of spatial dependence for the two herbivorous carabids collected in this study - *Harpalus tschiliensis* Schauberger and *Harpalus griseus* Panzer - ranged from 136.7 - 210.3 m, whereas that of the predatory carabid *Calathus halensi* Schailer ranged from 330.1 - 412.4 m. Based upon our results, we suggest that pitfall traps used for monitoring or sampling carabid beetles be set no further than 210 m apart for herbivorous species and 412 m apart for carnivorous species.

**Key Words** carabids, ground beetles, pitfall trapping design, geostatistics, sampled distance

Sampling is a key component of an integrated pest management (IPM) program. Development of effective, but simple and efficient sampling methods increases the likelihood of adoption in IPM programs and will provide data on insect population composition, numbers, density, and dispersion, thus providing information for decision-making criteria for the system. Pitfall trapping is a widely used, rather simple and inexpensive technique for sampling ground beetles (Coleoptera: Carabidae) (Barber 1931, Greenslade 1964). A number of studies have focused on the design or arrangement of pitfall traps to increase their efficiency in capturing beetles (Wallin 1985, Jensen et al. 1989, Weeks and McIntyre 1997, Holland and Smith 1999, Lemieux and Lindgren 1999). Winder et al. (2001) found that a pitfall trapping system with 5 traps, each filled with a wetting agent and placed adjacent to 1 of 2 plastic barriers placed perpendicular to each other and crossing each other at their midpoints, was more efficient in trapping carabid beetles than a single dry trap (increased efficiency by at least an order of magnitude) or 5 traps without the connecting barriers (2X more efficient). The 5 traps in each array were located where the barriers crossed each other

[1]Received 04 May 2010; accepted for publication 20 August 2010.

[2]Address inquiries (Qing-wen Zhang email: zhangqingwen@263.net; Zhang-wu Zhao email: zhaozw@cau.edu.cn)

(center) and 1 each at the ends of each barrier. This arrangement was particularly effective for sampling certain carabid and staphylinid beetles (Winder et al. 2001).

An objective of this study was to assess the utility of this barrier pitfall system trapping array for collecting and monitoring ground beetles inhabiting a peach orchard in the Shanxi Province of the Republic of China. To improve sampling efficiency, we also wanted to optimize the placement of trapping arrays within the orchard; thus, we used geostatistical analyses to calculate distances between trapping arrays.

Conventional statistics routinely calculate the distribution patterns of insect populations, but they do not quantitatively describe the spatial autocorrelation within an insect population. Geostatistical analysis provides an alternative approach for the characterization of spatially variable ecological data (Rossi et al. 1992, Williams et al. 1992), particularly for insect pest populations (Johnson 1989, Liebhold et al. 1993, Roberts et al. 1993, Rossi et al. 1993). A basic tool of geostatistics is the semivariogram, which plots the distance between sample pairs against a semivariance statistic (variation between those points) for all possible sample pairs at each distance. The semivariance for N sample pairs is calculated as:

$$y(h) = [1/2N(h)]\sum[Zi - Z(i+h)]^2,$$

where h is the lag distance between samples for variable z.

The Geostatistical Analyst software package (Gamma Design Software http://www.gammadesign.com) provides a comprehensive set of tools for creating surfaces that can be used to visualize, analyze, and understand spatial phenomena.

The geostatistical method has been widely applied in ecological entomology. Johnson (1989) showed that grasshopper populations in fields can be reliably predicted from roadside survey counts using spatial autocorrelation analysis instead of direct estimation. Williams et al. (1992) demonstrated the aggregated and spatially variable distributions of the soil-dwelling stages of the sugar beet wireworm, *Limonius californicus* (Mannerheim). Midgarden et al. (1993) described the spatially-structured, aggregated distributions of corn rootworm (*Diabrotica virgifera* Leconte) adults trapped on sticky boards. In northwestern Iowa, Rossi et al. (1993) estimated northern corn rootworm (*D. barberi* Smith & Lawrence) densities and evaluated the economic risk of possible pesticide treatments on a regional scale using geostatistical techniques and stochastic simulations of spatial variability. Gribko et al. (1995) developed a model to predict the likelihood of defoliation by gypsy moths, *Lymantria dispar* (L). Ellsbury et al. (1998) characterized the spatial variability in the adult emergence patterns of western and northern corn rootworms. Gilbert and Grégoire (2003) analyzed the spatial structure of the proportion of trees attacked by *Dendroctonus micans* (Kugelann), and showed a strong spatial scale interaction of this bark beetle with its environment; the resulting models enabled estimates of attack density at unsampled locations. Ge et al. (2005) measured the quantitative spatial heterogeneity of the egg population of cotton bollworm, *Helicoverpa armigera* Hübner, during a cotton-growing season in Hebei province China.

## Materials and Methods

The peach orchard used for this study is located in the town of Jiade, Linfen County, Shanxi Province in China (35°23′–36°57′ N, 110°22 - 112°34′ E). The area is characterized by a continental climate with an annual mean temperature of 8.9 - 12.1°C

(January mean = –4°C; July mean = 26°C), an annual rainfall of 453.9 - 688.4 mm (Ma and Zhang 2007), and a frost-free period of 193 - 227 d (data from http://baike.baidu.com/view/2250833.htm). The orchard was 60 ha in area and was planted in the cultivar 'Okubo,' which was introduced into China from Japan in1934. Trees were 5 years old in the orchard. During this study (April 2006 to October 2007), no insecticides were applied to the orchards, although all other cultural practices were continued as normal.

The pitfall trap design used in the study was that of Winder et al. (2001). Each individual sampling unit, or array, was comprised of 5 pitfall traps with two 0.5-m lengths of plastic barriers connecting the traps. The barriers crossed each other at their midpoints and were designed to channel ground-dwelling insects along the barriers to 1 of the 5 traps in the array. One trap was located in the center of the array where the 2 barriers intersected. The other traps were located one each at the eastern, western, northern and southern ends of the array. Each trap consisted of a 10-cm diam, 12 cm deep plastic cup set vertically in the soil such that the top of the cup was level with the soil surface. The cups were filled with 200 ml of water containing 20 ml of propylene glycol (Kunlun Lubricating Material Co., LTD, Tieling city, LiaoNing province, China) as a preservative. The cups were covered with a lid to prevent the trap filling with rain and irrigation water and to keep crawling insects and spiders from falling in during the periods between active sampling for ground beetles. Up to 54 trapping array systems were distributed throughout the orchard (Fig. 1).

A total of 24 two-day trapping periods were conducted at 2-wk intervals between April and October during 2006 and 2007. The lids were removed from the traps at the start of the trapping period, and ground beetles captured in the traps were collected 2 d later. Cups which had caught beetles were capped, and the samples and liquid were returned to the laboratory for analysis. Specimens were identified, and the dates of their collection entered into a spreadsheet. All carabids collected were identified to genus, and a representative sample was identified to species.

**Data analysis.** The numbers of the 3 most commonly-captured species of carabids - *Harpalus tschiliensis* Schauberger, *H. griseus* Panzer, and *Calathus halensis* Schaller – were recorded for each individual trap within an array system. The numbers captured in the center trap were compared with the captures from the other traps within the same array, and the relative abundances (also referred to as activity densities when using pitfall traps) were calculated for each of the commonly-trapped species.

Geostatistical analysis was used to examine the spatial autocorrelation of the carabid capture results. The semivariograms were computed for each species using the

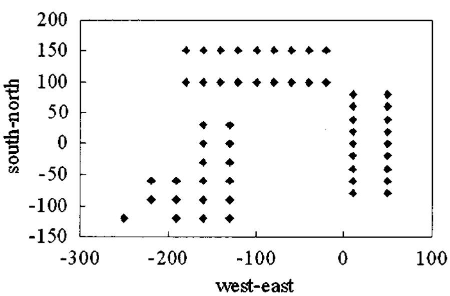


**Fig. 1. Fifty-four sample plots were distributed in the peach orchard.**

program GS+ for Windows 5.1. The number of individual beetles caught in a single 5-trap array system was defined as z. Expressing the results graphically, the center of the orchard was set at the origin. The x-axis specified the location of a 5-trap system to the west (negative values) or to the east (positive values) of the orchard center. Likewise the y-axis showed the position of a 5-trap system north (positive values) or south (negative values) relative to the orchard center. A contour map was produced using the kriged estimates of carabid relative abundance at 30-m intervals by finding the model which best fit the variogram, as indicated by $r^2$ values calculated using GS+ for Windows 5.1.

## Results

A total of 11,648 individuals of 3 commonly-collected carabid species were captured in the pitfall traps in the orchard during 2006 and 2007. During each year, > 2000 individuals were collected for *H. tschiliensis* and *H. griseus* each, whereas 700 - 1100 individuals of *C. halensis* were collected.

For 2006 and 2007, the numbers of carabids caught in the central trap of each array were significantly correlated with the numbers caught in the outlying traps within the same array system (Table 1, $r > 0.75$, $P < 0.001$). For *H. tschiliensis* and *H. griseus*, 2.7 times as many individuals were captured in the 5-trap system as a whole than in the central trap of the array alone. For *C. halensis* this ratio was only 2.3.

Gaussian models were used to describe the spatial structure of semivariograms for the capture data of the 3 carabid species (Fig. 2). Values of $r^2$ ranged from 0.707 - 0.883 (Table 2). The value of $C/C_0+C$ for the 3 species ranged from 0.80 - 0.97, indicating that the 3 species were strongly spatially autocorrelated. The Gaussian model for the data from 2006 and 2007 show a range of spatial dependence for *H. tschiliensis* and *H. griseus* ranging from 136.7 m to 210.3 m (Table 2). The range of spatial dependence for *C. halensis* was 330.1 m in 2006 and 841.8 m in 2007.

Contour maps were produced using kriged data from grid samples for the numbers of carabids captured per 5-trap array system, for each carabid species (Fig. 3). The highest abundances of the 3 species were recorded in the following areas of the orchard: *H. tschiliensis* in the southeast quadrant; *H. griseus* in the southwest and southeast quadrants; and *C. halensis* in the southwest quadrant (Fig. 3).

**Table 1. Linear regression parameter, which y was the individual numbers of beetles captured from the five traps and x was the individual numbers of beetles captured from the center trap.**

| Species | Year | r | Constant | Coefficient | *P* |
|---|---|---|---|---|---|
| *Harpalus tschiliensis* | 2006 | 0.850 | 7.535 | 2.935 | 0.000 |
| *Harpalus griseus* | 2006 | 0.899 | 8.267 | 2.886 | 0.000 |
| *Calathus halensis* | 2006 | 0.781 | 4.670 | 2.273 | 0.000 |
| *Harpalus tschiliensis* | 2007 | 0.948 | 5.522 | 2.782 | 0.000 |
| *Harpalus griseus* | 2007 | 0.916 | 5.572 | 2.941 | 0.000 |
| *Calathus halensis* | 2007 | 0.840 | 3.994 | 2.098 | 0.000 |

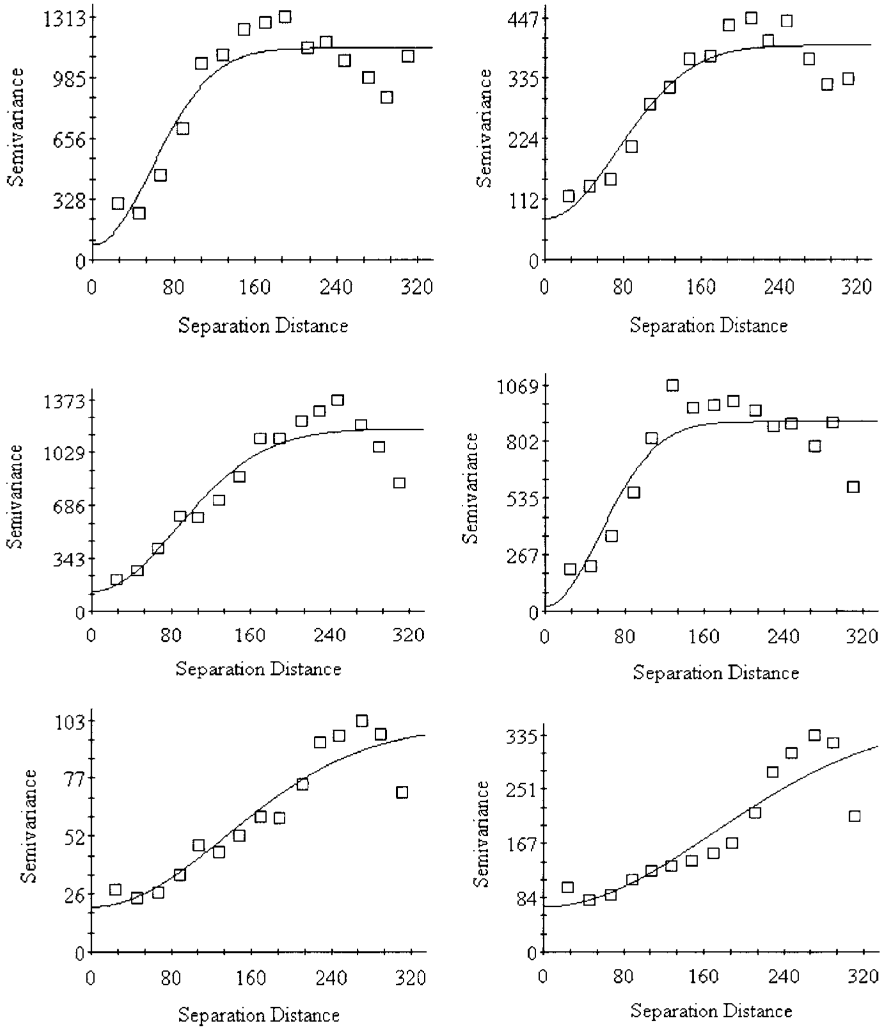


**Fig. 2. Standardized omnidirectional semivariograms for 3 carabids relative abundance in 2006 and 2007. *Harpalus tschiliensis* in 2006 (upper top); *Harpalus tschiliensis* in 2007 (upper right); *Harpalus griseus* in 2006 (middle left); *Harpalus griseus* in 2007 (middle right); *Calathus halensi* in 2006 (lower left); *Calathus halensi* in 2007 (lower right).**

## Discussion

As observed by Winder et al. (2001), the barriers used in the 5-trap array system increases the numbers of ground-dwelling insects captured in the pitfall traps. Our results further corroborated this with the capture rates of the outlying traps (east,

**Table 2. Most fitted omnidirectional semivariogram model parameter for *Harpalus tschiliensis* Schauberger, *Harpalus griseus* Panzer, and *Calathus halensis* Schaller.**

| Species | Year | Model | Nugget | Sill | $C/C_0+C$ | Range | $R^2$ |
|---|---|---|---|---|---|---|---|
| *Harpalus tschiliensis* | 2006 | Gaussian | 80.0 | 1140.0 | 0.930 | 143.9 | 0.851 |
| *Harpalus griseus* | 2006 | Gaussian | 128.0 | 1180.0 | 0.892 | 210.3 | 0.878 |
| *Calathus halensis* | 2006 | Gaussian | 20.0 | 100.5 | 0.801 | 330.1 | 0.880 |
| *Harpalus tschiliensis* | 2007 | Gaussian | 76.0 | 395.7 | 0.808 | 182.0 | 0.883 |
| *Harpalus griseus* | 2007 | Gaussian | 25.0 | 896.0 | 0.972 | 136.7 | 0.802 |
| *Calathus halensis* | 2007 | Gaussian | 69.6 | 356.8 | 0.805 | 412.4 | 0.815 |

west, south, and north) being enhanced by only one barrier, whereas those of the central trap being enhanced by both barriers. The central trap generally captured twice as many carabids as a single outlying trap, or about 40% of the total capture of the entire 5-trap array as a whole. This suggests that similar monitoring results might be obtained and time and materials saved by using a single trap with 4 barriers radiating at cardinal directions from the trap rather than using the complete 5-trap array system. This should be further investigated with objectives of the sampling program specifically defined.

Most arthropods can move between adjacent plants separated by up to 60 m (Miliczky and Horton 2005), but the range of spatial dependence for individual species may vary over several hundreds of meters (Ellsbury et al. 1998). Accordingly, we separated the site of each trap system by distances varying from 20 - 340 m. The distance between the individual traps within each 5-trap array system was small (only 0.5 m), so we set the Z variable as the number of carabids captured from all 5 traps rather than the number caught by each trap within an array. Usually a minimum of 20 sample pairs is needed at each given distance from the different sample sites to reliably estimate the semivariance. In this study, the semivariograms were calculated based on data from trap systems separated by 20 - 320 m because we had fewer than 20 sample pairs separated by more than 320 m. Only omnidirectional semivariograms were calculated because there was no significant directional heterogeneity in this orchard.

Based on our observations, both *H. tschiliensis* and *H. griseus* are herbivores, and their activities are dependent on soil and plant environmental factors (Ellsbury et al. 1998). The range of spatial dependence for both *H. tschiliensis* and *H. griseus* varied from 136.7 - 210.3 m. This result is similar to that of Ellsbury et al. (1998) who found that the range of spatial dependence of some beetles varies over several hundreds of meters. Based on our own observations, *C. halensi* is a predatory species. Its larger range of spatial dependence (more than 300 m) arises from competition with other

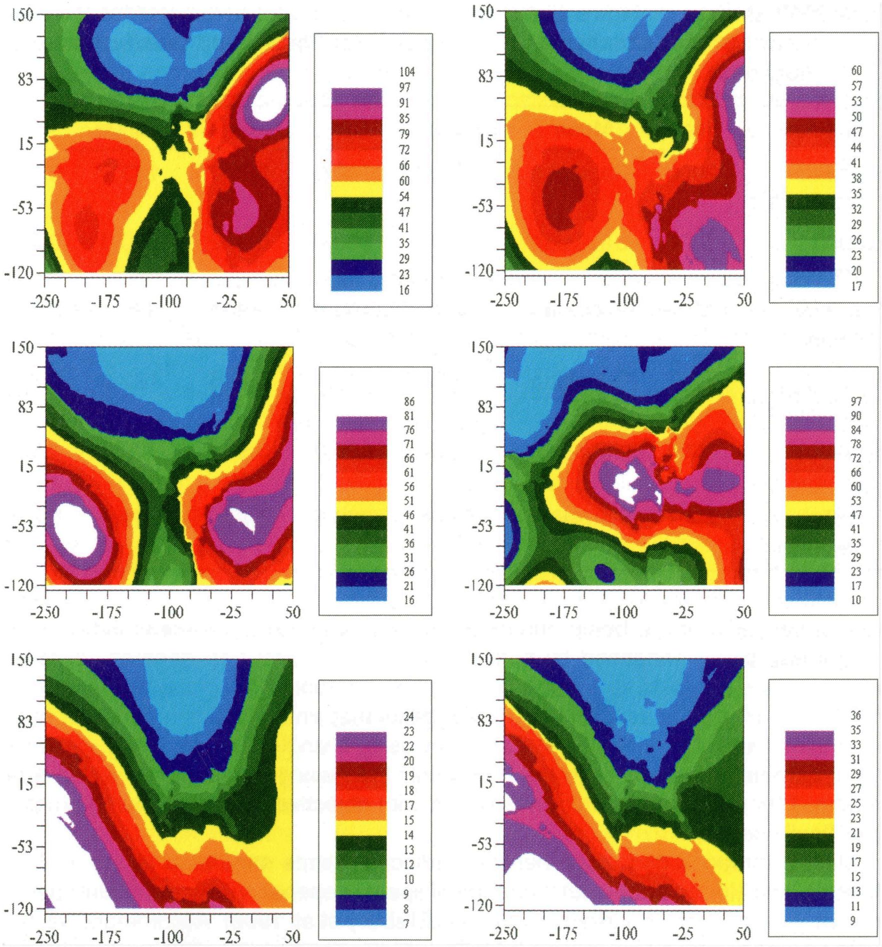


**Fig. 3. Contour maps showing interpolated 3 carabids density in 2006 and 2007. *Harpalus tschiliensis* in 2006 (upper left); *Harpalus tschiliensis* in 2007 (upper right); *Harpalus griseus* in 2006 (middle left); *Harpalus griseus* in 2007 (middle right); *Calathus halensi* in 2006 (lower left); *Calathus halensi* in 2007 (lower right).**

species for available prey. Because there is no spatial relationship between 2 sample sites when the distance between them exceeds the range of spatial dependence for a species (Liebhold et al. 1993), we suggest that traps be set no further than 210 m apart for herbivorous carabids and 412 m apart for carnivorous beetles.

Furthermore, our contour maps of the 3 carabid species showed the lowest densities in the northern part of the orchard. Ground beetles are usually regarded as ecological indicator species (Rainio and Niemela 2003) and can be affected by a variety of agricultural management practices and natural environmental factors (Niwa and

Peck 2002, Belaoussoff et al. 2003, Cartron et al. 2003, Larsen et al. 2003, Dávalos and Blossey 2004, Lopez et al. 2005, Gu et al. 2008, Nash et al. 2008). Harvey et al. (2008) suggested that carnivorous carabid species generally prefer areas characterized by open vegetation; whereas, herbivorous carabids generally prefer areas associated with high plant diversity. There were fewer plants and weeds in the northern parts of the orchard in our study due to the presence of a public paved road, and this may explain the lower numbers of herbivorous beetles in this area. The lower numbers of the carnivorous *C. halensi* may be due to the lower abundance of potential prey in the immediate area.

The range of spatial dependence of *C. halensi* varies from 330.1 - 412.4 m. Harvey et al. (2008) found that the composition of carabid communities was most affected by the year of sampling and that there was a dramatic shift in the relative proportions of the different trophic groups between years. Whereas pitfall traps provide an effective method of studying the activity of adult carabids and have been used in a multitude of studies (Greenslade 1964), pitfall trap catches are affected by variations in insect activity (Thiele 1977, Adis 1979) and weather (Mitchell 1963, Epstein and Kulman 1990); thus, results should be interpreted with caution.

These significant spatial autocorrelations in the distributions among 3 commonly-occurring carabid beetles were detected in an almost homogeneous landscape. These results can help to improve carabid survey methods using pitfall designs; however, future studies should focus on incorporating additional species, additional environmental factors, and aspects of beetle behavior to improve our understanding of the factors affecting carabid distribution.

## Acknowledgments

The authors thank Jian-ming Gao from the Senyuan Ecological Agricultural Development Ltd. in Linfen City, for providing the peach orchard used as the study site in this research. This research was funded by “948” projects in China (2006-G30-05).

## References Cited

**Adis, J. 1979.** Problems of interpreting arthropod sampling with pitfall traps. Zool. Anz. 202: 177-184.

**Barber, H. S. 1931.** Traps for cave-inhabiting insects. J. Elisha Mitchell Sci. Soc. 46: 259-266.

**Belaoussoff, S., P. G. Kevan, S. Murphy and C. Swanton. 2003.** Assessing tillage disturbance on assemblages of ground beetles (Coleoptera:Carabidae) by using a range of ecological indices. Biodivers. Conserv. 12: 851-882.

**Cartron, J. E. E., M. C. J. Molles, J. F. Schuetz, C. S. Crawford and C. N. Dahm. 2003.** Ground arthropods as potential indicators of flooding regime in the riparian forest of the middle Rio Grande, New Mexico. Environ. Entomol. 32: 1075-1084.

**Dávalos, A. and B. Blossey. 2004.** Influence of invasive herbgarlie mustard (*Alliaria petiolata*) on ground beetle (Coleoptera: Carabidae) assemblages. Environ. Entomol. 33: 564-576.

**Ellsbury, M. M., W. D. Woodson, S. A. Clay, D. Malo, J. Schumacher, D. E. Clay and C. G. Carlson. 1998.** Geostatistical characterization of the spatial distribution of adult corn rootworm (Coleoptera: Chrysomelidae) emergence. Environ. Entomol. 27: 910-917.

**Epstein, M. E. and H. M. Kulman. 1990.** Habitat distribution and seasonal occurrence of carabid beetles in east-central Minnesota. Am. Midl. Nat. 123: 209-225.

**Ge, S. K., R. I. Cattuthers, Z. F. Ma, G. X. Zhang and D. M. Li. 2005.** Spatial heterogeneity and population risk analysis of cotton bollworm, *Helicoverpa armigera*, in China. Insect Sci. 12: 255-262.

**Gilbert, M. and J. C. Grégoire. 2003.** Site condition and predation influence a bark beetle's success: a spatially realistic approach. Agric. For. Meteorol. 5: 87-96.

**Greenslade, P. J. M. 1964.** Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). J. Anim. Ecol. 33: 301-310.

**Gribko, L. S., A. M. Liebhold and M. E. Hohn. 1995.** Model to predict gypsy moth (Lepidoptera: Lymantriidae) defoliation using kringing and kgisdic regressing. Environ. Entomol. 24(3): 529-537.

**Gu, W. B., W. G. Sang, H. B. Liang and J. C. Axmacher. 2008.** Effects of Crofton weed *Ageratina adenophora* on assemblages of Carabidae (Coleoptera) in the Yunnan Province, South China. Agric. Ecosyst. Environ. 124: 173-178.

**Harvey, J. A., W. H. Putten, H. Turin, R. Wagenaar and T. M. Bezemer. 2008.** Effects of changes in plant species richness and community traits on carabid assemblages and feeding guilds. Agric. Ecosyst. Environ. 127: 100-106.

**Holland, J. M. and S. Smith. 1999.** Sampling epigeal arthropods: an evaluation of fenced pitfall traps using mark-release-recapture and comparisons to unfenced pitfall traps in arable crops. Entomol. Exp. Appl. 91: 347-357.

**Jensen, T. S., L. Dyring, B. Kristensen, O. Nielsen and E. R. Rasmussen. 1989.** Spring dispersal and summer habitat distribution of *Agonum dorsale* (Coleoptera, Carabidae). Pedobiologia (Jena) 33: 155-165.

**Johnson, D. L. 1989.** Spatial autocorrelation, spatial modeling, and improvements in grasshopper survey methodology. Can. Entomol. 121: 579-588.

**Larsen, K. J., T. T. Work and F. F. Purrington. 2003.** Habitat use patterns by ground beetles (Coleoptera:Carabidae) of northeastern Iowa. Pedobiologia (Jena) 47: 288-299.

**Lemieux, J. P. and B. S. Lindgren. 1999.** A pitfall trap for large-scale trapping of Carabidae: Comparison against conventional design, using two different preservatives. Pedobiologia (Jena) 43: 245-253.

**Liebhold, A. M., R. E. Rossi and W. P. Kemp. 1993.** Geostatistics and geographic information systems in applied insect ecology. Annu. Rev. Entomol. 38: 303-327.

**Lopez, M. D., J. R. Prasifka, D. J. Bruck and L. C. Lewis. 2005.** Utility of ground beetle species in field tests of potential nontarget effects of Bt crops. Environ. Entomol. 34: 1317-1324.

**Ma, Y. L. and F. Zhang. 2007.** Study on the ordination of climate factors in corn-growing regions of Shanxi by PCA. J. Shanxi Univ. (Nat. Sci. Ed.) 30: 102–106.

**Midgarden, D. G., R. R. Youngman and S. J. Fleischer. 1993.** Spatial analysis of counts of western corn rootworm (Coleoptera: Chrysomelidae) adults on yellow sticky traps in corn: geostatistics and dispersion indices. Environ. Entomol. 22: 1124-1133.

**Miliczky, E. R. and D. R. Horton. 2005.** Densities of beneficial arthropods within pear and apple orchards affected by distance from adjacent native habitat and association of natural enemies with extra-orchard host plants. Biol. Control 33: 249-259.

**Mitchell, B. 1963.** Ecology of two carabid beetles, *Bembidion lampros* (Herbst) and *Trechus quadristriatus* (Schrank): II. studies on populations of adults in the field, with special reference to the technique of pitfall trapping. J. Anim. Ecol. 32: 377-392.

**Nash, M. A., L. J. Thomson and A. A. Hoffmann. 2008.** Effect of remnant vegetation, pesticides, and farm management on abundance of the beneficial predator *Notonomus gravis* (Chaudoir) (Coleoptera: Carabidae). Biol. Control 46: 83-93.

**Niwa, C. G. and R. W. Peck. 2002.** Influence of prescribed fire on carabid beetle (Carabidae) and spider (Araneae) assemblages in forest litter in southwestern Oregon. Environ. Entomol. 31: 785-796.

**Rainio, J. and J. Niemela. 2003.** Ground beetles (Coleoptera:Carabidae) as bioindicators. Biodivers. Conserv. 12: 487-506.

**Roberts, E. A., F. W. Ravlin and S. J. Fleischer. 1993.** Spatial data representation for integrated pest management programs. Am. Entomol. 39: 92-107.

**Rossi, R. E., D. J. Mulla, A. G. Journel and E. H. Franz. 1992.** Geostatistical tools for modeling and interpreting ecological spatial dependence. Ecol. Monogr. 62: 277-314.

**Rossi, R. R., P. W. Borth and J. J. Tollefson. 1993.** Stochastic simulation for characterizing ecological spatial patterns and appraising risk. Ecol. Appl. 3: 719-735.

**Thiele, H. U. 1977.** Carabid Beetles in Their Environments. Springer-Verlag. New York.

**Wallin, H. 1985.** Spatial and temporal distribution of some abundant carabid beetles (Coleoptera: Carabidae) in cereal fields and adjacent habitats. Pedobiologia (Jena) 28: 19-34.

**Weeks, R. D. and N. E. McIntyre. 1997.** A comparison of live versus kill pitfall trapping techniques using various wetting agents. Entomol. Exp. Appl. 82: 267-273.

**Williams, L. I., D. J. Schotzko and J. P. McCaffrey. 1992.** Geostatistical description of the spatial distribution of *Limonous californicus* (Coleoptera: Elateridae) wireworms in the northwestern United States with comments on sampling. Environ. Entomol. 21: 983-995.

**Winder, L., J. M. Holland, J. N. Perry, C. Woolley and C. J. Alexander. 2001.** The use of barrier-connected pitfall trapping for sampling predatory beetles and spiders. Entomol. Exp. Appl. 98: 249-258.