

**DENSITY AND DIVERSITY OF PREDACEOUS
COCCINELLIDAE IN VARIOUS CROPPING SYSTEMS**

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**DENSITY AND DIVERSITY OF PREDACEOUS
COCCINELLIDAE IN VARIOUS CROPPING SYSTEMS**

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By

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JULY, 2019

Tender-heartedly dedicated

to

My parents

SureshBabu and

Yashodamma

Brother

Manjunath

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE, RAICHUR

UNIVERSITY OF AGRICULTURAL SCIENCES, RAICHUR

CERTIFICATE

This is to certify that the thesis entitled “**DENSITY AND DIVERSITY OF PREDACEOUS COCCINELLIDAE IN VARIOUS CROPPING SYSTEMS**” submitted by **Mr. KIRAN, S.** in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (AGRIUCLTURE) in AGRICULTURAL ENTOMOLOGY** to the University of Agricultural Sciences, Raichur, is a record of research work done by him during the period of his study in this university under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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(Kiran, S.)

LIST OF ABBREVIATIONS

ssp.	:	Sub species
<i>viz.</i> ,	:	Namely
<i>et al.</i> ,	:	And other people
sp.	:	Unidentified species
spp.	:	Multiple species
H'	:	Shannon-Weiner's diversity index
r	:	Correlation
R ²	:	Coefficient of determination
KAU	:	Kerala Agricultural University
NRC	:	National Research Centre
ENS	:	Effective Number of Species
D	:	Simpson's index
D _{Mg}	:	Margalef's Index
J	:	Pielou's evenness index
cm	:	Centi meter
Fig	:	Figure
Anon.	:	Anonymous
Avg.	:	Average

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Introduction

I. INTRODUCTION

The North East part of Karnataka is the second largest arid region in India and represents good crop and insect diversity. This region comprises of three agro-climatic zones of Karnataka namely *North-eastern transition zone* (Zone-1), *North-eastern dry zone* (Zone-2) and *Northern dry zone* (Zone-3). The first zone is somewhat cool with high rainfall compared to the other two zones. These regions are popularly known for their harsh climate in terms of temperature and rainfall (Ramachandra *et al.*, 2003).

The most popular crops grown in these regions are paddy, cotton, pulses and sugarcane, which not only harbour a diverse insect pest species representing both chewing and sucking group but also a good number of beneficial insect fauna (Swamy, 2015). Among different pest complex, sap feeders considered to be most troublesome due to their persistence and prolific breeding. However, some naturally occurring enemies' viz., ladybird beetle, lacewings, predatory bugs etc., are known to suppress the pest population. Among the natural enemies found in this region, coccinellids are the major predatory population balancing natural ecosystem (Geetha and Hegde, 2018)

The ladybird beetles are commonly referred as coccinellids and one of the important bio-control agents employed in various classical biological control programme (Kundoo and Khan, 2017). Coccinellids belong to the family Coccinellidae, under the biggest order Coleoptera and chiefly consists of predators.

Globally, the family Coccinellidae comprises of 6000 described species under 490 genera (Slipinski, 2007). In the Indian sub-continent around 510 species have been reported which includes phytophagous subfamily Epilachninae (Kuznetsov, 1997) among them, predatory coccinellids accounts approximately 400 species (Poorani, 2002).

The feeding nature, host range and specificity have rendered the coccinellids as one of the top biocontrol agents in biological control programme. Most of the preferred prey belongs to the hemipteran suborder Sternorrhyncha (aphids, adelgids, scales, mealybugs, whiteflies, and psyllids) (Obrycki *et al.*, 2009). They also utilize alternative foods such as pollen and nectar when prey is scarce (Lundgren, 2009). Importantly, the coccinellids are also regarded as bio-indicators (Iperti and Paoletti, 1999) and provide

more general information about the quality of the ecosystem in which they prevail (Andersen, 1999).

There are many predatory coccinellids which are well exercising natural control in different ecosystems including agriculture fields and orchards. In the history of biological control, coccinellids have greater credits than any other predatory insect species. For instance, in 1888, the vedalia beetle *Rodolia cardinalis* Mulsant was used for managing cottony cushion scale, *Icerya purchasi* Maskel in California (Hagen, 1974). The *Chilocorus nigrita* (Fabricius) was exported from India to Oman during 1985 for the control of *Aspidiotus destructor* Signoret (Kinawy, 1991). The introduction of *Curinus coeruleus* (Muls.) saved the subabul trees in and around Bangalore from the subabul psyllid during 1988 (Jalali and Singh, 1989). The *Cryptolemus montrouzieri* Mulsant was effectively utilized in the management of pink hibiscus mealy bug, *Maconellicoccus hirsutus* Green and papaya mealy bug, *Paracoccus marginatus* Williams & Granara de Willink (Mishra *et al.*, 2012). Apart from classical biological control, native fauna of coccinellids play a major role in suppressing the local pests. In order to understand their role, systematic survey and surveillance is necessary which provides good insight into their diversity and abundance.

The diversity is a concept that refers to the range of variation or differences among the set of entities (Anon. 2000). Since coccinellids are key predators they need to be conserved in agricultural and horticultural ecosystems, to achieve natural control of sucking pests (Ali and Rizvi, 2008). Species composition, diversity and relative abundance of coccinellids estimated through various diversity indices would be of great value for not only enriching our knowledge of the natural resource management in an ecosystem but also to initiate the research on exploration of potential predatory species for biological control programme. Knowledge of biodiversity and bio-ecology of coccinellids have immense value in the pest management strategies and add to the knowledge of predatory behaviour in relation to reproduction, population and occurrence of the pest and crops (Kolhekar, 2018).

The density of the coccinellid population has greater influences on the prey establishment. As the density of predator populations increases, the prey population declines thus acting as a prime control mechanism. For instance, aphid populations might explode over time and space (Borges *et al.*, 2006), in the absence of aphidophagous

coccinellids, indicating their interdependency (Fany and Petitt, 1994; Dixon and Agarwala, 1999).

The baseline data on the species complexity, diversity and abundance in different agricultural and horticultural ecosystem on predatory coccinellids in various cropping ecosystems of North East Karnataka is completely lacking. Further, experimental data on the predator-prey relationship between coccinellids and their prey is also not available. Hence, the present study was undertaken with the following objectives.

1. The species complexity of predatory coccinellids in different agricultural and horticultural ecosystem.
2. The diversity of predatory coccinellid species in different agricultural and horticultural ecosystems interpreted through various diversity indices.
3. Relationship between predatory coccinellid population and prevailing prey density in different agricultural and horticultural ecosystem.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

The review pertaining to the analysis on species complex, diversity of coccinellids through various diversity indices and the predator-prey relationship prevailing in different agricultural and horticultural ecosystem is covered under the following headings.

2.1 The species complex of predatory coccinellids in different agricultural and horticultural ecosystems

Verghese (1992) conducted a study to find out the composition of various predatory coccinellid species in the guava ecosystem of Indian Institute of Horticultural Research (IIHR), Bangalore. He recorded four species, *Cryptolemus montrouzieri*, *Cheilomenes sexmaculata* (Fabricius), *Pseudaspidimerus circumflexa* (Motschusky) and *Scymnus castaneus* (Sicard).

Rabindra *et al.* (2002) recorded seven coccinellid species as predators of sugarcane woolly aphid in Maharashtra during 2002. Among all the predators collected, *C. sexmaculata* was most predominant.

Zahoor *et al.* (2003) collected 8119 specimens of coleopteran insects, of which 4972 were the coccinellids representing 22 species. In the agricultural ecosystem, 2756 specimens were collected, in which 2027 were the coccinellids. Correspondingly, 2945 coccinellid specimens were recorded from forest area out of 5363 individuals. Coccinellids were most diversified group in the forest area than in crop area.

Joshi and Viraktamath (2004) conducted a survey to find out the predators and parasitoids of sugarcane woolly aphid in various regions of South-India. They recorded coccinellid species *viz.*, *Synonycha grandis* (Thunberg), *Coelophora biplagiata* Swartz and *Pseudoscymnus kurohime* (Miyatake) as most predominant.

A field study was conducted in upland rice fields of North Cameroon region by Woin *et al.* (2006). Results revealed 13 species of carnivorous coccinellids feeding on various species of aphids. Among them *Xanthadalia effusa* ssp. *rufescens* (Mulsant) and the *Scymnus* spp. were most predominant coccinellids.

Mayadunnage *et al.* (2007) collected a total of 2682 specimens of coccinellids in Sri Lanka. All the 15 species belonged to 12 genera of four tribes and three subfamilies *viz.*, Chilocorinae, Coccinellinae and Scymninae.

Ghahari *et al.* (2009) analysed the diversity of coccinellids in cotton fields and surrounding grassy areas of Iran from 2000-06. A total of 40 species from 17 genera (which include *Adalia*, *Anisosticta*, *Brumus*, *Chilocorus*, *Clitostethus*, *Coccinella*, *Cryptolaemus*, *Delphastus*, *Exochomus*, *Hippodamia*, *Nephaspis*, *Nephus*, *Oenopia*, *Propylea*, *Rodolia*, *Scymnus* and *Stethorus*) were revealed.

Khan *et al.* (2009) collected a total of 5525 specimens of coccinellids from 12 ecosystems *viz.*, apple, cherry, pear, plum, cherry, kale, cabbage, cauliflower, mustard, blue pine, willow, rose and euonymus during 2006 and 2007. Out of 15 identified species, 11 were from the subfamily Coccinellinae and four belonged to the subfamily Chilocorinae. Apple and pear ecosystem recorded highest number of coccinellids (13 species) and blue pine and rose recorded lowest number of coccinellids (2 species).

Rahatullah *et al.* (2011) conducted a survey in Dir Lower of Pakistan for a period of two years. Adult coccinellids were collected from Maidan, Jandool, Timergara and Adenzai. Identification revealed the presence of 14 different species belonging to subfamilies, Coccinellinae, Chilocorinae, Scymninae and Epilachninae.

In another study conducted by Abbas *et al.* (2013) in Pakistan, a total of 2204 adult coccinellids were collected. The collected specimens belonged to 12 species under four subfamilies, Coccinellinae, Chilocorinae, Epilachninae and Scymninae. *Coccinella septempunctata* (Linnaeus) and *C. sexmaculata* accounted for 19.50 per cent and were considered as more dominating and widely distributed species on all the crops in the study area.

Choudhary *et al.* (2014) sampled a total of 2301 specimens of predaceous coccinellids in the mango ecosystem belonging to 16 species of which seven species were reported for the first time from Jharkhand. The diversity of *Anegleis cardoni* (Weise), *C. sexmaculata* and *Illeis indica* Timberlake was highest compared to other species.

Ashok *et al.* (2015) studied the status of the diversity of predatory coccinellids from Nashik, Maharashtra. A total of 16 species were recorded. The subfamily

Coccinellinae represented nine species viz., *Illeis cincta* (Fabricius), *C. septempunctata*, *Coccinella transversalis* Fabricius, *C. sexmaculata*, *Psyllobora bisoctonotata* (Mulsant), *A. cardoni*, *Hippodamia variegata* (Goeze), *Hippodamia convergens* Guérin-Ménéville and *Pseudaspidimerus trinotatus* (Thunberg). The subfamily Sticholotidinae contained two species *Pharoscymnus flexibilis* (Mulsant) and *Pharoscymnus horni* (Weise). One species *Scymnus* (=Pullus) *latemaculatus* (Motschulsky) belonged to the subfamily Scymninae. Two species belong to the subfamily Chilocorinae, *C. nigrita* and *Brumoides suturalis* (Fabricius). Two species from the subfamily Coccidulinae, *Propylea dissecta* (Mulsant) and *Micraspis discolor* (Fabricius) were observed.

Chowdhury *et al.* (2015) conducted a survey to analyse the species composition of coccinellids in Indo-Bangladesh border during 2009-10. Eleven species were recorded during the study in which *Harmonia octomaculata* (Fabricius) (22.9%) and *Micraspis crocea* (Fabricius) (18.5%) were most predominant.

Harit (2015) conducted a survey in three different ecosystems viz., agriculture fields (including vegetables) unprotected forests and along riverside habitat from June-2012 to June-2013 in Champhai district of Mizoram state. Thirteen species of coccinellids were observed of which nine were predatory and four were polyphagous from above ecosystems.

Megha (2015) surveyed in three different ecosystems viz., agriculture, horticulture and organically grown crops for species composition of coccinellids. A total of 18 species were identified. Species viz., *C. transversalis*, *M. discolor*, *B. suturalis*, *C. sexmaculata*, *Chilocorus melas* Weise, *P. dissecta*, *Rodolia fumida* (Mulsant), *Coelophora bissellata* Mulsant, *Epilachna vigintioctopunctata* (Fabricius), *Telsimia bangalorensis* Kapur, *H. octomaculata*, *S. castaneus*, *I. cincta*, *Scymnus* (Pullus) *coccivora* Ayyar, *Illeis* sp. (Bistigmosa group), *Pseudaspidimerus flaviceps* (Walker), *H. variegata* and *Scymnus nubilis* Mulsant were present. *C. sexmaculata* was the most dominant predatory coccinellid species found in all the three crop ecosystems (144), followed by *H. variegata* (133). Species diversity was more in horticulture ecosystem (12 species) compared to agriculture and organic farming block recording 9 species in respective fields.

Sharma *et al.* (2015) surveyed for the fauna of predatory coccinellids in Himachal Pradesh from March-2011 to November-2013 in various agro-climatic zones. A total of

36 species of predatory coccinellids belonging to 24 genera, 11 tribes and four subfamilies were collected. Species richness varied with agro-climatic conditions and was highest (22 species each) under sub-tropical and sub-temperate climate followed by ten and seven species under wet temperate and dry temperate conditions.

Swaminathan *et al.* (2015) conducted a survey to identify major aphidophagous fauna in maize during summer (April to July 2013) and *Kharif* (July to October-2013) seasons in Rajasthan. Coccinellid predators *viz.*, *C. septempunctata*, *C. sexmaculata* and *B. suturalis* were recorded.

Ramya and Thangjam (2016) did a survey on diversity of coccinellids in the Assam lemon ecosystem during 2015-2016. Twelve coccinellids species *viz.*, *C. transversalis*, *Coelophora bowringii* (Crotch), *Coelophora saucia* (Mulsant), *Cryptogonus bimaculatus* (Kapur), *Cryptogonus* spp., *C. montrouzieri*, *Harmonia globata* (Linnaeus), *Harmonia dimidiata* (Fabricius), *Illeis confusa* (Timberlake), *Propylea* spp., *Platynaspis kapuri* (Chakraborty and Biswas) and *Scymnus* spp. were found feeding on various sucking pests.

Bhat (2017) conducted extensive surveys for three consecutive years in the Kashmir region. As many as 11 species of coccinellids were recorded *viz.*, *Adalia tetraspilota* (Hope), *Calvia punctata* (Mulsant), *C. sexmaculata*, *C. septumpunctata*, *Coccinella undecimpunctata* Linnaeus, *Priscibrumus uropygialis* (Mulsant), *H. variegata*, *Oenopia globata* (Linnaeus), *Platynaspidium saundersi* (Crotch), *Propylea luteopustulata* (Mulsant) and *Scymnus* sp. These species were found feeding on six aphid species on 12 vegetable crops.

Kumar *et al.* (2017) recorded 22 species of predatory coccinellids during the survey conducted from June-2010 to May-2011 in the Western plain zone of Uttar Pradesh. A total of 17 species of coccinellids were identified *viz.*, *C. sexmaculata*, *Cheilomenes sexmaculata* *ab rufafasciata* (Fab.), *C. septempunctata*; *P. dissecta*, *C. transversallis*, *C. nigrita*, *A. cardoni*, *M. discolor*, *B. suturalis*, *I. cincta*, *P. horni*, *Rodolia breviscula* (Weise), *P. bisoctonotata*, *H. variegata*, *Harmonia axyridis* (Pallas), *Hydrapsis maindroni* (Sicard) and *S. nubilus*.

Murali *et al.* (2017) conducted a survey to find out the predatory coccinellid fauna in the brinjal ecosystem at NBAIR farms Bangalore, Attur farm and farmers fields in

Chikkaballapura and Doddaballapura. A total of ten species of coccinellids were collected in the study area. The sub-family wise species composition showed that, subfamily Coccinellinae recorded six species, whereas, Chilocorinae and Scymninae recorded three and one species, respectively. *C. sexmaculata* was the dominant species in all the study areas.

Ahmed *et al.* (2017) carried out an extensive survey to find out diversity of the family Coccinellidae in the Sargodha district of Pakistan, to check the species richness and distribution of coccinellid beetles in seven selected districts (Bhera, Bhalwal, Kot Momin, Sahiwal, Sargodha, Shahpur and Silanwali). A total of 1,470 coccinellid specimens were collected from citrus, wheat, sugarcane, maize, parthenium and khabal grass. Nine species were classified, belonging to nine genera and four subfamilies.

Mohammed (2017) documented the existence of eight predatory coccinellids in soybean agro-ecosystems of Northern Ohio. In the survey 86 specimens of coccinellids were collected. *H. convergens* (72%) was the dominant species among all coccinellids sampled. Two invasive species *H. axyridis* and *C. septempunctata* were collected in extremely low numbers.

2.2 The diversity of predatory coccinellid species in different agricultural and horticultural eco-systems interpreted through various diversity indices

Zahoor *et al.* (2003) collected a total of 8119 specimens belonging to order Coleoptera, out of which 4972 were the coccinellids representing 22 species from both agriculture and forest ecosystem of Faisalabad. Shannon diversity was high in forest area (1.25) compared to the cropped area (1.158) which had less diversity. Simpson index was more in the cropped area (0.09) compared to forest area (0.07). Evenness was high in forest area (0.93) and lowest in the cropped area (0.91).

Woin *et al.* (2006) conducted a field study in upland rice fields in North Cameroon from 1999-02 to find out predatory coccinellids diversity. A total of 13 species of coccinellids were collected. Shannon diversity was highest (2.12) during 2002, Margalef's index was highest (13) during 2001 and the Pielou's evenness index was highest (0.88) during 2002.

Rekha *et al.* (2009) studied diversity of coccinellids in various crops (bhendi, cowpea, blackgram, paddy, tomato, chilly and bittergourd) of Madhurai district in Tamil Nadu. The diversity of coccinellids was more in paddy (0.82) with a species richness of 3.2 compared to cowpea which recorded diversity and species richness of 0.76 and 2.62, respectively. The diversity was more in tomato (0.88), species richness and dominance was highest in paddy (3.2 and 0.27, respectively).

Silva *et al.* (2010) conducted a study on effect of ground cover vegetation on the abundance and diversity of beneficial arthropods in citrus orchards of Portugal during 2002-03. Shannon index found to be, 0.68 and 1.17, respectively in suction and beating methods of collection in sowed selected plants.

Anbalagan *et al.* (2013) conducted a study on biodiversity of predatory coccinellids in four different crops (brinjal, cowpea, groundnut and okra) in North-eastern districts of Tamil Nadu during 2007-08. Shannon index and evenness was highest in okra recording Avg. of 2.05 and 0.78, respectively. Simpson index was highest in cowpea (Avg. = 0.22).

Vinothkumar (2013) collected a total of 13 species of coccinellids from four treatments (transplantation with weeding operation, direct seed sowing with weeding operation, transplantation without weeding operation, and direct seed sowing without weeding operation) of upland rice crop at different days after transplantation at Hybrid Rice Evaluation Centre, Tamil Nadu, for three years (*Kharif*-2010 to *Kharif*-2012). During 2011, Shannon index was highest (2.27) and Margalef's index was highest (3.83) in direct sowing without weeding treatment, Simpson index was highest (0.21) in transplanting with weeding treatment and Pielou's evenness index was highest (0.62) during 2010 in transplanting along with weeding treatment.

Choudhary *et al.* (2014) collected a total of 2301 specimens of predaceous coccinellids belonging to 16 species in the mango ecosystem in Jharkhand. The species diversity was compared with different locations and it was found that, the Shannon-Wiener diversity index ranged from 2.12 to 1.37 which shows, less species diversity but species were frequently present.

Swaminathan *et al.* (2015) surveyed for the aphidophagous predator in maize ecosystem in Rajasthan College of Agriculture, Udaipur during *Kharif* and summer

seasons. Shannon diversity index did not vary between the two seasons recording 1.24 and 1.25, respectively for *Kharif* and summer.

Hayat *et al.* (2016) reported a total of 41 species from six subfamilies from the Poonch division of Jammu and Kashmir. 37 species in Mirpur, 29 in Kotli and 41 in Bhimber were recorded. The calculated values of diversity indices showed that the highest diversity was recorded from Bhimber district (4.38) and lowest from Mirpur district (1.45).

Mondal *et al.* (2016) surveyed to find out predator biodiversity in the irrigated rice ecosystem of West Bengal. In the coccinellid population, Shannon diversity index and Simpson index were highest with 2.01 and 0.78, respectively during the flowering stage of the crop.

Ojija *et al.* (2016) studied insect fauna in the grassland and woodland ecosystems at Mebya, Tanzania. The grassland ecosystem was rich in terms of species richness (6.28), abundance (69.82 %) and diversity (3.208) of insects. High abundance and species diversity in grassland community suggests a stable ecosystem. Therefore, this study revealed that though the grassland community has the potential to support insect diversity, it also act as refugia for some insects from woodland community.

Pinjara *et al.* (2017) studied diversity of coleopteran fauna in *Kharif* pulses from three different locations of Southern Rajasthan. Survey resulted in collection of insect belonging to eight coleopteran families. Shannon diversity index ranged from 1.72 to 1.54. Maximum fauna was recorded in greengram at the farmer's field of Vallabh Nagar (1.72) and lowest fauna in blackgram at farmer's field of Badgaon (1.54).

Amala and Shivalingaswamy (2018) analyzed the diversity of parasitoids and predators in the sole cropped, intercropped, border cropped, and hedgerow cropped fields of guava during 2016–2017 in Kanakpura, Karnataka. Study suggested Shannon-Weiner index (3.09), Margalef's richness index (2.40) and evenness index (0.89) was higher in the inter/border/hedgerow cropped fields compared to the sole cropped ecosystems which recorded diversity of 1.73, species richness of 1.92 and evenness of 0.19.

Pooja (2018) studied diversity of predatory coccinellids in different ecosystems in Shivamogga. Survey revealed the presence of 11 coccinellid species. Calculation of

diversity indices showed that, diversity was more in agricultural fields (0.80) compared to horticultural gardens (0.66).

Rasheed and Buhroo (2018) studied the diversity of coccinellids in horticultural ecosystems like fruit orchards, vegetables and forest ecosystem in different districts of Kashmir from June-2014 to June-2015. The Shannon index was highest in the Anantnag district (2.33) and lowest in the Shopian district (2.29). The Simpson index was highest in the Shopian district (0.131) and lowest in Pulwama district (0.093). Margalef's index was highest in the Shopian district (1.96) and lowest in Anantnag district (1.89). Pielou's index was highest in the Anantnag district (0.910) and lowest in the Shopian district (0.895) was found.

Shanker *et al.* (2018) sampled coccinellid species belonging to 15 genera, under five tribes of the family Coccinellidae in paddy ecosystem. Margalef's richness index with a base 10 ranged from 9.07 to 14.00. The highest species richness present at Malan, Himachal Pradesh. *H. octomaculata* was most predominant in the southern regions and *C. septempunctata* was most abundant in the northern and hilly regions.

Sujatha *et al.* (2018) did comparative analysis of natural enemies in grape ecosystem in Vijayapur district of Karnataka during *Rabi* season of 2016-17(October-April). Study included three locations namely Vijayapur, Aliyabad and Tikota. Relative abundance recorded highest for coccinellids and lowest abundance for ichneumonids. The Simpson index values were 0.76, 0.79 and 0.81, Shannon index of 1.68, 1.70 and 1.73 and Evenness was 0.96, 0.93 and 0.87 in Vijayapur, Aliyabad and Tikota, respectively.

2.3 Relationship between predatory coccinellid population and prevailing prey density in the different agricultural and horticultural ecosystems

Agarwala and Bardhanroy (1999) reported two predaceous species of Coccinellidae, *M. sexmaculata* and *C. transversalis* on bean crops infested with the aphid, *Aphis craccivora* Koch in North-East India. The number of eggs and adults of the two coccinellid species increased in response to increase in the population of aphid.

Elliott and Kieckhefer (2000) studied the reaction of coccinellids to spatial variation in cereal aphid density. The population of *H. convergens* and *C. septempunctata* were correlated with aphid density in patches whereas, the density of *C.*

sexmaculata was not correlated. The density of two adult species of coccinellids was correlated with aphid density in three of four trials; this was an inference of the dominance in the fauna of species that strongly aggregated in patches with high aphid density.

Osawa (2000) conducted field study of aphidophagous coccinellid *H. axiridis* in Botanical garden of Kyoto University in central Japan. The relationship between the number of coccinellids and aphids in the spring and summer generation of 1987 recorded Avg. R^2 of 0.42 and 0.41, respectively and in 1988, Avg. R^2 of 0.39 and 0.40, respectively was recorded, which shows that, the density of prey and predator were significant and positively correlated.

Devi *et al.* (2002) examined the role of predators in managing cabbage aphid. The predator population increased with an increase in the aphid population. The correlation between them in terms of abundance indicated a significant positive relation ($r = 0.65$, $P = 0.05$), conversely, a negative correlation was obtained between temperature and rainfall with the aphid and predator population.

Rana (2006) studied the response of two coccinellid species, *C. septempunctata* and *M. sexmaculata* on its aphid prey *Lipaphis erysimi* (Kalt.). A correlation between aphid density and the abundance of coccinellids life stages (egg, larva and adult) on these host plants revealed that the egg and larval density was positively correlated to aphid numbers. Adult beetles, however, did not show a significant positive correlation with aphid numbers during all the three years of study.

Sreedevi *et al.* (2006) conducted field research to assess the diversity and abundance of predators in relation to pomegranate aphid in Bangalore during 2000-02. There was a significant positive correlation observed between aphid and its predator densities during both the years of study. *C. sexmaculata* was the most dominant species followed by *Scymnus* sp. that contributed to the total predators and significantly related to the aphid density.

Mellet and Schoeman (2007) recorded positive and density dependent interactions between aphids and coccinellids which were not influenced by *Bt*-cotton. A correlation of 0.874 was recorded in *Bt*-cotton and 0.719 in non *Bt*-cotton.

Monika and Rachna (2007) conducted a study on seasonal incidence of *Tetranychus urticae* Koch, a two-spotted spider mite and its predatory coccinellid, *S. punctillum* in summer and *Kharif* seasons of 2006-07 on okra. *T. urticae* population showed significant positive correlation with beetle population ($r = 0.88$).

Taleb and Sardar (2007) studied the predation efficiency of insect predators in suppressing red mite, *T. bioculatus* (Wood-Mason) attacking marigold. The rate of consumption of red mite by *Stethorus punctillum* (Weise) and *M. discolor* increased with increasing density of spider mite up to 30 mites and was positively correlated with its mite prey density.

Mehrkhoul *et al.* (2008) studied population dynamics and spatial distribution patterns of *T. urticae* and its predator *Stethorus gilvifrons* (Mulsant) on different agricultural crops. The reaction of *S. gilvifrons* to the population density of *T. urticae* was density dependent.

Sharanabasappa *et al.* (2009) studied the relationship between the sugarcane woolly aphid (SWA) and its natural enemy densities. Significant positive correlation of 0.88**, 0.90** and 0.84**, respectively was recorded between SWA and *Micromus igoratus* (Banks), *Dipha aphidivora* (Meyrick) and syrphid densities.

Devi *et al.* (2010) studied density, diversity and differential feeding potentials of aphidophagous insect predators in the tea ecosystem. Correlation between the density of aphid and its predators revealed a significant positive relation with syrphids ($r = 0.95$); coccinellids ($r = 0.97$) and neuropteran larvae ($r = 0.92$) ($P < 0.05$). This indicated significantly high positive correlation existed between aphids with its predators.

Roy *et al.* (2010) studied the efficiency of predatory coccinellids in the tea ecosystem. The population density of predatory coccinellid, *M. discolor* were positively correlated with the abundance of red spider mite, *Oligonychus coffeae* Nietner ($r = 0.705$) and tea aphid, *Toxoptera aurantii* (Boy.) ($r = 0.893$). Aphid pest and their predator (*M. discolor*) populations showed same patterns of abundance that reached peaks from January to March.

Vinothkumar (2013) studied the impact of pest population on coccinellids density in the upland rainfed rice agroecosystem in Bharathy variety from *Kharif* 2010-12 at

Hybrid Rice Evaluation Centre, Tamil Nadu. A positive correlation of 0.53 between the predatory coccinellid and its prey BPH in *Kharif* paddy was recorded.

Rakshan and Ahmad (2017) studied the association between the aphid and *C. sexmaculata* in both cowpea and field bean during 2012-14 in Bihar. The population of *A. craccivora* and its predator *C. sexmaculata* both attained two standard peaks during 2012-13 in cowpea and field bean. While, in the 2013-14 they attained 2-3 standard peaks which show a positive relationship between prey and predator in cowpea and field bean.

Pooja (2018) studied the density analysis of cowpea aphid and its predator *C. sexmaculata* in cowpea crop during 2017-18. The results revealed that both grub ($r = 0.788^{**}$) and adult ($r = 0.836^{**}$) coccinellid populations were highly significant and positively correlated with aphid population.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The material used and methods employed to carry out the investigations on identifying the species complexity, species diversity, their relation with prey density in different agricultural and horticultural ecosystems during 2018-19 is described under different headings.

The present investigations were carried out in the North East Karnataka, which consists of 3 agro-climatic zones viz., *North eastern transition zone (Zone-1)*, *North eastern dry zone (Zone-2)* and *Northern dry zone (Zone-3)*.

3.1 To study the species complexity of predatory coccinellids in different agricultural and horticultural eco-system

3.1.1 Study area

The survey was undertaken in the North eastern Karnataka from July-2018 to April-2019 in different cropping seasons (*Kharif*, *Rabi* and summer) and at different crop stages in various cropping ecosystems. The crop ecosystems included field crops (black gram, cowpea, green gram, maize, paddy and soybean), commercial crops (cotton and sugarcane) and horticultural crops (citrus and guava). Based on the crop area, districts were selected across the zones 1, 2 and 3 (Table 1). The locations of the survey conducted were mapped using the Arc-GIS 10.5 software (Fig. 1).

3.1.2 Sampling method

In pulse crops, predatory coccinellid survey was conducted in vegetative and reproductive stages of green gram and black gram in the transition zone of the study area. 31 fields were selected in the above two crops in which 73 blocks (1x1m) were closely examined for the existence of coccinellid population. Hand picking method of Jonathan (1995) was employed to collect the adults and grubs of coccinellids.

In paddy, predatory coccinellids were sampled from the fields of Upper Krishna Project (UKP) and Tungabhadra Project (TBP) area coming under the zones 2 and 3, respectively. Sampling was conducted during *Kharif* and *Rabi* seasons in both vegetative and reproductive stage of the crop. During the study, coccinellids were surveyed in 34 blocks (1x1m) of 153 fields. To collect coccinellid adult and grubs sweep net method of

Table 1. Survey conducted in different districts of three agroclimatic zones in different ecosystem during 2018-19

Sl. No.	Crop	Zone	Districts
1	Paddy	2 and 3	Raichur, Yadgir and Koppal
2	Maize	3	Ballari and Koppal
3	Cotton	2 and 3	Raichur, Yadgir and Ballari
4	Sugarcane	1, 2 and 3	Bidar, Gulbarga, Yadgir and Ballari
5	Black gram/cowpea/green gram / soybean	1	Bidar
6	Citrus	1, 2 and 3	Bidar, Yadgir, Raichur and Koppal
7	Guava		

Gadagkar *et al.* (1990) was employed. Same methodology was employed for survey of the predatory coccinellid in organic paddy also in 22 blocks selected in seven fields.

Maize crop was surveyed in zone-3 during *Kharif* and *Rabi*. In this crop also, vegetative and reproductive stages were chosen for the sampling. Totally 52 fields consisting of 140 blocks (1x1m) were considered for taking observation. Adults and grubs of coccinellids were collected by hand picking method.

Similar to paddy, cotton was also surveyed for predatory coccinellid population in both UKP and TBP command area. Here observations were recorded during vegetative, flowering and boll opening stages. Coccinellid specimens were collected through hand picking method in 87 blocks (1x1m) of 113 plots.

In sugarcane crop, survey was carried out in zones 1, 2 and 3 and the stages selected for predatory coccinellid survey was vegetative, formative and reproductive stage. Adults and grubs were collected in 31 blocks (1x1m) of 56 fields by hand picking method.

In citrus ecosystem, predatory coccinellid population was surveyed in zones 1, 2 and 3. In total 63 trees were sampled from 28 orchards for coccinellid population. From each tree adults were collected by umbrella method of McGavin (1997) by beating four branches situated in four different directions.

Similar to citrus, survey in guava ecosystem was also conducted in all the 3 zones during rainy, post-rainy and summer period. Out of 21 orchards surveyed, predatory coccinellid adults and grubs were handpicked from 131 trees. After the collection, adults were preserved in 70 per cent alcohol for future species identification.

3.1.3 Preparation of specimens for identification

The coccinellid specimens were sorted out as morpho species based on the the external characters observed under stereo-zoom microscope. Each morpho species was labelled separately with details of date, place and host of collection for species identification. Two replications of such morpho species were prepared and photographed with the help of stereozoom binocular microscope with auto-montage (Model: Leica M205C) (Plate 1). Specimens were sent to Dr. Vidya. C. V, Assistant Professor,

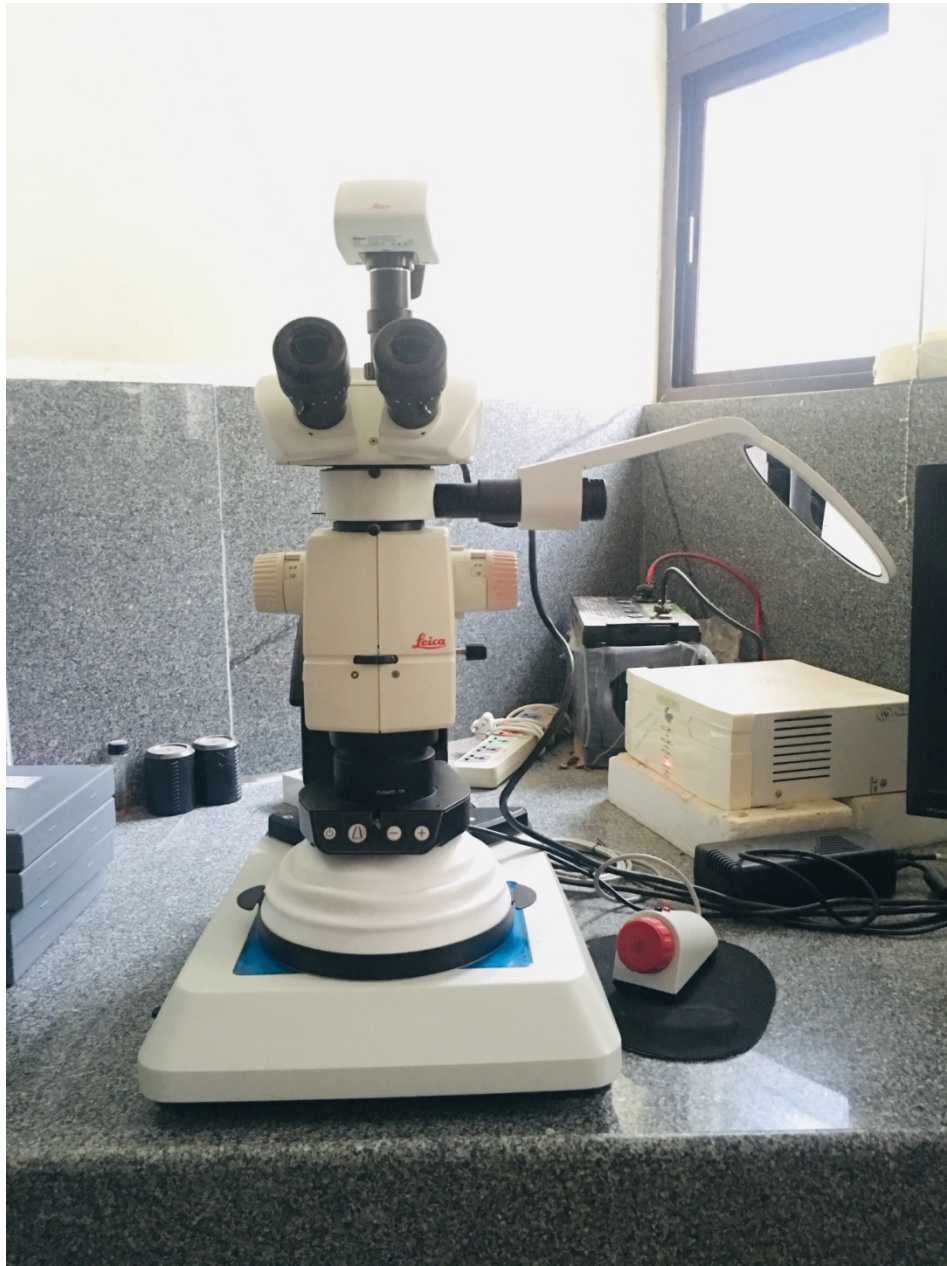


Plate 1. Stereozoom binocular microscope with auto-montage (Model: Leica M205C)

Department of Entomology, KAU, Thrissur and Dr. Poorani. J, Principal Scientist, Department of Entomology, NRC, Banana, Tiruchirapalli for species identification.

3.1.4 Rank abundance curve

After the identification process morpho species were reorganised under identified group and data was used for further analysis. Predator abundance rank list was prepared based on the number of each species recorded across the entire ecosystems. The rank abundance curve visually depicts both species richness and the species evenness. Species richness can be viewed as the number of different species on the chart, in other words, how many species were ranked. Species evenness is reflected in the slope of the line that fits the graph. A steep gradient indicates low evenness as the high-ranking species have much higher abundances than the low-ranking species. A shallow gradient indicates high evenness as the abundances of different species is similar. Further, the coccinellid species were classified into generalists and specialists based on the occurrence of a single species in more than one ecosystem or not.

3.2 To analyse the diversity of predatory coccinellid species in different agricultural and horticultural ecosystems interpreted through various diversity indices

Stage and season-specific observations were taken at different crop locations. The compiled data on the number and species of predatory coccinellid collected was used for diversity analysis. In the present study, indices *viz.*, Shannon-Weiner's diversity index (Shannon and Weiner, 1963), Effective Number of Species (Jost, 2016), Simpson's index (Simpson, 1949), species richness (Margalef, 1968, 1969) and species evenness (Pielou, 1975) were used for the diversity analysis.

3.2.1 Shannon-Weiner index (H')

This index is regarded as information index and is the most commonly used diversity index in ecology. Technically, this index quantifies the uncertainty associated with predicting the identity of new taxa in a given area. It will also explain the richness and evenness of individuals within each taxon. The diversity index was calculated by using the formula mentioned below.

$$H' = - \sum P_i (\ln P_i)$$

Where,

P_i = the proportional abundance of i^{th} species and

$\ln P_i$ = the natural log of P_i

Values of H' can range from “0 to 5”, although they typically range from “1.5 to 3.5”. The Shannon-Weiner Index assumes that the sample for the site was collected randomly.

3.2.1.1 Effective number of species (ENS)

The number of equally common species required to give a particular value of an index is called “Effective number of species”. The ENS is the number of species in a community with the equal abundance that would give H' for this metric. This is the true diversity of a community in question. ENS calculated by the following formula.

$$\text{ENS} = \text{Exp} (H')$$

Where,

H' = Shannon biodiversity index

3.2.2 Simpson's index (D)

Simpson's index (D) is a measure of diversity, was calculated to assess the dominance or rareness of any species in the ecosystem. The formula for calculating D is presented here under.

$$D = 1 - \sum n_i (n_i - 1) / N (N - 1)$$

Where,

n_i = the total number of organisms of each individual species,

N = the total number of organisms of all species

The value of D ranges from “0 to 1”. With this index, ‘0’ represents no abundance and, ‘1’ means infinite diversity, in other words, higher the value the higher the abundance.

3.2.3 Margalef's Index (D_{Mg})

This index is a measure of diversity used to assess the species richness in any ecosystem. The formula for calculating is presented below.

$$D_{Mg} = \frac{S-1}{\log_e N}$$

Where,

S = the number of species and

N = the total number of individuals

The value of D_{Mg} can be anything. With this index, '0' represents richness is too low and if the value is increasing means richness is high.

3.2.4 Pielou's evenness index (J)

This index describes the distribution of a species in an area. This index will quantify how equal the species are numerically in an ecosystem. It is calculated by the following formula.

$$E = \frac{H'}{\ln S}$$

Where,

H' = Shannon-Weiner index

\ln = the natural log of Pi

S = Total number of species observed

Pielou's evenness is constrained between "0 and 1". With this index, '0' represents evenness is too low and if the value is close to '1' means evenness is too high.

3.3 To understand the relationship between predatory coccinellid population and prevailing prey density in the different agricultural and horticultural ecosystem

Observation on predatory coccinellid density in relation to different prey density in different cropping ecosystem was taken during the study period. The different prey species observed include, aphids in maize, pulses and sugarcane, Plant hoppers in paddy, aphids and mealybugs in cotton, mealybugs in guava and psyllids in citrus.

The association between predator composition and prevailing prey density was studied by analysing the population density of prey (for cotton, guava and pulses- prey density per top 3cm shoot; for maize and sugarcane – prey density per 2.5cm² leaf area; for paddy – prey density collected per 5 net sweeps; for citrus – umbrella method) and its associated predatory coccinellid (both adult and grub) recorded per plant or tree.

Correlation and regression analysis was done with Microsoft Excel 2007 and SPSS software, based on predator density and prevailing prey density in each crop at different stages or seasons. Correlation values range between -1 to +1.

RESULTS AND DISCUSSION

IV. RESULTS AND DISCUSSION

Results on the species complexity, diversity of coccinellids and their relation with prey density in different agricultural and horticultural ecosystems during 2018-19 is presented here under.

4.1 The Species composition of predatory coccinellids in different agricultural and horticultural ecosystem

Survey conducted across various ecosystems in North eastern part of Karnataka resulted in a collection of 3306 specimens belonging to 36 species. The list of collected species during the survey period was recorded in their respective ecosystem (Plate 2, Table 2).

Total of 36 species collected belonged to seven tribes, viz., Aspedimerini, Chilacorini, Coccinellini, Scymnini, Serangini, Stethorini and Sticholitidini (Fig. 2). The tribe Coccinellini was the largest, comprising seven species, accounting for 83 per cent of the total collection. The tribe Scymnini recorded seventeen species (9%), the tribe Stethorini recorded two identified and four unidentified species (4%), the tribe Chilacorini recorded two species (1%), the tribe sticholitidini recorded two species (0.009%) and the tribe Serangini and the tribe Aspedimerini recorded a single species, accounting for three and 0.001 per cent, respectively.

Among the different ecosystems, the highest number of coccinellid species were observed in guava orchard (17), followed by citrus and maize (12 and 11, respectively). Twelve species were generalists, recorded in more than one ecosystem. The abundance of generalist predators recorded was in the following sequence, *Cheilomenes sexmaculata* (2575) and *Scymnus nubilus* (139) recorded in all the seven ecosystems. *Coccinella transversalis* (58) and *Brumoides suturalis* (26) were recorded in four ecosystems. *Harmonia octomaculata* (106), *Hippodamia variegata* (104) and *Chilocorus nigrita* (6) were recorded in three ecosystems. *Scymnus latemaculatus* (38), *Scymnus coccivora* (16), *Pseudaspidimerus* sp. (5) and *Micraspis* sp. (3) were recorded in two ecosystems. Remaining species were specialists and recorded in only one ecosystem in small numbers. *C. sexmaculata* was most abundant (2575) compared to all the species recorded. This is



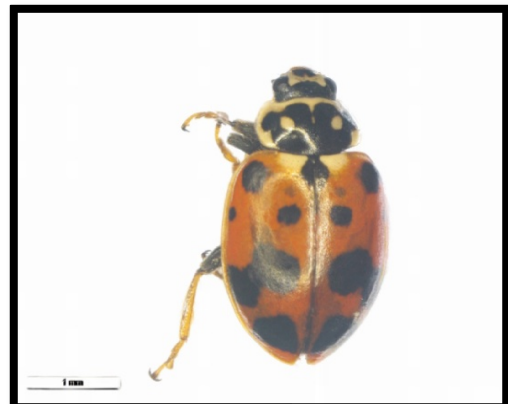
Chelomenes sexmaculata (Fabricius)



Coccinella transversalis Fabricius



Harmonia octomaculata (Fabricius)



Hippodamia variegata (Goeze)

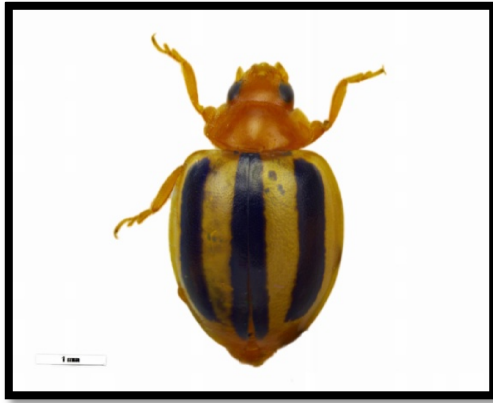


Micraspis sp.

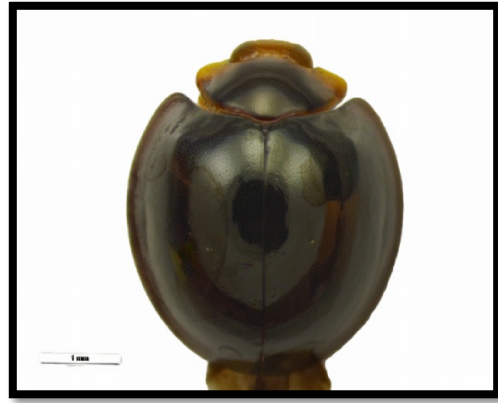


Propylea dissecta (Mulsant)

Plate 2a. Species of coccinellids collected across agricultural and horticultural ecosystems



Brumoides suturalis (Fabricius)



Chilocorus nigrita (Fabricius)



Serangium serratum Poorani



Nephus regularis (Sicard)



Nephus sp.



Pharoscymnus flexibilis (Mulsant)

Plate 2b. Species of coccinellids collected across agricultural and horticultural ecosystems



Pseudaspidimerus sp.



Pseudaspidimerus sp.



Pseudaspidimerus sp.



Scymnus castaneus Sicard.



Scymnus latemaculatus Motschusky



Scymnus (Pullus) coccivora (Ayyar)

Plate 2c. Species of coccinellids collected across agricultural and horticultural ecosystems



Scymnus (Pullus) coccivora (Ayyar)



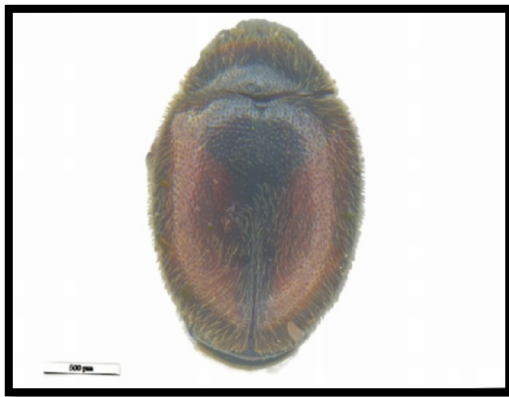
Scymnus (Pullus) coccivora (Ayyar)



Scymnus (Scymnus) nubilus Mulsant



Scymnus (Scymnus) nubilus Mulsant



Scymnus (Neopullus) sp.



Scymnus (Pullus) sp.1

Plate 2d. Species of coccinellids collected across agricultural and horticultural ecosystems



Scymnus (Pullus) sp.2



Scymnus (Pullus) sp.3



Scymnus (Pullus) sp.4



Scymnus (Pullus) sp.5



Scymnus (Pullus) sp.6



Scymnus sp. 1

Plate 2e. Species of coccinellids collected across agricultural and horticultural ecosystems



Scymnus sp. 2



Scymnus sp. 3



Scymnus sp. 4



Scymnus sp. 5



Stethorus tetranychii Kapur



Parastethorus indira (Kapur)

Plate 2f. Species of coccinellids collected across agricultural and horticultural ecosystems



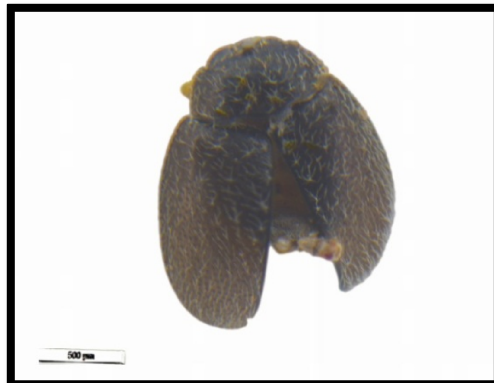
Stethorus sp. 1



Stethorus sp. 2



Stethorus sp. 3



Stethorus sp. 4

Plate 2g. Species of coccinellids collected across agricultural and horticultural ecosystems

Table 2. The collective rank list of the predatory coccinellids in various cropping systems

Sl. No	Species name	Specimens collected	Pulses	Inorganic Paddy	Organic paddy	Maize	Sugarcane	Cotton	Citrus	Guava
1	<i>Chielomenes sexmaculata</i> (Fabricius)	2575	413	27	3	1389	140	509	11	95
2	<i>Scymnus (Scymnus) nubilus</i> Mulsant	139	5	2	42	41	33	4	11	6
3	<i>Harmonia octomaculata</i> (Fabricius)	106	7	19	27	53	-	-	-	-
4	<i>Hippodamia variegata</i> (Goeze)	104	-	8	-	7	-	89	-	-
5	<i>Serangium serratum</i> Poorani	87	-	-	-	-	-	-	87	-
6	<i>Parastethorus indira</i> (Kapur)	81	-	-	-	-	-	-	81	-
7	<i>Coccinella transversalis</i> Fabricius	58	16	2	1	4	-	32	-	3
8	<i>Scymnus latemaculatus</i> Motschusky	38	-	-	-	-	-	33	-	5
9	<i>Brumoides suturalis</i> (Fabricius)	26	4	-	3	-	-	7	-	12
10	<i>Scymnus (Pullus) sp. 1</i>	21	-	-	-	-	-	-	-	21
11	<i>Scymnus (Pullus) sp. 4</i>	20	-	-	-	-	-	20	-	-
12	<i>Stethorus sp. 3</i>	20	-	-	-	-	-	-	20	-
13	<i>Scymnus (Pullus) sp.7</i>	19	-	-	-	-	-	16	-	3
14	<i>Scymnus (Pullus) coccivora</i> Ayyar	16	-	-	1	-	-	-	-	15
15	<i>Stethorus sp. 4</i>	14	-	-	-	-	-	-	14	-
16	<i>Scymnus (Pullus) sp. 5</i>	14	-	-	-	-	-	-	-	14
17	<i>Propylea dissecta</i> (Mulsant)	9	-	-	-	9	-	-	-	-
18	<i>Scymnus (Pullus) sp. 3</i>	7	-	-	-	-	-	7	-	-
19	<i>Scymnus sp. 2</i>	7	-	-	-	-	-	-	-	7
20	<i>Stethorus tetranychii</i> Kapur	7	-	-	-	-	-	-	7	-
21	<i>Chilocorus nigrita</i> (Fabricius)	6	-	2	-	2	-	2	-	-
22	<i>Scymnus sp. 4</i>	6	-	-	-	-	-	-	-	6

Cont.....

Sl. No	Species name	Specimens collected	Pulses	Inorganic Paddy	Organic paddy	Maize	Sugarcane	Cotton	Citrus	Guava
23	<i>Pseudaspidimerus</i> sp.	5	-	-	-	-	3	-	-	2
24	<i>Scymnus</i> sp. 3	5	-	-	-	-	-	-	-	5
25	<i>Scymnus castaneus</i> Sicard	3	-	-	-	-	-	-	3	-
26	<i>Scymnus</i> sp. 1	3	-	-	-	3	-	-	-	-
27	<i>Micraspis</i> sp.	3	-	1	-	2	-	-	-	-
28	<i>Nephus</i> sp.	2	-	-	-	-	2	-	-	-
29	<i>Scymnus (Pullus)</i> sp. 2	2	-	-	-	2	-	-	-	-
30	<i>Scymnus</i> sp. 5	2	-	-	-	2	-	-	-	-
31	<i>Pharoscymnus flexibilis</i> (Mulsant)	1	-	-	-	-	-	-	-	1
32	<i>Scymnus (Neopullus)</i> sp.	1	-	-	-	-	-	-	-	1
33	<i>Nephus regularis</i> (Sicard)	1	-	-	-	-	-	-	-	1
34	<i>Sticholotis</i> sp	1	-	1	-	-	-	-	-	-
35	<i>Stethorus</i> sp. 1	1	-	-	-	-	-	-	-	1
36	<i>Stethorus</i> sp. 2	1	-	-	-	-	-	-	1	-
	<i>Total</i>	3306	445	62	77	1451	179	686	235	198

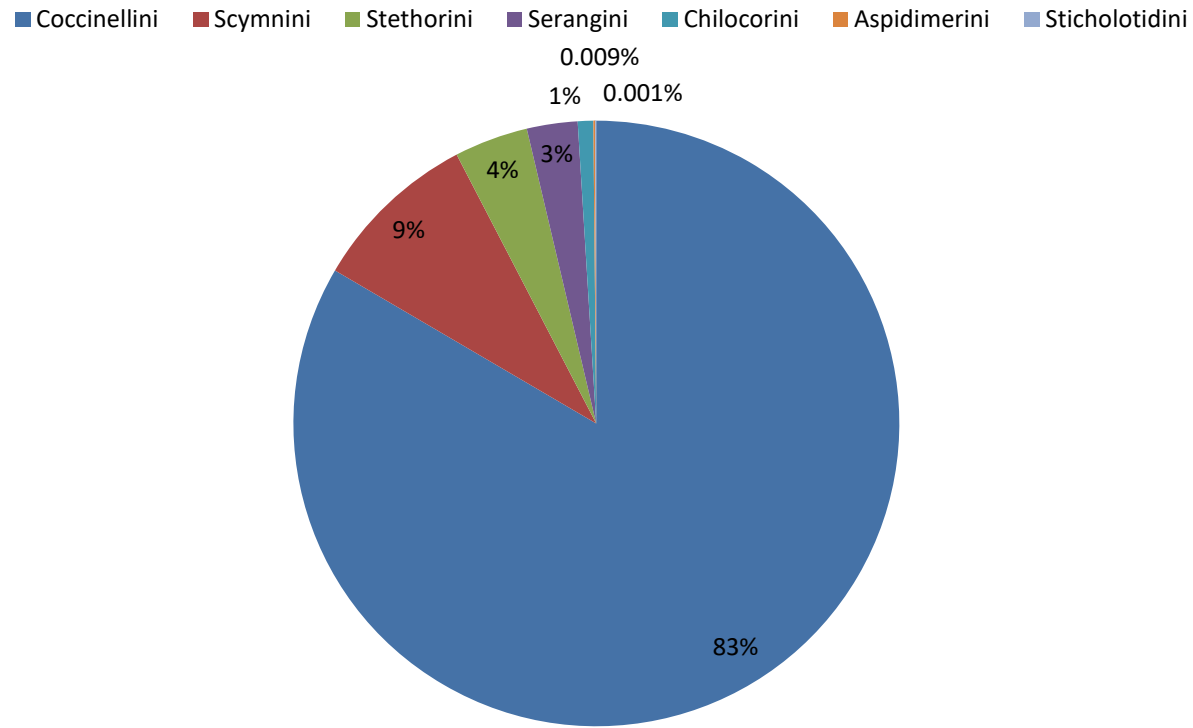


Fig. 2. Distribution of predatory coccinellid species across various tribes of the family Coccinellidae

in confirmity with earlier workers viz., Rekha *et al.* (2009), Abbas *et al.* (2013); Choudhary *et al.* (2014); Shanmugapriya and Muralidharan (2017), followed by *S. nubilus* (139), *H. octomaculata* (106) and *H. variegata* (104), whereas, other species were less than 100 in number. Irrespective of the cropping system, *C. sexmaculata* was the most predominant species in the present study. This present report is in line with study conducted by Pooja, (2018), Murali *et al.* (2017), Megha (2015) and Sharma *et al.* (2015).

The rank abundance curve, which informs the organization of species (Macagno and Palestrini, 2009), typically followed logarithmic distribution ($y = -14.008x + 353.9$; $R^2 = 0.1197$). The steep movement of rank abundance curve depicts the lower evenness prevailing in the predatory coccinellid population, in other words, diversity of predatory coccinellids in the present study is low (Fig. 3). This might be attributed to the over dominance of *C. sexmaculata* (77.8 %) over remaining 35 species (22.11 %).

4.1.1 Species composition in pulses

In pulse cropping ecosystem, five species viz., *C. sexmaculata*, *H. octomaculata*, *S. nubilus*, *B. suturalis* and *C. transversalis* were recorded in Kharif 2018-19 (Fig. 4) in black gram and green gram crop. *C. sexmaculata* was abundant (413) during both vegetative and reproductive stages, whereas, remaining species recorded in very few numbers. All five species found to be feeding on aphids (Table 2).

In both vegetative and reproductive sage of the crop *C. sexmaculata* was found to be more abundant recording 153 and 260, respectively and other species were very few in numbers (Fig. 4).

Similar recordings of above species as well as other species were recorded by earlier authors viz., Rekha *et al.* (2009), Megha (2015), Mukherjee and Suman (2017), Pooja (2018). Rekha *et al.* (2009) and Pooja (2018) have also recorded *C. sexmaculata* as most abundant predatory coccinellid in the agricultural ecosystem which include pulse crop, which is similar to the observations made in the present study.

The species composition did not vary in pulse ecosystem between the vegetative and reproductive stage. However, the abundance of the recorded species increased

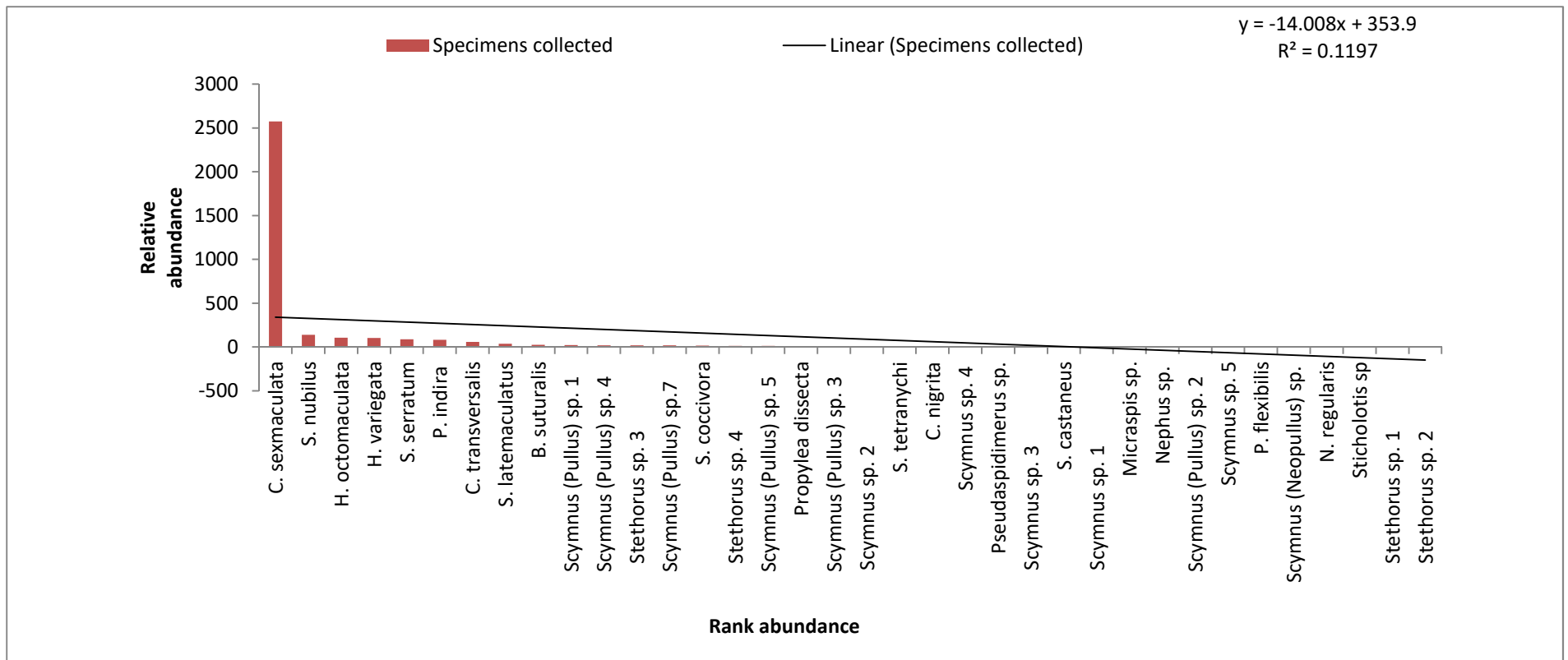


Fig. 3. Rank abundance curve of predatory coccinellid species recorded across different cropping systems

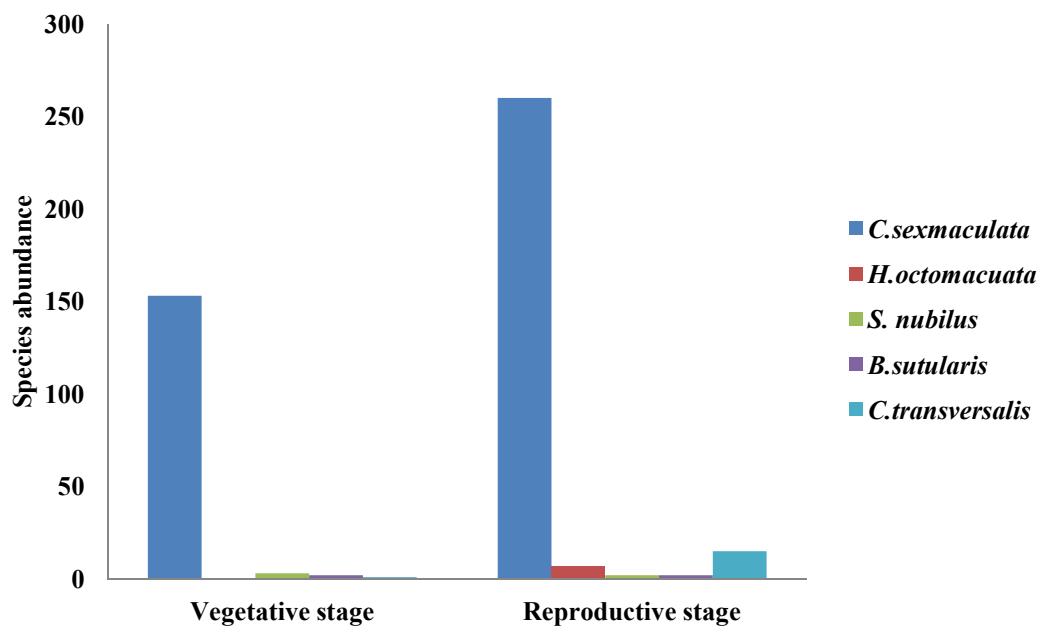


Fig. 4. Species composition of predatory coccinellids in pulse ecosystem

considerably. For instance, the number of *C. sexmaculata* recorded increased from 153 to 260 from vegetative to reproductive stage. This could be attributed to persistence of prey population and availability of pollen source during reproductive stage.

4.1.2 Species composition in maize

In maize crop, *C. sexmaculata*, *H. octomaculata*, *S. nubilus*, *H. variegata*, *Propylea disecta*, *C. transversalis*, *Scymnus* sp.2, *Scymnus* sp. 1, *Scymnus* sp. 5, *C. nigrita* and *Micraspis* sp. were recorded in *Kharif* and *Rabi* during 2018-19. *C. sexmaculata* was most abundant (1389) in both the seasons, whereas, remaining species recorded in very few numbers. All the eleven species were recorded to be feeding on aphids (Table 2 and Fig. 5).

In *Kharif* season, during the vegetative stage of the crop, six species were recorded with *C. sexmaculata*, as most abundant (437) followed by *H. octomaculata* (14). However, in the reproductive stage, 11 coccinellid species were recorded with once again *C. sexmaculata* was most abundant (889) followed by *H. octomaculata* (39) (Fig. 5).

The species composition varied considerably between the vegetative and reproductive stage. Species composition was higher in the reproductive stage (11 species) than in vegetative stage (6 species) and also the population of *C. sexmaculata* increased drastically from 437 to 889 from vegetative to reproductive stage. The reason could be the low chemical management practices, persistence of prey population and the rich pollen source yielding at the time of anthesis attract more number of coccinellids in the reproductive stage.

In the *Rabi* season, only two species viz., *C. sexmaculata* and *S. nubilus* were recorded during the vegetative stage of the crop, among which *C. sexmaculata* was most abundant (63), whereas, no predatory species was observed during the reproductive stage of the crop (Fig. 5).

Number of species recorded in *Rabi* crop is less compared to *Kharif* crop. The reason might be due to heavy usage of insecticides to get rid of invasive pest, fall armyworm, *Spodoptera frugiperda* (J.E.Smith) which would have led to non-availability of prey population as well as pesticide poisoning to coccinellid predators in the farmers' field.

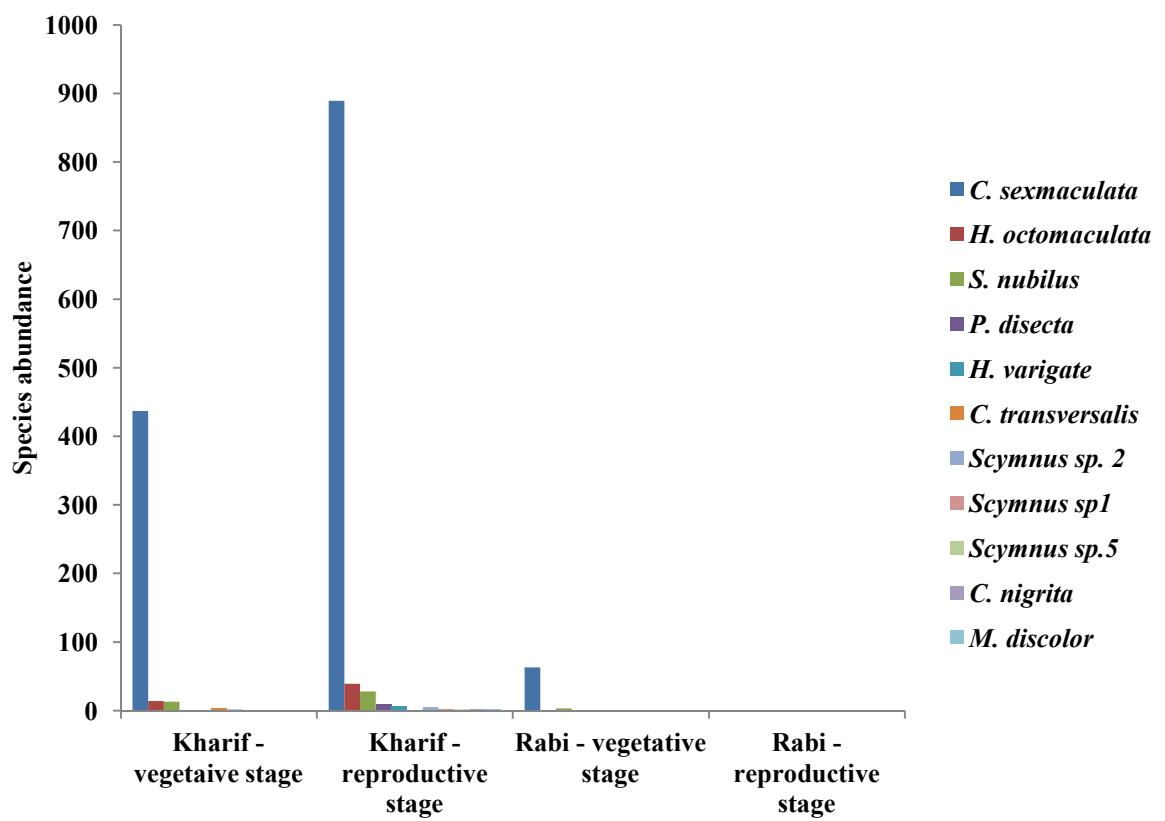


Fig. 5. Species composition of predatory coccinellids in maize ecosystem

Nine of the eleven species recorded in the present study were recorded by earlier authors (Rekha *et al.*, 2009; Megha, 2015; Swaminathan *et al.*, 2015; Sharma *et al.*, 2015; Pooja, 2018). Further, Pooja (2018) also have recorded *C. sexmaculata* as the most abundant predatory coccinellid in agriculture ecosystem which included maize crop, which is similar to the observation made in the present study.

4.1.3 Species composition in inorganic paddy

In paddy, *C. sexmaculata*, *C. nigrita*, *S. nubilus*, *H. variegata*, *Micraspis* sp., *C. transversalis*, *H. octomaculata* and *Sticholotis* sp. were recorded in both the zones 2 and 3, during the vegetative and reproductive stage of the crop in *Kharif* and *Rabi* during 2018-19. *C. sexmaculata* was most abundant (27) in both the seasons. All the eight predators recorded to be feeding on BPH (Table 2).

In zone-2, *C. sexmaculata*, *C. nigrita*, *C. transversalis* and *Micraspis* sp. were recorded (Fig. 6).

During the *Kharif*, in the vegetative stage of the crop, three species *viz.*, *C. sexmaculata*, *C. nigrita* and *Micraspis* sp. were recorded. However, during the reproductive stage, no individuals of predatory coccinellids were recorded. *C. sexmaculata* recorded as the most abundant species, while the remaining species were very few in numbers (Fig. 6).

During the *Rabi*, in the vegetative stage of the crop, no individuals of the predatory coccinellids were recorded. However in the reproductive stage, two species *viz.*, *C. sexmaculata* and *C. transversalis* were recorded. In this season also during both the stages, no individuals of the species found to be more in number in any of the stages (Fig. 6).

In zone-3, *C. sexmaculata*, *S. nubilus*, *C. nigrita*, *H. octomaculata*, *H. variegata*, *C. transversalis* and *Sticholotis* sp. were recorded (Fig. 6).

During the *Kharif*, in the vegetative stage of the crop, three species were recorded. However, in the reproductive stage, no individuals of the the species were recorded.

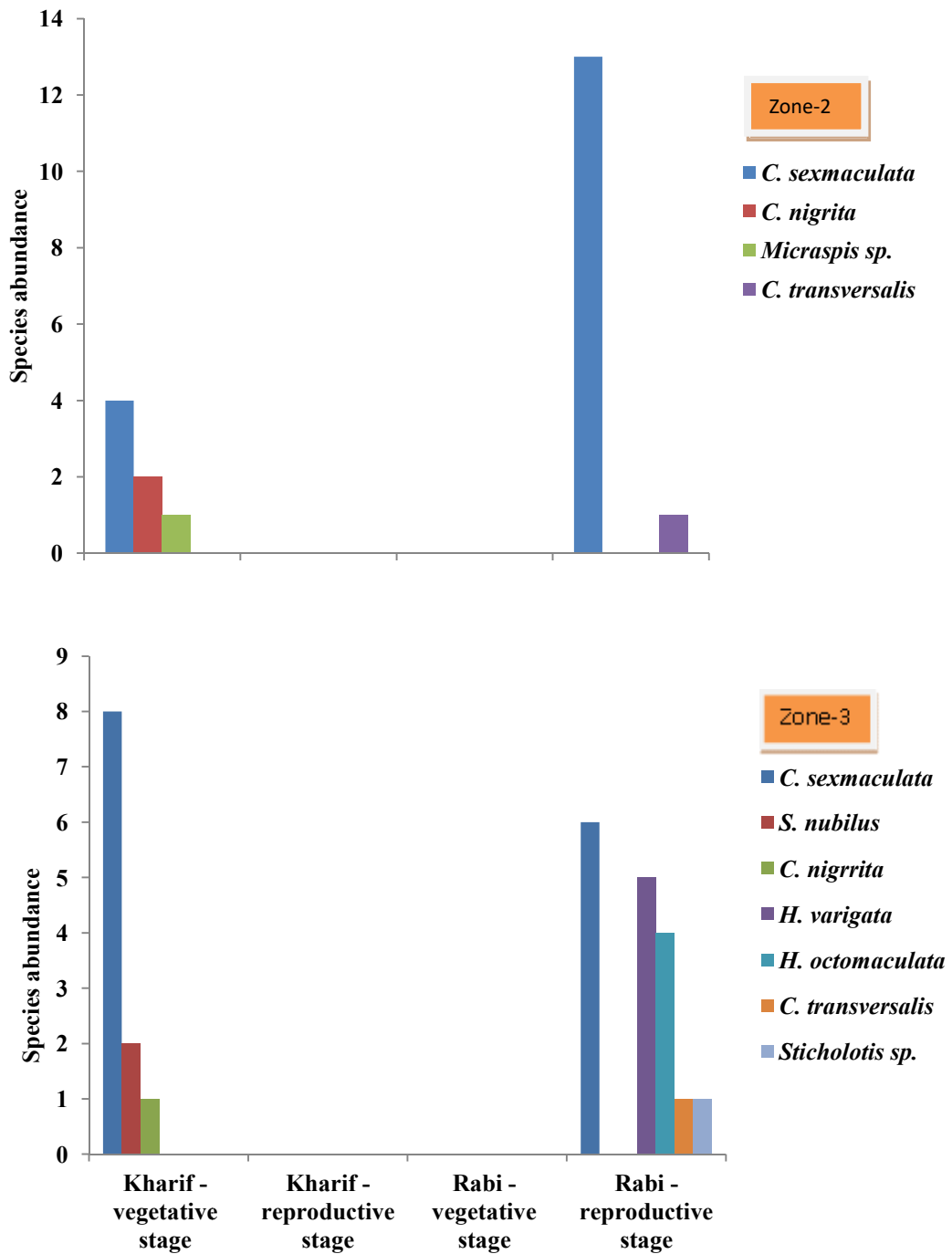


Fig. 6. Species composition of predatory coccinellids in inorganic paddy ecosystem of zone 2 and 3

During the *Rabi*, in the vegetative stage of the crop, no individuals of the predatory coccinellids were recorded. However, in the reproductive stage, five species were recorded.

The species composition in inorganic paddy of both zone 2 and 3 varied considerably. Zone-3 recorded highest number of coccinellids compared to Zone-2. In *Kharif*, during vegetative stage, the building up of BPH goes un-noticed, so taking this opportunity some coccinellid populations thrive well. However, in reproductive stage, rampant applications of insecticides kill pest as well as coccinellids. In *Rabi* crop the BPH population will not be as high as in *Kharif* (Mallikarjun, 2018), so application of insecticides will be low and during the reproductive stage pollen also attracts coccinellids to the paddy fields.

Six of the seven species recorded in the present study were recorded by earlier authors (Kandibane *et al.*, 2006; Rekha *et al.*, 2009; Vinothkumar, 2013; Chowdhury *et al.*, 2015; Shanker *et al.*, 2018). However, there is no record of *Sticholotis* sp. by other authors. Further, Vinothkumar (2013) have also recorded *C. sexmaculata* as the most abundant predatory coccinellid in paddy crop, which is similar to the observation made in the present study.

4.1.4 Species composition in organic paddy

In organic paddy, *C. sexmaculata*, *S. nubilus*, *S. coccivora*, *B. suturalis*, *H. octomaculata* and *C. transversalis* were recorded in the zone 2 and 3 during the vegetative and reproductive stage of the crop in *Kharif* and *Rabi* during 2018-19. In *Rabi*, *S. nubilus* was most abundant (42) in the vegetative stage, followed by *H. octomaculata* (27). Whereas, the remaining species were recorded in very few numbers (Table 2). No prey was recorded at the place of collection.

In zone-2, during *Kharif* stage of the crop, no individuals of the predatory coccinellids were recorded and in the *Rabi*, during vegetative stage of the crop, six predatory coccinellids were recorded with *S. nubilus* as most abundant (42) followed by *H. octomaculata* (27) and other species were very few in numbers (Fig. 7).

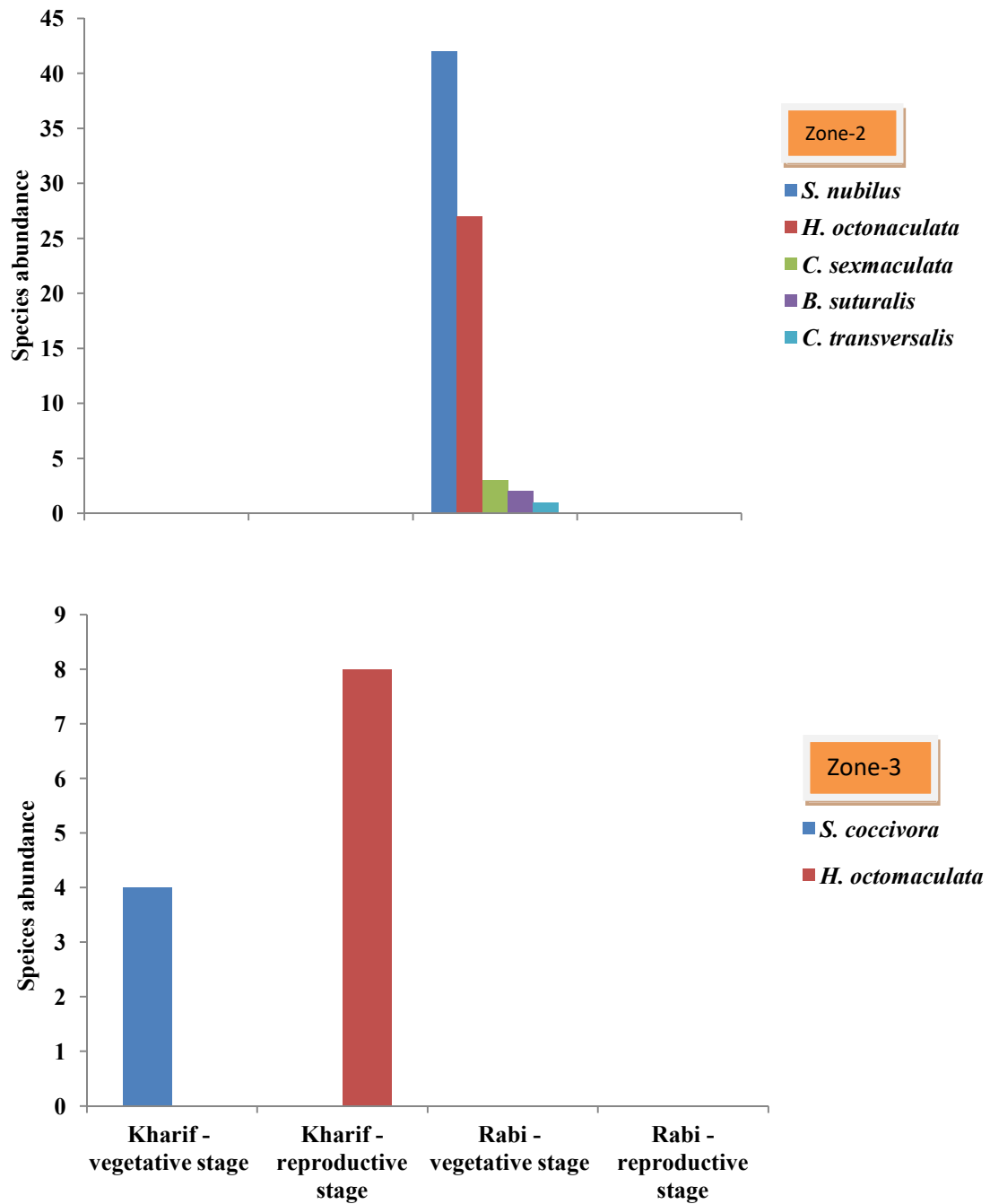


Fig. 7. Species composition of predatory coccinellids in organic paddy ecosystem of zone 2 and 3

In zone-3, *S. coccivora* was recorded during the vegetative stage of the crop and *H. octomaculata* during reproductive stage (Fig. 7). In *Rabi*, due to a shortage of water, no crop was grown.

Interestingly, the species composition varied between organic and normal paddy ecosystem. In normal paddy *C. sexmaculata* was most abundant (31) followed by *C. nigrita*. However, in organic paddy, *S. nubilus* was most abundant (42) followed by *H. octomaculata*. Surprisingly, many of the coccinellid predators recorded in normal paddy were not recorded in organic paddy. Another interesting observation was, predatory coccinellid found in organic paddy of zone-2 were without prey.

Only two out of six species of predatory coccinellids have been recorded by Rajan *et al.* (2019) in organic paddy condition. Lawanprasert *et al.* (2007) reported higher population of natural enemies particularly spiders, lady bird beetles and dragonflies in the organically grown paddy than conventional paddy.

4.1.5 Species composition in cotton

In cotton, *C. sexmaculata*, *C. nigrita*, *S. nubilus*, *H. variegata*, *C. transversalis*, *B. sutularis*, *S. latemaculatus*, *Scymnus (Pullus) sp. 3*, *Scymnus (Pullus) sp. 4* and *Scymnus (Pullus) sp. 7* were recorded in the zones 2 and 3 during the vegetative, flowering and boll opening stages of the crop in *Kharif* during 2018-19. *C. sexmaculata* was most abundant (509) followed by *H. variegata* (89). In vegetative and flowering stage predators found to be feeding on aphids and in boll opening stage recorded feeding on mealybugs.

In zone-2, 10 species were recorded with *C. sexmaculata* as most abundant (509) followed by *H. variegata* (88) and remaining species were recorded in very few numbers (Fig. 8).

During vegetative, flowering and boll opening stage of the crop, ten, four and six species were recorded, respectively. In all the stages, *C. sexmaculata* was most abundant (509) followed by *Scymnus (Pullus) sp. 7* in the vegetative stage (16) and *H. variegata* in the other two stages (54 and 34, respectively).

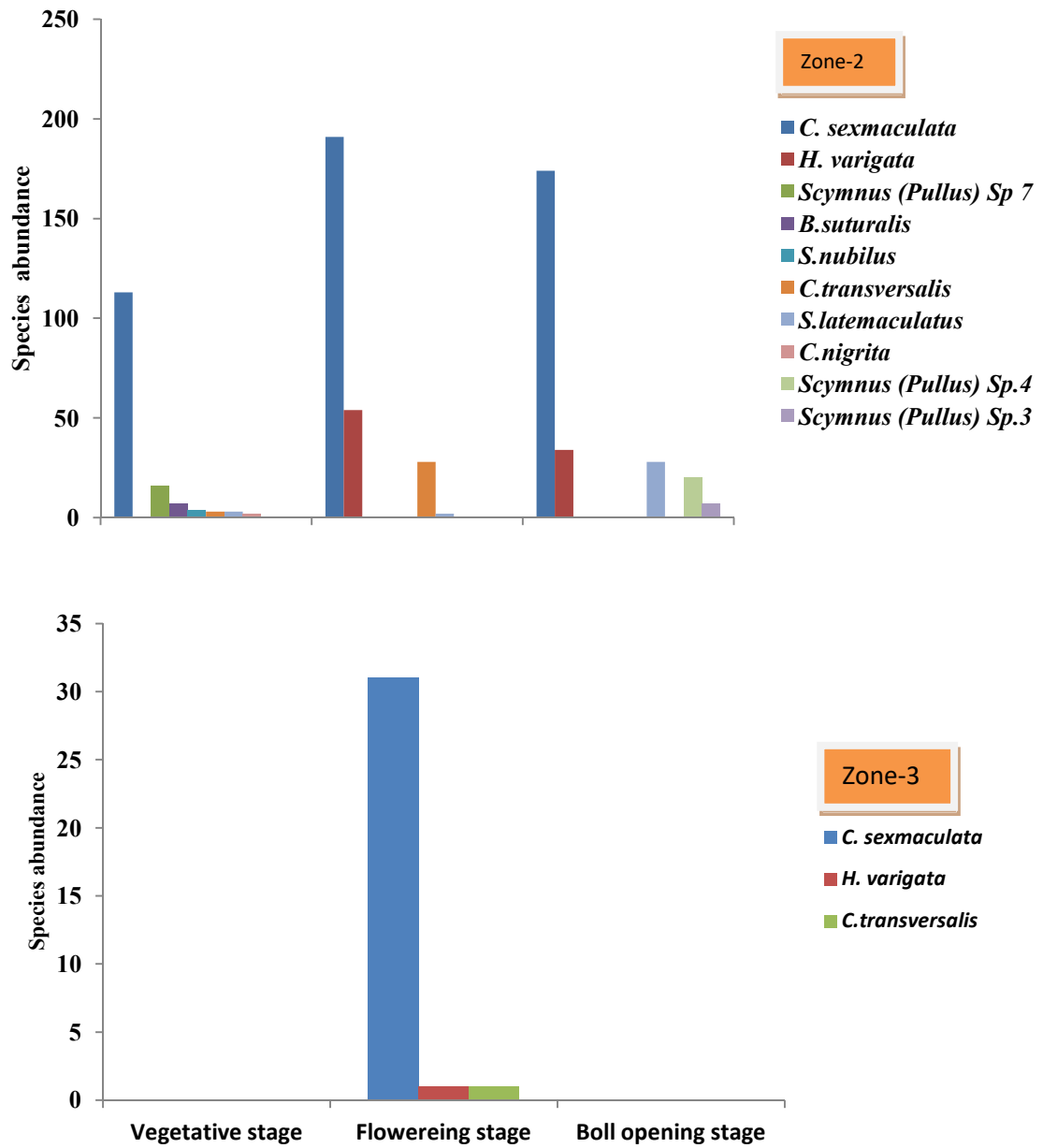


Fig. 8. Species composition of predatory coccinellids in cotton ecosystem of zone 2 and 3

In this zone high number of coccinellids were recorded from the rainfed areas, where in some fields due to the drought situation timely management didn't taken up. This resulted in appearance of sucking pest throughout the cropping season and also in reproductive stage pollen attracted the coccinellids, whereas, in boll opening stage mealybug infestation was at its peak. So the species composition and abundance was quite high in this zone.

In zone-3, *C. sexmaculata*, *H. variegata* and *C. transversalis* were recorded in the flowering stage with *C. sexmaculata* was most abundant (31) and remaining species were very few in number. In vegetative and boll formation stage of the crop, no individuals of the coccinellids were recorded (Fig. 8).

In this zone, crop was grown in TBP command area and farmers usually take up calendar based application of pesticides to manage various pests. This resulted in low species composition and abundance.

Similar observations on the above mentioned ten species were also recorded by several authors (Mohapatra, 2004; Vennila *et al.*, 2007; Rekha *et al.*, 2009; Kedar *et al.*, 2011; Shinde *et al.*, 2015; Pooja, 2018). Kedar *et al.* (2011) also reported similar trends on the incidence of coccinellids in cotton ecosystem with *C. sexmaculata* as most abundant in third week of September.

4.1.6 Species composition in Sugarcane

In sugarcane, *C. sexmaculata*, *S. nubilus*, *Nephus* sp. and *Pseudaspidimerus* sp. were recorded in all the 3 zones, during the vegetative, formative and reproductive stages of the crop, during 2018-19 with *C. sexmaculata* as most abundant (140) followed by *S. nubilus* (33) and remaining species were very few in number. In all the zones, predators found to be feeding on sugarcane woolly aphid (Table 2).

In zone-1, in the formative stage of the crop, only three species were recorded with *C. sexmaculata* as most abundant (44) followed by *S. nubilus* (19). However, during the vegetative and reproductive stages, no individuals of the predatory coccinellids were observed (Fig. 9).

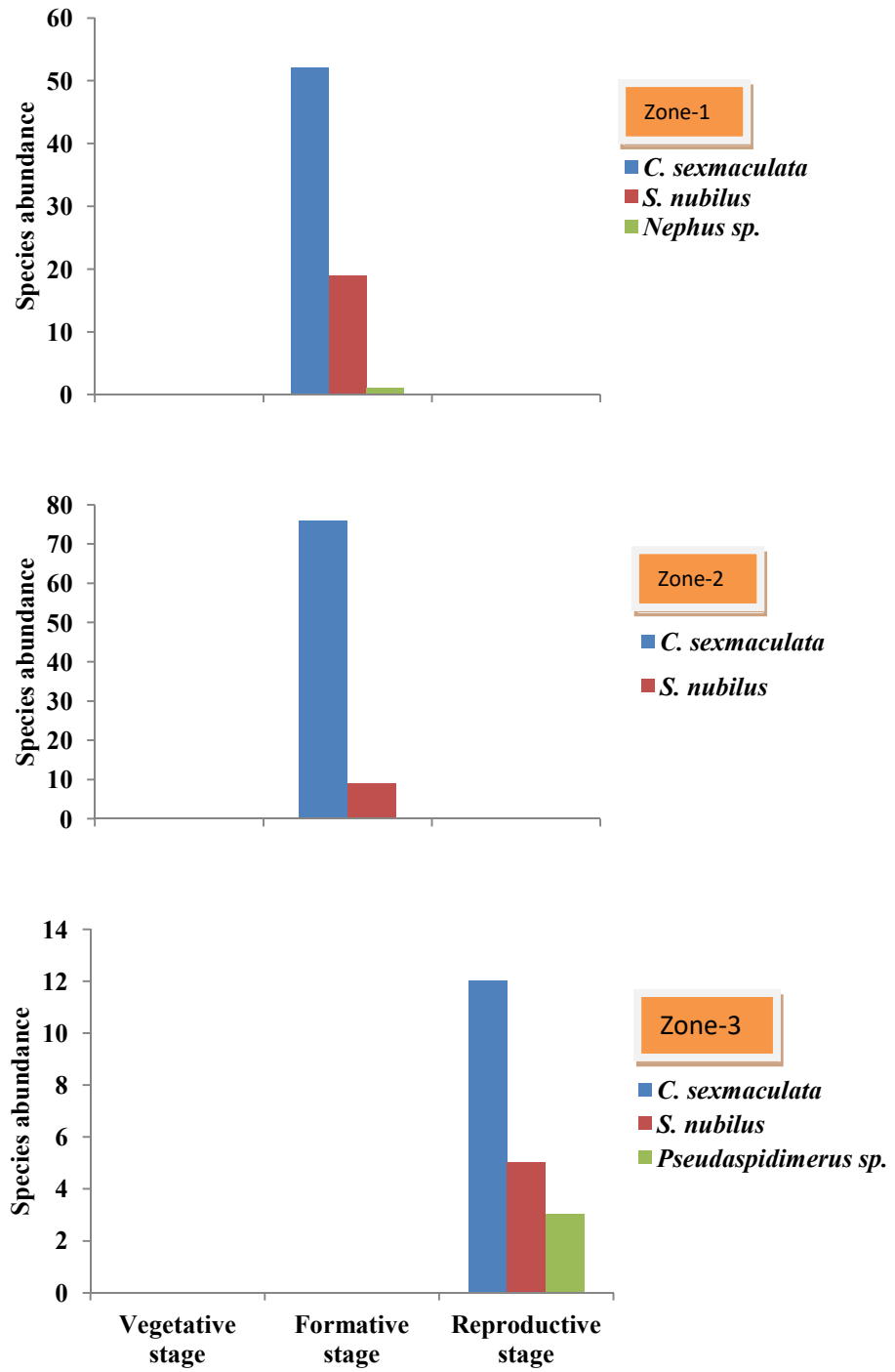


Fig. 9. Species composition of predatory coccinellids in sugarcane ecosystem of zone 1, 2 and 3

In zone-2, in the formative stage of the crop, only two species were recorded with *C. sexmaculata* was most abundant (65) followed by *S. nubilus* (9). In this zone also during the vegetative and reproductive stages, no individuals of the predatory coccinellids were recorded (Fig. 9).

In zone-3, survey was conducted only during the reproductive stage of the crop. Three species were recorded with *C. sexmaculata* as most abundant (12) followed by *S. nubilus* (5) (Fig. 9).

In zones 1, 2 and 3, there was no considerable change in the species composition of coccinellids. During the vegetative stage, chemical management practices will be more compared to formative and reproductive stage. So no coccinellid was recorded in vegetative stage. However, in formative and reproductive stage the persistence of pest will be more, this helped coccinellids to thrive well on prey (Goebel and Nikpay, 2017).

Only *C. sexmaculata* was recorded by earlier authors among four species (Rabindra *et al.*, 2002; Joshi and Viraktamath, 2004; Shailaja *et al.*, 2014). Apart from this many other coccinellids were also recorded by previous authors.

4.1.7 Species composition in citrus

In citrus, during *Kharif*, *Rabi* and summer, *Serangium serratum*, *C. sexmaculata*, *S. nubilus*, *Scymnus castaneus*, *Stethorus* sp. 2, *Stethorus* sp. 3, *Stethorus* sp. 4, *Stethorus tetranichae* and *Parastethorus indira* were recorded in all the three zones, during 2018-19. *S. serratum* was most abundant (87) followed by *P. indira* (81) (Table 2). In rainy and post-rainy season, predators found to be feeding on psyllids and in summer, they were feeding on mites.

In zone-1, six species were recorded with *S. serratum* as most abundant (67) followed by *Stethorus* sp. 4 (14), remaining species were very few in number (Fig. 10).

During rainy and summer season, three species were recorded in which *S. serratum* and *Stethorus* sp.4 were abundant (67 and 14) during the respective stages and other species were less in number. During *Rabi*, no individuals of the predatory coccinellids were recorded.

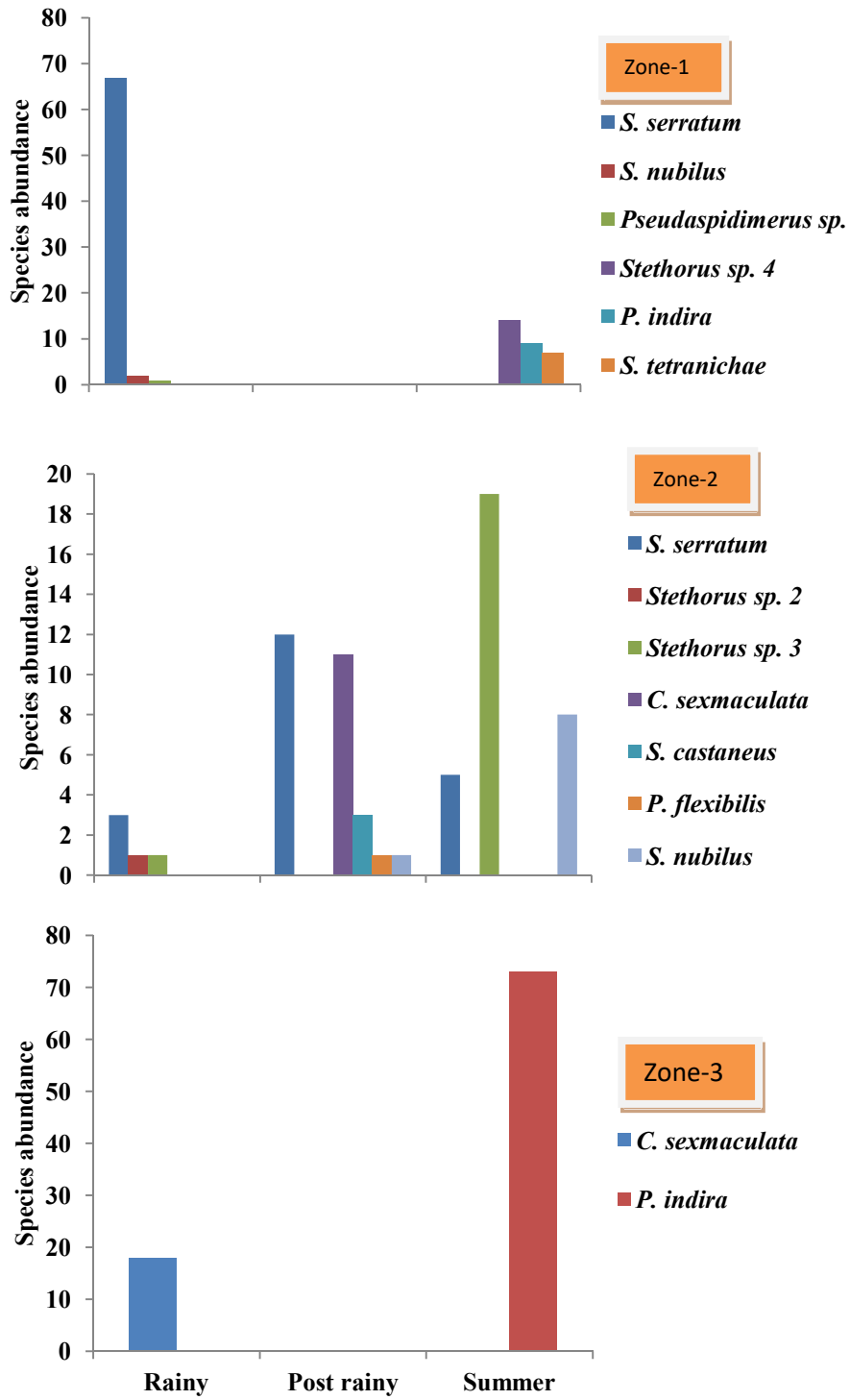


Fig. 10. Species composition of predatory coccinellids in citrus ecosystem of zone 1, 2 and 3

In zone-2, seven species were recorded with *S. serratum* and *Stethorus* sp. 3 as most abundant (20) and remaining species were very few in numbers (Fig. 10).

During rainy season, three species were recorded and all were very few in numbers and during *Rabi*, five species were recorded. Among all, *S. serratum* was abundant (12) followed by *C. sexmaculata* (11), whereas, remaining species were few in number. During summer, three species were recorded with *Stethorus* sp. 3 as most abundant (19) followed by *S. nubilus* (8) and *S. serratum* (5).

In zone-3, during rainy season 11 *C. sexmaculata* was recorded, in post-rainy season, no predators were recorded. During summer, mite feeding, 73 *P. indira* was recorded (Fig. 10).

The species composition and abundance varied most considerably between all the three zones. For instance, *S. serratum* was dominant species in zone-1 but in zone 2 and 3 *Stethorus* sp. were predominant. Eventhough, there was continuous presence of one or other predatory coccinellid across the study period. This may be attributed to low pesticide application. In all the three zones, during summer, mite specialist *Stethorus* sp. were noticed viz., *S. tetranichae*, *P. indira*, *Stethorus* sp. 2, *Stethorus* sp. 3 and *Stethorus* sp. 4 due to the activity of mites.

Five out of above nine species recorded in the present study were recorded by earlier authors (Gupta and Bhatia, 2000; Singh and Sharma, 2010; Sreedevi, 2010; Shailaja *et al.*, 2014; Ashok *et al.*, 2015; Ramya and Thangjam, 2016; Singh, 2017). However, *S. serratum*, *S. nubilus*, *Pseudaspidimerus* sp., *P. indira* and *S. tetranichae* were not recorded by any of the previous authors.

4.1.8 Species composition in guava

In guava, during rainy, post-rainy and summer, *Scymnus (Pullus)* sp.1, *Scymnus (Pullus)* sp.5, *Scymnus (Pullus)* sp.7, *S. nubilus*, *Scymnus* sp.2, *Scymnus* sp.3, *Scymnus* sp.4, *Scymnus (Neopullus)* sp., *S. coccivora*, *C. sexmaculata*, *C. transversalis*, *B. sutularis*, *Stethorus* sp.1, *Pharoscyms flexibilis*, *Pseudaspidimerus* sp., *S. latemaculatus* and *Nephus regularis* were recorded in zone 1 and 3, during 2018-19. *C. sexmaculata* was most abundant (95) followed by *Scymnus (Pullus)* sp.1 (21) and remaining species were few in numbers (Table 2). Coccinellids found to be feeding on mealybug and some

species of coccinellids viz., *Stethorus* sp.1 and *P. indira* on mites. In zone-2, no individuals of the coccinellids were recorded.

In zone-1, nine species were recorded with *Scymnus (Pullus)* sp.5 was most abundant (14) followed by *C. sexmaculata* (9), remaining species were very few in number (Fig. 11).

During rainy season, seven species were recorded in which *Scymnus (Pullus)* sp.5 was most abundant (14) and remaining species were very few in number. During post rainy season, no individuals of the predatory coccinellids were recorded. During summer, four species were recorded and all were very less in number.

In zone-2, no individuals of the predatory coccinellids were recorded.

In zone-3, 12 species were recorded with *C. sexmaculata* was most abundant (96) followed by *Scymnus (Pullus)* sp.1 (21) remaining species were very few in number (Fig. 11).

During rainy season, nine species were recorded with *C. sexmaculata* as most abundant (56) followed by *Scymnus (Pullus)* sp.1 (21) and remaining species were very few in number. During post-rainy, four coccinellids were recorded. In this season also, *C. sexmaculata* was most abundant (17) and remaining species were very few in number. During summer, six species were recorded and here also, *C. sexmaculata* was most abundant (13) followed by *S. coccivora* (12) and remaining species were very few in number.

The species composition and abundance varied considerably between zone 1 and 3. For instance, *C. sexmaculata* population was high (56) in zone-3 compared to zone-1 (09). Here also there was a continuous activity of coccinellids throughout the study period. This may be attributed to the perennial nature and low residue problems in guava orchards as mentioned by Mani and Krishnamoorthy (2007)

Fourteen out of 17 species recorded in the present study were recorded by earlier authors (Verghese, 1992; Mani and Krishnamoorthy, 2007; Shailaja *et al.*, 2014; Amala and Shivalingaswamy, 2018). Further, Mani and Krishnamoorthy (2007) have also

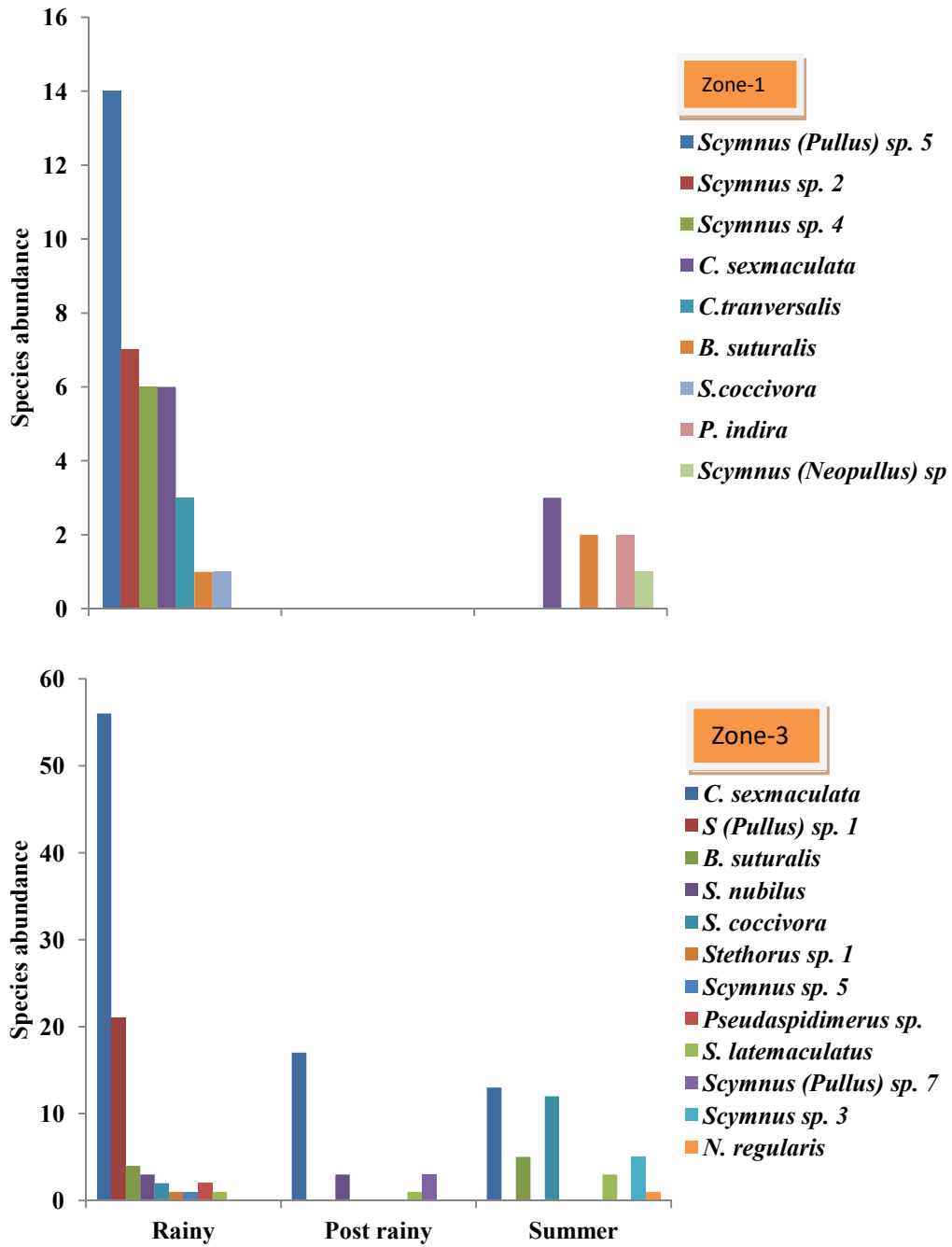


Fig. 11. Species composition of predatory coccinellids in guava ecosystem of zone 1 and 3

recorded *Scymnus* species as most abundant predatory coccinellids in guava orchards, which is in conformity with the observation made in the present study.

4.2 The diversity of predatory coccinellid species in different agricultural and horticultural eco-systems interpreted through various diversity indices

4.2.1 Pulse ecosystem

The various diversity indices derived for predatory coccinellid species population in pulse crops across different crop stages is explained hereunder. A perusal of the data depicted that, species diversity was more in the reproductive stage (0.37) compared to the vegetative stage (0.25). This is further supported by an index of effective number of species (ENS). ENS of 1.44 was recorded in the reproductive stage compared to 1.28 in the vegetative stage, which indicated that, reproductive stage of the pulse crop can support 1.44 species of coccinellids compared to 1.28 species in the vegetative stage (Table 3).

Simpson index varied very little between the stages recording 0.11 and 0.15 in vegetative and reproductive stages, respectively showing that species dominance is very low in this ecosystem irrespective of the stages. Species richness was lower in the vegetative stage (0.53) compared to the reproductive stage (0.77).

Evenness of 0.18 and 0.22 was recorded during the vegetative and reproductive stage, respectively. This explains that, the species evenness not varied much during both the stages.

The above results are not in line with the results of Pinjara *et al.* (2017) and Anbalagan *et al.* (2013) who reported higher Shannon diversity of 1.69 and 1.82, respectively. The variation in the results could be attributed to more number of species (10) recorded by them in the cowpea ecosystem compared to five species in the blackgram and greengram ecosystem in the present study. Further, the evenness in the present study was very low (0.18-0.22) which could be due to the abundance of a single species (*C. sexmaculata*) in the present study compared to other studies (0.61).

Table 3. Different diversity indices of predatory coccinellids in different stages of pulses ecosystem (black gram and green gram)

Indices	Pulses	
	Zone-1	
	Vegetative stage	Reproductive stage
Shannon diversity index (H')	0.25	0.37
ENS*	1.28	1.44
Simpson index (D)	0.11	0.15
Margalef's index (D_{Mg})	0.53	0.77
Pieulo's index (J)	0.18	0.22

*ENS – Effective number of species

4.2.2 Maize ecosystem

The different diversity indices for predatory coccinellid species over various crop stages of maize in both *Kharif* and *Rabi* seasons are as follows. The findings have shown that, species diversity was more in the reproductive stage of *Kharif* (0.46) compared to vegetative stages of both *Kharif* and *Rabi* seasons (0.34 and 0.11, respectively). This was further supported by the index of effective number of species (ENS) which was of 1.58 in the reproductive stage compared to 1.40 and 1.11 in the vegetative stage of both the seasons. The above results confirm that, reproductive stage of the maize crop can support 1.58 species of coccinellids compared to 1.40 and 1.11 species in the vegetative stages of both seasons (Table 4).

Simpson index varied very little between the stages recording 0.14 and 0.18, respectively in vegetative and reproductive stages of *Kharif* crop and 0.05 in the vegetative stage of *Rabi* season resulting in low species dominance in both the seasons. Species richness was lowest (0.22) in the vegetative stage of *Rabi* crop compared to the vegetative and reproductive stage (0.81 and 1.16, respectively) of the *Kharif* crop.

Evenness was more during vegetative stage (0.55) of *Rabi* season compared to both the stages (0.23 and 0.17, respectively) of *Kharif* season, which explains that, during the *Rabi*, the species were more evenly distributed compared to *Kharif* coccinellid population.

The results are not in line with the report of Zahoor *et al.* (2003) and Swaminathan *et al.* (2015), who have recorded high Shannon diversity indices (1.15 and 1.25, respectively) compared to our study (0.30) though even their recordings of coccinellids species were less. The reason could be variation in the evenness. Though in the present study the number of coccinellid species recorded was more, the evenness was low (0.14, 0.18 and 0.05) in both the seasons, resulting in the reduction of Shannon diversity index.

4.2.3 Paddy ecosystem

4.2.3.1 *Kharif* paddy

The results of the various diversity indices of the coccinellid species in paddy of zone 2 and 3 during *Kharif* and *Rabi* are presented. The results revealed that, species

Table 4. Different diversity indices of predatory coccinellids in different stages of cereals crop ecosystem of zone 2 and 3

Indices	Cereals											
	Maize (<i>Kharif</i>)		Maize (<i>Rabi</i>)		Paddy (<i>Kharif</i>)				Paddy (<i>Rabi</i>)			
	Zone-3				Zone-2		Zone-3		Zone-2		Zone-3	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Shannon diversity index (H')	0.34	0.46	0.11	Null	0.95	Null	0.93	Null	Null	0.25	Null	1.40
ENS*	1.40	1.58	1.11		2.60		2.55			1.29		4.05
Simpson index (D)	0.14	0.18	0.05		0.52		0.57			0.14		0.73
Margalef's index (D_{Mg})	0.81	1.16	0.22		1.02		0.91			0.37		1.41
Pieulo's index (J)	0.23	0.17	0.55		0.86		0.85			0.64		0.81

*ENS – Effective number of species

diversity during the vegetative stage was more or less similar (0.95 and 0.93) in both the zones. The ENS also supported this with recordings of 2.60 and 2.55, respectively species which can survive in the vegetative stages of the crop in *Kharif* and *Rabi* (Table 4).

The Simpson index was moderately high, with a recording of 0.52 and 0.57, respectively between the vegetative stages of both zones 2 and 3, indicating that, the dominance of species over the community was meager. The vegetative stage of zone-2 recorded the lowest (1.02) species richness compared to the vegetative stage (0.91) of zone-3.

More or less similar evenness was obtained in both the zones 2 and 3 (0.86 and 0.85, respectively) during the vegetative stage of *Kharif* crop, which shows the even distribution of species.

4.2.3.2 Rabi paddy

The survey data indicated that, species diversity was more (1.40) in the reproductive stage of the zone-3 when compared with the reproductive stage (0.25) of zone-2. The Effective Number of Species (ENS) indicator also supports this. ENS of 4.05 was recorded in zone-3 compared to 1.29 in zone-2 in reproductive stages of the crop, respectively. This suggests that more coccinellid species were supported in zone-3 than in zone-2 (Table 4).

In the reproductive stage of zone-2, Simpson index was very low (0.14) than in zone-3 (0.73) indicating that, the dominance of species in zone-3 was very high compared to zone-2. The reproductive stage of zone-2 showed the lowest species richness (0.37) in comparison with the reproductive stage of zone-3 (1.41).

Evenness was more or less similar during reproductive stages of zone 2 and 3, recording 0.64 and 0.81, respectively, which explains that, during the reproductive stage of zone-3, the species were more evenly distributed compared to zone-2.

The above results are contradiction with the results obtained by Vinothkumar (2013) in which species diversity (1.73) and richness (2.91) was recorded. Mondal *et al.* (2016) had also recorded higher species diversity and species dominance of 2.01 and 0.78, respectively during flowering stage of the paddy crop. However in the present study

diversity, dominance and richness indices recorded were low (Avg. 0.88, 0.5 and 0.93, respectively) (Table 8). The difference in results may attribute to the species distribution in the present paddy crop area. Earlier authors had recorded an evenness of 0.61, which when compared to our present study (0.86, 0.85, 0.64 and 0.81) was high.

4.2.4 Organic paddy ecosystem

In the vegetative stage of *Rabi* organic paddy of zone-2, a high diversity of Shannon index (0.97), ENS of 2.65 species suitable to that situation in the ecosystem, Simpson index with a moderate dominance of 0.56, high species richness of 0.92 and moderate evenness of 0.53 was recorded. However, the analysis was not done in other stages as well as in zone-3, either due to the occurrence of only one species or due to the total absence of coccinellids (Table 5).

4.2.5 Cotton ecosystem

4.2.5.1 Zone-2

A look at the data shows that, species diversity was more in the boll opening stage (1.06) compared to vegetative and flowering stages (0.90 and 0.92, respectively). This is further supported by ENS. In the boll opening stage ENS of 2.91 was recorded compared to 2.47 and 2.53, respectively in the first two stages, which indicate that, boll opening stage of the crop can support 2.91 species of coccinellids compared to 2.47 and 2.53 species, respectively in vegetative and flowering stages (Table 6).

The Simpson index varied very little between the stages recording 0.41, 0.50 and 0.53, respectively in vegetative, flowering and boll opening stages of the crop, illustrating the moderate dominance of species in the ecosystem. Species richness was lowest in the flowering stage (0.53) of the crop compared to vegetative and boll opening stage (1.20 and 0.71).

Evenness was high during the flowering stage (0.63) compared to vegetative and boll opening stage (0.35 and 0.58, respectively) of the crop, which explains that, the species were more evenly distributed in flowering stage compared to the other two stages.

The above results are in confirmation with the reports of Zahoor *et al.* (2003) who has recorded Shannon diversity of 1.15 in the agricultural ecosystem which consists of

Table 5. Different diversity indices of predatory coccinellids in different stages of organic paddy ecosystem of zone 2 and 3

Indices	Organic paddy							
	Paddy (Kharif)		Paddy (Rabi)		Paddy (Kharif)		Paddy (Rabi)	
	Zone-2				Zone-3			
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Shannon diversity index (H')			0.97					
ENS*			2.65					
Simpson index (D)	Null	Null	0.56	Null	Null	Null	Null	Null
Margalef's index(D _{Mg})			0.92					
Pieulo's index (J)			0.53					

*ENS – Effective number of species

Table 6. Different diversity indices of predatory coccinellids in different stages of commercial crops ecosystem of zone 1, 2 and 3

Indices	Commercial crops														
	Cotton						Sugarcane								
	Zone-2			Zone-3			Zone-1			Zone-2			Zone-3		
	Vegetative stage	Flowering stage	Boll opening stage	Vegetative stage	Flowering stage	Boll opening stage	Vegetative stage	Formative stage	Reproductive stage	Vegetative stage	Formative stage	Reproductive stage	Vegetative stage	Formative stage	Reproductive stage
Shannon diversity index (H')	0.90	0.92	1.06	Null	0.27	Null	Null	0.64	Null	Null	0.45	Null	Null	Null	0.93
ENS*	2.47	2.53	2.91		1.31			1.90			1.57				2.55
Simpson index (D)	0.41	0.50	0.53		0.12			0.41			0.33				0.56
Margalef's index (D_{Mg})	1.20	0.53	0.71		0.57			0.46			0.67				0.66
Pieulo's index (J)	0.35	0.63	0.58		0.43			0.63			0.39				0.85

*ENS – Effective number of species

cotton also. In the present study also more or less similar Shannon diversity of 0.96 was recorded. An increase in the diversity of coccinellids in the boll opening stage could be attributed to the occurrence of mealybug in high population which could have led to the build-up of coccinellids. Ahmadov and Hasanova (2016) had also recorded peak activity of coccinellids in the boll opening stage.

4.2.5.2 Zone-3

The flowering stage of the crop recorded Shannon index of 0.27, ENS of 1.31, Simpson index of 0.12, species richness of 0.57 and evenness of 0.43. All the indices showed that the diversity of predatory coccinellids in this zone was very low. In vegetative and boll opening stage due to the absence of coccinellids analysis was not done (Table 6).

The above results are in confirmation with the report of Shinde *et al.* (2015) who had recorded less diversity (0.10). Low diversity indices in this zone may be due to high disturbance faced by the coccinellids in the form of pesticide application.

4.2.6 Sugarcane ecosystem

The various diversity indices derived for predatory coccinellid species population in sugarcane across different stages in zone 1, 2 and 3 have been presented. Diversity indices were calculated in formative stages of zone 1 and 2 and reproductive stage of zone-3 sugarcane crop. Data showed that, when compared with formative stages (0.64 and 0.45, respectively) of zone 1 and 2, species diversity was higher at the reproductive stage (0.93) of zone-3. The ENS also further supports this. In the reproductive stage, 2.55 ENS was recorded, but during formative stages, 1.90 and 1.57, respectively, which implies that the reproductive stage of the crop can support 2.55 coccinellid species compared to 1.90 and 1.57 species in formative stages respectively (Table 6).

During the formative stage of zone-2, the Simpson index was lowest (0.33) reported than in the formative stage (0.41) of zone-1 and the reproductive stage (0.56) of zone-3, showing that. In the reproductive stages of the crop, dominance of the species was high compared to formative stages. In the formative stage of zone-1, species richness was low (0.46) compared to formative and reproductive stages (0.67 and 0.66) of zone 2 and 3, respectively.

In comparison to the formative stage (0.63 and 0.39, respectively) of the crop in zone 1 and 2, evenness was more during the reproductive stage (0.85) in zone-3. Showing that, species were distributed more evenly in the reproductive stage compared to formative stage, irrespective of the number of species.

The above results are in contrast with the results of Zahoor *et al.* (2013) who obtained higher diversity values (1.15) from agricultural ecosystem which includes sugarcane also, than the present study (0.67). The diversity of coccinellids in the sugarcane ecosystem is less due to the occurrence of other predators like brown lacewings and also the ant activity prevailing in the ecosystem hinder the activity of coccinellids. Sharanabasappa *et al.* (2009) found the increased activity of *Micromus igoratus* and *Dipha aphidivora* in the formative and reproductive stages of the crop.

4.2.7 Citrus ecosystem

Data showed that, compared with zone 1 and 3 (1.07 and 0.49, respectively), there was an increase in the species diversity of coccinellids in zone-2 (1.59). The ENS further supports this. In zone-2, 4.91 ENS was recorded as compared to 2.91 and 1.64, respectively in zones 1 and 3. Showing that, in zone-2 citrus plants can sustain 4.91 coccinellid species, compared to 2.91 and 1.64, respective species in zone 1 and 3 (Table 7).

The Simpson index in zone-3 (0.32) was lowest compared to zone 1 and 2 (0.52 and 0.76, respectively), explaining that, species dominance was more in zone-2 compared to the other two zones. Zone-3 recorded a lower species richness (0.22), compared to both zone 1 and 2 (1.08 and 1.51, respectively).

In zone 2 and 3, evenness index was two folds more (0.82 and 0.70, respectively) relative to zone 1 (0.48), which illustrates that in zone 2 and 3, the distribution of species was more even than in zones 1, regardless of the number of species that may dominate a species in the ecosystem.

The above results are in line with the results recorded by Silva *et al.* (2010) who had reported same diversity (1.17) compared to the present study (1.05). However, no reports are available to compare the other diversity indices with the present study.

Table 7. Different diversity indices of predatory coccinellids in different periods of fruit ecosystems of zone 1, 2 and 3

Indices	Fruit crops					
	Citrus			Guava		
	Zone-1	Zone-2	Zone-3	Zone-1	Zone-2	Zone-3
Shannon diversity index (H')	1.07	1.59	0.49	1.80	Null	1.61
ENS*	2.91	4.91	1.64	6.06		5.00
Simpson index (D)	0.52	0.76	0.32	0.79		0.66
Margalef's index (D_{Mg})	1.08	1.51	0.22	2.16		2.58
Pieulo's index (J)	0.48	0.70	0.82	0.67		0.35

*ENS – Effective number of species

4.2.8 Guava ecosystem

The analysis of the information showed that, the species diversity was more in zone-1 (1.80) compared to zone-3 (1.61). The ENS also supports this further with ENS of 6.06 was recorded in zone-1 compared to 5.00 in zone-3, which indicates that, guava crop in zone-1 can support 6.06 species of coccinellids compared to 5.00 species in zone-3 (Table 7).

The Simpson's index was low in zone-3 than in the zone-1 with 0.66 and 0.79, respectively in zone 3 and 1, briefing that the species dominance was more in zone-1 compared to zone-3. In zone-1 (2.16), species richness was least than in zone-3 (2.58).

In zone-1 (0.67), evenness value was higher than in zone-3 (0.35) which illustrates that, in zone-1 as compared to zone-3, species were more uniformly distributed regardless of the number of species that may dominate a species in the ecosystem.

The above results are in confirmation with the results obtained by Amala and Shivalingaswamy (2018) who had recorded similar species diversity of 1.73. However, the species richness of the previous study was low (1.92) compared to the present study species richness (2.37). The difference in richness might be attributed to the number of species recorded. Earlier author had recorded five species. However, in the present study 17 species were recorded.

4.2.9 Inorganic paddy against organic paddy predatory coccinellid diversity

No considerable difference was observed between the coccinellid diversity in organic and inorganic paddy. Shannon diversity, ENS, species dominance and species richness of 0.88, 2.62, 0.5 and 0.93, respectively were recorded in inorganic paddy crop. More or less similar results were also obtained in organic paddy crop (0.97, 2.65, 0.56 and 0.92, respectively) (Table 8).

4.2.10 Predatory coccinellid diversity across various cropping ecosystems

The various diversity indices derived for predatory coccinellid species diversity across the North eastern Karnataka are presented. Shannon diversity index recorded highest in guava ecosystem (1.70) and lowest recorded in pulse (0.31). The ENS also supports this with 5.53 in guava and 1.36 in pulses. Highest Simpson index was noticed in

Table 8. Different diversity indices of predatory coccinellids in different agricultural and horticultural ecosystem

Indices	Pulse	Maize	Inorganic paddy	Organic paddy	Cotton	Sugarcane	Citrus	Guava
Shannon diversity index (H')	0.31	0.40	0.88	0.97	0.79	0.67	1.05	1.70
ENS*	1.36	1.67	2.62	2.65	2.30	2.10	3.16	5.53
Simpson index (D)	0.13	0.13	0.5	0.56	0.39	0.4	0.55	0.73
Margalef's index (D_{Mg})	0.65	0.73	0.93	0.92	0.75	0.60	0.93	2.37
Pieulo's index (J)	0.20	0.32	0.79	0.53	0.50	0.62	0.67	0.51

*ENS – Effective number of species

guava ecosystem, recording 0.73 and lowest recorded in both pulse and maize ecosystem (0.13). Further, the Margalef's species richness was more in guava ecosystem (2.37) and less in sugarcane ecosystem (0.60). More even species distribution was observed in inorganic paddy ecosystem (0.79) and less species evenness was observed in pulse ecosystem (0.20). This higher diversity in guava orchards may be due to perennial nature of the crop and a great reduction in pesticide load leading to fewer residue problems and environmental pollution by practicing biological control of the pests in guava eco-system as reported by Mani and Krishnamoorthy (2007). More or less similar situation with respect to minimum pesticide application was observed in the guava orchards of the present study (Fig. 12 and Table 8).

4.3 Relationship between predatory coccinellid population and prevailing prey density in the different agricultural and horticultural ecosystem

4.3.1 Prey-predatory relationship in pulses

The interaction between prey and predator during the *Kharif* crop in zone-1 exerted a significant positive relation ($r = 0.6940^{**}$) which shows that, as the prey population increases the predator population also increases (Table 9).

Coefficient of determination ($R^2 = 0.4818$) indicates that predatory coccinellids influence the prey density to the extent of 48.18 per cent. The regression equation ($y = 0.0884x + 0.0794$) reveals that, for every unit change in prey population leads to 0.16 unit change in predator population.

The above results are in line with the results of Rakshan and Ahmad (2017) who reported a positive relationship between the density of aphid and *C. sexmaculata* on various pulse crops. Pooja (2018) also reported that both grub ($r = 0.788^{**}$) and adult ($r = 0.836^{**}$) of *C. sexmaculata* were highly significant and positively correlated with aphid population.

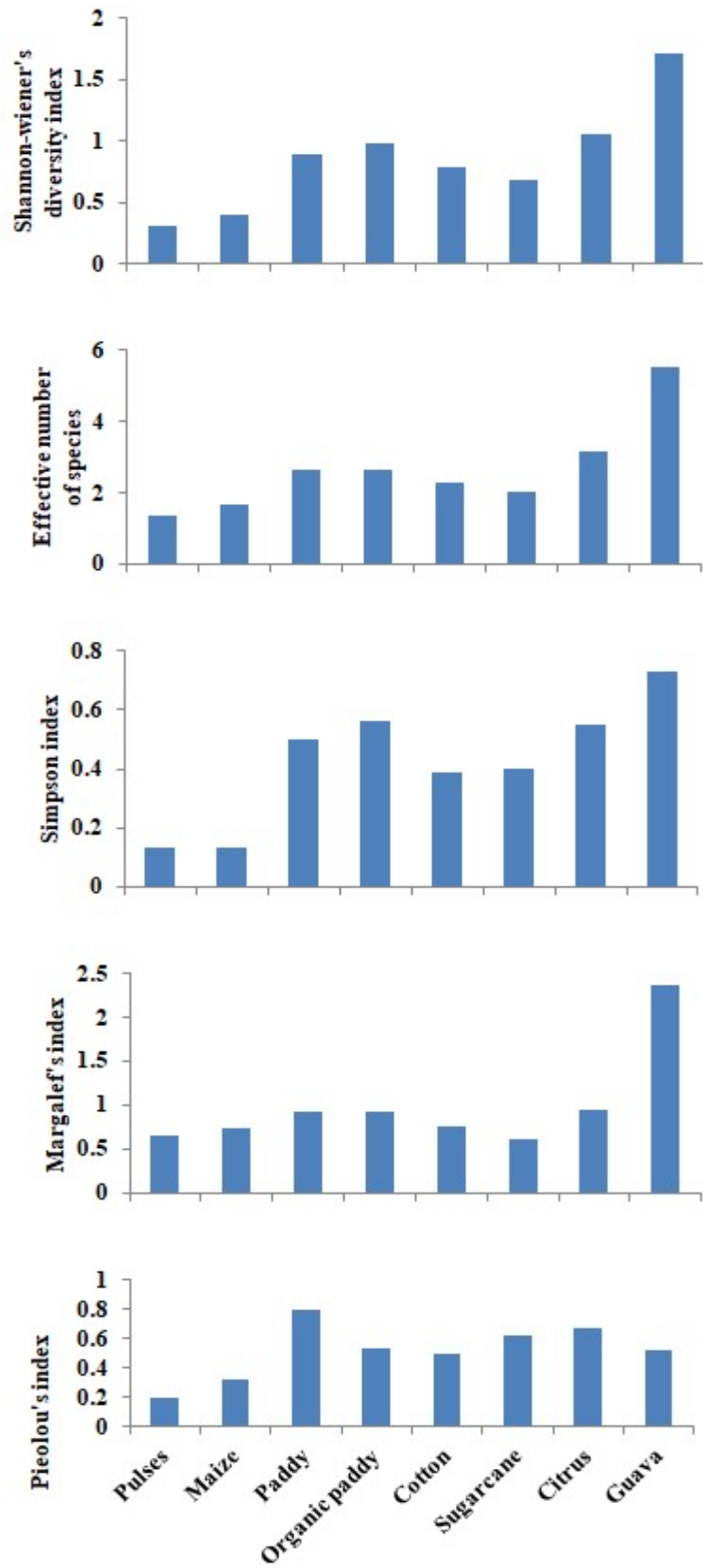


Fig. 12. Predatory coccinellid diversity analysis across different agricultural and horticultural ecosystem

Table 9. Relationship between prey and predator in cereals and pulses

Crop	Season	Zone	Particulars		
			r	R ²	Regression equation
Pulses	<i>Kharif</i>	1	0.6940**	0.4818	$y = 0.0884x + 0.0794$
Maize	<i>Kharif</i>	3	0.6864**	0.4712	$y = 0.1023x + 0.3346$
Maize	<i>Rabi</i>	3	0.5080**	0.2581	$y = 0.0965x + 1.1445$
Paddy	<i>Kharif</i>	2	0.7789	0.6067	$y = 0.1011x + 0.7528$
Paddy	<i>Kharif</i>	3	0.9681**	0.9373	$y = 0.1475x - 0.6749$
Paddy	<i>Rabi</i>	2	0.6922*	0.4889	$y = 0.2643x + 0.3286$
Paddy	<i>Rabi</i>	3	0.9121**	0.8321	$y = 0.1958x + 0.6814$
Paddy (organic)	<i>Kharif</i>	3	0.549	0.3013	$y = 0.2222x + 0.0278$

*Correlation significant at the 0.05 level; ** Correlation significant at the 0.01 level; r – correlation coefficient; R² - Coefficient of determination

4.3.2 Prey-predatory relationship in maize

4.3.2.1 *Kharif* maize

The prey and predator population exerted a significant positive relation ($r = 0.6864^{**}$) which indicates that, when the prey population increases the predator population also increases.

Coefficient of determination ($R^2 = 0.4712$) indicates, the variation in the prey population is influenced to the extent of 47.12 per cent by the predator population. The regression equation ($y = 0.1023x + 0.3346$) reveals that, for every unit change in prey population leads to 0.43 unit change in predator population (Table 9).

4.3.2.2 *Rabi* maize

In zone-3, prey and predators had a significant positive relation ($r = 0.5080^{**}$) which explains that, when the prey population increases the predator population also increases.

Coefficient of determination ($R^2 = 0.2581$) tells that, the prey population variation is influenced by the predatory population to the extent of 25.81 per cent. The regression equation ($y = 0.0965x + 1.1445$) shows that the change in prey population for every unit leads to 1.24 unit change in predator population (Table 9).

Above results in both *Kharif* and *Rabi* maize explains that, a positive correlation existed between the prey and predator and are in confirmation with the results obtained by Swaminathan *et al.* (2016) who also got a positive correlation of 0.94* and 0.84* between the aphid and predatory coccinellid density in both *Kharif* and summer seasons.

4.3.3 Prey-predatory relationship in paddy

4.3.3.1 *Kharif* crop in zone-2

A positive relation ($r = 0.7789$) was recorded between the prey and predator, which shows that, as the population of the prey rises predator population also rises.

Coefficient of determination ($R^2 = 0.6067$) shows that, differences in the prey population was influenced by the predator population up to 60.17 per cent. The regression

equation ($y = 0.1011x + 0.7528$) shows that, for every unit change in the prey population leads to 0.85 unit change in predator population (Table 9).

4.3.3.2 *Kharif* crop in zone-3

Here also, prey and predator population exerted a significant positive relation ($r = 0.9681^{**}$) in other words, the population of predators also rises when the prey population rises.

Coefficient of determination ($R^2 = 0.9373$) shows that, the variation in prey population is influenced by the predator population to the extent of 93.73 per cent. The regression equation ($y = 0.1475x - 0.6749$) shows that, for every unit change in the prey population leads to -0.52 unit change in predator population (Table 9).

4.3.3.3 *Rabi* crop in zone-2

Significant positive relation was existed between the prey and predator ($r = 0.6922^*$) which explains that, as the population of prey rises predator population will also rises.

Coefficient of determination ($R^2 = 0.4889$) illustrates, prey population variation was influenced up to 48.89 per cent by the predator population. The regression equation ($y = 0.2643x + 0.3286$) reveals that, for every unit change in the prey population leads to 0.59 unit change in the predator population (Table 9).

4.3.3.4 *Rabi* crop in zone-3

Prey and predator population exerted a relationship of significant positive relation ($r = 0.9121^{**}$) which implies that, when prey population increases the predator population will also increases.

Coefficient of determination ($R^2 = 0.8321$) reveals, prey population variations was influenced up to 83.21 per cent by the predator population. The regression equation ($y = 0.1958x + 0.6814$) reveals that, 0.8772 unit change in predator population is due to unit change in prey population (Table 9).

The above results of paddy grown in zone 2 and 3 during *Kharif* and *Rabi* explains that, there was a positive correlation existed between the predatory coccinellids and the

BPH. These results are in line with the results of Vinothkumar (2013) who also recorded a positive correlation of 0.527 between the predatory coccinellid and its prey BPH on Paddy in *Kharif* season.

4.3.4 Prey-predatory relationship in organic paddy

Interaction between prey and predator population during the *Rabi* crop in zone-3 tells that, prey and predator population exerted positive relation ($r = 0.549$) which tells that, there is a similar trend in the growth of prey and predator (Table 9).

Coefficient of determination ($R^2 = 0.3013$) illustrates that, 30.13 per cent of prey population variations was due to predatory population. The regression equation ($y = 0.2222x + 0.0278$) tells that, change of each unit in prey population leads to 0.25 unit change in predator population.

4.3.5 Prey-predatory relationship in cotton

4.3.5.1 Zone-2

In zone-2, prey and predator population put up a significant positive relation ($r = 0.5270^{**}$) which tells that, when the prey population increases the predator population also increases.

Coefficient of determination ($R^2 = 0.2778$) implies that, 27.78 per cent prey population variation is due to predatory population. The equation of regression ($y = 0.1955x - 0.3163$) reveals that a unit change in the prey population results in -0.12 unit change predator population (Table 10).

4.3.5.2 Zone-3

Here also, a significant positive relation was observed between prey and predator population ($r = 0.6936^{**}$) in other words, as the population of prey rises, the predator population will also rises.

Coefficient of determination ($R^2 = 0.4811$) tells that, the variation in prey population was influenced by the predator population up to 48.11 per cent. The regression equation ($y = 0.0863x + 0.2899$) tells that, for every unit change in prey population leads to 0.37 unit change in predator population (Table 10).

Table 10. Relationship between prey and predator in commercial crops

Crop	Zone	Particulars		
		r	R²	Regression equation
Cotton	2	0.5270**	0.2778	$y = 0.1955x - 0.3163$
Cotton	3	0.6936**	0.4811	$y = 0.0863x + 0.2899$
Sugarcane	1	0.8429**	0.7106	$y = 0.1444x - 1.4681$
Sugarcane	2	0.7112**	0.5059	$y = 0.1658x - 0.5859$
Sugarcane	3	0.7755**	0.6016	$y = 0.1147x - 0.5545$

** Correlation significant at the 0.01 level; r – correlation coefficient; R² - Coefficient of determination

The above results in both zone 2 and 3 explains that, prey and predator density is positively correlated and these results are in confirmation with the result of Mellet and Schoeman (2007), aphid abundance on cotton crop was correlated positively with coccinellid adult and larval population ($r = 0.719$).

4.3.6 Prey-predatory relationship in sugarcane

4.3.6.1 Zone-1

The prey and predator population exerted a significant positive relation ($r = 0.8429^{**}$), showing that, when the prey population increases the predator population will also increases.

Coefficient of determination ($R^2 = 0.7106$) indicates, the variation in the prey population was up to 71.06 per cent influenced by the predator population. The regression equation ($y = 0.1444x - 1.4681$) reveals that, for every unit change in the prey population leads to -1.32 unit change in the predator population (Table 10).

4.3.6.2 Zone-2

A significant positive relation ($r = 0.7112^{**}$) was present between prey and predator populations, in other words, the predator population will increases when the prey population increases.

Coefficient of determination ($R^2 = 0.5059$) shows that, prey population variation was influenced up to 50.59 per cent by the predator population. The regression equation ($y = 0.1658x - 0.5859$) shows that, for each unit change in the prey population there would be a -0.42 unit change in predator population (Table 10).

4.3.6.3 Zone-3

In this zone also, a significant positive relation ($r = 0.7755^{**}$) was existed between the prey and predator populations, explaining that, when the prey population rises the predator population will also rises.

Coefficient of determination ($R^2 = 0.6016$) illustrates that, Prey population variation was influenced by predator population up to 60.16 per cent. The regression

equation ($y = 0.1147x - 0.5545$) shows that, for each unit change in the prey population there would be a -0.43 unit change in the predator population (Table 10).

The above results explain that, in all the above 3 zones, there was a positive correlation existed between the predatory coccinellids and sugarcane woolly aphid. These results are in line with results obtained by Sharanbasappa *et al.* (2009) who also got an average significant positive correlation of 0.82** and 0.86**, respectively between the prey and predator densities of sugarcane woolly aphid and its natural enemies in a two-year study.

4.3.7 Prey-predatory relationship in citrus

4.3.7.1 Zone-1

The prey and predator population exerted a significant negative relation ($r = -0.5151^*$) in other words, the predator population decreases as a result of the increase in the prey population.

Coefficient of determination ($R^2 = 0.2654$) indicates that, the variation in prey population was influenced by predator population to an extent of 26.54 per cent. The regression equation ($y = -0.1861x + 6.7366$) reveals that, changes in the prey population for every unit lead to 6.55 unit of the change in the predator population (Table 11).

4.3.7.2 Zone-2

The prey and predator population exerted a significant positive relation ($r = 0.9039^{**}$) which implies that, when the prey population increases the predator population also increases.

Coefficient of determination ($R^2 = 0.8172$) indicates, the variation in the population of prey was influenced by 81.72 per cent of predator. The regression equation ($y = 0.4457x + 0.5194$) explains that, for each unit change in the prey population, the predator population will change by 0.96 unit (Table 11).

Table 11. Relationship between prey and predator in fruit crops

Crop	Zone	Particulars		
		r	R²	Regression equation
Citrus	1	- 0.5151*	0.2654	$y = -0.1861x + 6.7366$
Citrus	2	0.9039**	0.8172	$y = 0.4457x + 0.5194$
Guava	1	0.0296	0.0009	$y = 0.001x + 1.8073$
Guava	3	0.7005**	0.4907	$y = 0.1875x + 1.1847$

*Correlation significant at the 0.05 level; ** Correlation significant at the 0.01 level;
r – correlation coefficient; R² – Coefficient of determination

4.3.8 Prey-predatory relationship in guava

4.3.8.1 Zone-1

The relationship of a positive correlation ($r = 0.0296$) has been recorded between the prey and predator populations, meaning that the population of predators will increase with an increase in the prey population.

Coefficient of determination ($R^2 = 0.0009$) illustrates that, predator population influence up to an extent of 0.09 per cent of the variation in the population of prey. The regression equation ($y = 0.001x + 1.8073$) shows that 1.80 unit of predator population changes for every unit change in the prey population (Table 11).

4.3.8.2 Zone-3

However, in zone-3, the prey and predator population put up a relationship of significant positive relation ($r = 0.7005^{**}$) which explains that, when the prey population increases the predator population also increases.

Coefficient of determination ($R^2 = 0.4907$) indicates that, the variation in the prey population was influenced by the predator population up to 49.07 per cent. The regression equation ($y = 0.1875x + 1.1847$) reveals that, for every unit change in the prey population leads to 1.37 unit change in the predator population (Table 11).

The prey-predator relationship in most of the crops obtained a significant positive correlation, which is in line with the previous authors *viz.*, Pooja (2018), Rakshan and Ahmad (2017), Vinothkumar (2013), Swaminathan *et al.* (2016); Mellet and Schoeman (2007), Sharanbasappa *et al.* (2009). However, the citrus crop of zone-1 recorded negative correlation with prey and predatory populations which is similar to Anisiu (2014); Stevens (2010). Pschorn-Walcher and Zwolfer (1956) and Crawley (1975) explained as the prey population increases predator population might also decrease. So it concludes that, in nature, there cannot not be a positive or negative association between the prey and predator constantly, instead they might fluctuate according to the situations.

SUMMARY AND CONCLUSION

V. SUMMARY AND CONCLUSION

The present study on species complexity of predatory coccinellids, analysis of species diversity with various diversity indices and prey-predator association in accordance with their respective density was carried out in various agricultural and horticultural ecosystem of North eastern Karnataka during 2018-19. The outcomes of these investigations are summarized here under.

A total of 36 species of predatory coccinellids belonging to seven tribes of the family Coccinellidae was recorded in the first three agro-climatic zones of Karnataka state (zone 1, 2 and 3). The tribe Coccinellini was most abundant compared to all the tribes with about 83 per cent of the total species abundance, next to that were tribe Scymnini recording 9 per cent and remaining tribes were less than 5 per cent. The guava orchards recorded a highest number of predatory coccinellid species (17 species) followed by maize and cotton (11 and 10 species, respectively). Among all the species recorded *Cheilomenes sexmaculata* and *Scymnus nubilus* were recorded in the entire ecosystem and their population was also highest compared all the species (2575 and 139 specimens, respectively). In other words, *C. sexmaculata* was the most predominant species in the entire ecosystem. However, in citrus ecosystem, *Serangium serratum* and *Stethorus* species were predominant. The species *S. serratum* was recorded for the first time from the citrus ecosystem feeding on citrus psyllid, *Diaphorina citri* Kuwayama, which is also a new host species recorded for this predator.

The maximum Shannon diversity, effective number of species and Simpson dominance index of predatory coccinellids was recorded (1.70, 5.53 and 0.73, respectively) in guava ecosystem and minimum Shannon and Simpson dominance of 0.31 and 0.13, respectively was recorded in pulse and maize crop. Further, least ENS (1.36) was recorded in pulse crop. The Margalef's species richness recorded was more in guava ecosystem (2.58) and less in sugarcane ecosystem (0.60). The Pielou's evenness was highest in the citrus ecosystem (0.67) and lowest in pulse ecosystem (0.2).

Studies on prey-predator relationship with respect to population density revealed, a significant positive relationship between the population buildup of both prey and

predator. However, citrus ecosystem of zone-1 recorded a negative relationship. The regression values recorded an average of $R^2 = 0.5016$, in other words, the variation in the prey population across the selected crops was influenced by 50.68 per cent on predator population.

Conclusions

From the above study the following conclusions have been made.

1. There was rich predatory coccinellid diversity in this study area.
2. The predatory coccinellids species recorded highest from the guava ecosystem followed by cotton and maize.
3. Irrespective of the stage, season and zone, the species *C. sexmaculata* was the most predominant in the entire ecosystem except in citrus ecosystem, where *S. serratum* was the predominant species.
4. Among the 36 species, 11 were generalist predators and remaining were specialists.
5. Diversity indices indicated that, guava ecosystem is having highest diversity compared to all other ecosystem.
6. *S. serratum* was first time recorded from citrus ecosystem feeding on citrus psyllid (a new host).
7. In most of the ecosystem, coccinellid populations were highly significant and positively correlated with the various prey populations.

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VI. REFERENCES

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APPENDIX

APPENDIX

Checklist of predatory coccinellids recorded in North East Karnataka in agricultural and horticultural ecosystems

A check list is a skeletal classification of groups listed by taxa for quick references and used as an aid in arrangement of collection. All the collected specimens were compiled and checklist was prepared in a systematic sequence. The families, sub-families, generic and species were listed alphabetically. Further, synonyms and distribution of the each species under each genus were presented below.

Superfamily: CUCUJOIDEA

Family: COCCINELLIDAE

Subfamily: CHILOCORINAE

Tribe: CHILOCORINI

***Brumoides* Chapin, 1965a**

Brumoides Chapin, 1965a

1. *suturalis* (Fabricius)

= *Coccinella suturalis* Fabricius, 1798

= *Brumus suturalis*: Mulsant, 1850

= *Brumoides suturalis*: Chapin, 1965

Distribution: India: Goa; Karnataka; Tamil Nadu; Punjab; Maharashtra; Uttar Pradesh; Manipur; Pakistan. Bangladesh. Sri Lanka. Himalayas. Bhutan. Nepal.

***Chilocorus* Leach, in Brewster, 1815**

1. *nigrita* (Fabricius)

= *Coccinella nigrita* Fabricius, 1798

= *Chilocorus nigrinus*: Mulsant, 1850

= *Chilocorus nigrita*: Bielawski, 1957

Distribution: India: Karnataka; Kerala; Andhra Pradesh; Tamil Nadu; Maharashtra. Pakistan. Sri Lanka. Bangladesh. Myanmar. China. Indonesia. Thailand. South Africa. Seychelles. Pacific. Brazil.

Subfamily COCCINELLINAE

***Cheilomenes* Dejean, 1836**

Cheilomenes Dejean, 1836

Menochilus Timberlake, 1943

1. *sexmaculata* (Fabricius)

- = *Coccinella sexmaculata* Fabricius, 1781
- = *Coccinella 4-plagiata* Swartz in Schönherr, 1808
- = *Cheilomenes sexmaculata*: Dejean, 1837
- = *Cheilomenes quadriplagiata*: Dejean, 1837
- = *Cheilomenes sexmaculata* var. *flavofasciata* Mulsant, 1850
- = *Orcus mollipes* Olliff, 1895
- = *Cheilomenes sexmaculata* var. *australis* Weise, 1908
- = *Menochilus sexmaculatus*: Timberlake, 1943
- = *Menochilus quadriplagiatus*: Timberlake, 1943
- = *Chilomenes hiugaensis* Takizawa, 1917
- = *Menochilus sexmaculatus*: Timberlake, 1943
- = *Cydonia triangulifera* var. *inops* Mulsant, 1866
- = ‡*Micraspis inops*: Chunram & Sasaji, 1980

Distribution: Throughout India. Bangladesh. Pakistan. Sri Lanka. Bhutan. Myanmar. Malaysia. Indonesia. Philippines. Vietnam. China. Japan. Oriental. Australia.

‡Note: Iablokoff-Khnzorian (1982) incorrectly used *M. inops* (Mulsant) for the widespread Indian species. Mulsant's original type material is a *Cheilomenes* and *inops* is only a colour form of *C. sexmaculata*.

***Coccinella* Linnaeus, 1758**

Coccinella Linnaeus, 1758

Coccinella (Dobzhanskia) Iablokoff-Khnzorian, 1979

1. *transversalis* Fabricius

- = *Coccinella transversalis* Fabricius, 1781
- = *Coccinella repanda* Thunberg, 1781

Distribution: India. Nepal. Sri Lanka. Bangladesh. Indo-china. Indonesia. Japan. Australia. New Zealand.

***Harmonia* Mulsant, 1846**

Harmonia Mulsant, 1846

Leis Mulsant, 1850

Ballia Mulsant, 1853a

Callineda Crotch, 1871

Stictoleis Crotch, 1874

Ptychanatis Crotch, 1874

*Rhopaloned*a Timberlake, 1943

1. *octomaculata* (Fabricius)

= *Coccinella octomaculata* Fabricius, 1781

= *Coccinella arcuata* Fabricius, 1787

= *Harmonia arcuata* var. *octomaculata*: Mulsant, 1850

= *Harmonia arcuata*: Mulsant, 1850

= *Harmonia octomaculata*: Mader, 1932: 215.-Bielawski, 1957

= *Harmonia octomaculata* var. *arcuata*: Mader, 1932.

= *Coccinella arcuata* var. *octomaculata*: Korschefsky, 1932

= *Ptychanatis octomaculata*: Kamiya, 1965a

Distribution: Almost throughout India. Pakistan. Nepal. Bangladesh. Sri Lanka. Wide spread in the Orient. Micronesia. Australia.

***Hippodamia* Chevrolat, in Dejean, 1836 (Canepari, 1990; Pope, 1992)**

Hippodamia Chevrolat, in Dejean, 1836

Hippodamia (*Hippodamia*): Iablokoff-Khnzorian, 1982

Hemisphaerica Hope, 1840: 157.-Mulsant, 1850

Adonia Mulsant, 1846: 39; 1850

Hippodamia (*Parippodamia*) Iablokoff-Khnzorian, 1979

Hippodamia (*Adonia*): Iablokoff-Khnzorian, 1982

1. *variegata* (Goeze)

= *Coccinella variegata* Goeze, 1777

= *Adonia variegata*: Mulsant, 1846

= *Hippodamia variegata*: Belicek, 1976: 338.

= *Hippodamia* (*Adonia*) *variegata*: Iablokoff-Khnzorian, 1982

Distribution: India: Jammu-Kashmir; Uttar Pradesh; Himachal Pradesh; Maharashtra. Nepal. Pakistan. Afghanistan. Tibet. Mongolia. China. Northern and eastern Africa. Palearctic.

***Micraspis* Chevrolat, in Dejean, 1836 (Canepari, 1990; Pope, 1992)**

Micraspis Chevrolat, in Dejean, 1836

Alesia Mulsant, 1850

Verania Mulsant, 1850

Cisseis Mulsant, 1850

Cissella Weise, 1895a

Menevillidea Brethes, 1923

Pseudoverania Mader, 1941

1. *discolor* (Fabricius)

= *Coccinella discolor* Fabricius, 1798

= *Verania discolor*: Mulsant, 1850

= *Micraspis discolor*: Kamiya, 1965a

= *Coccinella simplex* Thunberg, 1820

Distribution: India. Bangladesh. Sri Lanka. Pakistan. Oriental. Palaearctic.

***Propylea* Mulsant, 1846**

Propylea Mulsant, 1846

Oenopia (Pania) Mulsant, 1850

Pania: Iablokoff-Khnzorian, 1979

1. *dissecta* (Mulsant)

= *Lemnia (Vola) dissecta* Mulsant, 1850

= *Lemnia dissecta*: Mulsant, 1866

= *Propylea japonica* ab. *dissecta*: Korschefsky, 1932

= *Propylea dissecta*: Crotch, 1874

= *Lemnia mystacea* Mulsant, 1853

= *Harmonia feliciae* Mulsant, 1866

= *Propylaea fallax* Yablokov-Khnzoryan, 1977

Distribution: India: AS; Tamil Nadu; Karnataka; Uttar Pradesh. Bangladesh. Nepal.

Subfamily SCYMNINAE

Tribe Aspidimerini

***Pseudaspidimerus* Kapur, 1948b**

Pseudaspidimerus Kapur, 1948b

Tribe Scymnini

***Nephus* Mulsant, 1846**

Scymnus (Nephus) Mulsant, 1846

Nephus: Motschulsky, 1866

Nephus (Bipunctatus) Fürsch, 1987b

Nephus (Geminosipho) Fürsch, 1987b

Nephus (Parascymnus); Fürsch, 1987b

Aponephus Booth., 1991

1. *regularis* (Sicard)

= *Scymnus (Nephus) regularis* Sicard, 1929a

= *Nephus regularis*: Chelliah, 1965

Distribution: India: Andra Pradesh; Assam; Karnataka; Tamil Nadu. Pakistan. China.

***Scymnus* Kugelann, 1794**

Scymnus Kugelann, 1794

Subgenus *Scymnus (Neopullus)* Sasaji, 1971

Scymnus (Neopullus) Sasaji, 1971

Scymnus (Caledonus) Bielawski, 1973

Subgenus *Scymnus (Pullus)* Mulsant, 1846

Scymnus (Pullus) Mulsant, 1846

Pullus: Motschulsky, 1866

1. *castaneus* Sicard

= *Scymnus (Pullus) castaneus* Sicard, 1929a

= *Scymnus (Pullus) castaneus*: Korschefsky, 1931

Distribution: India: Tamil Nadu; Andra Pradesh; Karnataka; Kerala. Bangladesh.

2. *coccivora* Ayyar

= *Scymnus coccivora* Ayyar, 1925

= *Scymnus (Pullus) coccivora*: Korschefsky, 1931

= *Pullus coccidivora*: Chelliah, 1965

= *Scymnus (Pullus) elegans* Sicard, 1929a

= *Scymnus (Pullus) elegans* var. *clathratus* Sicard, 1929a

Distribution: India: Andra Pradesh; Karnataka; Tamil Nadu; Goa; Uttar Pradesh.
Pakistan. Bangladesh. Sri Lanka. Malaysia.

3. *latemaculatus* Motschulsky

= *Scymnus latemaculatus* Motschulsky, 1858

= *Scymnus quadrillum* auctt.: Kapur, 1942

= *Nephus quadrillum*: Iablokoff-Khnzorian, 1972

= *Scymnus transversoplagiatus* Motschulsky, 1858

= *Pullus taiwanus* Ohta, 1929

= *Scymnus (Pullus) taiwanus*: Kamiya, 1965c

Distribution: India: Karnataka; Tamil Nadu; Lakshadweep Islands; Goa. Bangladesh. Sri Lanka. Thailand. Taiwan.

Subgenus *Scymnus (Scymnus)* s. str.

1. *nubilus* Mulsant

= *Scymnus nubilus* Mulsant, 1850

= *Scymnus (Scymnus) nubilus*: Korschefsky, 1931

= *Scymnus curtisii* Mulsant, 1850

= *Scymnus suturalis* Motschulsky, 1858

= *Scymnus stabilis* Motschulsky, 1866

= *Scymnus lateralis* Sicard, 1913

Distribution: India: Assam; Karnataka; Lakshadweep Islands; Maharashtra; Orissa; Tamil Nadu; West Bengal; Goa. Pakistan. Bangladesh. Sri Lanka. Nepal. Myanmar. China. Asia Minor.

Tribe Stethorini

***Stethorus* Weise, 1885b**

Scymnus (Stethorus) Weise, 1885b

Stethorus Weise, 1899

Nephopullus Brethes, 1925

Stethorus (Allostethorus) Iablokoff-Khnzorian, 1972

Stethorus (Parastethorus) Pang & Mao, 1975

1. *indira* Kapur

= *Stethorus indira* Kapur, 1950

= *Stethorus (Parastethorus) indira*: Yu, 1996

Distribution: India: West Bengal; Meghalaya. China. Thailand.

2. *tetranych* Kapur

= *Stethorus tetranych* Kapur, 1948c

Distribution: Bangladesh. Thailand.

Subfamily STICHOLOTIDINAE

(=Sticholotinae)

Tribe Serangiini

***Serangium* Blackburn, 1889**

Serangium Blackburn, 1889

1. *serratum* Poorani

= *Serangium serratum* Poorani, 1999

Distribution: India: Karnataka; Tamil Nadu.

Tribe Sticholotidini (=Pharini)

***Pharoscymnus* Bedel, 1906**

Pharus Mulsant, 1850

Pharoscymnus Bedel, 1906

Pharoscymnus (Gymnopharus) Sicard, 1909

1. *flexibilis* (Mulsant)

= *Scymnus (Diomus) flexibilis* Mulsant, 1853

= *Scymnus flexibilis*: Crotch, 1874

Pharus flexibilis: Weise, 1900

= *Pharoscymnus flexibilis*: Korschefsky, 1931

Distribution: India: Bihar; Jammu-Kashmir; Karnataka; Andhra Pradesh. Pakistan.

***Sticholotis* Crotch, 1874**

Sticholotis Crotch, 1874

Gymnoscymnus Blackburn, 1892

Density and diversity of predaceous Coccinellidae in various cropping ecosystems

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ABSTRACT

The present investigation on the density and diversity of predaceous Coccinellidae was carried out on the three agro-climatic zones of North East Karnataka during 2018-19. Crops such as pulses, inorganic paddy, organic paddy, maize, cotton and sugarcane, citrus and guava have been surveyed at different stages and seasons to see the predatory coccinellid composition along with its density. During the survey, 36 species of predatory coccinellids were recorded across the seven ecosystems. Species composition was highest in guava, recording 17 species, followed by cotton and maize (11 and 10 species, respectively). Pulse ecosystem recorded a lowest species composition of five. In the entire ecosystem *Cheilomenes sexmaculata* (Fabricius) was the common and dominant species recording 2575 specimens, however, in citrus, *Serangium serratum* Poorani and *Stethorus* species were dominant. The species *S. serratum* was recorded for the first time from the citrus, feeding on citrus psyllid, *Diaphorina citri* Kuwayama, which is also a new host species recorded for this predator. Results with respect to the diversity analysis indicated that, diversity, effective number of species, dominance and richness were highest in guava ($H' = 1.80$, $ENS = 6.06$, $D = 0.79$ and $D_{Mg}=2.58$, respectively) and lowest diversity and dominance of 0.30 and 0.13, respectively was recorded in pulse and maize. Further, lowest ENS and richness was recorded in pulses and sugarcane (1.36 and 0.60, respectively). The evenness was highest recorded in inorganic paddy and lowest in pulses ($J = 0.67$ and 0.20, respectively). Studies on prey-predator relationship with respect to population density revealed, a significant positive relationship between the population buildup of both prey and predator. The regression values recorded an average of $R^2 = 0.5016$, in other words, the variation in the prey population across the selected crops was influenced by 50.16 per cent on predator population.