

**BEHAVIOURAL RESPONSE OF *CHILOCORUS BIPUSTULATUS* (COLEOPTERA: COCCINELLIDAE) TO VARIATION IN *UNASPIS EUNYMI* (HOMOPTERA: DIASPIDIDAE) DENSITY AT SPATIAL SCALES**

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**ABSTRACT:** The behavioral response of *Chilocorus bipustulatus* L. to variation in eunymus scale, *Unaspis eunymi* Comstock density at different patches was examined under laboratory conditions ( $27 \pm 2^\circ\text{C}$ ,  $70 \pm 5\%$  of RH, 16L: 8D). Different densities of eunymus female scales were set on *Eunymus japonicus* leaves under a stereomicroscope and were placed in plastic containers. Plastic containers were arranged randomly equidistant from one another in the cage. The experimental procedure involved introducing different number of female predator separately in the center of the cage. The patterns of percentage of time spent on each patch, revealed a tendency for aggregation on the patches of high prey densities. Predators spent proportionately more time on high density patches than on low ones. The proportion of predators found in each patch also indicated aggregation of predators in high density patches. The values of aggregation index for 1 to 16 female predators were all greater than zero showing the concentration of the predator in patches with high prey densities. The percentage of prey eaten was variable in different prey patch densities, showing a density dependence tendency. It was found in this research that *Chilocorus bipustulatus* aggregated in high density patches of its prey, but the pattern of predation, was variable at different patch densities of the prey. Density dependent pattern of predation has been shown to suppress pest population and even contribute to population stability.

**KEY WORDS:** Aggregation, density dependent, *Chilocorus bipustulatus*, *Unaspis eunymi*

The Asian diaspidid scale insect, *Unaspis euonymi* Comstock is an important pest of woody landscape plants especially, *Eunymus japonicus* in many parts of the world. In cases of heavy outbreaks, host plants are destroyed and becomes as a real problem in landscapes (Brewer & Oliver, 1984; Driesche et al., 1998; Schmutterer, 1998; Ozyurt & Ulgenturk, 2007). The predator, *Chilocorus bipustulatus* has been recorded as an active natural enemy of the scale insects, soft scales and whiteflies (Viggiani, 1985; Stathas et al., 2003; Yigit et al., 2003).

Host populations are generally patchily distributed and parasitoids must forage between patches (Waage & Hassell, 1982; Hassell & Waage, 1984). A patch can be considered as spatial subunits of the foraging area in which aggregation of hosts occurs (Hassell & Southwood, 1978). The dimension of a patch is determined by the forager itself (Rosenheim et al., 1989). The foraging behavior of individuals is clearly related to the dynamics of the population. The proper recognition of a patch boundaries is crucially important in studying the dynamic consequences of spatial heterogeneity, and provides a good example of how the population

ecologists must rely on the study of animal behavior, as more information on the behavior of individuals provide appropriate insights into population dynamics (Hassell & May, 1985). Non random searching behavior will result in spatial heterogeneity in the pattern of predation. Lessells' (1985) review on the spatial distribution of parasitism showed that all possible responses can occur in natural and laboratory systems. Patterns of density dependence, inversely density dependence and independent of density were common among parasitoids. A similar result has also been found by Walde & Murdock (1988). It has been shown that both direct and inverse density dependent pattern of predation can contribute to population stability, and whether direct or inverse relationships have the greater effect, depends upon the characteristics of the prey's spatial distribution (Hassell, 1984, 1985; Chesson & Murdoch, 1986; Reeve et al., 1994). However, all aspects of aggregation would increase stability in the population (Godfray, 1994; Maron & Harrison, 1997; Murdoch et al., 2005).

Optimal foraging theory predicts that parasitoid or predators will search so as to maximize the rate of predation, and the optimal time allocation involves concentration of search on higher host density patches (Cook & Hubbard, 1977; Hubbard & Cook, 1978). According to Rohani et al. (1994) and Hassell (2000) sufficient strong direct or inverse density-dependent distributions of parasitoids can strongly stabilize the interactions, while insufficient parasitoid aggregation leads to local instability, if the host rate of increase is above some threshold level, a range of interesting global dynamics can occur. Different degrees of parasitoid aggregation can also have a marked effect on equilibrium levels. Parasitoids have the greatest effects in reducing host equilibria when their distribution most closely tracks that of the hosts.

An investigation on the effects of density and spatial distribution of *Aphis gossypii* Glover on feeding rate and foraging behavior of the lady beetle, *Harmonia axyridis* Pallas showed that the predators concentrated their searching activities on host plants with higher density of aphids. The consumption rate of the predator was higher in the prey high patch densities (Yasuda & Ishikawa, 1999). An aggregative behavior was also shown by the parasitoids, *Trissolcus grandis* Thomson and *T. semistriatus* Nees when parasitizing different patch densities of *Eurygaster integriceps* Put. eggs (Amir Maafi, 2000; Asgari, 2001). However, in another study done by Matsumoto et al. (2004) it was shown that parasitism by *Aphytis yanonensis* DeBach et Rosen was temporally density-dependent on the arrowhead scale (*Unaspis yanonensis* Kuwana) population density at the whole-orchard level of Satsuma mandarin orange (*Citrus unshiu* Marc.), while parasitism by *Coccobius fulvus* Compere et Annecke) was not. Parasitism by *A. yanonensis* or by *C. fulvus* was rarely positively correlated to scale density at the single-tree level, and spatial density-dependence was hardly detected at all at this level. Most analyses of combined parasitism rates were similar to rates of parasitism by *C. fulvus* alone. Contrary to conventional wisdom of

biological control theory, this study demonstrates that density dependence is not necessarily detected, even in a system in which a natural enemy has long held pest density stable at low levels. This and other studies, showing that density-dependent parasitism, if they exist, are too weak to stabilize scale–parasitoid interactions, strongly suggest that density dependence is not necessarily essential to the success of classical biological control, thus supporting the view of Murdoch et al. (1984). That questioned this hypothesis and documented that density dependence was not a prerequisite for the success of biological control.

In this research the behavioral response of *Chilocorus bipustulatus*, to the spatial distribution of the eunymus scale, *Unaspis eunymi* was examined under laboratory conditions.

## MATERIALS AND METHODS

### *Insects and their densities*

Six white oblong plastic containers (1 x 8 x 10 cm) were placed in a cylindrical transparent polythene cage measuring 70 cm in diameter and 30 cm in height. Some small holes (1.5 cm in diameter) were made on the sides of the cage for aeration. The top of the cage and small holes were covered with muslin. Plastic containers were arranged randomly equidistant from one another in the cage. Densities of eunymus female scales (5, 10, 20, 30, 40 or 50 prey per patch) were set on *Eunymus japonicus* leaves under a stereomicroscope and placed in each plastic container. Each container was lined with a piece of moist sponge to provide leaf moisture. The experimental procedure involved introducing 1, 2, 4, 8 or 16 female lady beetles in the center of the cage. The lady beetles were obtained from a stock culture and were deprived of prey for 24 h prior to the start of the experiment. Each experiment was replicated five times. Each experiment lasted 24 h, then the predators were removed from the cage. The number of prey eaten in each patch was recorded. All experiments were performed in a growth chamber (27 ± 2°C, 70 ± 5 % of RH, 16L: 8D).

### *Distribution and patch time allocation by the predator*

In order to determine the distribution and the time spent by the predator per each prey patch, observation was made at last 10 minutes of second, sixth and eighth hour from the start of each experiment using a stop watch. The data relating to the distribution of predators on different prey patches were analysed using the model of Hassell & May (1973), which involved a nonlinear technique :

$$\beta_i = C \alpha_i^\mu$$

Where  $\beta_i$  is the proportion of the predator that occurs in ith patch,  $\alpha_i$  is the corresponding proportion of the prey in patch i,  $\mu$  is an aggregation index, which measures the degree of to which predator distribution corresponds with that of the prey, and C is a normalisation constant. Predators are thus uniformly spread between patches where  $\mu = 0$ , and

aggregation will increase as  $\mu$  increases (if  $\mu < 0$ , the predator would be aggregating in the low density patches (an unlikely occurrence), if  $\mu = \infty$  all predators are in the patch of highest prey density leaving the remainder as refuges. SAS and Excel softwares were used for analysis of data and drawing the figures.

## RESULTS

### *Prey consumption at different prey patches*

The percentages of prey (*Unaspis eunomi*) eaten by different numbers of *Chilocorus bipustulatus* females at different prey patches were variable at different prey patch densities (Fig. 1). The percentage of prey was highly density dependent ( $R^2=0.886$ ) when two predators were introduced into prey patches and a low level of density dependence in predation at other predator densities.

### *Distribution and patch time allocation by the predator*

The percentage of the total observed time spent by the adult predator in patches of different densities are shown in Figure 2. A similar trend was observed in time allocated in each patch by the different densities of the predator. The proportion of predators found in each patch indicated aggregation of predators in high prey density patches (Fig. 3). The values of aggregation index ( $\mu$ ) for 1 to 16 female predators were all greater than zero showing the concentration of the predator in patches with high prey densities (Table 1).

## DISCUSSION

The proportion of time spent on each patch, revealed a tendency for aggregation on the patches of high prey densities. Observation showed that the predators spent proportionately more time on high density patches than on low ones. In a similar study in the laboratory, the coccinellid, *Stethorus chengi* Sasaji showed a clear aggregative response to its prey patch densities, *Panonychus citri* McGregor, as spending more total time in high-density prey patches. Density-dependent, density-independent, and inversely density-dependent predation were mainly caused by mutual interference and aggregation among the predators (Cheng et al., 1993). The relationship between the proportion of *Chilocorus bipustulatus* in each patch and the proportion of prey per patch showed aggregation of predators in high density patches. However, the pattern of predation was variable at different patch density of the prey, ranging from highly density dependent to low degree of density dependence. The forager's behaviour determines spatial distribution of parasitism and predation in host patches (Schooler et al., 1996). According to optimal foraging theory, parasitoids or predators search in a way to maximize the rate of predation, and the optimal time allocation

involves concentration of search in patches with higher host densities (Cook & Hubbard, 1977; Hubbard & Cook, 1978).

Results found in this research are similar to those obtained by Yasuda and Ishikawa (1999) when studying the effect of *A. gossypii* (Glover) spatial distribution on the aggregative behavior of the multicolored Asian lady beetle, *Harmonia axyridis* Pallas. This lady beetle consumed more aphids in high patch densities than those in low ones. Two predaceous species of Coccinellidae, *Menochilus sexmaculatus* Fabricius and *Coccinella transversalis* Fabricius, occurred abundantly in bean crops (*Vigna catjang*) infested with the aphid *Aphis craccivora* in north east India (Agarwala & Bardhanroy, 1999).

Discovery rates of egg patches of *Lobesia botrana* Denis & Schiffermuller a major pest in vineyards by *Trichogramma cacoeciae* Marchal was density dependent but the exploitation rate was always inversely density-dependent according to host density (Barnay et al., 1999). Agee et al. (1990) and Lin (1993) found that lady beetles utilize several cues to find out their prey. They aggregate where the prey odors are prevalent and spent more time searching in these areas. *Mastrus ridibundus* (Gravenhorst) adults a parasitoid of the codling moth, *Cydia pomonella* (L.) also showed a positive aggregative response to host density. In the field-release experiment, trees with naturally occurring higher host densities had greater probability of being attacked by *M. ridibundus*. The probability of attack increased while percentage of parasitism decreased in relation to host density. This suggests that despite the aggregative response of the adult parasitoids to host density there was no evidence for density-dependent aggregation of parasitism. The number of hosts attacked in relation to host density showed an asymptotic curve that was similar to that of the laboratory-based functional response for a single parasitoid (Bezemer & Mills, 2001).

An aggregation was shown by *Trissolcus grandis* Thomson and *T. semistriatus* Nees as egg parasitoids of *Eurygaster integriceps* Put, on different patch densities of host eggs. However, the percentage of parasitism resulting from this pattern of foraging was density dependent at low host densities and inversely density dependent at high patch densities (Amir Maafi, 2001; Asgari, 2002). This domed pattern of parasitism has been found to occur rarely in host-parasitoid systems. It has been suggested that constraints imposed by egg-limitation or time limitation, or imperfect information on patch quality on the foraging natural enemy are likely to produce either inversely density dependent parasitism or domed density relationships (Lessels, 1985).

It has been suggested that the aggregation of natural enemies in patches with high host densities is the crucial component in natural enemy behavior that results in successful biological control and an increase in stability (Waage & Hassell, 1982; Hassell, 1984; Hassell & May, 1988; Maron & Harrison, 1997). Maron & Harrison (1997) in a study on the spatial pattern formation in an insect-parasitoid system showed that parasitoids emerging from a population outbreak of tussock

moth, *Orgyia vetusta* Boisduval, suppressed the growth of nearby experimental populations of the moth, while experimental populations farther away were able to grow. This result explained the observed localized nature of tussock moth outbreaks and illustrated how population distributions can be regulated by dynamic spatial processes. Similar results were obtained by Murdoch et al.(2005). They elucidated the mechanisms causing stability and severe resource suppression in a consumer–resource system. The parasitoid, *Aphytis sp.* as a consumer was able to control rapidly an experimentally induced outbreak of the resource, California red scale, an agricultural pest, and imposed a low, stable pest equilibrium. However, they concluded that the resulting stability in that biologically non-diverse agricultural system was a property of the local interaction between those two species, not of spatial processes or of the larger ecological community.

It was found in this research that *Chilocorus bipustulatus* aggregated in high density patches of its prey, *Unaspis eunomi*. Despite this, the pattern of predation, however, was variable at different patch densities of the prey, ranging from highly density dependent ( a strong aggregative response) to low level of density dependence. Density dependent pattern of predation has been shown to suppress pest population and even contribute to population stability (Hassell, 1985; Chesson & Murdoch, 1986; Reeve et al., 1994; Godfray, 1994; Maron & Harrison, 1997; Murdoch et al.,2005).

Table 1. Regression analysis (non-linear) and analysis of variance for the proportion of predators (*Chilocorus bipustulatus*) found per patch described by the model of Hassell and May (1973) .

Predator Density	Normalization Constant (C)	Aggregation index ( $\mu$ )	R <sup>2</sup>	F	P
1	1.30 ± 0.75	1.18 ± 0.42	0.999	29.99	< 0.0001
2	5.67 ± 6.2	2.24 ± 0.88	0.935	21.12	< 0.0001
4	0.89 ± 0.46	0.90 ± 0.35	0.999	27.03	< 0.0001
8	0.81 ± 0.20	0.87 ± 0.16	0.999	120.16	< 0.0001
16	1.19 ± 0.24	1.12 ± 0.81	0.999	222.34	< 0.0001

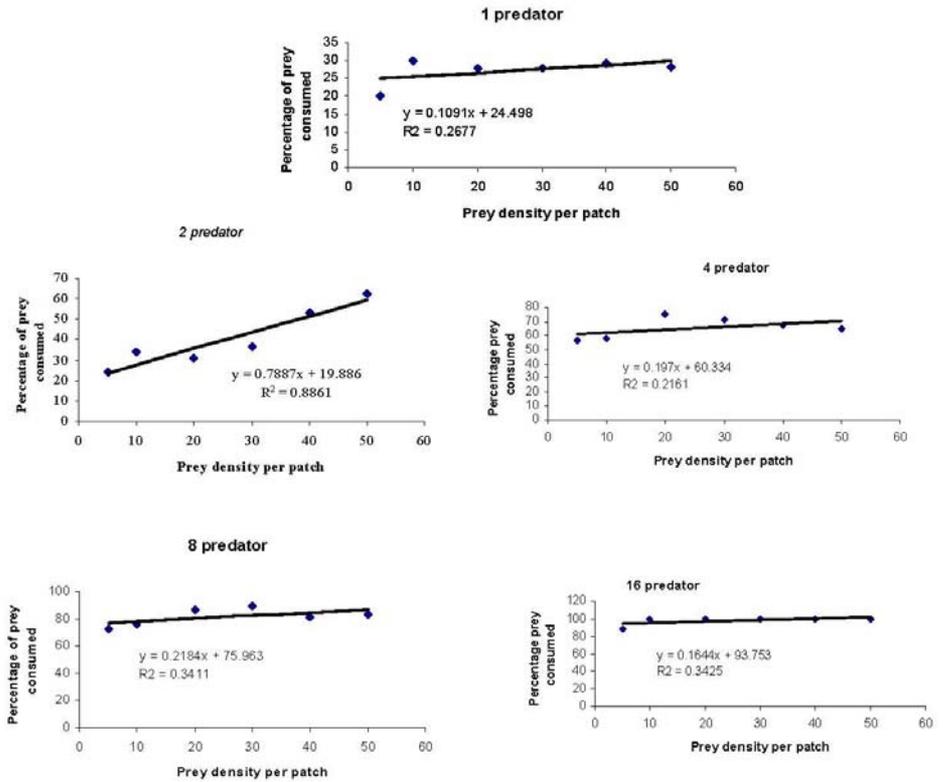


Fig.1. Percentage prey (*Unaspis eunomi*) eaten by different number of *Chilocurus bipustulatus* females at different prey patches.

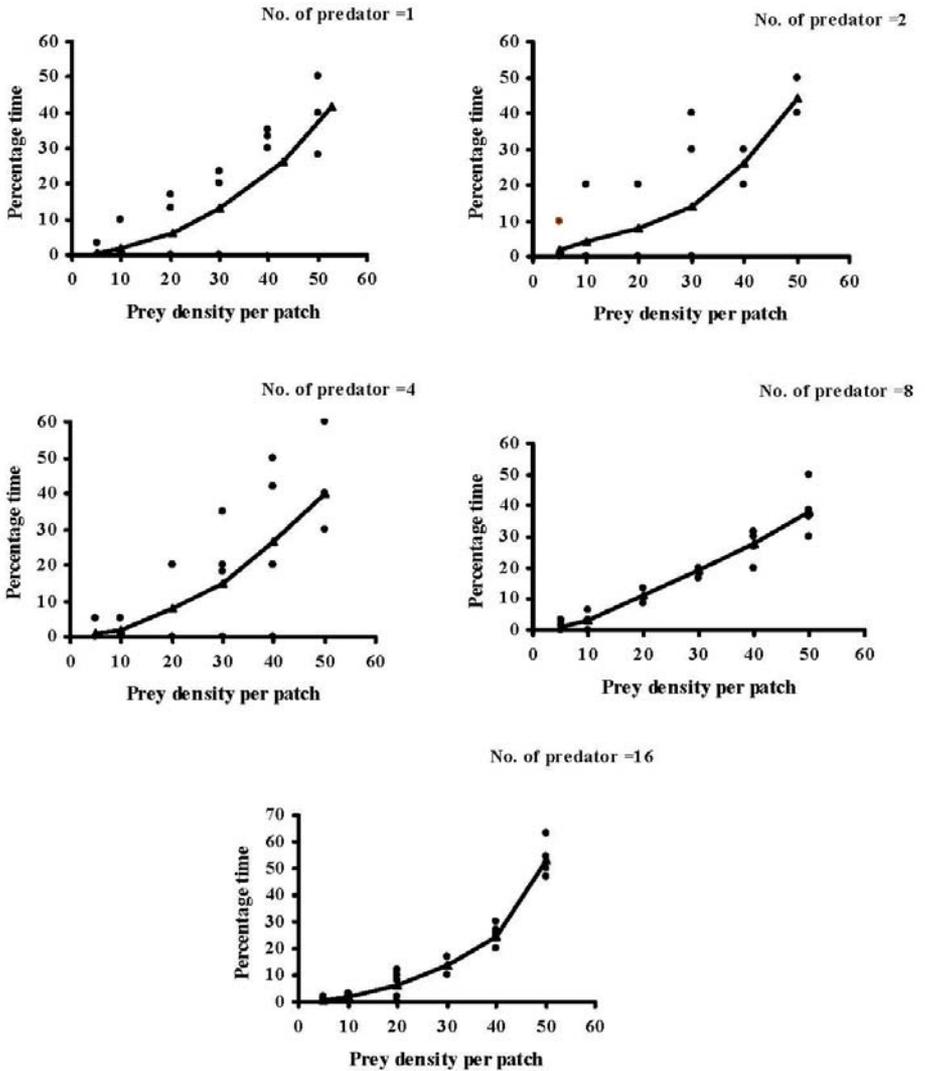


Fig. 2. Percentage time spent by different number of *Chilocurus bipustulatus* females on different prey (*Uanspis eunymi*) patches.

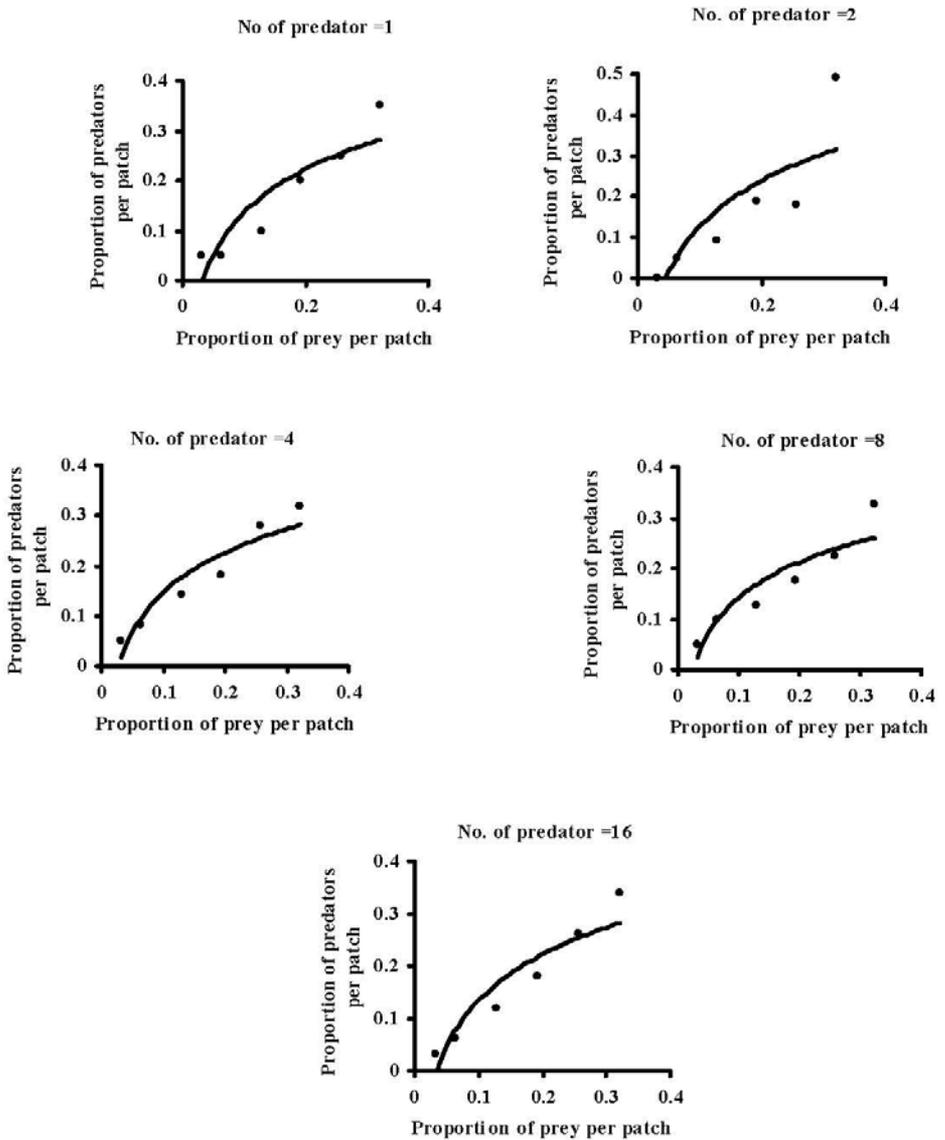


Fig. 3. The relationship between the proportion of *Chilocurus bipustulatus* females in each patch and the proportion of prey (*Uanspis eunymi*) per patch. The curves were fitted using the model given by Hassell and May (1973) involving a nonlinear technique. Results for 1 to 16 females.

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