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Diversity of Encyrtidae (Hymenoptera: Chalcidoidea) collected with Malaise traps in the tropical dry forest of San Javier, Sonora, Mexico

Diversidad de Encyrtidae (Hymenoptera: Chalcidoidea) recolectada con trampas Malaise en el bosque tropical caducifolio de San Javier, Sonora, México

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Abstract. Results of a faunistic study of the Encyrtidae family (parasitoid wasps) of the tropical dry forest of San Javier, Sonora, Mexico are presented. The study was carried out from November 2003 to October 2004. Collections using Malaise trapping were made during 5 days of every month. A total of 52 species, 27 genera and 2 subfamilies were recorded. The subfamily with the largest number of recorded species was Encyrtinae, with 19 genera and 32 species, followed by Tetracneminae, with 8 genera and 20 species. The genus with the largest number of recorded species was *Metaphycus* with 10. Species richness was analyzed using parametric models; the best-fitting model was the Logarithmic, which is unbounded. Species had low abundance. Species richness and abundance varied with time, with the highest values recorded in the dry season. The fauna of San Javier was more similar to that of Huautla, Morelos, than to that of Huatulco, Oaxaca, both previously studied.

Key words: Hymenoptera, parasitoid wasps, diversity, phenology, Mexico.

Resumen. Se presentan los resultados del estudio de la fauna de la familia Encyrtidae (avispas parasitoides) en el bosque tropical caducifolio de San Javier, Sonora, México. El estudio se llevó a cabo de noviembre del 2003 a octubre del 2004. Las recolectas se realizaron durante 5 días de cada mes, el método de recolecta fue trampas Malaise. Se registró un total de 52 especies, 27 géneros y 2 subfamilias. La subfamilia con el mayor número de especies fue Encyrtinae, con 19 géneros y 32 especies, seguida por Tetracneminae con 8 géneros y 20 especies. El género con mayor número de especies fue *Metaphycus* con 10. El valor de la riqueza estimada de especies fue analizado usando los modelos paramétricos, el mejor fue el logarítmico, el cual es indefinido. Las especies no fueron abundantes. La riqueza y abundancia de las especies varió con el tiempo, registrándose el valor más grande durante la temporada de secas. La fauna fue más parecida a la de Huautla, Morelos que a la de Huatulco, Oaxaca, ambas previamente estudiadas.

Palabras clave: Hymenoptera, avispas parasitoides, diversidad, fenología, México.

Introduction

Diversity of hymenopteran parasitoids in tropical regions is generally higher than in any other region of the world (Wolda, 1983; Noyes, 1989). In contrast, tropical regions are the least studied and their biodiversity is being lost more quickly (Wilson, 1988). Tropical Dry Forests (TDF) are the most reduced by cultivation, with almost half of the biome's native habitats replaced with cultivated lands; they show a very rapid increase of change in habitat and climate; an increasing impact by invasive species, a continuing overexploitation of their resources, and a rapid increase in pollution (Millennium Ecosystem Assessment, 2005).

In Mexico, tropical dry forest covers about 8% of the national territory (Trejo, 1998) and unlike the humid tropical communities, which share much of their richness with Central America, they have a large number of endemics (Ceballos and García, 1995). Unfortunately, this community is the most globally threatened (Janzen, 1988), and the study of its biodiversity is becoming increasingly

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urgent to generate information that will contribute to its conservation.

Among insects, Encyrtidae is a group of highly diverse micro-hymenopterans (Noyes, 1989). They play an important role in communities, as they are endoparasitoids or hyperparasitoids of other arthropods (Noyes, 1988). They are of great biological importance in natural communities, since they help to regulate the populations of many species of insect hosts (Noyes, 1988).

Considering this scenario, a group of researchers from the Institute of Biology, of the Universidad Nacional Autónoma de México (UNAM) initiated a long term project to understand the diversity and distribution patterns of various groups of insects in the TDF in Mexico. As part of this project, studies were conducted in 8 regions of the country. The Encyrtidae of 2 of the 8 collected localities [Huautla, Morelos (Rodríguez-Velez and Wolley, 2005) and Huatulco, Oaxaca (Rodríguez-Velez et al., 2009)] have been previously analyzed.

This contribution presents results of survey work on the family Encyrtidae in San Javier, Sonora, Mexico, and a comparison with the 2 previously analyzed regions, in order to provide a better understanding of its local and temporal diversity and also to increase the existing general knowledge of this group in TDF.

Materials and methods

Study site. The Sierra San Javier is located in the central-eastern part of Sonora, Mexico, in the extreme southwest of the Sierra Aliso (Varela-Espinosa, 2005). The area under study is located between 28° 32' 17" - 28° 36' 41" N and 109° 44' 22"- 109° 39' 54" W. The climate is of the type (A) Ca (wo) (x') (e') according to the Koppën classification modified by García (García, 1981). It is characterized as semi hot temperate with a hot summer, with predominance of rain in summer and low rainfall in winter, and a thermal oscillation of 14.2 °C. The annual average temperature is 18.7 °C and the annual average precipitation is 638.2 mm (Varela-Espinosa, 2005). The TDF is the dominant vegetation, which varies in composition and structure according to the relief of the region. Dominant species at medium elevations are *Lysiloma divaricatum*, *Jatropha cordata*, *Chloroleucum mangenese*, and *Croton flavescens* (Varela-Espinosa, 2005).

Collection method. The collection method was Malaise traps type Townes (Townes, 1972). These traps were designed to catch flying insects (Steyskat, 1981), and they have shown to be a method with a constant efficiency and representation in the capture of insects (Kitching et al., 2001). They have also been used with great success to collect micro-hymenopterans (Noyes, 1982). Six Malaise traps were placed in different locations inside the forest and remained in the same place throughout the year. Each trap was operated for 5 days of every month. Seventy percent ethanol was used as a preservation fluid. Fieldwork was carried out between November 2003 and October 2004. Encyrtidae from Huautla, Morelos and Huatulco, Oaxaca were collected in the same way as those from San Javier but in different years (Huautla: November 1995 – October 1996, Huatulco: February 2005 – January 2006). This permitted a better comparison of diversity of Encyrtidae among localities.

Laboratory work. Laboratory work included the processing of 67 samples (5 of the 72 original samples were lost); this process involved the separation of the encyrtids from each sample, as well as drying, mounting, and labeling them. Before mounting, the specimens were dehydrated using different ranks of alcohol and amyl acetate to prevent the specimen's collapse. Identification of encyrtids was made with the help of specialized literature, such as keys to the genera of Nearctic Encyrtidae (Noyes et al., 1997) and Neotropical Encyrtidae (Noyes, 1980), and by comparison with scientific collections.

Methods of analysis. The values of richness and abundance are the number of species and individuals collected. Diversity was analyzed with the Shannon-Weiner (H´)´ s index; also from Shannon's index, evenness was calculated, which is a measure of the homogeneity of species abundance in the community. Dominance was analyzed with the Simpson´s index, which weights towards the abundance of the most common species. These values were obtained with the program Past (Hammer et al., 2001).

Because the species richness of any sample obtained usually underestimates actual species richness values of individuals in a locality (Chazdon et al., 1998), an alternative statistical method proposed by Díaz-Francés and Gorostiza (Díaz-Fracés and Soberón, 2005) was used to determine how close we were to collecting the real richness of the encyrtids obtained with Malaise traps. The parametric models used were Logarithmic, Clench, and Exponential, which assume that the probability of finding a new species depends on the size of the list and the time spent in the field (Díaz-Fracés and Soberón, 2005). These estimation methods were fitted to data sets through user-friendly Species Accumulation Function software available free on the Internet at: http://www.cimat.mx/index.php?m=266. Species collected in the 6 Malaise traps during 5 days of each month were considered as a sample (12 in total).

For the phenology analysis, the data were assigned to 2 seasons: the rainy season which lasted from June to November, and the dry season, which lasted from December to May. The difference in richness and abundance of the Encyrtidae species was observed for each season to understand the local and temporal distribution pattern of the species.

The similarity index (Bray-Curtis) was calculated among 3 localities with TDF as dominant vegetation: Huautla, Morelos; Huatulco, Oaxaca; and San Javier, Sonora. These values were obtained with the program BioDiversity Pro (McAlleece et al., 1999).

Voucher specimens. All the material was deposited in the entomological collection of the Institute of Biology of UNAM (CNIN).

Results

Richness. Fifty-two species of Encyrtidae were collected, of which 17 could be identified to species level with certainty. The remainder belongs to undescribed species. The complete list is presented in Appendix 1.

The 52 recorded species belong to 27 genera distributed in 2 subfamilies. The subfamily with the greatest number of genera and species is Encyrtinae, with 19 genera (70% of the total) and 32 species (62% of the total). Tetracneminae is represented by 8 genera (30%) and 20 species (38%). The genus represented by the greatest number of species was *Metaphycus* with 10, followed by *Anagyrus* with 6, *Acerophagus* with 4, and *Ooencyrtus*, *Gyranusoidea* and *Tetracnemus* with 3 each, and *Cheiloneurus* and *Coccidencyrtus* with 2, while the remaining genera were represented by only 1 species. Seventy percent of the genera were represented by only 1 species. González-Hernández and Woolley (2001) referred to 7 genera for the state of Sonora, of which 4 were collected in the Sierra San Javier.

Estimated richness. After 12 months of collecting, 52 different species had been observed. The observed species-accumulation data and the estimated species-accumulation curves under the 3 different models (Logarithmic, Clench and Exponential) were fitted using the Species Accumulation Function freeware program (Fig. 1).

The best-fitting model was the Logarithmic; which was only 2.614 times more probable than the second-best-fitting model, Clench, and 9.635 times more probable than the Exponential model. The Clench model was only 3.685 times more probable than the Exponential model. Nevertheless, the 3 models predicted long-term behaviors. The total number of species under the Clench model was 73.86 and 54.99 under the Exponential model, the total number of species under the Logarithmic model was unbounded.

Abundance. A total of 142 individuals were collected throughout the study. Species were not abundant, many

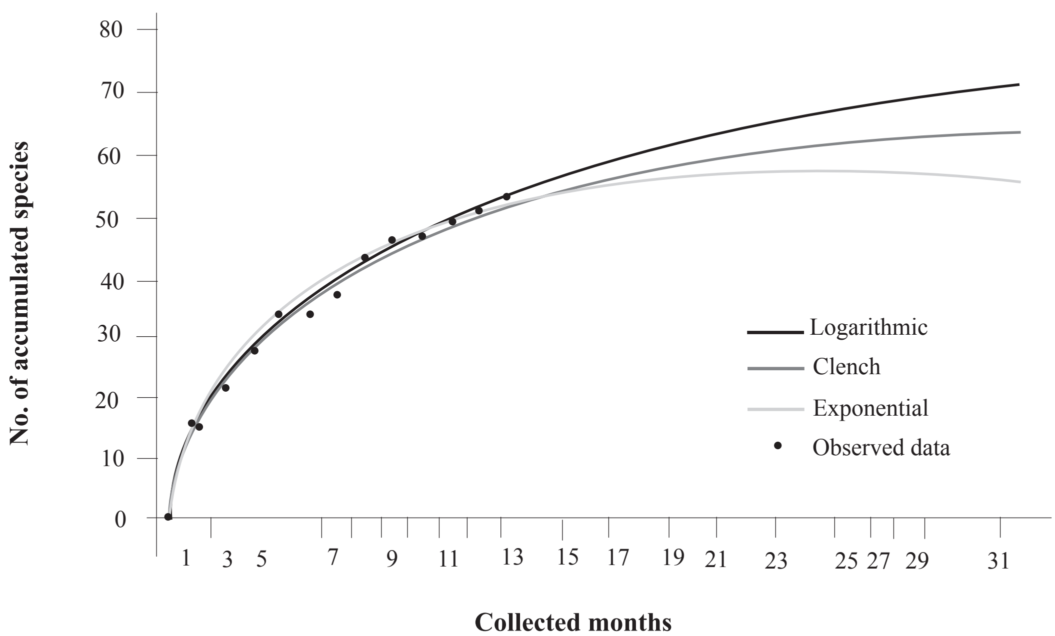

Figure 1. Observed and estimated species accumulation curves of the Encyrtidae fauna of San Javier, Sonora, Mexico.

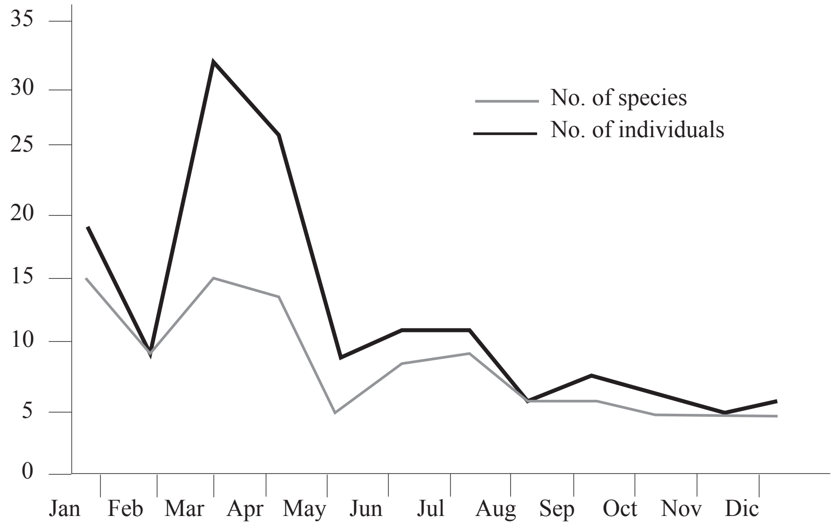

Figure 2. Pattern of species richness and abundance of Encyrtidae recorded per month in San Javier, Sonora, Mexico.

were represented by singletons. The most abundant genus was *Anagyrus*, with 38 individuals, followed by *Ooencyrtus* with 32 and *Metaphycus* with 14 individuals, *Pseudleptomastix* with 10, *Pseudaphycus* with 9, *Rythidothorax* with 5, *Aenasius* and *Tetracnemus* with 4, *Cheiloneurus* and *Gyranusoidea* with 3, *Coccidencyrtus*, *Leptomastix* and *Trjapitzinellus* with 2, the remaining genera are represented by only 1 individual.

The most abundant species was *Anagyrus* sp. 3 with 25 individuals, followed by *Ooencyrtus pityocampae* with 21, *Pseudleptomastix* sp. 1 with 10, *Ooencyrtus* sp. 1 and *Pseudaphycus* sp.1 with 9, *Anagyrus aligarhensis* and *Rythidothorax marlatti* with 5, *Anagyrus lopezi* with 4, *Metaphycus stanleyi* with 3, 8 species were represented with only 2 specimens and 35 species with only 1 individual.

Phenology. The diversity values calculated with the Shannon's index by month varied during the year (Table 1), with the lowest value (1.3) recorded in May, October, November, and December, and the highest (2.5) recorded in January. The lowest value of evenness was recorded in March (0.68) and the highest (1) in February, August, and November (Table 1). Dominance was the lowest in January and April (0.09) and the highest in May, October and December (0.28) (Table 1).

The number of species active varied with time and was the greatest during the dry season (Table 2). The highest number of species was recorded during January (15), March (15), and April (14), and the lowest number during May, October, November, and December, with 4 for each month (Fig. 2). Seasonally, 28 species (54% of total) were only present during the dry season, 14 (27%) during the rainy season, and 10 (19%) during both seasons (Table 2). There were also temporal differences in abundance. The greatest number of individuals was recorded in March (32) and the lowest in November (4) (Fig. 2). Ninety-nine individuals were present during the dry season, 70% of the total abundance. Forty-three individuals were present during the rainy season, 30% of the total (Table 2).

Thirty-five species (67%) were only active 1 month, 9 (17%) for 2 months, 1 (2%) for 3 months, 3 (6%) for 4 months, 1 (2%) for 5 months, 2 (4%) for 7 months and 1 (2%) for 9 months. This indicates that the adults of 84% of the species were active for less than 2 months out of the entire year. Of the 7 species recorded as active during 4 or more months, 6 were active during both seasons and 1 only for the dry season.

Comparison with other regions with tropical dry forest. Huautla, Morelos and Huatulco, Oaxaca, are localities with tropical dry forest. These localities were collected as the same way as San Javier, Sonora, for periods of 1 year with monthly collecting for 5 days each, each with 6 Malaise traps per month. The number of species recorded in San Javier (52 species), was lower than the number of species recorded in the region of Huautla (82 species), (Rodríguez-Velez and Woolley, 2005) and higher than Huatulco (17 species) (Rodríguez-Velez et al., 2009).

Eight species recorded from San Javier (15% of the total) are shared with Huautla and Huatulco, 17 (33%) species are shared only with Huautla, and 1 (2%) species is shared only with Huatulco. Of the 27 genera recorded from San Javier, 6 (22% of the total) (*Anagyrus*, *Gyranusoidea*,

Table 1. Diversity, evenness and dominance for the Encyrtidae collected with Malaise traps in the locality of San Javier, Sonora, Mexico

	Jan	*Feb*	*Ma*	*Apr*	*Ma*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dic*
Diversity	2.5	2.1	2.3	2.4	1.3	1.9	2.1	1.6	1.5	1.3	1.3	1.3
Evenness	0.87	1	0.68	0.86	0.93	0.89	0.94	1	0.94	0.94	1	0.94
Dominance	0.09	0.11	0.14	0.09	0.28	0.15	0.12	0.2	0.22	0.28	0.25	0.28

Diversity and evenness were calculated with the Shannon's index. Dominance was calculated with the Simpson's index.

Table 2. Percentage of number of species and abundance of the Encyrtidae collected with Malaise traps in the localities of San Javier, Huautla, and Huatulco during the rainy and dry seasons

	Rainy Season		*Dry Season*		*Both Seasons*
Localities	*No. of species*	*Abundance*	*No. of species*	*Abundance*	*No. of species*
San Javier	27%	30%	54%	70%	19%
Huautla	36%	55%	43%	45%	21%
Huatulco	47%	50%	47%	50%	6%

Table 3. Diversity values per month of the Encyrtidae collected with Malaise traps in the localities of Huautla, and Huatulco

	Jan	*Feb*	*Ma*	*Apr*	*Ma*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dic*
Huautla	2.7	2.5	2.8	2.5	2.1	1.8	1.8	1.6	1.5	1.07	1.8	2.3
Huatulco		0.2	0.5	1		0.2	0.03	1	1	0.5		0.5

Diversity was calculated with the Shannon's index.

Metaphycus, *Ooencyrtus, Pseudleptomastix* and *Rythidothorax*) are shared with Huautla and Huatulco, 7 (26%) (*Acerophagus, Aenasius, Cheiloneurus, Epanusia, Holcencyrtus, Prochiloneurus, Pseudaphycus*) only with Huautla, and 1 (4%) (*Encyrtus*) is shared only with Huatulco. The species similarity index was 42% for San Javier and Huautla, 30% for San Javier and Huatulco, and 18% for Huautla and Huatulco

The highest diversity value was registered during the dry season for the localities of San Javier and Huautla. Huatulco had high values during both dry and rainy seasons (Table 1 and 3). The diversity of Huatulco is notably lower than the diversity of San Javier and Huautla.

The number of species was higher during the dry season for the localities of San Javier and Huautla. Huatulco had the same richness value in both seasons (Table 2). The abundance was higher during the dry season only for San Javier, lower for Huautla and equal for Huatulco (Table 2).

Discussion

According to the species richness recorded in San Javier, Sonora, and the estimated richness values obtained with the parametric models, the recorded richness is probably lower than the true number of species present in the area. The best-fitting model was the Logarithmic, which is an unbounded model. It may indicate that the area under consideration is too large, or the taxa poorly known, or both (Díaz-Frances and Gorostiza, 2002). In San Javier, the geographical area is large and the Encyrtidae fauna poorly known. Encyrtids had not previously been collected systematically for this region. Therefore it is natural that the best-fitting-model was the Logarithmic.

For the 2 regions analyzed previously (Huatulco and Huautla), the best-fitting model also was the Logarithmic. The 2 regions have large geographical areas and encyrtids are poorly known. In both areas it was the first time that encyrtids were systematically collected. Therefore the data sets of the 3 regions best fit the unbounded model; this process can be considered in the early stages of a study (Díaz- Frances and Gorostiza, 2002), as it is the case for the 3 analyzed areas.

The low number of species recorded may reflect limitations of the sampling technique, combined with diverse aspects of the natural history of this group, which together may influence the effectiveness of collections. Collecting in the 3 studied localities was through Malaise traps, which provided a representative sample of encyrtids in the area and collected even the smallest insects. However, it is probable that rare species of encyrtids with short life spans have not been collected since their activity, as adults did not coincide with the days of collecting (5 days per month). The apparent rarity of some species, together with their short periods of activity (67% of species from San Javier, 88% of species from Huatulco and 71% of those from Huautla were active only for a month, and 67%, 88% and 65% of the species from San Javier, Huatulco, and Huautla, respectively, were represented only by 1 individual), the heterogeneity of the tropical dry forest, and the characteristics of the forest soil and topographic variation, which cause changes in the floristic composition (Trejo, 1998), all of them decrease the probability of collecting species that only appear in specific habitats or that are closely linked with scarce resources in the ecosystem, such as hosts or feeding plants. Finally, a long-term study using more Malaise traps in different microhabitats and more days per month is needed to test the hypothesis that the fauna of Encyrtidae has not been fully collected in the TDF with Malaise traps.

One aspect that could influence the difference in richness and abundance of recorded Encyrtidae between regions is the state of conservation of the forest and habitats in each area. The general information analyzed of Insecta of the TDF, shows that richness and composition of species between regions exhibit great variation. This variation apparently does not follow a latitudinal or altitudinal pattern, and there are species that are not shared with any of the other studied regions (Noguera et al., 2002). The percentage of endemic species for some groups also has been high. The same pattern is found for Encyrtidae, as 56% of recorded species are not shared with any other region.

Species richness of San Javier and Huautla shows a marked seasonality, being higher during the dry season, unlike Huatulco, which showed no seasonal pattern. An increased collecting effort in the region of Huatulco, may find a similar pattern to that of other localities.

Although this work provides only a preliminary approximation of the extraordinary diversity of Encyrtidae in the TDF of Mexico, it can be a starting point for the protection of these insects in these natural areas.

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Appendix 1. List of species of Encyrtidae recorded in the region of Sierra San Javier, Sonora, Mexico. The list includes subfamilies, genera, species, and number of individuals per species and month of collecting.

Subfamily	***Genus***	***Species***	***No. of ind.***	**Month of Collecting**
Encyrtinae	*Acerophagus* Smith, 1880	sp. 1	1 ♀	XI
	Bennettisca Noyes, 1980	sp. 1	1 ♀	XI
	Cheiloneurus Westwood, 1833	sp. 1	2 ♀	IV, XII
		sp. 2	1 ♂	I
	Coccidencyrtus Ashmead, 1900	sp. 1	1 ♀	VII
		sp. 2	1 ♂	III
	Encyrtus Latreille, 1809	*infelix*	1 ♂	VIII
	Ginsiana Erdös & Novicky, 1955	sp. 1	1 ♂	IV
	Metaphycus Mercet, 1917	*flavus* (Howard, 1881)	1 ♀	VI
		helvolus (Compere, 1926)	1 ♀	IV
		lounsburyi (Howard, 1898)	1 ♀	II
		luteolus (Timberlake, 1916)	2 ♀	III, V
		mexicanus (Howard, 1898)	1 ♀	XII
		stanleyi Compere, 1940	3 ♀	III, IV
		sp. 1	1 ♀	I
		sp. 2	1 ♀	II
		sp. 3	2 ♀	I, III
		sp. 4	1 ♂	I

Appendix 1. Continues.

	Microterys Thomson, 1876	sp. 1	1 ♀	I
	Moorella Cameron, 1913	sp. 1	1 ♀	X
	Oesol Noyes & Woolley, 1994	sp. 1	1 ♂	VIII
	Ooencyrtus Ashmead, 1900	*pityocampae* (Mercet, 1921)	19 ♀, 2 ♂	I, II, III, IV, V, VI, VII, IX, XI
		sp. 1	6 ♀, 3♂	I, II, III, IV, V
		sp. 2	2 ♀	VII, VIII
	Paratetracnemoidea Girault, 1915	*americana* Gordh, 1985	1 ♂	VI
	Prochiloneurus Silvestri, 1915	sp. 1	1 ♀	IV
	Protyndarichoides Noyes, 1980	sp. 1	1 ♀	XI
	Pseudaphycus Clausen, 1915	sp. 1	9 ♀	II, III, IV, X
	Rhytidothorax Ashmead, 1900	*marlatti* Ashmead, 1900	2 ♀, 3 ♂	I, II, III, IX
	Syrphophagus Ashmead, 1900	sp. 1	1 ♀	IV
	Trjapitzinellus Viggiani, 1967	*microrphanos* Gordh, 1973	2 ♀	II, III
	?	sp. 1	1 ♂	VIII
Tetracneminae	*Aenasius* Walker, 1846	*advena* Compere, 1937	1 ♂	IX
		vexans Kerrich, 1967	1 ♀	VII
		sp. 1	1 ♀	VII
		sp. 2	1 ♂	I

Appendix 1. Continues.

Anagyrus Howard, 1896	*aligarhensis* Agarwal & Alam, 1959	5 ♀	II, III, IV
	lopezi (De Santis, 1964)	4 ♀	II, IV, VII, VIII
	pseudococci (Girault, 1915)	1 ♀	III
	sp. 1	1 ♂	I
	sp. 2	2 ♀	I, III
	sp. 3	25 ♂	I, III, IV,VI, VII, IX, XI
Epanusia Girault, 1913	sp.1	1 ♀	VII
Gyranusoidea Compere, 1947	sp. 1	1 ♀	VII
	sp. 2	1 ♂	I
	sp. 3	1 ♀	X
Holcencyrtus Ashmead, 1900	*osborni* (Timberlake, 1923)	1 ♂	III
Leptomastix Förster, 1856	sp. 1	2 ♀	I, VI
Pseudleptomastix Girault, 1915	sp. 1	7 ♀, 3 ♂	III, IV, V, VI, IX, X, XII
Tetracnemus Westwood, 1837	sp. 1	1 ♀	IV
	sp. 2	1 ♀	VI
	sp. 3	2 ♂	I, VI