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APPLICATION OF SPATIAL ANALYSIS TECHNIQUE IN SEARCHING BEHAVIORS RESEARCH OF INSECTS: A CASE STUDY OF *STETHORUS PARAPAUPERCULUS*

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ABSTRACT

In this study, the spatial behaviors of insects' searching track were investigated. Spatial analysis techniques were employed to extract spatial attribute information from the prey-searching tracks of *Stethorus parapauperculus* Pang. The variations in the searching distance and searching angle before and after feeding were compared. The results indicated that the *S. parapauperculus* tended to move along straight lines and form acute angles before feeding; and the track points were mainly concentrated in the peripheral regions of the observation area. The subjects searching distances between adjacent tracking points of before feeding were generally longer than after feeding. After feeding, the subjects changed directions more frequently, resulting in more circuitous movement tracks and increased searching angles. In particular, the subjects' movements were mostly concentrated in the areas surrounding the initial prey sightings. The parameters of the movement tracks were easily obtained through spatial analysis techniques; thus a new method of studying insect behavioral ecology was provided.

Keywords: spatial analysis; searching behavior; Arc GIS; *Stethoruspara pauperculus* Pang.

INTRODUCTION

Insects generally exhibit a series of complicated behaviors, which were formed gradually through continuous and prolonged evolutionary processes. The behavior characteristics of predatory insects are closely associated with their survival and competitive abilities and, therefore, are essential to determining the effectiveness of pest control methods. Previous studies concerning the behavior of nature enemy (such as predatory ladybugs) searching for target pests have mostly been conducted through direct observation and manual recording. The variations in the distance, direction, and other parameters of insect movements have primarily been measured manually (Zou *et al*., 1996; Wang *et al*., 2004). Due to the development of information technologies, video recording has gradually been applied to the insect movement tracking. Insect searching movements can be automatically recorded, and the values of some parameters can be obtained by applying information technologies. However, such tracking devices are not only high in cost, but also require the monitored insects to fall within a certain size range (Wu *et al*., 2009). Existing studies regarding the searching movements of insects primarily focus on two-dimensional distributions in that movement curves are considered to be combinations of two-dimensional points. Parameters can be obtained and analyzed from two-dimensional tracking curves and points through spatial analysis methods. Spatial analysis is an important facet of Geostatistics, with applications in planning, environmental, and agricultural fields (Huang *et al*., 2007; Li and Gao, 2004; Chuai *et al*., 2011). Currently, spatial analysis is mostly used in large-scale studies (province-, county-, or city-wide) (Hu *et al*., 2007; Huang *et al*., 2007), and rarely used in small-scale studies. Using spatial analysis to study the searching behaviors of insects would not only expand the small-scale applications of spatial analysis, but would also provide a new method for studying insect behavioral ecology.

Most predatory ladybugs alter their search methods to improve their search efficiencies after feeding. For example, the searching behaviors of *Adaliabipunctata* Linnaeus, *Harmonia axyridis* Pallas, *Coccinella septempunctata* Linnaeus, *Adoniavarie gata*Goeze and *Propylea japonica* Thunbergall vary before and after feeding (Banks, 1957; Nakamuta, 1982; Zou *et al*., 1991; Zou *et al*., 1997; Wang *et al*., 2004). *Stethorusparapauperculus*Pangis a natural enemy of numerous pests, such as *Tetranychus cinnabarinus* Boisduval, *Eotetrany chussex maculates* Riley and *Tetranychus piercei* Mcggregor(Cheng *et al*., 1989; Fu *et al*., 2007; Zhang *et al*., 2010). Identifying the characteristics of the prey-searching behaviors of predatory is essential to understanding the ecological mechanisms and relationships among predators and prey. In this study, conventional insect behavioral study methods were combined with spatial analysis, and the searching behaviors of *S. parapauperculus* before and after feeding with a preywere compared and analyzed in order to provide a new method for studying insect searching movements.

MATERIALS AND METHODS

EXPERIMENTS

Subjects: The *S. parapauperculus*used in this study were collected from the Environment and Plant Protection Institute of CATAS laboratory in Danzhou city in Hainan Province, China. The subjects were fed *T. cinnabarinus* in an indoor environment temperature of 23-26°C and humidity of 70±5%. Cassava was used as the host plant for the *T. cinnabarinus*. First-generation ladybugs were used for the experiments.

Method: A 3 days old *S. parapauperculus*adult(hunger 24 hours) was placed in the center of a petri dish (15 cm in diameter and 1.5 cm in height). The petri dish was then covered with transparent preservative film. After the ladybug was allowed to move freely in the petri dish for 1 minute, a 0.3-mm marker was used to record the movement of the subject on the preservative film. The tracking lasted for 3 minutes, and a tracking point was drawn every 15 seconds. Then, a *T. cinnabarinus* female adult was placed near the *S. parapauperculus*. After the subject fed on the prey, its movement was recorded again for 3 minutes; the method is the same as above. This experiment involved six *S. parapauperculus* subjects. All of the experiments were conducted in an indoor environment at a temperature of 23-26 °C, a humidity of 70±5%, and a light intensity of 200-230 lx.

Data processing: After all of the experiments were complete, the transparent preservative film pieces with the movement tracks were placed on A4-sized graph paper (1×1 mm). Life-sized scans were obtained and saved as documents in *jpg* format. The files were projected using ArcGIS 10.0, and the tracking points and lines were digitalized in order to obtain the victories data.

Using the ArcGIS 10.0 spatial analysis module, the victories data was processed. The curve length and distance between each pair of adjacent tracking points were calculated. The victories data was then overlaid in order to obtain the spatial distributions of the tracking points before and after feeding.

The curve length to distance ratio (β) of each pair of adjacent points was within the range of [1, +∞), which reflected the changes in angle between the adjacent points. Smaller value of β indicated smaller angle changes and vice versa.

ANOVA tests on the parameters (searching distance and searching angle) of the movements of *S. parapauperculus* before and after feeding were conducted using SPSS 20.0. The spatial distributions of the tracking points and lines were plotted using ArcGIS 10.0.

RESULTS AND DISCUSSION

Distributions of searching tracks: The distributions of the digitalized tracking points and lines of the movements revealed differences in the movements before and after feeding (Fig. 1). Before feeding, its searching tracks were primarily located in the peripheral regions of the observation area. After feeding, the tracks were concentrated in smaller regions, and a higher number of turns occurred.

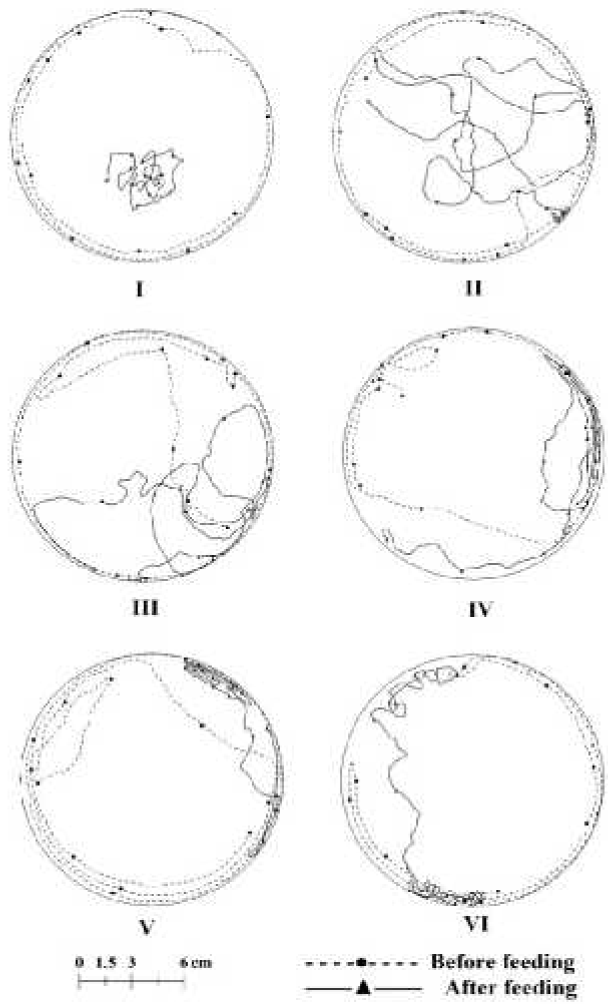

Fig. 1 Distribution of *Stethorusparapauperculus*Pang searching tracks

Using spatial analysis, the victories tracking points were overlaid (Tang and Yang, 2006), and the resulting distributions of all of the points reflected the overall distributions of the subjects' search tracks (Fig. 2). Before feeding, few tracking points (< 10%) were distributed within the 5.5-cm circle in the center of the observation area. However, after feeding, the tracking points were distributed more evenly throughout the entire area. The points located in the middle of the study areas increased after feeding, accounting for approximately 34.6% of the total points. The differences in the distributions of the tracking points indicated that the *S. parapauperculus*exhibited different searching behaviors before and after feeding. This result was similar to those of studies concerning *C. septempunctata*, *P. japonica*, and *A. variegate* (Nakamuta, 1982; Zou *et al*., 1991; Zou *et al*., 1997).

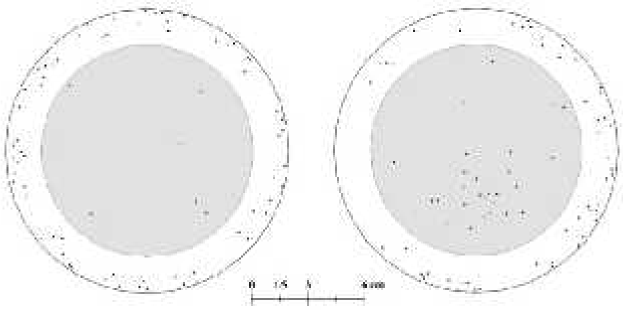

Fig. 2 Distribution of track points in searching area

Searching distance: The lengths of the curves between the adjacent tracking points were derived by performing operations on the victories tracking data from the attribute table. The subjects traveled further before feeding than after feeding. The average total lengths of the tracks before and after feeding were 84.6 cm and 60.5 cm, respectively. The lengths of the curves between the adjacent tracking points varied. The curves before and after feeding were most different (4.5-cm difference) in the 60-75 second time interval. This indicated that the subjects shortened their searching distances in order to improve their searching efficiencies during the 15 seconds after feeding. For some time after feeding, the majority of the subjects changed directions frequently in the areas surrounding the first prey (Zou *et al*., 1997). This could be a searching strategy used by the subjects to improve their food-searching efficiency.

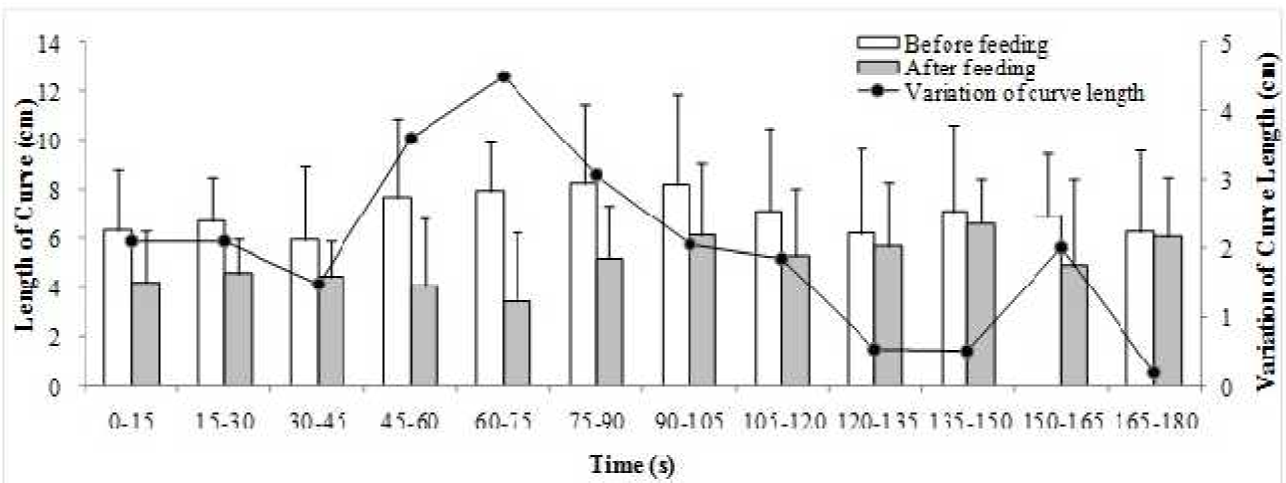

Fig. 3 Comparison of the curves lengths between adjacent track points

Searching angle: The curve length to distance ratios (β) between the adjacent tracking points before and after feeding were 1.28±0.33 and 2.07±0.56, respectively (Fig. 4). This indicated that the movement angles changed more frequently after feeding than before feeding. Before feeding, the subjects' searching movements were essentially straight with acute angles. After feeding, the searching angles were larger, resulting in more apparent circuitous movement characteristics. In addition, the angle differences before and after feeding indicated a transition in the searching type.

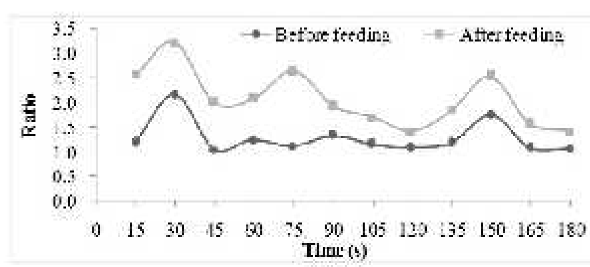

Fig. 4 The average curvilinear angle variation

Conclusion: After feeding, the *S. parapauperculus* subjects frequently searched the areas surrounding the first prey sightings in a more circuitous pattern. Before feeding, the subjects' movements were concentrated in the peripheral regions of the study areas. In addition, the searching distance of before feeding was longer than after feeding and the searching angle of before feeding varied less than that after feeding.

Spatial analysis tools were successfully applied to the parametric analyses of the insects' movements. The distance and curve length between each pair of adjacent tracking points, as well as the overall spatial distribution pattern, were obtained by performing attribute operations on the victories tracking points and lines of the insects' movements. The distribution of the insects' movements within the study areas was observed intuitively by overlaying the repeated or processed movement tracks. In addition, spatial analysis was used to obtain the searching ranges, searching speeds, and other parameters of the insects' movements. This process could be used to lessen the workload of plotting and measuring movement tracks, which are conventionally performed by hand. Thus, spatial analysis could be implemented as a new approach for studying the searching behaviors of insects.

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