



## Research Article

# Ichneumonid fauna associated with rice ecosystems of Tamil Nadu, India

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**ABSTRACT:** Surveys were conducted to explore the Ichneumonid fauna in rice ecosystems of Tamil Nadu during 2015-16 in three different rice growing zones viz., western zone, Cauvery delta zone and high rainfall zone. Totally 604 Ichneumonid individuals were collected from rice ecosystem in the present study. These 604 individuals represent 14 subfamilies, 24 genera and 33 species. Alpha and beta diversity were computed for the three zones and the diversity indices (Simpson's index, Shannon-Wiener index, Pielou's index) revealed western zone as the most diverse zone, while Cauvery delta zone being the least diverse. *Leptobatopsis indica* was the dominant Ichneumonid species in the rice ecosystem with a relative abundance of 8.1 %. On comparing the species similarities using the Jaccard's index among the three zones taken in pairs, it was found that 12 per cent similarity between Western and Cauvery delta zones and no similarity between high rainfall and Cauvery delta zones and 25 per cent similarity between high rainfall and western zones.

**KEY WORDS:** Diversity, Ichneumonidae, parasitoids, rice ecosystem

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## INTRODUCTION

Rice (*Oryza sativa* L.), is an annual grass native to Asia. Rice fields, together with the associated irrigation ponds, ditches and ridges often constitute the traditional landscape in rural environments and are a key ecosystem of Asia (Kiritani, 2009). In India, rice is not just food stuff, but a culture. Tamil Nadu, one of the leading rice growing states in India, has been cultivating rice from time immemorial as this state is endowed with all favourable climatic conditions suitable for growing rice. Rice fields harbour a rich and varied fauna than any other agricultural crop (Heckman, 1979; Fritz *et al.*, 2011). The fauna is dominated by micro, meso and macro arthropods inhabiting the soil, water and vegetation sub-habitats of the rice fields. The different communities of terrestrial arthropods in the rice field include pests, their natural enemies (predators and parasitoids) and other neutral insects that inhabit or visit the vegetation as tourists (Heong *et al.*, 1991). Insect pests are reported as the major threat to its production. More than 800 species of insects are known

to infest rice, of which about 20 species are of economic importance. The overall losses due to insect pest damage in rice are estimated as 25 per cent (Pathak and Dhaliwal, 1981; Dale, 1994). Farmers generally rely on insecticides to combat pest problems of rice. Indiscriminate use of insecticides resulted in the loss of biodiversity of beneficial organisms like parasitic hymenopterans (Dudley *et al.*, 2005). Reduction in the mortality of parasitic hymenopterans due to insecticides is essential for greater sustainability in rice pest management (Heong and Hardy, 2009; Gurr *et al.*, 2011). They show greater stability to ecosystem than any group of natural enemies of insect pests because they are capable of living and interacting at lower host population level. To aid this means of pest control, it is essential that the diversity of Ichneumonids needs to be studied and documented (Dey *et al.*, 1999).

Ichneumonidae is one of the largest and taxonomically difficult families of Ichneumonoidea and are primary or

secondary parasitoids attacking a large range of insect orders in their various stages of development, thereby playing a pivotal role in the control of insect pests in nature. Adults are often associated with moist habitats and extensive ground cover (Matthews, 1974; van Achterberg, 1984). Diversity of Ichneumonids associated with rice ecosystem is poorly studied and far from satisfaction especially in Tamil Nadu. Any additional knowledge in diversity, taxonomy and biology is of potential practical value. In this context, the present study was undertaken to explore the diversity of Ichneumonid fauna in rice ecosystems of Tamil Nadu.

## MATERIALS AND METHODS

### Sites of collection

The survey was carried out in the rice fields during 2015-16 in three different agro climatic zones of Tamil Nadu State viz., western zone (District representation: Coimbatore at, Paddy Breeding Station, Coimbatore, 427 m, 10° 59' 43.24" N 76° 54' 59.22" E), Cauvery delta zone (District representation: Thiruvavur at, Krishi Vigyan Kendra, Needamangalam, 26 m, 10° 46' 23.93" N 79° 25' 0.96" E)

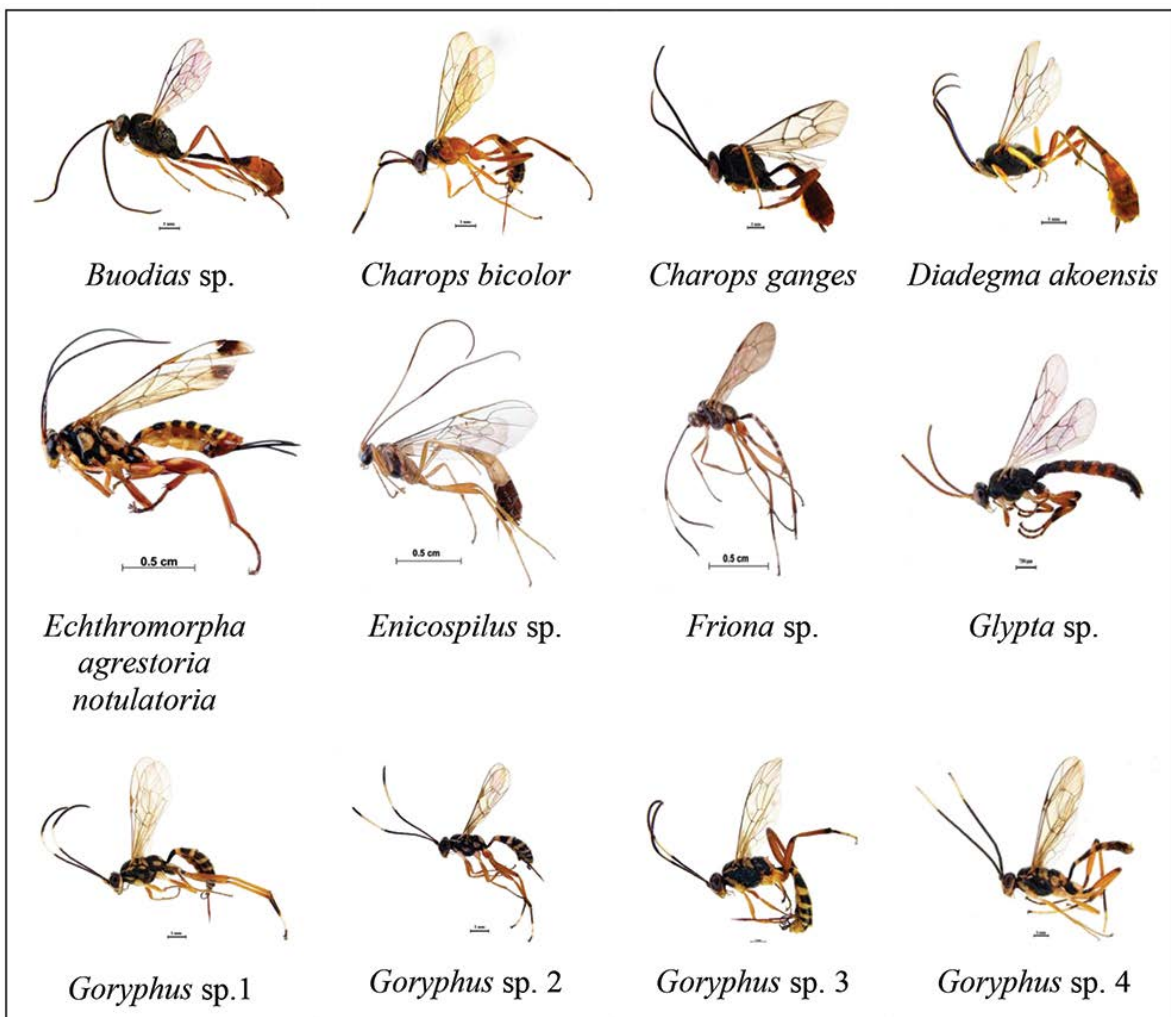
and high rainfall zone (District representation: Kanyakumari at Agricultural Research Station, Thirupathisaram, 17 m, 8° 12' 16.70" N 77° 26' 57.84" E) (Figure 1). Collections were made for 20 consecutive days in each zone to give equal weightage and to minimize chances of variations in collection. The time of sampling in each zone was decided by the rice growing season of the zone and the stage of the crop i.e., 20 days during August- September, 2015 in western zone, October- November, 2015 in high rainfall zone and December, 2015 – January 2016, in Cauvery delta zone.

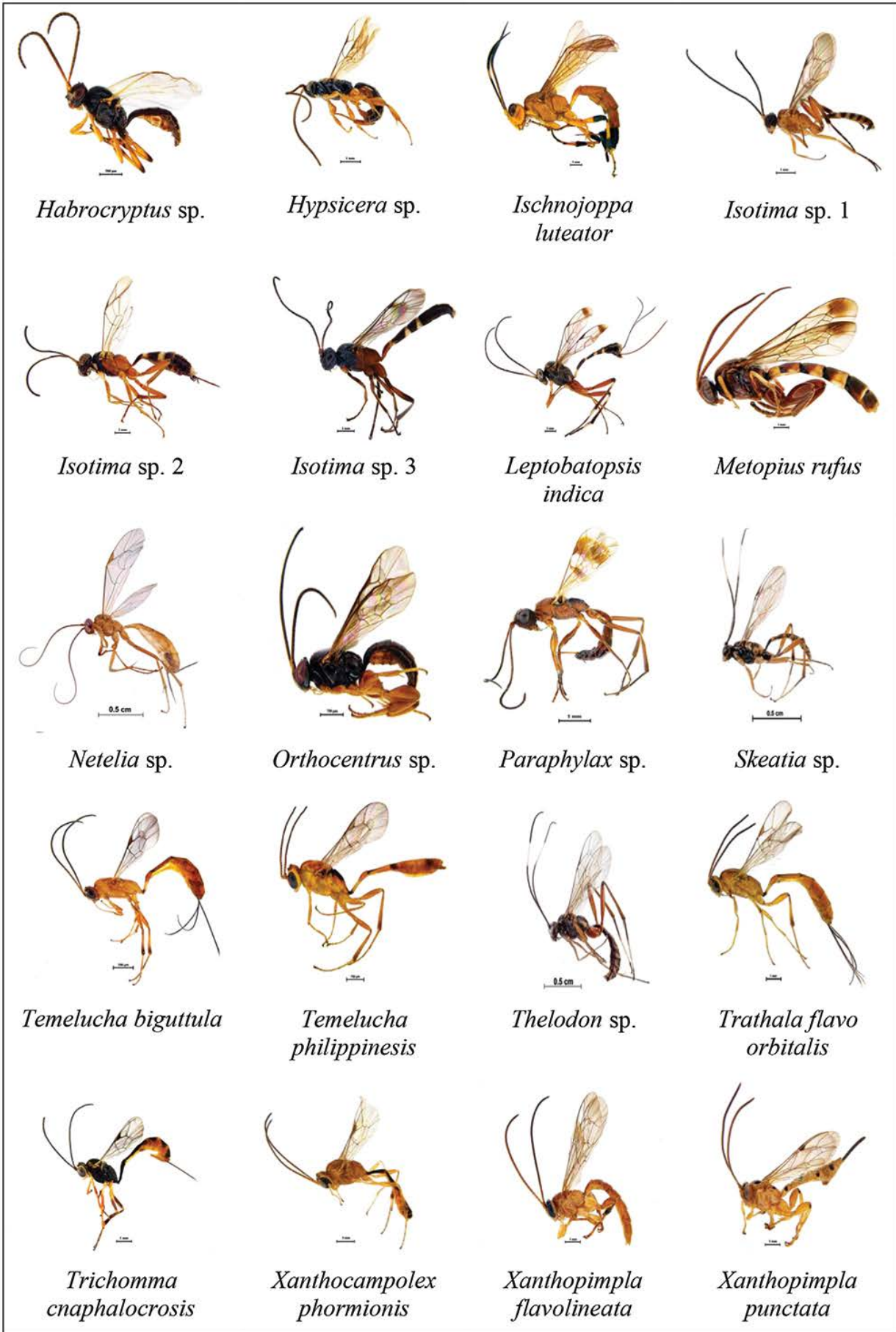
### Methods of collection

Collections of ichneumonids were made by sweep net, yellow pan traps, one set kept at ground level and another erected at canopy levels (Daniel *et al.*, 2018). All the three sampling methods were employed continuously for 20 days.

### Sweep net

The net employed for collecting was essentially similar to an ordinary insect net with 673 mm mouth diameter and a 1076 mm long aluminum handle. The frame can be fitted







**Fig. 1. Thirty-three species of Ichneumonidae collected from three rice growing zones of Tamil Nadu**

to one end of the handle. This facilitates easy separation of the frame. The long handle allows the net to be used as far as possible making the sweeping easier and effective. The net bag was made up of thin cotton cloth. It measures about 600 mm in length and has a well-rounded bottom. The top of the bag which fits around the frame was made up of canvas. The canvas was folded over the frame and sewed in position. Sweeping of vegetation was as random as possible from ground level to the height of the crop. Sweeping was done in early morning and late evening hours for about half an hour per day which involved 30 sweeps. One to and fro motion of the sweep net was considered as one sweep.

#### **Yellow pan traps kept at ground level**

This trap was based on the principle that many insects are attracted to bright yellow colour. Yellow pan traps are shallow trays of 133 mm×195mm and 48 mm deep and was of bright yellow in colour. Altogether, twenty yellow pan traps were installed at ground level in each site on the bunds, half-filled with water containing a few drops of commercially available detergent (to break the surface tension) and a pinch of salt (to reduce the rate of evaporation and to prevent rotting of trapped insects). The spacing between traps was standardized as 1.5 m. The traps were set for a period of 24 hours (Example: traps set at 10 AM on one day were serviced at 10 AM on the following day).

#### **Yellow pan traps erected canopy level**

Erected yellow pan traps were installed at the crop canopy by means of polyvinyl chloride pipes fitted below, with a screw attachment and were installed in 10 numbers per site in the same fashion as yellow pan traps kept at ground level

#### **Preservation and identification of the specimens up to family level**

The parasitoids thus collected were preserved in 70%

ethyl alcohol. The dried specimens were mounted on pointed triangular cards and studied under a Stemi (Zeiss) 2000-C, Labomed Zoom Stereo Luxeo 4D and Photographed under Leica M 205-A stereo zoom microscopes. The insects were identified through conventional taxonomic techniques by following standard keys.

#### **Measurement of diversity**

##### **Relative density**

Relative density of the species was calculated by the formula, Relative Density (%) = (Number of individuals of one species/Number of individuals of all species) X 100.

##### **Alpha diversity**

Alpha diversity of the zones was quantified using Simpson's diversity Index (*SDI*) Shannon-Wiener index ( $H'$ ), Margalef Index ( ) and Pielou's Evenness Index (*EI*).

##### **Simpson's index**

Simpson's diversity index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. It is calculated using the formula,  $D = \sum n(n-1)/N(N-1)$  where  $n$  = total number of organisms of a particular species and  $N$  = total number of organisms of all species (Simpson, 1949). Subtracting the value of Simpson's diversity index from 1, gives Simpson's Index of Diversity (SID). The value of the index ranges from 0 to 1, the greater the value the greater the sample diversity.

##### **Shannon-Wiener index**

Shannon-Wiener index ( $H'$ ) is another diversity index and is given as follows:  $H' = -\sum Pi \ln(Pi)$ , where  $Pi = S/N$ ;  $S$  = number of individuals of one species,  $N$  = total number of all individuals in the sample,  $\ln$  = logarithm to base  $e$  (Shannon & Wiener, 1949) the higher the value of  $H'$  the higher the diversity.

**Margalef index**

Species richness was calculated for the three zones using the Margalef index which is given as Margalef Index,  $= (S-1)/\ln(N)$ ;  $S$  = total number of species,  $N$  = total number of individuals in the sample (Margalef, 1958).

**Pielou's evenness index**

Species evenness was calculated using the Pielou's Evenness Index ( $EI$ ). Pielou's Evenness Index,  $EI = H'/\ln(S)$ ;  $H'$  = Shannon-Wiener diversity index,  $S$  = total number of species in the sample (Pielou, 1966). As species richness and evenness increase, diversity also increases (Magurran, 1988).

**Beta diversity**

Beta diversity is a measure of how different (or similar) ranges of habitats are in terms of the variety of species found in them. The most widely used index for assessment of Beta diversity is Jaccard Index (JI) (Jaccard, 1912), which is

calculated using the equation:  $JI \text{ (for two sites)} = j / (a+b-j)$ , where  $j$  = the number of species common to both sites A and B,  $a$  = the number of species in site A and  $b$  = the number of species in site B. We assumed the data to be normally distributed and adopted parametric statistics for comparing the sites.

**Statistical analysis**

The statistical test ANOVA was also used to check whether there was any significant difference in the collections from three zones. The data on population number were transformed into  $X+0.5$  square root before statistical analysis. The mean individuals caught from three different zones were analyzed by adopting Randomized Block Design (RBD) to find Least Significant Difference (LSD). Critical Difference (CD) values were calculated at five per cent probability level. All these statistical analyses were done using Microsoft Excel 2016 version and Agres software version 3.01.

**Table 1. Comparison of Ichneumonids collected from three rice growing zones of Tamil Nadu**

Species	Zones						Total			
	Western		Cauvery Delta		High Rainfall		No.	%	F	P
	No.	%	No.	%	No.	%				
<i>Buodias</i> sp.	9	4.1	0	0.0	11	4.8	20	3.3	2.24	0.09
<i>Charops bicolor</i>	4	1.8	0	0.0	4	1.8	8	1.3	1.80	0.17
<i>Charops ganges</i>	0	0.0	27	17.0	0	0.0	27	4.5	6.10	0.00
<i>Diadegma akoensis</i>	12	5.5	0	0.0	22	9.7	34	5.6	2.10	0.13
<i>Echthromorpha agrestoria notulatoria</i>	2	0.9	9	5.7	0	0.0	11	1.8	3.39	0.04
<i>Enicospilus</i> sp.	9	4.1	0	0.0	0	0.0	9	1.5	3.67	0.03
<i>Friona</i> sp.	0	0.0	42	26.4	0	0.0	42	7.0	7.76	0.00
<i>Glypta</i> sp.	19	8.7	0	0.0	0	0.0	19	3.1	4.45	0.01
<i>Goryphus</i> sp. 1	0	0.0	0	0.0	31	13.7	31	5.1	5.80	0.00
<i>Goryphus</i> sp. 2	33	15.1	3	1.9	0	0.0	36	6.0	3.60	0.03
<i>Goryphus</i> sp. 3	0	0.0	17	10.7	0	0.0	17	2.8	5.22	0.00
<i>Goryphus</i> sp. 4	0	0.0	0	0.0	9	4.0	9	1.5	2.08	0.13
<i>Habrocryptus</i> sp.	17	7.8	0	0.0	0	0.0	17	2.8	4.12	0.02
<i>Hypsicera</i> sp.	0	0.0	32	20.1	0	0.0	32	5.3	5.32	0.00
<i>Ischnojoppa luteator</i>	1	0.5	0	0.0	7	3.1	8	1.3	3.55	0.03
<i>Isotima</i> sp. 1	16	7.3	4	2.5	0	0.0	20	3.3	3.38	0.04
<i>Isotima</i> sp. 2	1	0.5	0	0.0	8	3.5	9	1.5	2.48	0.09
<i>Isotima</i> sp. 3	24	11.0	0	0.0	0	0.0	24	4.0	5.74	0.00
<i>Leptobatopsis indica</i>	0	0.0	0	0.0	49	21.6	49	8.1	5.63	0.00
<i>Metopius rufus</i>	5	2.3	0	0.0	0	0.0	5	0.8	2.43	0.09
<i>Netelia</i> sp.	8	3.7	0	0.0	0	0.0	8	1.3	3.23	0.04
<i>Orthocentrus</i> sp.	0	0.0	12	7.5	0	0.0	12	2.0	3.52	0.03
<i>Paraphylax</i> sp.	0	0.0	0	0.0	34	15.0	34	5.6	7.21	0.00

<i>Skeatia</i> sp.	7	3.2	0	0.0	0	0.0	7	1.2	3.70	0.03
<i>Temelucha biguttula</i>	0	0.0	0	0.0	6	2.6	6	1.0	2.80	0.06
<i>Temelucha philippinensis</i>	11	5.0	0	0.0	0	0.0	11	1.8	3.97	0.02
<i>Theلودon</i> sp.	0	0.0	13	8.2	0	0.0	13	2.2	1.99	0.14
<i>Trathala flavo orbitalis</i>	14	6.4	0	0.0	0	0.0	14	2.3	5.44	0.00
<i>Trichomma cnaphalocrosis</i>	0	0.0	0	0.0	12	5.3	12	2.0	3.52	0.03
<i>Xanthocampoplex phormionis</i>	0	0.0	0	0.0	9	4.0	9	1.5	3.67	0.03
<i>Xanthopimpla flavolineata</i>	23	10.6	0	0.0	14	6.2	37	6.1	2.26	0.11
<i>Xanthopimpla punctata</i>	0	0.0	0	0.0	3	1.3	3	0.5	1.00	0.37
<i>Xanthopimpla stemmator</i>	3	1.4	0	0.0	8	3.5	11	1.8	1.31	0.27
Total No. collected	218	-	159	-	227	-	604	-	-	-
Species Number	19	-	09	-	15	-	33	-	-	-

%- Relative Density, No. Total number of individuals collected, F-Value, P-Value

**Table 2. Diversity indices of Ichneumonidae from three rice growing zones of Tamil Nadu**

Zones	Mean No. of Ichneumonidae collected/day	Std. Error	SID	H'	$\alpha$	El	$\beta$ %
Western	10.90 (3.21)	± 1.60	0.92	1.15	3.34	0.39	W and C – 12
Cauvery Delta	7.95 (2.46)	± 2.47	0.83	0.89	1.57	0.40	C and H – 0
High Rainfall	11.35 (3.03)	± 2.55	0.89	1.04	2.58	0.38	H and W -25
S.ED	0.42	-	-	-	-	-	-
CD (p=0.05)	0.86	-	-	-	-	-	-

Figures in parentheses are square root transformed values; in a column, means followed by a common letter(s) are not significantly different by LSD (p=0.05).

SID- Simpson's Index of Diversity, H' - Shannon-Wiener Index, -Margalef index,

El- Pielou's index,  $\beta$ -Beta diversity (Jaccard Index) W- Western Zone, C- Cauvery Delta Zone, H- High Rainfall Zone

**Table 3. Ichneumonidae collected in the study with their host**

Parasitoid	Host	Reference
<i>Buodias</i> sp.	Lepidoptera	Rao <i>et al.</i> , 1970
<i>Charops bicolor</i>	<i>Chilo</i> sp.	Rao <i>et al.</i> , 1970
<i>Charops ganges</i>	<i>Pelopidas</i> sp.	Rao <i>et al.</i> , 1970
<i>Diadegma akoensis</i>	<i>Scirphophaga</i> sp.	Nandakumar and Pramod, 1998
<i>Echthromorpha agrestoria notulatoria</i>	<i>Parnara guttata</i>	Rao <i>et al.</i> , 1970
<i>Enicospilus</i> sp.	<i>Sesamia inferens</i>	Rao <i>et al.</i> , 1970
<i>Friona</i> sp.	Crambidae	Rao <i>et al.</i> , 1970
<i>Glypta</i> sp.	Spiders	Jonathan, 2006
<i>Goryphus</i> sp. 1	Crambidae	Nath and Indrani, 1979
<i>Goryphus</i> sp. 2	Crambidae	Nath and Indrani, 1979
<i>Goryphus</i> sp. 3	Crambidae	Nath and Indrani, 1979
<i>Goryphus</i> sp. 4	Crambidae	Nath and Indrani, 1979
<i>Habrocryptus</i> sp.	Unknown	-
<i>Hypsicera</i> sp.	Tineidae	Jonathan, 2006
<i>Ischnojoppa luteator</i>	<i>Pelopidas mathias</i> , <i>Scirphophaga incertulas</i>	Jonathan, 2006
<i>Isotima</i> sp. 1	Crambidae	Jonathan, 2006

<i>Isotima</i> sp. 2	Crambidae	Jonathan, 2006
<i>Isotima</i> sp. 3	Crambidae	Jonathan, 2006
<i>Leptobatopsis indica</i>	<i>Cnaphalocrocis medinalis</i>	Jonathan, 2006
<i>Metopius rufus</i>	<i>Mythimna separata</i>	Katiyar and Gargav, 1971
<i>Netelia</i> sp.	<i>Spodoptera</i> sp	Rao <i>et al.</i> , 1970
<i>Orthocentrus</i> sp.	Lepidoptera	Jonathan, 2006
<i>Paraphylax</i> sp.	Spiders	Rao <i>et al.</i> , 1986
<i>Skeatia</i> sp.	Crambidae	Jonathan, 2006
<i>Temelucha biguttula</i>	<i>Scirpophaga incertulas</i>	Rao <i>et al.</i> , 1970
<i>Temelucha philippinensis</i>	<i>Cnaphalocrocis medinalis</i>	Rao <i>et al.</i> , 1970
<i>Theلودon</i> sp.	Lepidoptera	Jonathan, 2006
<i>Trathala flavo orbitalis</i>	<i>Scirpophaga incertulas</i>	Jonathan, 2006
<i>Trichomma cnaphalocrosis</i>	<i>Cnaphalocrocis medinalis</i>	Kaur <i>et al.</i> , 2000
<i>Xanthocampolex phormionis</i>	Crambidae	Jonathan, 2006
<i>Xanthopimpla flavolineata</i>	<i>Chilo</i> sp.	Pati and Mathur, 1982
<i>Xanthopimpla punctata</i>	<i>Chilo</i> sp.	Pati and Mathur, 1982
<i>Xanthopimpla stemmator</i>	<i>Chilo</i> sp.	Pati and Mathur, 1982

## RESULTS AND DISCUSSION

Totally 604 ichneumonid individuals were collected from rice ecosystem in the present study. These 604 individuals represent 14 sub families, 24 genera and 33 species. *Trichomma cnaphalocrosis* Uchida was the only species that was collected under the subfamily Anomaloninae. Two species *viz.*, *Glypta* sp. and *Leptobatopsis indica* (Cameron) were collected under the subfamily Banchinae. Under the subfamily Campopleginae, four species *viz.*, *Charops bicolor* (Szépligeti), *Charops ganges* Cushman, *Xanthocampolex phormionis* Gupta and Gupta, and *Diadegma akoensis* (Shiraki) were collected. Species such as *Temelucha biguttula* (Munakata), *Temelucha philippinensis* (Ashmed) and *Trathala flavo orbitalis* (Cameron) were collected under the sub-family Cremastinae. Thirteen species from subfamily Cryptinae, *viz.*, four species of *Goryphus* Holmgren and three species of *Isotima* Foerster, one species each of the six genera, *Buodias* sp., *Friona* sp., *Habrocryptus* sp., *Skeatia* sp., *Theلودon* sp. and *Paraphylax* sp. were also identified in the collections. Under Ichneumoninae, *Ischnojoppa luteator* (Fabricius) was the only species found. *Hypsicera* sp. and *Metopius rufus* (Ashmead) were collected under Metopiinae subfamily. *Enicospilus* sp. was the only species that was collected under the subfamily Ophioninae and *Orthocentrus* sp. was the only species that was collected under the subfamily Orthocentrinae. Under Pimplinae subfamily, four species *viz.*, *Echthromorpha agrestoria notulatoria* (Fabricius), *Xanthopimpla flavolineata* Cameron, *Xanthopimpla punctata* (Fabricius), and *Xanthopimpla stemmator* (Thunberg) were collected. Among the 33 species that were collected in the

present study, *L. indica* was found to be the most dominant species in rice ecosystem with a relative density of 8.1 per cent. Totally 19 species were collected from western zone, 9 species from Cauvery delta zone and 15 species from high rainfall zone (Table 1). In the present study, 9 species were collected from the western zone alone *viz.*, *Enicospilus* sp., *Glypta* sp., *Habrocryptus* sp., *Isotima* sp. 3, *M. rufus*, *Netelia* sp., *Skeatia* sp., *T. philippinensis* and *T. flavo orbitalis*. From Cauvery delta zone alone, six species were collected *viz.*, *C. ganges*, *Friona* sp., *Goryphus* sp. 3, *Hypsicera* sp., *Orthocentrus* sp. and *Theلودon* sp. From high rainfall zone alone, 8 species were collected *viz.*, *Goryphus* sp. 1, *Goryphus* sp. 4, *L. indica*, *Paraphylax* sp., *T. biguttula*, *T. cnaphalocrosis*, *X. phormionis* and *X. punctata*. Species such as *Buodias* sp., *C. bicolor*, *D. akoensis*, *I. luteator*, *Isotima* sp. 2, *X. flavolineata* and *X. stemmator* were collected from both high rainfall and western zones. Interestingly, no species was found common to both western zone and high rainfall zone. Three species *viz.*, *E. agrestoria notulatoria*, *Enicospilus* sp. *Goryphus* sp. 2. and *Isotima* sp. 1 were found common to western and Cauvery delta zones. The ANOVA test results clearly indicated that, the P-value of 22 species such as *D. akoensis*, *E. agrestoria notulatoria*, *Friona* sp., *Glypta* sp., *Goryphus* sp. 1, *Goryphus* sp. 2, *Goryphus* sp. 3, *Habrocryptus* sp., *Hypsicera* sp., *I. luteator*, *Isotima* sp. 1, *Isotima* sp. 3, *L. indica*, *Netelia* sp., *Orthocentrus* sp., *Paraphylax* sp., *Skeatia* sp., *T. philippinensis*, *T. flavo orbitalis*, *T. cnaphalocrosis* and *X. phormionis* was lesser than 0.05 and so it is evident that there was significant difference between the zones for these 22 species.

Mean number of ichneumonids collected per day from western zone was  $10.90 \pm 1.60$ , while it was  $7.95 \pm 2.47$  from Cauvery delta zone and  $11.35 \pm 2.55$  from high rainfall zone. From the present study, it was found out that western zone was the most diverse zone with a Simpson's index of 0.92, followed by high rainfall zone (0.89) and Cauvery delta zone (0.83). The Shannon- Wiener index for western, Cauvery delta and high rainfall zones was 1.15, 0.89 and 1.04, respectively. Margalef index also indicated that western zone was the species rich zone (3.34) followed by high rainfall zone (2.28) and Cauvery delta zone (1.57). As far as species evenness was concerned, Cauvery delta zone is high in evenness (0.40), followed by western zone (0.39) and high rainfall zone (0.38) (Table 2).

On comparing the species similarities using the Jaccard's index among the three zones taken in pairs, it was found that 12 per cent similarity was observed between Western and Cauvery delta zones and no similarity between high rainfall and Cauvery delta zones and 25 per cent similarity between high rainfall and western zones. Host insects of the parasitoid that were collected in the present study were provided in Table 3.

The difference in indices among the zones may be due to the factor that the enhancement of biodiversity in rice would depend on the biodiversity of the surrounding environment; after transplanting rice, many organisms including pests, natural enemies and neutral species immigrate to colonize rice paddies from the surrounding environment (Buchs 2003). Daniel *et al.* (2017) obtained similar results by conducting experiments to assess the diversity of Pteromalidae of rice ecosystems in Tamil Nadu. The species composition among elevational zones can indicate how community structure changes with biotic and abiotic environmental pressures (Shmida and Wilson, 1985; Condit *et al.* 2002). Studies on the effect of elevation on species diversity of taxa such as spiders (Sebastian *et al.* 2005), moths (Axmacher and Fiedler, 2008), paper wasps (Kumar *et al.* 2008) and ants (Smith *et al.* 2014) reported that species diversity decreased with increase in altitude. However, according to Janzen (1976), diversity of parasitic Hymenoptera is not as proportionately reduced by elevation as in other insect groups, a fact that is in support of our results. A similar study conducted by Shweta and Rajmohana (2016) to assess the diversity of members belonging to the subfamily Scelioninae also declared that the elevation did not have any major effect on the overall all diversity patterns. Daniel and Ramaraju (2019) conducted experiments in Tamil Nadu to understand the diversity patterns of 28 different families under Hymenoptera and found out that High rainfall zone is the most diverse zone in the state. Diversity also

depends on the varietal preference of the natural enemies (Daniel *et al.*, 2019a). The Elevational Diversity Gradient (EDG) in ecology proposes that species richness tends to increase as elevation increases, up to a certain point creating "diversity bulge" at moderate elevations (McCain & Grytnes, 2010). The elevation dealt with in this work ranged from 17-427 m which was not very high. So taking into account the scale and extent of elevational gradients, it can be said that species diversity and richness have not showed any correlation i.e. species diversity and richness were not proportional with that of elevation. Daniel and Ramaraju (2017) assessed the diversity of chalcididae among three rice growing tracts of Tamil Nadu and concluded that there was no correlation between elevation and species richness. This fact supports our present study. Daniel *et al.* (2019b) conducted research to find out the diversity patterns of Braconidae in Tamil Nadu and concluded that High rainfall zone and Western zone were rich in the diversity of Cauvery delta zone. Studies on the altitudinal variation of parasitic Hymenoptera assemblages in an Australian sub-tropical rainforest by Hall *et al.* (2015) did not record any distinct assemblage at each altitude, at the morphospecies level, even though there was a clear separation between 'upland' and 'lowland' assemblages. To detect minute changes in species assemblages, species level sorting is found to give the best result (Grimbacher *et al.* 2008). The area under cultivation turns out to be a very important factor with respect to abundance and species density in rice fields (Wilby *et al.* (2019b) 2006). Diversity of parasitoids also depends on weather factor prevailing in the area of the study (Daniel *et al.*, 2019c). Diversity of Mymaridae in Tamil Nadu state were assessed by Daniel *et al.* (2019d) and concluded that High rainfall zone and Western zones were more diverse. All these findings matched with our present findings.

## CONCLUSION

This study reveals the diversity of ichneumonids of three different rice ecosystems of Tamil Nadu, where the western zone is the most diverse and the Cauvery delta zone being the least. The reasons for the significant changes in diversity of parasitoids and their host insects are to be further studied. Influence of weather factors on the diversity patterns of parasitoids, varietal preferences of parasitoids and elevational influence on the abundance of parasitoids are to be further studied. There is much scope for research to be taken on these aspects.

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## REFERENCES

- Axmacher JC, Fiedler K. 2008. Habitat type modifies geometry of elevational diversity gradients in Geometrid moths (Lepidoptera: Geometridae) on Mt. Kilimanjaro, Tanzania. *Trop Zool.* **21**: 243-251.
- Buchs W. 2003. Biotic indicators for biodiversity and sustainable agriculture-introduction and background. *Agric Ecosyst Environ.* **98**: 1-16. [https://doi.org/10.1016/S0167-8809\(03\)00068-9](https://doi.org/10.1016/S0167-8809(03)00068-9).
- Condit R, Pitman N, Leigh EG, Chave J, Terborgh J, Foster RB, Nunez P, Aquilar S, Valencia R, Villa, G, Muller-landau, HC, Losos E, Hubbell SP. 2002. Beta diversity in tropical forest trees. *Science* **295**: 666-69. <https://doi.org/10.1126/science.1066854>. PMID: 11809969.
- Dale D. 1994. Insect pests of the rice plant - Their biology and ecology. pp. 363-487. In: Heinrichs EA (Ed.) *Biology and management of rice insects*. Wiley Eastern Ltd., India & IRRI, Manila, Philippines.
- Daniel JA, Ramaraju K. 2017. Diversity of chalcidids (Chalcididae: Hymenoptera) among three rice growing zones of Tamil Nadu, India. *J Entomol Zool Studies.* **5**(3): 541-46.
- Daniel JA, Ramaraju K, Kumar SM, Jeyaprakash P, Chitra N. 2019a. Study on varietal preferences and seasonal incidence of parasitoids of rice pests. *Entomon* **44**(1): 65-72. <https://doi.org/10.33307/entomon.v44i1.427>.
- Daniel JA, Ramaraju K, Ranjith AP. 2019b. On a collection of braconidae from three rice growing zones of Tamil Nadu. *Indian J Entomol.* **81**(1): 18-24. <https://doi.org/10.5958/0974-8172.2019.00040.3>.
- Daniel JA, Ramaraju K, Kumar SM, Jeyaprakash P, Chitra N. 2019c. Influence of weather on the parasitoid catches in three rice growing agroclimatic zones of Tamil Nadu. *Indian J Entomol.* **81**(1): 55-60. <https://doi.org/10.5958/0974-8172.2019.00032.4>.
- Daniel JA, Ramaraju K, Ramesh Kumar A. 2019d. Comparative studies of mymarid diversity from three different zones of paddy ecosystem in Tamil Nadu, India. *Entomon.* **44**(3): 173-82. <https://doi.org/10.33307/entomon.v44i3.458>.
- Daniel JA, Ramaraju K, Raseena Farsana VK, Sureshan PM. 2017. Diversity of Pteromalids (Pteromalidae: Hymenoptera) among three rice growing Zones of Tamil Nadu, India. *Ann Plant Prot Sci.* **25**(2): 298-303. <https://doi.org/10.5958/0974-0163.2017.00013.1>.
- Daniel JA, Ramaraju KS, Mohan Kumar, Jeyaprakash P, Chitra N. 2018. A study on five sampling methods of parasitic hymenopterans in rice ecosystem. *J Biol Control* **32**(3): 187-92. <https://doi.org/10.18311/jbc/2018/22104>.
- Daniel JA, Ramaraju K. 2019. Diversity of parasitic Hymenoptera in three rice-growing tracts of Tamil Nadu, India. *J Threat Taxa* **11**(13): 14681-90. <https://doi.org/10.11609/jott.4529.11.13.14681-14690>.
- Dey D, Raghuraman, M, Gupta SL, Ramamurthy VV. 1999. A checklist of the biodiversity of hymenopterous parasitoids associated with rice agroecosystem. *Shashpa* **1**: 1-128.
- Dudley N, Baldock D, Nasi R, Stolton S. 2005. Measuring biodiversity and sustainable management in forests and agricultural landscapes. *Philos Trans R Soc Lond B Biol Sci.* **360**(1454): 457-70. <https://doi.org/10.1098/rstb.2004.1593>. PMID: 15814357, PMCID: PMC1569449.
- Fritz LL, Heinrichs EA, Machado V, Andreis TF, Pandolfo M, Salles SM, Oliveira JV. 2011. Diversity and abundance of arthropods in subtropical rice growing areas in the Brazilian south. *Biodivers Conserv.* **20**(10): 2211-24. <https://doi.org/10.1007/s10531-011-0083-3>.
- Grimbacher PS, Catterall CP, Kitching RL. 2008. Detecting the effects of environmental change above the species level with beetles in a fragmented tropical rainforest landscape. *Ecol Entomol.* **33**: 66-79.
- Gurr GM, Liu J, Read DMY. 2011. Parasitoids of Asian rice planthopper (Hemiptera: Delphacidae) pests and prospects for enhancing biological control. *Ann Appl Biol.* **158**: 149-76. <https://doi.org/10.1111/j.1744-7348.2010.00455.x>.
- Hall CR, Burwell CJ, Nakamura A, Kitching RL. 2015. Altitudinal variation of parasitic Hymenoptera assemblages in Australian subtropical rainforest. *Austral Entomol.* **54**: 246-58. <https://doi.org/10.1111/aen.12114>.
- Heckman CW. 1979. Rice field ecology in North East Thailand. *Monogr Biol.* **34**: 228. <https://doi.org/10.1007/978-94-009-9591-8>.
- Heong KL, Hardy B. 2009. Planthoppers: New Threats to the Sustainability of Intensive Rice Production Systems in Asia. International Rice Research Institute, Philippines; p. 257-80.
- Heong KL, Aquino GB, Barrion AT. 1991. Arthropod community structures of rice ecosystems in the

- Philippines. *Bull Entomol Res.* **81**(4): 407-16. <https://doi.org/10.1017/S0007485300031977>.
- Jaccard P. 1912. The distribution of the flora in the alpine zone. *New Phytologist* **11**: 37-50. <https://doi.org/10.1111/j.1469-8137.1912.tb05611.x>.
- Janzen DH. 1976. Changes in the arthropod community along an elevational transect in the Venezuelan Andes. *Biotropica* **8**: 193-203. <https://doi.org/10.2307/2989685>.
- Jonathan JK. 2006. Ichneumonologia Indica, Part-I, Hymenoptera: Ichneumonidae, Published by the Director, Zool. Suru. India, Kolkata; p. 1-680.
- Katiyar OP, Gargav VP. 1971. New record of some parasites of rice army worms. *JNKVV Res J.* **5**(1): 56.
- Kaur S, Shenhmar M, Brar KS. 2000. Parasitoids of insect pests of rice in the Punjab. *Insect Environ.* **6**(2): 82-83.
- Kiritani K. 2009. *A comprehensive list of organisms associated with paddy ecosystems in Japan*. Saga: Daido Printing Co. Ltd; p.1-90.
- Kumar A, Longino JT, Colwell RK, Donnell SO. 2008. Elevational patterns of diversity and abundance of Eusocial paper wasps (Vespidae) in Costa Rica. *Biotropica* **41**: 338-46. <https://doi.org/10.1111/j.1744-7429.2008.00483.x>.
- Magurran EA. 1988. Ecological Diversity and its Measurement. Croom Helm, Australia; p. 215. <https://doi.org/10.1007/978-94-015-7358-0>.
- Margalef R. Temporal succession and spatial heterogeneity in phytoplankton. 1958. p. 323-47. In: Buzzati-Traverso AA (Ed.). *Perspectives in marine biology*. Berkeley: University of California Press.
- Matthews RW. 1974. Biology of Braconidae. *Ann Rev Entomol.* **19**: 15-32. <https://doi.org/10.1146/annurev.en.19.010174.000311>.
- McCain CM, Grytnes J. 2010. Elevational Gradients in Species Richness. eLS, Published; Online: 15 Sep 2010. <https://doi.org/10.1002/9780470015902.a0022548>.
- Nandakumar C, Pramod MS. 1998. Survey of natural enemies in a rice ecosystem. *Insect Environ.* **4**(6): 16.
- Nath DS, Indrani SH. 1979. Ichneumonid parasitoids of the rice yellow borer in West Bengal, India. *IRRI Newsl.* **4**(2): 19.
- Pathak MD, Dhaliwal GS. 1981. Trends and strategies for rice insect problems in tropical Asia. International Rice Research Institute Research Paper; p. 15.
- Pati P, Mathur KC. 1982. New records of parasitoids attacking rice leaf folder *Cnaphalocrocis medinalis* Guenee in India. *Curr Sci.* **51**(18): 904-05.
- Pielou EC. 1966. The measurement of diversity in different types of biological collections. *J Theor Biol.* **13**: 131-144.
- Rao VN, Israel P, Behera KS. 1986. Spiders in rice fields and their egg parasitoids. *Int Rice Commission Newslett.* **35**(2): 40-42.
- Rao VP, Chacko MJ, Phalak VR, Rao D. 1970. Leaf feeding caterpillars of paddy and their natural enemies in India. *J Bombay Nat Hist Soc.* **66**(3): 455-77.
- Sebastian PA, Mathew MJ, Beevi SP, Joesph J, Biju CR. 2005. The spider fauna of the irrigated rice ecosystem, in central Kerala, India. *J Arachnol.* **33**: 247-55. <https://doi.org/10.1636/05-08.1>.
- Shannon CE and Wiener W. 1949. *The Mathematical Theory of Communication*. Urbana, University of Illinois Press; p. 177.
- Shmida A, Wilson MV. 1985. Biological determinants of species diversity. *J Biogeography* **12**: 1-20. <https://doi.org/10.2307/2845026>.
- Shweta M, Rajmohana K. 2016. Egg parasitoids from the subfamily Scelioninae (Hymenoptera: Platygasteridae) in irrigated rice ecosystems across varied elevational ranges in southern India. *J Threat Taxa* **8**(6): 8898-904. <https://doi.org/10.11609/jott.2061.8.6.8898-8904>.
- Simpson EH. 1949. Measurement of species diversity. *Nature* **163**: 688. <https://doi.org/10.1038/163688a0>.
- Smith MA, Hallwachs W, Janzen DH. 2014. Diversity and phylogenetic community structure of ants along a Costa Rican elevational gradient. *Ecography* **37**: 001-12. <https://doi.org/10.1111/j.1600-0587.2013.00631.x>.

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van Achterberg, C. 1984. Essay on the phylogeny of Braconidae (Hymenoptera: Ichneumonidae). *Tijdschr Entomol.* **105**: 41-58.

Wilby A, Lan LP, Heong KL, Huyen NPD, Quang NH, Minh NV, Thomas MB. 2006. Arthropod diversity

and community structure in relation to land use in the Mekong Delta, Vietnam. *Ecosystems* **9**: 538-49. <https://doi.org/10.1007/s10021-006-0131-0>.