UNIVERSIDADE DE SÃO PAULO
MUSEU DE ZOOLOGIA

Alvaro Doria dos Santos

Estudo taxonômico das espécies brasileiras de *Charops* Holmgren, 1859
(Ichneumonidae, Campopleginae)

São Paulo
2018

ALVARO DORIA DOS SANTOS

Taxonomic study of the Brazilian species of *Charops* Holmgren, 1859
(Ichneumonidae, Campopleginae)

(Estudo taxonômico das espécies brasileiras de *Charops* Holmgren, 1859
(Ichneumonidae, Campopleginae))

Dissertation submitted to the Graduate Program
of the Museu de Zoologia da Universidade de
São Paulo to obtain the degree of Master of
Science in Systematics, Animal Taxonomy and
Biodiversity

Advisor: Dr. Carlos Roberto F. Brandão

Co-advisor: Dr. Helena Carolina Onody

São Paulo

2018

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Cataloging in Publication

Santos, Alvaro Doria dos

Estudo taxonômico das espécies brasileiras de *Charops* Holmgren, 1859 (Ichneumonidae, Campopleginae) / Alvaro Doria dos Santos; orientador Carlos Roberto Ferreira Brandão; co-orientadora Helena Carolina Onody. São Paulo, 2018.
141 f.

Dissertação (Mestrado) - Programa de Pós-Graduação em Sistemática, Taxonomia e Biodiversidade, Museu de Zoologia, Universidade de São Paulo, 2018.
Versão original

1. Hymenoptera. 2. Ichneumonidae. 3. Taxonomia. I. Brandão, Carlos Roberto Ferreira, orient. II. Onody, Helena Carolina, co-orient. III. Título.

CDU 595.798

Nome: Santos, Alvaro Doria dos

Título: Estudo taxonômico das espécies brasileiras de *Charops* Holmgren, 1859 (Ichneumonidae, Campopleginae)

Dissertação apresentada ao Programa de Pós-Graduação do Museu de Zoologia da Universidade de São Paulo para obter o título de Mestre em Ciências (Sistemática, Taxonomia Animal e Biodiversidade).

Aprovado: ____ / ____ / _____

Comissão Julgadora

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To mom and dad

ACKNOWLEDGMENTS

I would first like to thank my advisor Dr. Carlos Roberto Ferreira Brandão for giving me the opportunity to work in his laboratory, to support my study and related research and for constant incentive.

I would also like to acknowledge my co-advisor Dr. Helena Carolina Onody for the continuous support, patience, motivation, and for sharing her experience and huge knowledge on Ichneumon wasps (I owe you tons of chocolate).

The financial support provided by CNPq (Conselho Nacional do Desenvolvimento Científico e Tecnológico) was essential for the accomplishment of this study.

I am grateful to my fellow labmates: Dr. Kelli Ramos, Dr. Monica Antunes Ulyssea, Tamires Andrade, Juliana Menezes, Éliton Vieira, Camila Pereira and Helen Ferreira for the friendly work environment and companionship.

A special thank to Ms. Livia Pires do Prado for sharing many ideias that helped to improve this study and to Dr. Gabriel Biffi for giving me various tips on photography and QGIS shapes.

My sincere thanks go to Dr. Bernardo F. Santos for sending me photographs of the holotype of *Charops annulipes* Ashmead, 1890. Also, goes to Ms. Manuel Iturriaga Monsisbay and to my colleague Joel Lastra for sending me photographs of many Ichneumonidae type specimens, including the lectotype of *Charops luctuosus* (Cresson, 1865) of the Entomological Collection of the Instituto de Ecología y Sistemática in Cuba and to the various curators and researchers that sent material or received me in their laboratories.

I am grateful to Dr. Antônio Santos Silva, Ms. Francisco Eriberto and Dr. Sônia Casari for the clarification of several taxonomic problems that arose during the elaboration of this work.

I am also deeply thankful to all professors of the Systematics, Animal Taxonomy and Biodiversity MZSP Graduate program that shared their immense knowledge during the many courses I took in these two last years. To all the Museu de Zoologia staff who collaborated directly or indirectly in the preparation of this study, with a special thank to the librarian Dione Seripierri for correcting the references; Tania Lopes for helping me with text formatting; Gustavo, Ricardo, Marta and Viviane Neves for

always attending my desperate bibliographical requests; Mariana Shinohara, Marlene Rocha, Marta Grobel, Omair Tizzot and Sonia Favaro for helping me with all the bureaucracy.

A special thanks to my friends Bruno Zilberman and Rafael Sousa that shared with me their knowledge in many subjects, helping me to improve this work and in my personal growth. Also, to my friends Carolina Cuezco, Elias Araujo, Juan Rodriguez, Juarez Fuhrmann, Joice Constantini, Letizia Migliore, Mauricio Moura, Olívia Evangelista, Pedro Ivo, Rodolfo Probst, Tiago Carrijo, Thiago Tadeu and many others whom I may have forgotten but are in my heart.

Finally, I must express my very profound gratitude to my beloved girlfriend Maria, an amazing Chiropterologist, who is always providing support and encouragement that helped me to achieve my goals and to my family which provides unfailing support even when I'm not always present.

“It has been said that it is dangerous to study the parasitic Hymenoptera, for many of those who do, end up in mental institutions, become alcoholics, or are, at least, a little odd.”

Marjorie C. Townes - A. A. Girault and His Privately Printed Papers, 1972.

RESUMO

Insetos parasitoides são conhecidos pela sua distinta estratégia de vida, na qual para concluir o seu ciclo de vida necessariamente matam os seus hospedeiros. Oitenta por cento das espécies de parasitoides pertencem à ordem Hymenoptera (abelhas, formigas e vespas). Dentre as vespas parasitoides destaca-se a família Ichneumonidae, que possui mais de 25 mil espécies nominais e apresenta grande diversidade de hábitos e hospedeiros. Apesar do grande número de espécies já descritas, existe uma baixa representatividade de espécies conhecidas de regiões tropicais devido, principalmente, à escassez de estudos taxonômicos na região. O presente estudo teve por objetivo compilar as informações sobre a biologia de Ichneumonidae a partir de uma extensa revisão da literatura e realizar um estudo taxonômico das espécies de *Charops* Holmgren, 1859 (Campopleginae) que ocorrem no Brasil. Foi observado que cerca das 950 espécies de Ichneumonidae que ocorrem no Brasil, menos de 10% possuem algum registro de hospedeiro. Tais registros estão concentrados principalmente nas regiões sul e sudeste do Brasil aonde se concentra a maior quantidade de taxonomistas do país. Além disso, grande parte dos registros referem-se a hospedeiros de importância econômica nas culturas de milho, soja e algodão. Pouco se sabe sobre a interação entre parasitoides/hospedeiros em biomas naturais brasileiros. Foram encontradas 33 espécies que apresentam registro de ocorrência dúbio para o Brasil. Apesar de ser uma das subfamílias com maior número de registros de hospedeiro, Campopleginae permanece relativamente carente de estudos taxonômicos no Brasil. Um exemplo disso é o gênero *Charops* que apesar de apresentar registros para o Brasil (em nível de gênero), nunca foi estudado através de um viés taxonômico. O estudo de 614 exemplares deste gênero revelou 9 espécies novas para o Brasil, sendo estas as primeiras espécies descritas para a América do Sul. Sua distribuição geográfica conhecida foi ampliada e ilustrada em mapas de distribuição. Imagens de alta resolução e uma chave de identificação para essas espécies são fornecidas.

Palavras-chave: Brasil, Hymenoptera, hospedeiros, Ichneumonidae, taxonomia, vespas parasitoides

ABSTRACT

Parasitic insects are known for their distinct life strategy: they necessarily kill their hosts in order to complete their life cycle. Eighty percent of parasitoids species belongs to the order Hymenoptera (bees, ants and wasps). Among parasitoid wasps Ichneumonidae stands out with more than 25 thousand species and a great diversity of habits and hosts. Despite the large number of species already described, there is a low representativeness of species in tropical regions, mainly due to the lack of taxonomical studies in those areas. The objective of the present study was to compile the information on the biology of Ichneumonidae through an extensive literature review and to conduct a taxonomic study of the species of *Charops* Holmgren, 1859 (Campopleginae) occurring in Brazil. It was observed that out of the 950 species of Ichneumonidae registered in Brazil, less than 10% present some host records. These records are mainly concentrated in the south and southeast of the Brazil where the relatively largest number of taxonomists are concentrated. In addition, most of the records relate to hosts of economic importance in corn, soybean and cotton crops. Little is known about the parasitoid / host interaction in natural Brazilian biomes. Also, thirty-three species with dubious occurrence in Brazil were found. Notwithstanding Campopleginae being one of the subfamilies with the highest number of host records, taxonomical studies on it are still scarce in Brazil. An example is the genus *Charops*, which despite having recorded for Brazil at genus level, has never been studied through a taxonomic point of view. The study of 614 specimens of this genus revealed 9 new species from Brazil, being the first described for South America. Its geographical distribution record is expanded and illustrated in distribution maps. High resolution images and a key for these species are also provided.

Key-words: Brazil, Hymenoptera, hosts, Ichneumonidae, taxonomy, parasitoid wasps

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ABBREVIATIONS

An. Antenna	Lto. lateral ocellus
Ann. Annelus	Mcx. Middle coxa
Ar. Areola	Mdo. median ocellus
Atcp. Anterior transverse carina of propodeum	Mspl. Mesopleural groove
Atms. Axillary trough of mesonotum	MI. Mid leg
Atmt. Axillary trough of metanotum	Mlcpr. Median longitudinal carina of propodeum
Atp. Anterior tentorial pit	Mscu. Mesoscutum
Bl. Bulla	Msp. Malar space
Bs. Basal area	Mspi. Mesepimeron
Cly. Clypeus	Mspl. Mesopleuron
Cr. Cercus	Msp. Mesepisternum
Epcn. Epicnecium	Mss. Mesosoma
Epic. Epicnemial carina	Mtp. Metapleron
Epo. Epomia	Mts. Metasoma
Fcx. Fore coxa	Mvf. Mandibular ventral flange
Fl. Fore leg	Ont. Ovipositor Notch
Fm. Femur	Os. Outer spur
Fs. Flagellar Segment	Os. Ovipositor Sheaths
Gn. Gena	Otr. Ocellar triangle
Hcx. Hind coxa	Ovi. Ovipositor
Hd. Head	Ped. Pedicel
HI. Hind Leg	Pc. Perpendicular carina
Hyp. Hypoepimeron	Plc. Pleural carina
Is. Inner spur	Prd. Propodeum
Jx. Juxtacoxal area	Prpl. Propleuron
Jxc. Juxtacoxal carina	Prt. Pronotum
Llcpr. Lateral longitudinal carina of propodeum	Ps. Propodeal spiracle.
Lt. lower tooth	Psct. postscutellum
Ltg. Laterotergite	Pt. Petiolar area
	Ptcm. Posterior transverse carina of mesothoracic venter

Ptcp. Posterior transverse carina of propodeum

Saa. Supra-antennal area

Sc. Scape

Sca. Supraclypeal area

Sct. Scutellum

Smtc. Submetapleural carina

Sp. Spiracle

St. Sternite

Ster. Sternaulus

Sup. Subpeciolar Process

Tb. Tibia

Teg. Tegula

Tgs. Tergosternal suture

Thr. Thyridium

Tr. Tarsomere

Trc. Trochanter

Trl. Trochantellus

Ut. upper tooth

Vtx. Vertex

Measurements

BWM. Basal width of mandible

DBC. Distance between 2m-cu bulla and 4/Cu vein

DBM. Distance between 2m-cu bulla and 2/M vein

DOA. Distance between ovipositor notch and ovipositor apex

DOE. Distance between lateral ocelli and eye

FFH. First flagellomere height

FFW. first flagellomere width

HF. Height of Face

ID. Interocelar distance

LFW. Length of fore wing

LM. Length of mandible

LMP. Length of mesopleuron

LO. Length of ovipositor

LOD. Lateral ocelli diameter

LRT. Length of remaining tarsomeres

LT1. Length of tarsomere 1

LTE1. Length of tergite 1

LTE2. Length of tergite 2

MS. Malar space

OA. Ovipositor notch angle

SFH. Second flagellomere height

SH. Spiracle height

SHC. Size of hind coxa

SPN. Size of propodeum neck

SW. Spiracle width

WF. Width of Face

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1. Chapter I - Introduction: On parasitoid wasps

In 1913 Reuter coined the term parasitoid (“Parasitoidea”) for the group of insects that he defined as “parasitic predatory insects”. Wheeler (1923) supported this term and discerned parasites from parasitoids by the last one being described as “extremely economical predators” since parasitoids kills its hosts but, before killing them, they “spare” the host as much as possible to use its resources. A parasitoid can be defined as an organism that grows inside or on a single host and kills it as a necessary part of its own development (Poulin, 2011).

There are many life strategies among the so called parasitoidism. Parasitoids can affect directly the metabolism of its host by allowing (referred as koinobiont) or inhibiting or retarding (idiobiont) its final development. Despite a few exceptions, koinobionts parasitoids usually develop inside their hosts (endoparasitoids) and idiobionts outside of their hosts (ectoparasitoids). Furthermore, koinobionts parasitoids are frequently specialists while idiobionts are normally generalists (Quicke, 1997).

Due to their nature, parasitoids are important agents of biological control, acting directly on their hosts populational fluctuation (Wallner, 1987). For this reason, many species are used in biological control programs of agricultural pests. One example is the tiny (less than 1mm) wasps of the genus *Trichogramma* Westwood, 1833; egg parasitoids of ten insect orders, these wasps are applied in the biological control of important pests such as *Ostrinia* Hübner, 1825 and *Spodoptera frugiperda* (Smith, 1797) (Smith, 1996; Parra & Zucchi, 2004). A successful biological program highly depends on the knowledge of the parasitoid biology (Parra, 2002) and an extensive number of experiments were made to allow the use of this wasp in the field (Parra & Zucchi, 2004).

In all terrestrial ecosystems, parasitoids have been considered as a keystone group controlling their hosts populations. Since these organisms occupy high trophic levels and usually are very specialized, they are likely to be subject to local or global extinctions (Shaw & Hochberg, 2001). Anton *et al.* (2007) studying the effect of habitat fragmentation on the population of the butterfly *Maculinea nausithou* (Bergstraesser, 1779) and its specialist parasitoid *Neotypus melanocephalus* (Gmelin, 1790) (Ichneumoninae) observed a higher genetic differentiation in *N. melanocephalus* due

to a combination of small local population sizes and haplodiploidy, showing that the parasitoid was more sensitive to habitat fragmentation than its host.

Paradoxically, parasitoid wasps are one of the most neglected groups regarding conservation studies and extinction risks (Shaw & Hochberg, 2001). Of seven orders of insects known as Parasitoids, Hymenoptera (ants, bees and wasps) stands out, representing 80% of the species (Quicke, 1997) with a great amount of these species parasitizing insect groups of economic importance (Yu *et al.*, 2016). Forbes *et al.* (2018) based on the hypotheses that most of holometabolan insects are parasitized by one or more parasitoid wasps, suggests that the diversity of these species may exceed the number of Coleoptera species by 3 times.

During the evolutionary history of Hymenoptera, parasitoidism life strategy appeared only once, probably at the beginning of the Triassic (~245mya) (Peters *et al.*, 2017). There is a high propensity that the common ancestor of Orussoidea + Apocrita was an ectoparasitoid of xylophagous Hymenoptera and Coleoptera (Gibson, 1985; Whitfield, 1992; Downton & Austin, 2001; Peters *et al.*, 2017).

Peters *et al.* (2017) identified a major radiation (between 266-195 mya) of the clade Parasitoida (Proctotrupomorpha + [Ceraphronoidea + Ichneumonoidea]) concomitant with the diversification of its major host lineages (e.g., Hemiptera, Holometabola).

Among parasitoid wasps, Ichneumonidae Latreille, 1802 is the largest and the most cosmopolitan group, containing approximately 25000 described species in 1600 genera (Yu *et al.*, 2016). This family is the sister group of Braconidae forming together the above-mentioned superfamily, based on of both morphological (Sharkey & Wahl, 1992) and molecular data (Derr *et al.*, 1992; Downton & Austin, 1994; Quicke, 2009) evidences.

Ichneumonidae differs from Braconidae by having the following diagnosis (Wahl & Sharkey, 1993): fore wing with 2m-cu vein present and vein 1Rs+M absent; hind wing with 1r-m opposite or apical to the separation of veins R1 and Rs; metasomal tergite 2 separated from 3 and their junction flexible (figure 1).

Figure 1. Differences between Ichneumonidae and Braconidae wasps. Fore wing with 2m-cu vein present in Ichneumonidae (A) and absent in Braconidae (B); vein 1Rs+M absent in Ichneumonidae (A) and present in Braconidae (B). Arrow indicating metasomal tergite 2 separated from 3 in Ichneumonidae (C) and fused in Braconidae (D).

Ichneumonidae is megadiverse with 44 subfamilies including all parasitoid life strategies (Yu *et al.*, 2016). This diversity of traits allowed a relatively high diversification within this family (Peters *et al.*, 2017) which is subdivided in seven informal groups of subfamilies: Xoridiformes, Labeniformes, Pimpliformes, Brachycyrtiformes, Ichneumoniformes, Orthopelmatiformes and Ophioniformes (*sensu* Quicke, 2009, 2015).

Xoridiformes and Labeniformes, both idiobiont ectoparasitoids of xylophagous insects (Coleoptera and Hymenoptera), are probably the most basal groups of Ichneumonidae (Quicke, 2009). This way of life is shared with Orusidae, the sister group of Apocrita.

The endoparasitoid koinobiont strategy appears to be the most common condition found in the other subfamilies, although many convergences led to ectoparasitism (Quicke, 2015). This habitat shifting led to specific specializations that enable them to deal with this new environment (host gut), which may be very hostile to the presence of the parasitoid (Quicke, 1997). Endoparasitoids have the challenge to subvert hosts immune systems that is always trying to recognize the parasitoid to encapsulate and kill it (Quicke, 1997).

Passive and active strategies enabled them to overcome this problem. Passive strategies basically prevent local contact or detection by the immune system. On the other hand, active strategies inhibit the immune system through wasp venoms, teratocytes, and viruslike particles known as Polydnaviruses (Whitfield, 1997; Webb, 1998). The virus Polydnaviridae is associated with Braconidae and Ichneumonidae wasps, evolving independently on each family (Whitfield, 1997). Replicated in ovary calyx cells, the virus is injected within the wasp's egg inside the host. Inside the host, the Polydnaviruses are responsible for the failure of the immune response allowing the development of the parasitoid (Webb, 1998). This wasp/virus association is so successful that, in some cases, wasp's venom may become redundant (Dorémus *et al.*, 2013).

Despite the army race between endoparasitoids and its hosts, the interior of the host presents a hostile habitat that, however, protects the parasitoid from physical damages and water loss (Quicke, 1997).

Ichneumonidae is known for its anomalous latitudinal distribution, first observed by Owen & Owen (1974); by comparing ichneumonid samples from Uganda, Sierra Leone and England they found a more diverse fauna in higher than lower latitudes. This phenomenon was studied in many papers that proposed different hypothesis (*e.g.* Janzen & Pond, 1975; Rabinowit & Price, 1976; Gauld *et al.*, 1992; Sime & Brower, 1998).

However, any conclusion about ichneumonid latitudinal distribution can be hasty, since most of the diversity in tropical forests of parasitoid wasps (mainly of small sized wasps) is still unknown due primarily to a lack of taxonomical studies (Veijalainen *et al.*, 2012; Quicke 2012). Veijalainen *et al.* (2012) found 177 likely undescribed orthocentrine (koinobionts) species with low sampling efforts in Central America and Ecuador.

Biodiversity in Brazil is highly threatened by human activities, a distinct trait of the ongoing sixth mass extinction (Barnosky *et al.*, 2011). For example, the Brazilian Atlantic Forest, home of eight thousand endemic animal and plant species, is extremely fragmented with only 7% of its original coverage remaining (Tabarelli *et al.*, 2005). Increased forest and climate degradation doubled the frequency of forest fires in Amazon Forest (Alencar *et al.*, 2015). More than 50% of original Cerrado area gave place to agricultural lands and pasture (Klink & Machado, 2005). Anthropogenic

actions also affect Pantanal wetlands (Harris *et al.*, 2005) and the neglected Cerrado (Santos *et al.*, 2011).

A considerable number of fauna surveys accessing sundry biomes were done in Brazil (e.g. Kumagai & Graf, 2000; Guerra & Penteado-Dias, 2002; Tanque & Frieiro-Costa, 2011). However, many of these efforts to comprehend our Ichneumonid diversity do not treat individuals at species level, which affects the results of conservation assessments and hence decision making (Brooks *et al.*, 2004).

The comparative meagerness of studies related to this family in Brazil and in South American countries motivated this study, which aims to add taxonomic and ecological knowledge to the Brazilian Ichneumonidae fauna. The state of the art of Brazilian Ichneumonidae ecology was investigated through an extensive review of the host-parasitoids records in the country presented in Chapter II. Chapter III deals with the taxonomic study of the Brazilian species of *Charops* Holgrem, 1859.

2. Chapter II - What we know about Ichneumonidae biology in Brazil: a literature review of 121 years of host/parasitoid association records

2.1. Introduction

Parasitoid wasps are highly adapted to locate their hosts. For example, their antennae and ovipositor are equipped with numerous mechano and chemosensorial sensillae (Quicke, 1997). Internal (e.g. hunger, physiological condition, experience, egg load) and external factors (e.g. light, temperature, humidity, wind, chemicals) acting on the adult female wasp have great influence on host searching and acceptance (Vinson, 1998).

After emerging from the egg, some species will search for hosts almost instantly and others experience a preoviposition period in which they do not search for hosts (Vinson, 1998). For example, *Tranosema rostrale* (Brischke, 1880) (Campopleginae) parasitoid of *Choristoneura fumiferana* (Clemens, 1865) (Lepidoptera: Tortricidae) lacks a pre-mating or preoviposition period in laboratory conditions (Seehausen *et al.*, 2016). On the other hand, another Campopleginae species, *Diadegma semiclausum* (Hellén, 1949) showed a preoviposition period of almost ten hours in laboratory conditions (Pourian *et al.*, 2015).

Concerning females experience, Vinson (1998) classified three types: the first one is the innate behavior that determines to what kind of stimuli the wasp will respond. The second is the experience *per se* that improves the response of host selection over the time in which the wasp spend locating and oviposition in hosts. The third one is the associative learning allowing females to associate new cues besides the innate cues.

By studying the ichneumon wasp *Campoletis sonorensis* (Cameron, 1886) in a wind tunnel bioassay, Mcauslane *et al.* (1991) observed that this wasp showed an innate response from volatiles of damaged plants that usually are attacked by its host. Females that experienced oviposition beforehand showed an increased response from hosts and damaged plants cues stimulation than “naive” females. Also, they observed that females that had previous oviposition experience are more likely to try novel host plants.

The number of mature eggs that the female is carrying may affect the choice of potential hosts (Vinson, 1998). Ueno & Ueno (2015) studying females of *Itoplectis*

naranyae (Ashmead, 1906) observed that individuals carrying relatively more eggs are prone to broaden their range of acceptable hosts, preventing from dying before laying all her eggs.

Frass, honeydew and pheromones serve as chemical clues for the wasp to find its host location (Quicke, 1997). Other important substances known as “herbivore-induced plant volatiles” (HIPVs) produced by plants when attacked by herbivores insect are relatively easily detected by parasitoids (Vet & Dicke, 1992). Parasitoids take advantage of this clue given by the plant (which will be benefited by presence of the parasitoid) to find their host in a phenomenon known as tritrophic interaction (Vet & Dicke, 1992). Ohara *et al.* (2003) observed females of *Diadegma semiclausum* (Hellén, 1949) more attracted to host-infested cabbages than to uninfested. The source of attraction were the volatiles emitted from cabbage plants while attacked by *Plutella xylostella* (Linnaeus, 1758) larvae.

Physical cues also affect host choices. Glass beads coated with host recognition kairomone were used in a trial with the wasp *Telenomus heliothidis* Ashmead, 1893, parasitoid of *Heliothis virescens* (Fabricius, 1777). Beads from different formats were offered to the wasp which preferred spherical coated beads to spheroidal “hosts” (Strand & Vinson, 1983).

As observed above, parasitoid wasps have an intricate history of coevolution with their hosts and associated plants. Unfortunately, only 5300 species (one fifth of the total of recorded Ichneumonidae species) have host records (Yu *et al.*, 2016). This number decreases to around two thousand species when we include associated plant (Yu *et al.*, 2016). Other taxonomical levels besides species share this scarcity of biological data. One example is the Nesomesochorinae subfamily with 60 described species (some of them very conspicuous), although only one biological record is recognized for this subfamily (Quicke, 2015).

Due to their trophic position, parasitoids species diversity also reflects their hosts diversity. Anderson *et al.* (2011) observed a stronger relationship between wasp’s abundance and richness and overall arthropods than other parasitoid insects and overall arthropods indicating that the first may be used as bioindicators of arthropod diversity in agricultural landscapes. Maeto *et al.* (2009) used the Braconidae wasps to monitor reforestation efforts in Indonesian degraded grasslands. Identifying parasitoid/hosts taxa increases the effectiveness of arthropod monitoring (Anderson *et*

al., 2011). Also, the knowledge on the correct association between parasitoid and its host is essential for biological control of agricultural pests, being the first of many steps for a successful biocontrol program (Parra, 2002).

3. Chapter III - Taxonomical study of the Brazilian species of *Charops* Homlgren 1859 (Ichneumonidae, Campopleginae).

3.1. Introduction

Campopleginae (Porizontinae sensu Townes 1970a) is a cosmopolitan subfamily of Ichneumonidae which contains 66 genera and 2127 nominal species (Yu *et al.*, 2016). This subfamily can be distinguished from other Ichneumonidae by the following diagnosis (Wahl & Sharkey, 1993): clypeus usually not distinctly separated from face; mandible often with ventral flange; ventroposterior corner of propleuron with strongly produced lobe touching or overlapping pronotum, mesotibial and metatibial spurs not separated from tarsomere 1 by a sclerotized bridge; sternalus of mesopleuron almost always absent or short; very rarely reaching mesocoxa; posterior transverse carina of the mesothoracic venter usually complete; propodeum usually with fairly complete set of carinae; fore wing with areolet closed or open; hind wing with vein 1/RS varying from slightly longer to shorter than vein 1rs-m; metasomal segment 1 usually long and slender, widened apically, with or without glymma, and spiracle near apex; metasoma usually weakly to strongly compressed laterally, at least apically in females; ovipositor short to long, often upcurved, dorsal subapical notch almost always present.

This subfamily has been included in the Ophioniformes group which synapomorphy is the long lateral oviducts, often longer than the ovaries (Quicke, 2015). Ophioniformes includes 16 subfamilies and it is divided in three informal groups: Lower, Middle and Higher Ophioniformes. Campopleginae belongs to the last subgroup together with Anomaloninae, Cremastinae, Hybrizontinae, Nesomesochorinae and Ophioninae (Quicke 2009, 2015). Quicke (2009), through the use of molecular and morphological data, recovered Cremastinae as sister group of the clade [Campopleginae + Nesomesochorinae].

Campopleginae are mostly endoparasitoids of immature stages of Lepidoptera, Coleoptera, Diptera, Hymenoptera (usually Symphytan families), Trichoptera and Raphidioptera (according to Aspöck, 2002; 90-95% of snake fly larvae parasitoids belong to Campopleginae) (Yu *et al.*, 2016).

As mentioned before, members of this subfamily attack many Lepidoptera pests (Yu *et al.*, 2016) which makes this group the most well studied if compared to other Ichneumonidae, regarding its applicability in biological control (Quicke, 2015). For example, there are more than 80 published papers concerning the biology of *Venturia canescens* (Gravenhorst, 1829), see Yu *et al.* (2016). Other example is the genus *Diadegma* Förster, 1869, which species are very effective in the biological control of *Plutella xylostella* (Linnaeus, 1758) (Azidah *et al.*, 2000). Most Campopleginae species are solitary and typically host specific (Quicke, 2015).

As previously discussed, little is known about the diversity and ecology of Ichneumonidae in Brazil; the Campopleginae is not an exception. With 55 species and 13 genera occurring in Brazil (Yu *et al.*, 2016), most fauna surveys commonly identify Campopleginae specimens at genus level, morphospecies (e.g. Comério, Onody & Benassi, 2012) or even at subfamily level only (Kumagai & Graf, 2002). Some of Campopleginae genera are very large (e.g. *Dusona* with 400 species worldwide, Yu *et al.*, 2016) with poorly defined species delimitation making identification and classification of these wasps an arduous process (Gauld, 1984).

Only three taxonomical revisions were made on Brazilian genera of Campopleginae: *Campoctonus* Viereck, 1912, *Microcharops* Roman, 1910 and *Venturia* Schrottky, 1902, in which many Brazilian species were recorded (Walley, 1977; Wahl, 1986; Gupta, 1987). The genera *Jomine* Graf & Kumagai, 1998 and *Aiura* Onody & Penteado-Dias, 2006 seems to occur only in Brazil.

*Charops*¹ Holmgren, 1859 is a relative small and cosmopolitan genus, comprising 30 described species (Yu *et al.*, 2016). Only two species are known to occur in the Neotropical region: *C. annulipes* Ashmead (1890) and *C. luctuosus* Cresson (1865) from Mexico and Cuba respectively (Gonzalez-Moreno & Bordera, 2011; Alayo & Hernández, 1978). Although Taxapad (2016) does not register *Charops* in Brazil, its genus level occurrence has been documented in areas of the Brazilian Southwest and Paraná, in different phytophysiognomies including Cerrado (Marconato *et al.*, 2008), Atlantic Forest (Onody & Penteado-Dias, 2009), “organic” crops (Sandonato *et al.*, 2010) and other rural areas (Kumagai & Graf, 2000; Pereira *et al.*, 2015).

Species of *Charops* are known to be koinobiont endoparasitoids of Lepidoptera larvae attacking the following families (Yu *et al.*, 2016): Arctiidae, Dilobidae,

¹ a female word from greek (χάρωψ) which means bright eyes (Hopper, 1959).

Geometridae, Hesperidae, Lycaenidae, Lymantriidae, Noctuidae, Nolidae, Nymphalidae, Papilionidae, Pieridae, Pyralidae, Sphingidae, Tortricidae, Zygaenidae.

After killing its host, they construct cocoons (white with black stripes) (figure 1) which usually hang from the underside of the leaves (Gupta & Maheshwary, 1970; Sathe & Chougale, 2014). Palaniswami & Pillai (1983) observed a life cycle of 22-27 days of *C. hersei* parasitising *Theretra oldenlandiae*.

Figure 1. Cocoon of *Charops* sp. n. I.

The relationship between *Charops* and other Campopleginae genera was hypothetised by the only phylogenetics work for this subfamily (Miah & Bhuiya, 2001). Miah & Buiya (2001) placed *Charops* as sister group of *Scenocharops* Uchida, 1932 and *Casinaria* Holmgren, 1859 as sister group of *Charops*+*Scenocharops*. The relationship of these three genera is reflected on their very similar morphological appearance; all three genera have strongly emarginated eyes and a suture separating the first metasomal sternite from the tergite near its upper margin in lateral view.

Gravenhorst (1829) first described *Campoplex* as a subgenus of *Ophion* with 105 species. One of these species was *Ophion (Campoplex) decipiens* Gravenhorst, 1829 which was the species that Holmgren (1859) based to describe the genus

Charops. He described *Charops* jointly with the description of the above-mentioned species making it genus type by monotypy. It is important to notice that *Campoplex* was already erected to genus and Holmgren agrees with that information since he recognized *Campoplex* as genus in the same publication. However, he wrote the species name as “*Charops (Campoplex) decipiens* Gravenhorst, 1829” indicating that *Charops* was transferred from *Campoplex*. However, this may mislead the reader to think that a new subgenus was created. In his following publication Holmgren (1860) wrote the species name as *Charops decipiens* with the original name as *Campoplex decipiens*. All publications after Holmgrens (1860) continued to propagate the original combination as *Campoplex decipiens* although the correct original name is *Ophion (Campoplex) decipiens* Gravenhorst, 1829 (e.g. Townes *et al.*, 1965; Gupta & Maheshwary, 1970; Choi & Lee, 2008)

In 1874, Walker described *Charops luteipes* (originally cited as “*Charops (?) luteipes*”) being the second species of the genus and the first from Japan. Walker wasn't sure about the genus, thus the question mark between the generic and specific name. The type was considered lost by Townes in 1965 and the original description does not include a generic diagnosis making it impossible to know if it really belongs to *Charops*.

In late 19th century, two species were added to the genus: *Charops breviceps* described by Kriechbaumer (*in* Magretti, 1884) from the Afrotropical region and *Charops annulipes* Ashmead, 1890, first described from the Nearctic region. *C. annulipes* was recorded in the Neotropical region (Gonzalez-Moreno & Bordera, 2011) for the first time.

Another Afrotropical species was presented by Cameron in 1905 named *Charops spinatarsis* from Cape Colony and Stellenbosch in South Africa.

In 1906, Cameron described *Charops cariniceps*, *Trichomma brevipenne* and *T. cariniscutum*. Townes & Townes (1973) synonymized *T. cariniscutum* to *T. brevipenne* which was also transferred (and the specific name corrected) to *Charops brevipennis*.

Two years later, Szépligeti (1908) added three species to the genus: *C. ater*, *C. fuliginosus* and *C. tegularis* (synonymized under *C. spinatarsis* by Townes & Townes, 1973). Cameron described *C. malayanus* in 1909, the first species from Borneo. In 1913, Morley described *C. obtusus* from Sri Lanka. Gupta & Maheshwary (1970)

considered *C. malayanus* as a subspecies of *C. obtusus* based on the original description of the first one.

Roman (1910), examined the type series of *C. ater* and found another species which was named *C. diversipes*. In the same publication, he also described a subspecies of *C. tegularis* known as *C. tegularis obscurior* which was erected to species level (*C. obscurior*) by Townes & Townes (1973).

Also, in 1910 Szépligeti described *Agrypon atrum* from Indonesia. Townes *et al.* (1961) transferred this species to *Charops* as *Charops atra* (Szépligeti, 1910).

The first Australian species was *C. pulchripes* described by Girault in 1925. Townes (1970b) designed a lectotype and commented on the closely relationship with the Indo-Papuan species *C. brachypterum* (transferred from *Anomalon brachypterum* by Townes, Townes & Gupta, 1961). Cushman in 1927 described *C. ganges*, the first species from India, collected in Dehradun.

In 1932 Uchida described *C. taiwanus* from China and *Zacharops striatus* from Japan. Later Uchida (1941) considered *Zacharops* a subgenus of *Charops*. In 1945 Townes synonymized *Zacharops* to *Charops*, therefore *Z. striatus* became *C. striatus* (Uchida, 1932). Seyrig (1935) described *C. armatus*, another Afrotropical species from Tanzania.

Townes *et al.* (1961) synonymized *Charops decipiens* to *C. cantator* (DeGeer, 1778) (which was transferred from *Ichneumon* by Roman in 1936), *C. bicolor* was transferred from *Agrypon*; the specific name *C. sumatrensis* was re-established from the senior synonym and transferred to *Charops* from *C. gongropelma* forming *C. sumatrensis* (Tosquinet, 1903).

In 1970, Gupta & Maheshwary studied the Indian species of *Charops*. They recorded eight species including four new: *C. aditya*, *C. hersei*, *C. nigrita* and *C. plauta*. They also described the larval morphology of *C. biocolor*, *C. obtusa obtusa*, *C. ganges*, *C. aditya* and *C. hersei*. In the same year, Maheshwary studied the fauna of Taiwan (China) and made a key for Taiwanese species.

In 2003, Sathe *et al.* (2003) described two species from India: *C. charukeshi* and *C. patmangiri*. The most recent species is *C. maroccanus* described by Horstmann in 2008 from Morocco. Choi & Lee (2008) studied the fauna from the Eastern Palearctic Region and provided a key for its species.

Although documented in Brazil, any taxonomical study for this genus has never been made, revealing an important gap of knowledge of this genus in the Neotropical region.

3.2. Objectives

The objective of this study was to carry out a thorough taxonomic study of the Brazilian species of *Charops*, to describe and illustrate the new species, and to present distributions maps and an identification key for these species. An emended diagnosis for the genus *Charops* is also provided to include the recorded morphological diversity and a new concept of the genus.

4. Conclusions

- Ichneumonidae fauna is poorly known in Brazil both taxonomically and biologically;
- Thirty-three Ichneumonidae species have dubious occurrence records in Brazil;
- Less than 10% of the Ichneumonidae Brazilian species have host records and nothing is known about ten of 24 subfamilies occurring in the country. Future surveys in the underexplored areas may reveal new biological records and species;
- Distribution range of *Charops* genus in Brazil was extended and now includes Acre, Amazonas, Bahia, Mato Grosso, Piauí, Rio Grande do Sul and Roraima states;
- The nine new species of *Charops* described in this study are the first ones recorded in Brazil and South America;
- A new concept of the genus *Charops* was presented to accommodate the morphological diversity of the new species described;
- Number of flagellomeres, sculpturation pattern of the propodeum, shape of supraclypeal area and color patterns are the best morphological characters that distinguish Brazilian species.

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