Open Access Research Journal of
Science and Technology
Journals home page: https://oarjst.com/
ISSN: 2782-9960 (Online)

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(REVIEW ARTICLE)

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Biological control performed by the Ibaliidae family (Insecta: Hymenoptera)

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Open Access Research Journal of Science and Technology, 2022, 06(01), 075–092

Publication history: Received on 19 September 2022; revised on 25 October 2022; accepted on 27 October 2022

Article DOI: https://doi.org/10.53022/oarjst.2022.6.1.0075

Abstract

The Family Ibaliidae (Insecta: Hymenoptera) is the only endoparasitoid of Siricidae larvae found in forested areas in Europe, Asia and North America. The Ibaliidae are distributed in the following countries: France, England, Germany, Austria, Russia, and introduced in New Zealand, Tasmania, mainland Australia, Uruguay and Brazil. The hosts are: *Sirex noctilio* Fabricius, 1793, (Hymenoptera: Siricidae) and *Urocerus gigas* (Linnaeus, 1758) (Hymenoptera: Siricidae). The objective of this work is to report the potential of Family Ibaliidae as insect regulators. The objective of this paper is to report the potential of the Ibaliidae as insect regulators (Insecta: Hymenoptera). The bibliographic verification of Figitidae was carried out from 1970 to 2022. Manuscripts published in scientific journals and digital platforms on the subject were examined.

Keywords: Hyperparasitoids; *Pinus*; Pine; *Sirex; Ibalia leucospoides*

1. Introduction

The Ibaliidae are a small family of the Cynipoidea superfamily of Hymenoptera. Ibaliidae differ from most cynipoids in that the larvae are parasitoids on other wasp larvae of the Siricidae group (Figures 1, 2 and 3) [1,2].

Source: Sundukov YN. First record of the family Ibaliidae (Hymenoptera) from the Kuril Archipelago, Russia}. 2018. DOI:10.25221/FEE.358.3

Figure 1 Family Ibaliidae female from Tretyakovo, Kunashir Island, and side view

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Source: http://www.waspweb.org/cynipoidea/Ibaliidae/Classification/index.htm

Figure 2 Specimen Ibaliidae Family

Source: https://www.inaturalist.org/taxa/825271-Ibalia-jakowlewi/browse_photos

Figure 3 Specimen Ibaliidae Family

1.1. Diagnostic characters

Forewing with extremely long and narrow radial cell; 1st tarsomere of hind leg longer than the others together; metasome heavily compressed. It has the largest representatives of the superfamily, measuring from 10.0 to 30.0 mm (Figures 4, 5, 6, 7, 8, 9, 10 and 11) [3,4,5,6].

Source: https://stringfixer.com/pt/Ibaliidae

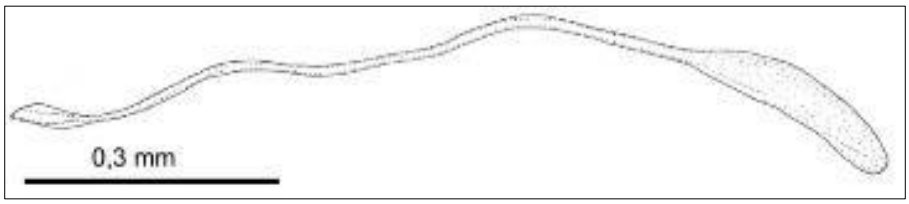
Figure 4 Mesosome Ibaliidae Family

Source: https://stringfixer.com/pt/Ibaliidae

Figure 5 Forewing Ibaliidae Family

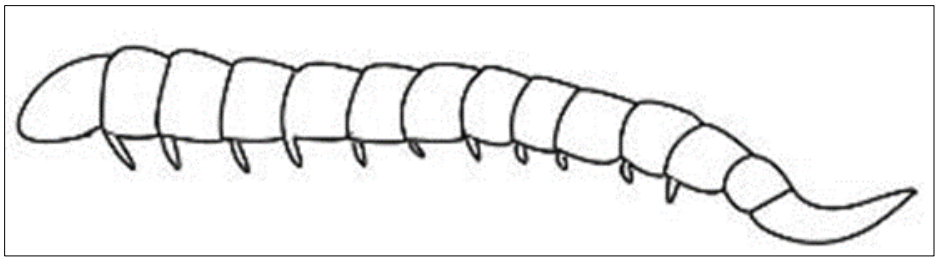
Source: https://stringfixer.com/pt/Ibaliidae

Figure 6 Posterior tarsus Ibaliidae Family



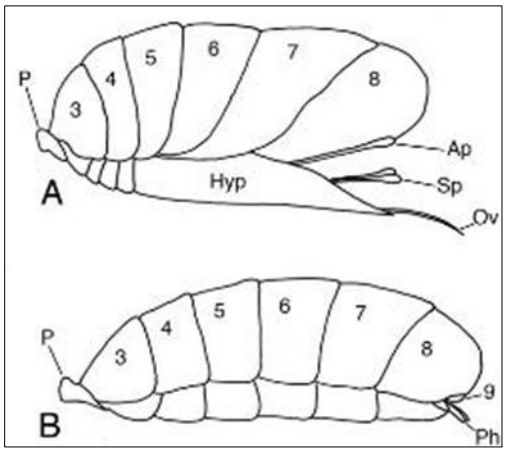
Source: https://www.wikiwand.com/en/Ibaliidae

Figure 7 *Ibalia rufipes* Cresson, 1879 egg (Ibaliidae)



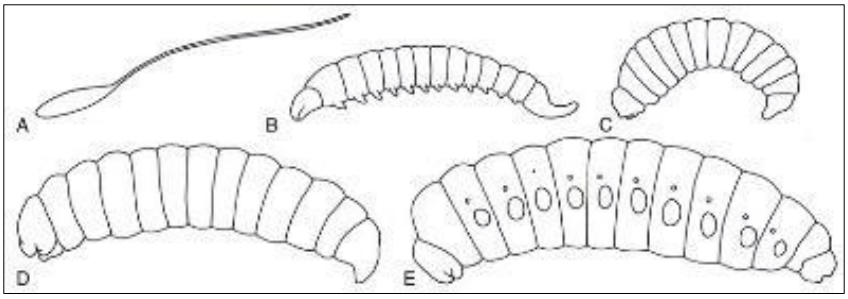
Source: https://www.wikiwand.com/en/Ibaliidae

Figure 8 Ibaliidae larva



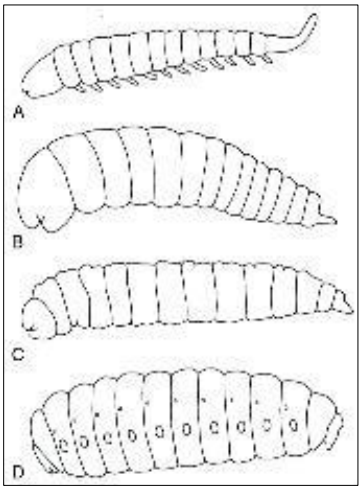
Source: Simplified after Chrystal (1930), and Ronquist and Nordlander (1989**)**

Figure 9 Lateral view of the female abdomen with hypopygium partially folded out. The hypopygium is the elongated sternite of the 7th abdominal segment and is used to guide the ovipositor during egg deposition. (B) Male abdomen. Abbreviations: 3-9, abdominal tergites 3-9; Ap, anal plate (=modified 9th tergite); Hyp, hypopygium; Ov, ovipositor; P, petiolus; Ph, phallus; Sp, sheath plate of the ovipositor



Source: Simplified after Spradbery (1970)

Figure 10 (A) Egg with appendage. Total length approx. 1.7 mm. (B) First larval instar. Length ca. 1.1 mm. (C) Second larval instar. Length ca. 2.3 mm. (D) Third larval instar. Length ca. 3.9 mm. (E) Fourth larval instar. Length approx. 1 cm. Note the strongly reduced tracheal opening in the first abdominal segment



Source: Simplified after Chrystal (1930)

Figure 11 (A) First larval instar. Length usually below 2 mm. (B) Second larval instar. Length usually below 3 mm. (C) Third larval instar. Length up to 6 mm. (D) Fourth larval instar. Length ca. 1 cm scale

1.2. Biology

Before starting to lay, the female of Ibaliidae carries out an inspection of the tree's bark, with the aid of her antennae. When she finds a suitable spot, she introduces her antennae into the *S. noctilio* laying hole and inspects the tunnels made by her host's female. For the laying it, the female lowers the seventh pair of abdominal stemites (hypopygy), introducing it into the cracks in the tree bark, performing rhythmic movements, up and down, for the deposition of eggs. Parasitoids of broaching wasps Siricidae (Hymenoptera). The larva lives it in its first instars as an endoparasite, and later exits the host and lives on the remaining host tissues (Figures 12A and 12B) [5,6,7,8].

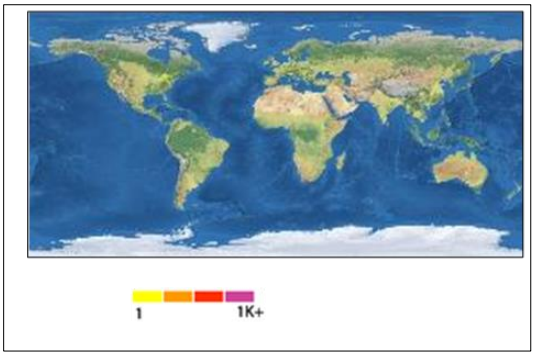
Source: https://ukrbin.com/show_image.php?imageid=84916

Figure 12A Specimen Family Ibaliidae looking for its host

Source: https://www.apreflorestas.com.br/wp-content/uploads/2018/04/Doc.76-2.ed-Manual-para-controle-da-vespa-da-madeira.pdf

Figure 12B larva of the host Family Ibaliidae

1.3. Distribution



Source: https://v3.boldsystems.org/index.php/Taxbrowser_Taxonpage?taxid=461

Figure 13 Collected from 3 countries. Top 20: Show All Countries

Canada	3	United States	2	Norway	1

The family occurs in the Palearctic and Nearctic Regions, as well as a genus in New Guinea. It consists of 19 species divided into 3 genera. *Ibalia leucospoides* was probably introduced in Brazil, along with its host, *Sirex noctilio* (Siricidae) (Figure 13) [7,8].

1.4. Taxonomy

Family Ibaliidae

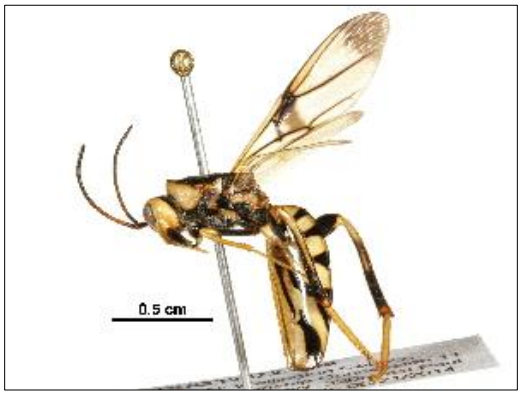
Subfamily Eileenellinae Kovalev, 1994.

Genus Oriental region. *Eileenella, Heteribalia* and *Ibalia*.

Genus *Heteribalia* Sakagami, 1949 (Oriental and eastern Palaearctic regions). **Species:** *Heteribalia aureopilosa* (Maa, 1949), *Heteribalia confluens* (Maa, 1949), *Heteribalia divergens* (Maa, 1949), *Heteribalia nishijimai* Sakagami, 1949, *Heteribalia subtilis* (Maa, 1949), *Heteribalia miltopronotum* sp. nov. and *Heteribalia sichuanensis* sp. nov.

Genus *Ibalia* Latreille, 1802 (Holarctic; introduced to Australia, New Zealand and South Africa), **Subgenus and Species:** *Ibalia (Ibalia)* Latreille, 1802, *Ibalia aprilina* Kerrich, 1973, *Ibalia arizonica* Liu & Nordlander, 1992, *Ibalia kirki* Liu & Nordlander, 1992, *Ibalia leucospoides* (Hochenwarth, 1785), *Ibalia montana* Cresson, 1879, *Ibalia ruficollis* Cameron, 1884, *Ibalia rufipes* Cresson, 1879.

Subgenus and Species: *Ibalia (Tremibalia)* Kierych, 1973, *Ibalia anceps* Say, 1824 (Canada, USA), *Ibalia hunanica* Liu & Nordlander, 1994, *Ibalia jakowlewi* Jacobson, 1899, *Ibalia japonica* Matsumura, 1912, *Ibalia mirabilis* Yasumatsu, 1941 and *Ibalia ornata* Belizin, 1968 (Figures 14, 15, 16, 17 and 18) [7,8,9,10,11,12].



Source: ID: BIOUG32372-B03. License: Creative Commons - Attribution (2017) License Holder: CBG Photography Group, Centre for Biodiversit

Figure 14 Subfamily Ibaliinae

Source: http://www.waspweb.org/Cynipoidea/Ibaliidae/index.htm

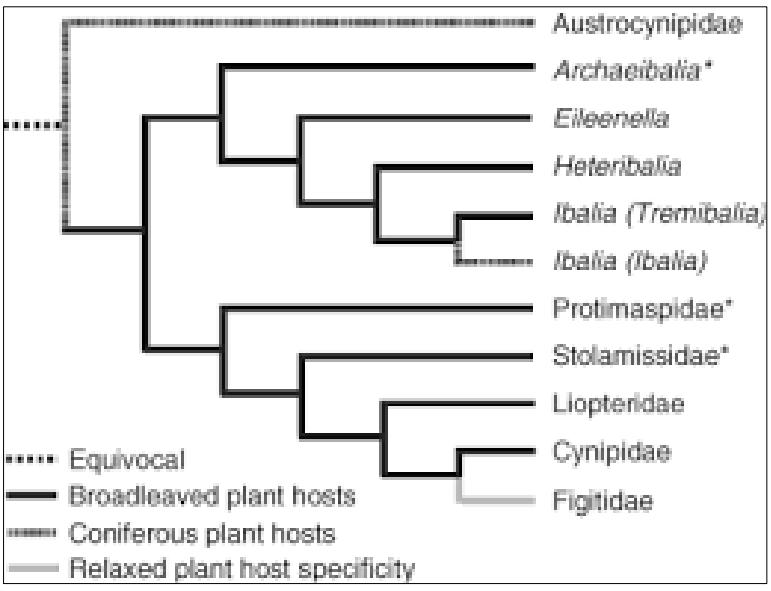
Figure 15 Subgenus *Ibalia* (Tremibalia) Kierych, 1973. *Ibalia leucospoides* (Hochenwarth, 1785)

Source: http://www.waspweb.org/Cynipoidea/Ibaliidae/index.htm

Figure 16 Subgenus *Ibalia (Tremibalia)* Kierych, 1973. *Ibalia anceps* Say, 1824

Source: https://resjournals.onlinelibrary.wiley.com/doi/10.1111/j.1365-3113.2009.00494.x

Figure 17 Fossil of the Family Ibaliidae (Hymenoptera). Eocene (Lutetian) Baltic amber. *Archaeibalia succinica* Liu & Engel gen. et sp. nov.



Source: https://resjournals.onlinelibrary.wiley.com/doi/10.1111/j.1365-3113.2009.00494.x

Figure 18 Pylogeny Ibaliidae Baltic amber Ibaliidae (Hymenoptera: Cynipoidea)

Objective

The objective of this paper t is to report the potential of the Family Ibaliidae as insect regulators (Insecta: Hymenoptera).

2. Methods

According to Marchiori 2022 [12].

3. Studies conducted and selected

3.1. Study 1

Ibalia leucospoides (Hochenwarth, 1785) (Figure 19).

Source: https://www.biolib.cz/en/image/id165413/

Figure 19 *Ibalia leucospoides* (Hochenwarth, 1785)

The genus *Ibalia* is the only endoparasitoid of Siricidae larvae found in forested areas in Europe, Asia and North America. *Ibalia leucospoides* is distributed in the following countries: France, England, Germany, Austria, Russia, and introduced in New Zealand, Tasmania, mainland Australian, Uruguay and Brazil. The hosts of *Ibalia leucospoides* (Hochenwarth, 1785) are: *Sirex noctilio* Fabricius, 1793, (Hymenoptera: Siricidae) and *Urocerus gigas* (Linnaeus, 1758) (Hymenoptera: Siricidae) (Figure 20).

Source: https://indexgrupo.com.br/vespa-da-madeira/

Figure 20 *Sirex noctilio* Fabricius, 1793, (Hymenoptera: Siricidae)

The biological control of *S. noctilio* with parasitoids began in New Zealand in 1927, with the collection of these organisms in Europe Between 1959 and 1960, *I. leucospoides* was introduced in Tasmania, through collections in the New Zealand.

The larval stage is composed of four instars, three of which occur inside the host larva, and the last one externally, when the parasitoid larva is found in the wood galleries. They differ from the larvae of *S. noctilio*, by the absence of the supra-anal spine, characteristic of the larvae of the wood wasp (Figure 21).

Source: https://commons.wikimedia.org/wiki/File:Urocerus_gigas_female_%2831992206422%29.jpg

Figure 21 *Urocerus gigas* (Linnaeus, 1758) (Hymenoptera: Siricidae)

The first signs of the pre-pupal stage are the gradual wrinkling of the cuticle and the appearance, on the head, of two purple spots, which will be the future eyes. At this stage, the parasitoid moves to the vicinity of the bark of the tree, where it pupates, remaining for five to six weeks.

The duration of the development of the egg until the emergence of the adult, in Brazil, was of 90 to 95 days, observed in adults of *S. noctilio* of short development cycle. However, in England, observed a cycle of not less than three years. *Ibalia leucospoides* locates its host by the odor emanating from the laying holes made by the host female. Observed that the factor responsible for the attraction of the parasitoid is the *Amylostereum areolatum* Boidin, 1958 (Russulales: Stereaceae) (Figure 22).

Source: https://www.commanster.eu/Commanster/Fungi/Russula/SuRussula/Amylostereum.areolatum.html

Figure 22 *Amylostereum areolatum* Boidin, 1958 (Russulales: Stereaceae)

The attraction of the parasitoid is olfactory and that it is due, in part, to the presence of the symbiont fungus and, mainly, due to valgum secretion emanating from the body of the host larva. It also verified that this attractive secretion is present in high concentration in the larval frass. *Ibalia leucospoides* has a preference for the symbiotic fungus of *S, noctylium* [13,14,15,16,17,18].

3.2. Study 2

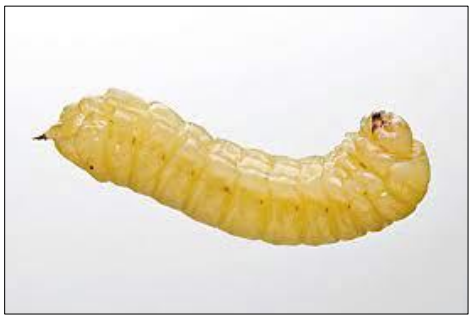
The presence of *Ibalia leucospoides* (Hochenwarth, 1785) was recorded in Brazil, for the first time, in December 1990, in stands of *Pinus*, attacked by the wood wasp, in the municipality of São Francisco de Paula-RS.

Currently, it is likely to be present in almost all municipalities in Rio Grande do Sul and Santa Catarina where the wasp-wood occurs and in Paraná, where the presence of the pest is more recent. Reviews indicate parasitism of up to 39%, with an average close to 25% (Figure 23).

Source: https://www.biolib.cz/en/image/id133455/

Figure 23 *Ibalia leucospoides* (Hochenwarth, 1785)

Ibalia leucospoides is an endoparasitoid of first and second instar eggs and larvae. The parasitoid is attracted to the oviposition holes of the host, when the fungus, *Amylostereum areolatum* Boidin, 1958 (Russulales: Stereaceae) starts its growth. Then the female introduces her ovipositor in the laying holes of *Sirex* and deposits an egg within the first or second instar egg or larva (Figure 24).



Source: https://www.apreflorestas.com.br/wp-content/uploads/2018/04/Doc.76-2.ed-Manual-para-controle-da-vespa-da-madeira.pdf

Figure 24 Larva of *Sirex* (Hymenoptera: Siricidae)

It goes through three stages within the host and, in the fourth and final instar, it leaves the host's body and feeds on the larva, destroying it. It remains in the galleries of the host and goes close to the bark to pupate, emerging in spring-summer, the same time as its host [19].

3.3. Study 3

The species *Ibalia leucospoides* (Hochenwarth, 1785) was introduced in Brazil along with its host and has been recorded in all areas with the presence of the pest. The species *Megarhyssa nortoni* (Cresson, 1864) (Hymenoptera: Ichneumonidae) and *Rhyssa persuasoria* (Linnaeus, 1758) (Hymenoptera: Ichneumonidae) were introduced in Brazil between 1996 and 2003, from Tasmania, in a cooperative project between Embrapa Florestas, the Forest Service of the United States Department of Agriculture and the International Institute for Biological Control in England (*Rhyssa persuasoria* (Linnaeus, 1758) (Hymenoptera: Ichneumonidae) (Figures 25 and 26).

Source: http://www.waspweb.org/Cynipoidea/Ibaliidae/Ibalia/index.htm

Figure 25 *Ibalia leucospoides* (Hochenwarth, 1785)

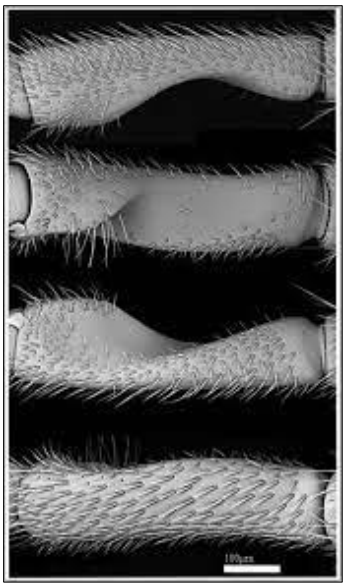
Source: https://br.pinterest.com/pin/534239574521704478/

Figure 26 *Rhyssa persuasoria* (Linnaeus, 1758) (Hymenoptera: Ichneumonidae)

However, due to problems that occurred both in their introduction (small number and high mortality) and in field releases (clear cut of pine plantations where the first releases occurred), the establishment of these parasitoids in Brazil has not been confirmed.

- **Biological aspects of** *I. leucospoides*. Adult females have a black head with antennae. almost as long as the abdomen. The chest is black in color, and at least twice as long as it is wide. the wings 32 Manual for the control of the wood wasp in pine plantations are gray in color and the legs are dark, tending to for reddish colors. The female's abdomen, in dorsal view, it is similar to a blade.

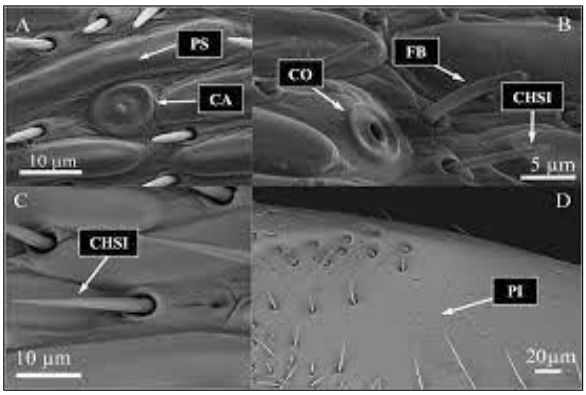
They vary in size from 7.5mm to 14.1mm. The main difference in males is the characteristic of the abdomen, which in lateral view presents a very different, presenting the posterior portion much less acute. They measure between 6.5 to 12 mm in length. Female (right) and male (left) of parasitoid *I. leucospoides*. The adult emergence period occurs between the months of November and January and between April and May (in smaller numbers) (Figure 27).



Source: Robertson DJ, Gandhi KJK. Morphology of Male and Female Antennal Sensilla of *Ibalia leucospoides ensiger* (Hymenoptera: Ibaliidae). Annals of the Entomological Society of America. 2018; 111(1): 13–20

Figure 27 A 360° SEM of the first antennal segment of male *Ibalia leucospoides* (Hochenwarth, 1785)

Ibalia leucospoides is an endoparasitoid, which lays its eggs in first and second stage larvae of the wood wasp. Go through four stages of larval development, three of which are within the wood wasp larvae and the latter externally, when come out of the larva, destroying it. At this stage they remain in the galleries built by the wood wasp, when will they pupate, close to the shell. They usually emerge one year after the posture (Figure 28).



Source: Robertson DJ, Gandhi KJK. Morphology of Male and Female Antennal Sensilla of *Ibalia leucospoides ensiger* (Hymenoptera: Ibaliidae). Annals of the Entomological Society of America. 2018; 111(1): 13–20

Figure 28 Different sensilla types on flagellomere of *Ibalia leucospoides* (Hochenwarth, 1785) including (A) PS and CA, (B) CO, and FB, (C) CHSI, and (D) PI on the first flagellomere of male. Note the different scale on each image

- Increase in the population of *I. leucospoides* in the field the parasitoid *I. leucospoides* has a great capacity to dispersion, following its host. However, it is possible increase levels of parasitism, by releasing adults of the insect in plantations attacked by the wood wasp, as follows:
- select trees attacked by the wood wasp and, among the months of September and October, collect short logs measuring 0.80 cm from the third plant medium;
- 2.the same logs collected can also be used for assess parasitism by the nematode (see item 6.2.5);
- pack the logs in 200 L drums or in cages;
- when starting the adult emergency, usually from the beginning of November, collect, every two days, the adults of the parasitoid and continue collecting until the first fortnight of January;
- store the insects in a refrigerator at a temperature of 8 °C, for up to 10 days, in 350 mL containers, containing a maximum of 10 insects in each container;
- for transport to the field, the insects must be transferred into a styrofoam box, containing, at the bottom, a layer of ice and, on top of it, sheets of newspaper;
- the parasitoid must be released next to groups of trap trees or close to trees attacked by the pest, in proportion of 100 parasitoids every 10 ha [20].

3.4. Study 4

The representatives of the Cynipoidea Superfamily are part of the Parasitic Section belonging to the Hymenoptera Apocrita. They are arranged in five families that bring together a total of 3,000 named species, but the real diversity of the group is estimated at more than 20,000 (Figure 29).

Source: https://www.flickr.com/photos/69610519@N08/35750196524

Figure 29 Cynipoidea Superfamily

The Cynipoidea are present in all zoogeographical regions and their distribution coincides with that of insects and host plants. More than 50% of its members behave as primary or secondary parasitoids of other endopterygotic insects, useful or harmful for agriculture; the rest are galligenous or tenants in other zoocecidians.

Taking into account the biological importance of the cinipoidea and its scarce knowledge in the Neotropical region, the purpose of this contribution is to present an updated synthesis of the information about its diversity in this region.

3.4.1. Classification

The different supraspecific classifications proposed during the last century for the ordering of the representatives of the superfamily Cynipoidea provide little information about their phylogenetic relationships and are generally artificial.

Austrocynipidae

Considered the most primitive family, it is known only from Australia and has only one described species. Parasitoids in echophorid Lepidoptera larvae (Figure 30).

Source: http://www.waspweb.org/cynipoidea/Austrocynipidae/index.htm

Figure 30 Austrocynipidae Family

Ibaliidae

Most of its representatives are of Holarctic distribution. It brings together 20 described species, distributed in three genera. They parasitize hymenopteran symphyte larvae that attack trees, both softwood (coniferous) and hardwood.

Liopteridae

This is a cosmopolitan group with 150 described species, gathered in 10 genera, ordered into four subfamilies. They parasitoid Coleoptera larvae of Cerambycidae and Buprestidae (Figure 31).

Source: http://www.waspweb.org/cynipoidea/Liopteridae/index.htm

Figure 31 Liopteridae Family

Figitidae

This family has a cosmopolitan distribution. It brings together 1411 species, distributed in 132 genera, arranged in nine subfamilies. Are parasites of Diptera, Neuroptera and Hymenoptera larvae (Figures 32 and 33).

Source: https://alchetron.com/Figitidae

Figure 32 Figitidae Family

Source: https://bugguide.net/node/view/1495207

Figure 33 Cynipidae Family

Cynipidae

Most of its representatives are from Holarctic distribution. It brings together 1369 species, distributed in 77 genera, ordered according to some authors in six tribes [21,22,23,24,25,26,27,28,29].

3.5. Study 5

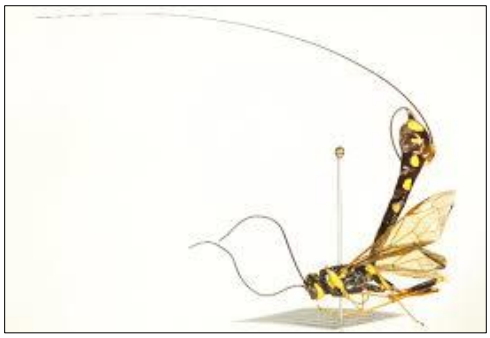
3.5.1. Biological control of Sirex noctilio Fabricius, 1793 *in Chile (South America).*

The vast experience in countries such as New Zealand and Australia has shown that the introduction of biological control agents is the most effective measure for the control of *Sirex noctilio* Fabricius, 1793. The most widely used species in the world for pest control has been a nematode of the family Neotylenchidae, called *Deladenus siricidicola* Bedding, 1968 (Nematoda: Neotylenchidae) which has proven to be very successful where it has been introduced. A complex of parasitoids complements its actions, among which *Ibalia leucospoides* (Hochenwarth, 1785) (Hymenoptera: Ibaliidae), *Rhyssa persuasoria* (Linnaeus, 1758) (Hymenoptera: Ichneumonidae) and *Megarhyssa nortoni* (Cresson, 1864) (Hymenoptera: Ichneumonidae) (Figure 34).

Source: https://lucasdorioverde.portaldacidade.com/noticias/economia/embrapa-registra-nematoide-para-controle-biologico-da-vespa-da-madeira

Figure 34 *Deladenus siricidicola* Bedding, 1968 (Nematoda: Neotylenchidae)

Megarhyssa nortoni and *R. persuasoria* and *I. leucospoides* were introduced and released in Australia and New Zealand in the 1960s, after going through a quarantine, without any reported attack on any organism other than the control objective These parasitoids have helped to control the populations of *S. noctilio* in the countries mentioned above, preventing it from continuing to cause economic and environmental damage (Figure 35).



Source: https://v3.boldsystems.org/index.php/Taxbrowser_Taxonpage?taxid=342372

Figure 35 *Megarhyssa nortoni* (Cresson, 1864) (Hymenoptera: Ichneumonidae)

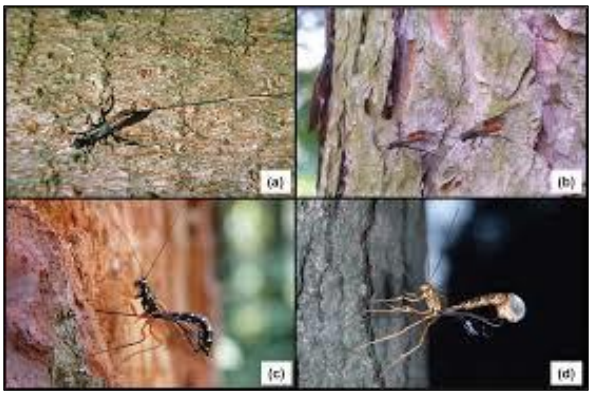
Ibalia leucospoides and another specific parasitoid used to control *Sirex noctilio*, this species native to Europe, had been previously brought into the country by the SAG (Servicio Agrícola y Ganadero), for the control of *Urocerus gigas* (Linnaeus, 1758) (Hymenoptera: Sericida). Exotic species associated with weakened *Pinus radiata* D. Don (Pinaceae) trees. When *S. noctilio* was established in the country, *I. leucospoides* had a wide geographical distribution and was soon detected attacking first and second stage eggs and larvae of the plague. It is important to mention that *I. leucospoides* is closely related to species of the Siricidae Family, which attack conifers (Figure 36).

Source: https://ukrbin.com/show_image.php?imageid=87480

Figure 36 *Ibalia leucospoides* (Hochenwarth, 1785) (Hymenoptera: Ibaliidae)

In total, more than 11,000 specimens of *M. nortoni* have been released from SAG production centers and forestry companies. *Rhyssa persuasoria* was produced by the SAG and released between 2008 and 2009 in two regions, and its establishment in the country was not detected. Additionally, 172 thousand specimens of *I. leucospoides* have been pealed.

The releases carried out by the SAG are carried out prioritizing those areas where the control levels are less than 50%, with a greater presence of the pest, which border the area in danger, as well as the possibility that the parasitoids can disperse in search of its prey (*S. noctilio*), for which it is necessary to have a vision of the connectivity between the stands where the releases will take place (Figure 37).



Source: Coyle DR, Kamal, Gandhi JK. The Ecology, Behavior, and Biological Control Potential of Hymenopteran Parasitoids of Wood wasps (Hymenoptera: Siricidae) in North America. Environmental Entomology 2012; 4(4):731-749

Figure 37 (a) and (b); procuring parasitoid or host; (c) and (d): ovipositor introducing the larva and its egg

For *I. leucospoides* each release nucleus it is composed of 100 specimens (between males and females). *Ibalia leucospoides* is also widely established in the country, its distribution range extends from the Valparaíso Region to the Aysén Region. Meanwhile, the emergence of *I. leucospoides* was concentrated between December and March of each season, with the largest emergencies occurring between January and March (Figure 38).

Photo: Iuliia Timofeeva /Shutterstock.com

Figure 38 The Paraná pine or araucaria (*Araucaria angustifolia* species) (Division Coniferophyta) Gymnosperms, typical conifer from southern Brazil

In the Metropolitan Region, in the analyzed samples the parasite has not been detected, but if the presence of *I. leucospoides*; while in the Aysén Region it has not yet been detected the parasite, but the parasitoids *I. leucospoides* and *M. nortoni* were detected [30,31,32,33,34,35,36].

4. Conclusion

Before starting to lay, the female of Ibaliidae carries out an inspection of the tree's bark, with the aid of her antennae. When she finds a suitable spot, she introduces her antennae into the *S. noctilio* laying hole and inspects the tunnels made by her host's female. For the laying it, the female lowers the seventh pair of abdominal stemites (hypopygy), introducing it into the cracks in the tree bark, performing rhythmic movements, up and down, for the deposition of eggs.

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