REVIEW OF CHALCIDOID PARASITOIDS (HYMENOPTERA: CHALCIDOIDEA) OF XYLOPHAGOUS BEETLES

Hosseinali Lotfalizadeh*

* Department of Plant Protection, Faculty of Agriculture, Islamic Azad University, Tabriz Branch, Tabriz, Iran. E-mail: lotfalizadeh2001@yahoo.com

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ABSTRACT: Xylophagous beetles (XBs) are one of the economically important pests of woody plants especially in the forest ecosystems. Over 89 genera (4.2% of known genera) and 208 species of parasitoids (Hym.: Chalcidoidea) have been recorded from XBs worldwide. About 264 distinct parasitoid-host associations between Chalcidoidea and XBs were identify. It appears to provide effective control in many cases. XBs are mostly parasitized by species belonging to the chalcidoid families Chalcididae (6%), Encyrtidae (14%), Eulophidae (15%), Eurytomidae (10%), Eupelmidae (11%), Pteromalidae (41%), and rarely by species belonging to other families such as Leucospidae, Mymaridae, Torymidae and Trichogrammatidae. Most of the genera associated with XBs are widely distributed in the same zoogeographical region, while 14 are cosmopolitan. Fourthy genera have limited distributions to a zoogeographical region, of which 70% are found only in the Palaearctic, 17.5% in the Nearctic, and the rest in the Afrotropical, Australian, Neotropical and Oriental regions.

KEY WORDS: Xylophagous beetles, Coleoptera, parasitoids, association, Hymenoptera, Chalcidoidea.

Xylophagous insects are found in many insect orders such as Coleoptera, Lepidoptera, Hymenoptera and Diptera (Csóka & Kovács, 1999). Within these orders, insects belonging to several families of the order Coleoptera are well-known pests of woody plants including different families of trees in the orchards and forests. Severe infestations can kill trees directly or by the fungal disease (Lotfalizadeh & Khalghani, 2008). This group attack trees that are weakened or dying due to stress factors such as drought, disease, smog, mechanical injury and primary pests. Sometimes the mass outbreaks of different bark and wood boring insects can cause enormous economic losses in the forests e.g. the Hungarian coniferous forests (Lakatos & Thuroczy, 2002). Some of xylophagous beetles (XBs) are vectors of plant pathogens such as the elm bark beetles that transport Dutch elm disease. Faccoli et al. (2005) mentioned pine forests growing decrease in Europe and Northern Africa by the bark beetles feeding and pathogen transmitting.

Coleoptera with mutualistic relationships with bacteria, fungi and protists are generally considered beneficial insects in the forest ecosystems because of decomposition of dead woody plants, whether alive or dead.

XBs are large and cosmopolitan families such as Anobiidae, Bostrichidae, Cerambycidae, Buprestidae and Scolytidae (Williams & Langor, 2002; Lotfalizadeh & Khalghani, 2008). However, some xylophagous are found within the families Lucanidae, Scarabaeidae, Eucnemidae, Elateridae, Lymexylonidae, Anthribidae and Curculionidae (Williams & Langor, 2002). "Bark beetles of the world" (http://www.barkbeetles.org/) is a web site that concentrates on the biology of Scolytidae, with a large searchable database. Another database (http://www.fond4beetles.com/Buprestidae/index.html) is focused on Jewel beetles (Buprestidae).

The natural enemies of this group of pests are pathogens, predators and parasitoids. In the present work the focal point is the chalcidoid parasitoids. Several families of the superfamily Chalcidoidea are potential parasitoids of Coleoptera including xylophagous groups. Chalcidoid wasps (Hymenoptera: Chalcidoidea)- representing about 22,000 species in 19 families- are an interesting group of insects, which show exquisite life histories and diverse types of host relationships. Although chalcidoids are generally considered beneficial insects in agricultural situations, they can also be pests when their populations attack on XBs of ecological importance, e.g. beetles used for decomposition of dead woody plants. Also some of them are hyperparasitoid of XBs through their primary parasitoids such as Ichneumonidae and Braconidae. Lakatos & Thuroczy (2002) mentioned a great number of various parasitoid species found in the Hungarian coniferous forests including the families Pteromalidae, Eurytomidae, Encyrtidae, Eulophidae, Mymaridae from Chalcidoidea and further species of families Platygastridae from Proctotrupoidea, Braconidae, Ichneumonidae from Ichneumonoidea and Bethylidae from Chrysidoidea.

Considering the importance of this group of pest, their biocontrol agents can be very important, and within these natural enemies, chalcidoid hymenopterous as parasitoid of XBs are very impotent group in controlling these pests. No works have focused especially on a broad assessment of XBs-Chalcidoidea associations world widely. The Chalcidoidea Database (http://www.nhm.ac.uk/entomology/chalcidoids/index.html) is a searchable electronic databases web site with useful data on biology, associations, distribution and taxonomy of Chalcidoidea.

Several general references contain synoptic information about the parasitism of chalcidoids species in different countries or regions (Austin et al., 1994; Andrianova and Makhmadzieev, 1980; Bakke, 1956; Balazy, 1968; Beaver, 1967; Berisford, 1969; 1974; Bickel, 1985; Bosman and Meijeraan, 1969; Buhroo et al., 2002; Hedqvist, 1967; Kamijo, 1981; Lakatos and Thuroczy, 2002; Loerch and Cameron, 1983; Lotfalizadeh and Khalghani, 2008; Lozano and Campos, 1993; Markovic and Stojanovic, 2003; Mendel, 1985, 1986; Mendel and Halperin, 1982; Mendel and Gurevitz, 1985; Parihar and Kampantzov, 1997; Pettersen, 1976; Reid, 1957; Stojanovic and Markovic, 2007; Weslien, 1992; Williams and Langor, 2002; Yanovskii, 1986; Yang, 1987, 1996; Yunap, 1986; Zhang et al., 2005). Because of the importance of this group of parasitoids in XBs complex control, further researches should be carried out. Further study can increase our knowledge on these benefit groups of insects that in the most case all of collected species have not been identified. On the other hand, little information is available in the literature concerning the parasitoid-host associations of chalcidoids and XBs in natural or near-natural settings, the fact that influences our perception of the true diversity of such associations and diminishes our ability to draw from the full range of these associations for use in biological control efforts. Such studies could be aided by tools to help in identifying the complex fauna of benefit species. Therefore, this review was made because of necessity of more correct evaluation of importance of the superfamily in natural control, and also for evaluation of their potential importance in the control of density of XBs. The objectives of this study are (1) to provide an extensive, referenced, tabulation of XBs-parasitoids associations worldwide; and (2) to review these data for patterns of biological and/or biological control interest.

MATERIALS AND METHODS

Approximately 138 literatures were searched and the data related to parasitoids of xylophaous beetles were extracted to identify references that cited XBs-chalcidoid parasitoids association. A list of parasitic chalcidoids has been developed according to literature records. Biological information on the association of each species with XBs is summarized. For species with taxonomic and biological literature, a brief summary and key reference are given here (see Table 1).

The families Anobiidae, Bostrichidae, Cerambycidae, Buprestidae and Scolytidae that may be named as xylophagous, phloeophagous, woodborers and bark beetles in the literatures are considered as XBs in this review.

The following data on associations were recorded from the literature: (1) scientific name and family of chalcidoid parasitoid species, and (2) bibliographic citation information.

Associations were recorded only if parasitoid taxa were identified i.e., associations in which either the parasitoid taxon was identified only to family or order rank were excluded. Only in the family Mymaridae two unknown species are included because of conserve this family in the associated fauna to XBs.

After the initial compilation of parasitoid-host associations, the scientific names and family associations of all nominal taxa were checked in Noyes (2010) for accuracy, and available taxonomic and most recent nomenclatural changes were considered. The known distributions of geographically restriction of each parasitoid were presented. The abbreviations of zoogeographic regions are as follow: AFT, Afrotropical region; AUS, Australian region; NEA, Nearctic; NET, Neotropical region; ORL, Oriental region; PAL, Palaearctic region. Associated species or genera with XBs that present in three or more zoographical regions have been considered as a cosmopolitan species or genera.

RESULTS AND DISCUSSION

This review indicates various number of chalcidoid species living in or from XBs and identify 264 distinct parasitoid-host associations between Chalcidoidea and XBs (Table 1). These associations involve 89 genera and 208 identified parasitoid species on five families of XBs.

The number of world species of Chalcidoidea associated with XBs and their distribution are presented. In summarizing known data on parasitoids of XBs, I establish ten families of the chalcidoid wasps as the associated ones. Within the chalcidoids wasps, the families that have been known as parasitoids of XBs include Chalcididae, Encyrtidae, Eulophidae, Eurytomidae, Eupelmidae, Leucospidae, Mymaridae Pteromalidae, Torymidae and Trichogrammatidae. Lakatos and Thuroczy (2002) mentioned some other groups of parasitoids such as Braconidae, Ichneumonidae (Ichneumonoidea), Platygastridae, Diapriidae (Proctotrupoidea) and Bethylidae (Chrysidoidea) as associated to XBs that their host relations are still not clarified.

Out of 2100 or so valid chalcidoid genera, 4.2% of them are reliably known to contain species that are parasitic on XBs. These 89 genera contain about 208 described species. It seems that the Chalcidoidea is the largest group of natural insect enemies of XBs. In Mymaridae the precise numbers of species have not been identified (Lakatos and Thuroczy 2002).

Taxa in three families predominate: Pteromalidae 47 genera (53% of Chalcidoidea genera) and 83 species (40% of chalcidoid species); Eulophidae 10

genera (11%) and 31 species (15%); and Eupelmidae 6 genera (6%) and 23 species (11%). According to this investigation, Pteromalids (41%) and Eulophids (15%) are the dominant parasitoids (Fig. 4), nevertheless, undoubtedly a large number of various parasitoid species haven't been determined yet.

Grouped by chalcidoid family, 41% of all associations involve the family Pteromalidae, 6% the Chalcididae, 14% the Encyrtidae, 15% the Eulophidae, 10% the Eurytomidae, 11% the Eupelmidae, and 1% each of the families: Mymaridae, Torymidae and Trichogrammatidae (Fig. 3).

Grouped by XB family, 40% of all associations involve the Scolytidae, 27% the Buprestidae, 18% the Cerambycidae, 10% the Anobiidae and 6% the Bostrychidae (Fig. 1). Two chalcidoid families show a clear majority of associations with a single XB family: Pteromalidae with Scolytidae (75% of pteromalid associations) and Eulophidae with Scolytidae (48% of eulophid associations). The bostrychid family has not reported as host of Torymidae.

Chalcidoid parasitoids diversity of each XBs families are summarized in Fig. 5. In addition to the number of chalcidoid species recorded for various XBs families, the number of chalcidoid species (and genera) known for those XB species within their respective family is also recorded (Fig. 6). Among XBs families, the greatest parasitoid diversity was recorded for the family Scolytidae (Fig. 6). The highest number of recorded parasitoids genera and species is found in the Palaearctic region (72-148), followed by the Nearctic (33-50), Oriental (28-35), Neotropical (18-19), Afrotropical (11-13) and Australian (12-13) regions (Fig. 6). Fourthy-one genera have limited distributions to a zoogeographical region, of which 70% are found only in the Palaearctic, 17.5% in the Nearctic, and the rest in the Afrotropical, Australian, Neotropical and Oriental regions.

Table 1 includes the entire chalcidoid hymenopterous parasitoid genera and species recorded on XBs families world widely.

Given this reality that some of XBs (e.g. Bark beetles) are economically important pest, hence, it is important to be able to distinguish which parasitoid species may be useful in combating those threats. This study broadly documents the current knowledge of global chalciodid-XB parasitoid-host associations as a preliminary step for assessing the use of chalcidoid parasitod as targeted parasitoids to control XBs.

PARASITOID ASSOCIATIONS

Chalcidid association- Chalcididae currently includes 89 genera and approximately 1500 species placed in five subfamilies in the world (Noyes, 2010). Only 13 species in four genera are reported from XBs. The number of associations between Chalcididae and XBs, at first glance, seems disproportionately highly relative to the small species diversity of the families Cerambycidae, Buprestidae, Bostrichidae and Scolytidae (Figs 3-5). Part of this may be suggested the possibility of entrance of the chalcidid parasitoids -with relatively large and stout body- into the large galleries of these families. However, there are some small species belong to the family of Scolytidae have been reported as host of this group of parasitoids, that I also suggest the possibility of a broader role for the Chalcididae in the suppression of XBs populations. It includes four genera and 13 species (6%) of the family Chalcididae which attack XBs worldwide (Fig. 4). These species are widely distributed in the tropical regions.

The strong majority of chalcidid associations with XBs in the family Buprestidae (67%) bears further study for the possible discovery of additional

parasitoids for buprestid beetles biological control efforts. This family was not recovered on Anobiidae.

Encyrtid association- Encyrtidae currently includes 483 genera and aproximatly 4000 species placed in two subfamilies in the world (Noyes, 2010). Thirteen genera including 28 species have been recorded on different families of XBs (see Table 1). Most of them are distributed in the Palaearctic region and about 60% of them associated with Cerambycidae. It belongs 14% of total parasitoids associated to XBs (Fig. 3).

These microhymenoptera have relatively minute size that permites them to entrance all of XB's galleries. The encyrtidae is one of the most useful families in biological control mostly on Hemiptera and Coleoptera. It seems that their associations need furthers attention because only 2.7% of know genera are associated with XBs.

In this family *Oobius agrili* as a solitary and parthenogenic egg parasitoid, was introduced from China to use as a biocontrol agent in USA to control of *Agrilus planipennis* (Col.: Buprestidae) (Bauer et al., 2008).

Eulophid association- Eulophidae is one of the large families of chalcidoids. It currently includes 332 genera and more than 4500 species (Noyes, 2010) arranged in four subfamilies. Parasitic eulophids on XBs belong 31 species in ten genera (Fig. 4). Among these, only five genera of Tetrastichinae (*Aprostocetus* Westwood, *Baryscapus* Förster, *Tetrastichus* Haliday, *Planotetrastichus* Yang, *Phymastichus* LaSalle), two genera of Euderinae (*Boučekastichus* Andriescu, *Wichmannia* Ruschka), one genus of Eulophinae (*Pnigalio* Schrank) and one genus of Entedoninae (*Entedon* Dalman) include parasitoids of XBs. It is mostly associated with Scolytidae (44%) and Buprestidae (29%) (Table 1). Eulophidae are second specious group of parasitoid community associated with XBs (Fig. 4). Such as latter family they are small wasps that may be simplify to access in the XB's galleries.

Bauer et al. (2008) mentioned *Tetrastichus planipennisi* as a classical biological control of *Agrilus planipennis* (Col.: Buprestidae) in USA (introduced from China).

Eupelmid association- This family includes 48 genera and approximately 1000 species placed in three subfamilies (Calosotinae, Eupelminae and Neanastatinae) in the world (Noyes, 2010). Some these genera that attack insects in plant stems or wood. Out of 48 so valid eupelmid genera, six (*Balcha* Walker, *Calosota* Curtis, *Eusandalum* Ratzeburg and *Pentacladia* Westwood from Calosotinae *Eupelmus* Dalman from Eupelminae and *Metapelma* Westwood from Neanastatinae) are reliably known to contain species that are parasitic on XBs. These six genera have 23 described species, mostly associated with Scolytidae (39%) and Buprestidae (39%).

This relatively large family is widely distributed through the world but most of the genera associated with XBs are not widely distributed and occur in one zoogeographical region (mostly Palearctic) of the world (Table 1), while there is not any cosmopolitan eupelmid species. It seems that this family is not studied sufficiently in the other regions. One of the reasons of this problem may be the difficulty of their collection by known methods *e.g*. sweeping. Because there are brachypterous and apterous forms in this family, therefore rearing on dead twigs with exit holes can be a recommended method.

Eurytomid association- Classification of Eurytomidae followed here is that of Lotfalizadeh et al. (2007). Eurytominae is the largest subfamily that contains species, which exhibit a range of biologies and includes all the XBs parasitoids species in the family. Within this subfamily, *Eurytoma* is a specious genus with remarkably varied biology, including organisms that are parasitic, inquilinous, phytophagous, entomophagous and gall inducing. Many of the species of *Eurytoma* occur as parasitic in XBs.

All of XBs parasitoids species (20 species) include in this family belong to the genus *Eurytoma* (except *Endobia donacis*) (Fig. 4). These species are from two species groups, *morio*-group and *nodularis* (Lotfalizadeh et al., 2007) or *robusta*-group (Zerova and Seryogina, 2006). Lotfalizadeh et al. (2007) believe that *morio* group is not good placed in the genus *Eurytoma* because of lacking postgenal depression. But these species have hairy metacoxa, relatively inflated marginal vein and distinctive costal cell bearing numerous white hairs on its ventral surface. On the contrary the *nodularis* group has a conspicuous mesopleural ventral shelf, carinate fore coxae and the petiolate female gaster (Lotfalizadeh et al., 2007).

In summary, the adults of those eurytomid taxa parasitoids of XBs can be separated from other chalcidoid families by typical characters of the family Eurytomidae (mostly black coloration, quadrate pronotum and punctuate notum). After Pteromalidae, Eulophidae and Eupelmidae, this family includes a large part (10%) of parasitoids of XBs (Fig. 3). Its association with the families Scolytidae and Buprestidae with 36% is dominant. In this family, *Endobia donacis* is a cosmopolitan species.

Pteromalid association- Pteromalidae, one of the large families of Chalcidoidea, currently includes 587 genera and approximately 3500 species placed in 30 subfamilies throughout the world (Noyes, 2010). Several groups of pteromalid are parasitoids of XBs that belong to Pteromalinae, Cerocephalinae, Cleonyminae, Louriciinae, Macromesinae and Euderinae (Fig. 2). Of which Pteromalinae is most specious group. Also most cleonymines are parasitoids or supposed parasitoids of XBs (Bouček, 1988; Gibson, 2003). Therefore, it seems that the Cleonyminae may be need more attention as XBs parasitoids. But biology of the Cleonyminae genera is mostly unknown; therefore these genera are excluded in this review. According to literatures 1) some of them have unknown biology but they are probably parasitoids of XBs such as *Lycisca* Spinola, *Westwoodiana* Girault, *Striatacanthus* Gibson (Gibson, 2003) or they are parasitoids of XBs larvae probably mainly of Buprestidae and Cerambycidae such as *Thaumasura* Westwood (Bouček, 1988); 2) some others are parasitoids of the larvae of unknown XBs in dead tree trunks and logs such as *Mesamotura* Girault, *Parepistenia* Dodd (Bouček, 1988); 3) some genera are apparently parasitoids of XBs such as *Neboissia* Bouček (Bouček, 1988).

The Pteromalidae are the well known generalists parasitoids of XBs and form a very large part of chalciodid fauna associated with XBs (Fig. 3). Within the recovered families approximately 41% of reared species belongs to Pteromalidae. They outshine the Chalcididae, Encyrtidae, Eulophidae, Eurytomidae, Eupelmidae and Torymidae in both species richness and spectrum of XBs hosts that they attack (Fig. 5 and Table 1). About 80% of them are widely distributed in the Palaearctic region (Table 1). This family show the broadest range of associations with XB families, but a distinct plurality (55%) of its associations were with the family Scolytidae. Also their association with other families were

calculated as follow: 17% with Buprestidae, 13% with Anobiidae, 8% with Cerambycidae and 7% with Bostrychidae.

The pteromalid parasitoid fauna of XBs comprise 83 of described species in 47 genera. Dzhanokmen (1991) reviewing trophic association of the family Pteromalidae, listed 14 genera for Anobiidae, eight genera for Buprestidae and 17 genera for Scolytidae within five subfamilies (Pteromalinae, Cerocephalinae, Cleonyminae, Miscogasterinae and Macromesinae) that attach XBs. She did not mention the families Cerambycidae and Bostrychidae as hosts of Pteromalidae.

The preponderance of pteromalid associations with XBs in the family Scolytidae, suggests that additional taxa in this family might be good targets for further study for control of this group of agricultural pests. Solitary parasite is predominant in this family. They can be the primary or secondary parasite of Coleoptera (Dzhanokmen, 1991).

They are potentially important natural enemies of many pest insects and there are some successful utilization in biological control programs. Bouček and Rasplus (1994) listed some of them such as *Perniphora robusta* (L.) and *Cheiropachus quqdrum* (F.) that were introduced from Europe respectively to New Zealand and North America against Scolytidae. The pteromalids associated with XBs are mostly ectoparasite that acts predominantly as larval parasite. These wasps are rarely associated with adult such as *Tomicobia seitneri* (Ruschka, 1924) on several species of *Ips* (Col.: Scolytidae) (Dzhanokmen, 1991). This family has ten species in nine genera that were widely distributed and are cosmopolitan (see Table 1).

Mymaridae association- Mymaridae currently includes 99 genera and more than 1400 species in the world (Noyes, 2010). All of the members of the family so far known are parasitic in habit and develop in the eggs of different insect orders (Lin et al., 2007). Very few reliable host records exist for more than 1400 mymarid taxa. Although members of this family are almost exclusively egg parasitoids, Lakatos and Thuroczy (2002) and Lin et al. (2007) reported two unknown species of *Anaphes* Haliday and *Prionaphes* Hincks respectively develop as parasitoids of the XBs in the Palaearctic and Australian regions.

Trichogrammatid association-They are tiny wasps that are egg parasitoid of different orders of insects. World Trichogrammatid currently includes 96 genera and approximately 900 species in the world (Noyes, 2010) of which two species have so far been reported as XB associates. They are found on XBs of the families Scolytidae and Cerambycidae and include 1% of XB's parasitoids (Fig. 3). It seems that these minute wasps (smaller than 1 mm) can enter easily in the XB's galleries but our knowledge of their controlling task of XBs is rudimentary. Two listed species in this research are widely distributed (see Table 1).

Torymid association- This family contains about 1000 species placed in 73 genera in the world (Noyes, 2010). Much useful information on the biology of Torymidae is available in summarized forms in Grissell (1995). He discussed in detail the subfamily systematics of torymids and accordingly, the family includes Megastigminae and Toryminae. Only three species in two genera (*Ecdamua* and *Microdontomerus*) was reported on XBs families (except Bostrychidae).

This family with its characteristic morphology (long ovipositor) should have an important task in XBs control, because of their sheltered habitat. Hence, it seems its importance as the biocontrol agent of XBs needs to be reviewed in the world fauna.

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Table 1. Chalcidoid parasitoids of xylophagous beetles worldwide with their geographical distribution, host families and literature cited.

Parasitods	Zoogeographical distribution*	Hosts family	Reference
Chalcididae			
Acanthochalcis nigricans Cameron, 1884	NEA, NET	Buprestidae	Halstead and Haines (1985)
Phasgonophora sulcata Westwood, 1832	NEA	Buprestidae	Peck (1963), Haack et al. (1981)
Tanycoryphus conglobatus Steffan, 1950	AFT	Bostrychidae	Herting (1973)
criniger Steffan, 1950	AFT	Bostrychidae	Herting (1973)
occultus Steffan, 1957	AFT	Buprestidae	Herting (1973)
tibialis (Nikol'skaya, 1960)	PAL	Buprestidae	Nikol'skaya (1960), Lotfalizadeh & Khalghani, (2008), Lotfalizadeh et al. (2009)
Trigonura californica Rohwer, 1917	NEA	Buprestidae	Peck (1963)
elegans (Provancher, 1887)	NEA	Buprestidae	Peck (1963)
chrysobathra Yang, 1994	PAL	Buprestidae	Yang et al. (1994)
ruficaudis (Cameron, 1913)	ORL, PAL	Buprestidae, Cerambycidae	Lotfalizadeh & Khalghani (2008)
sphenoptera Nikol'skaya, 1960	PAL	Buprestidae	Nikol'skaya (1960), Lotfalizadeh & Khalghani (2008)
tenuicaudis Waterston, 1922	ORL	Buprestidae, Cerambycidae	Narendran (1986)
ulmi Burks, 1959	NEA	Scolytidae	Peck (1963), Herting (1973)
Encyrtidae			
Austroencyrtus ceresii (Liao & Tachikawa, 1984)	ORL	Cerambycidae	Trjapitzin (1989)
Amauroencyrtus micans De Santis, 1985	NEO	Cerambycidae	De Santis (1985)
Avetianella ambigua Zhang & Huang, 2004	PAL	Cerambycidae	Zhang & Huang (2004), Zhang et al. (2005)
batocerae (Ferrière, 1936)	ORL	Cerambycidae	Noyes, 2008
buprestidis Gordh and Trjapitzin, 1981	NEA	Buprestidae	Gordh & Trjapitzin (1981), Zhang et al. (2005)
capnodiobia Trjapitzin, 1968	PAL	Buprestidae	Trjapitzin (1963), Trjapitzin, (1989), Zhang et al. (2005)
coombsi Schmidt and Noyes, 2003	AUS	Cerambycidae	Schmidt & Noyes (2003), Zhang et al. (2005)
depressa (Girault,1916)	NEA	Cerambycidae	Gordh (1979), Gordh & Trjapitzin (1981), Zhang et al. (2005)
longoi Siscaro, 1992	PAL	Cerambycidae	Austin et al. (1994)
xystrocerae Zhang & Huang, 2005	PAL	Cerambycidae	Zhang et al. (2005)
Baeoanusia xanthopleuron Schmidt & Noyes, 2003	AUS	Cerambycidae	Schmidt & Noyes (2003)
Cerchysiella togashii Tachikawa, 1988	PAL	Cerambycidae	Tachikawa (1988)
Dionencyrtus cordylomerae (Risbec, 1951)	AFT	Cerambycidae	Herting (1973)
fiorentinoi De Santis, 1985	NEO	Cerambycidae	De Santis (1985)

Heterococcidoxenus *schlechtendali* (Mayr, 1876)	PAL	Scolytidae	Lotfalizadeh & Khalghani (2008)
Oobius *abditus* Annecke, 1967	AFT	Buprestidae	Annecke (1967), Zhang et al. (2005)
agrili Zhang & Huang, 2005	PAL	Buprestidae	Zhang et al. (2005)
funestus Annecke, 1967		Buprestidae	Annecke (1967), Zhang et al. (2005)
rudnevi (Novicky, 1928)	PAL	Cerambycidae	Trjapitzin (1963), Trjapitzin (1989)
taybekovi Myartseva & Trjapitzin, 1979	PAL	Buprestidae	Myartseva (1979), Trjapitzin (1989), Zhang et al. (2005)
zahaikevitshi Trjapitzin, 1963	PAL	Buprestidae	Trjapitzin (1989), Zhang et al. (2005)
Ooencyrtus *moneilemae* Gahan, 1925	NEA	Cerambycidae	Peck (1963)
ovidivorus (Girault, 1925)	AUS	Cerambycidae	Girault (1925)
Orianos *brazai* Noyes, 1990	ORL	Buprestidae	Noyes (1990)
Protyndarichoides *aligarhensis* (Fatma & Shafee, 1985)	ORL, PAL	Scolytidae	Springat & Noyes (1990), Fatma & Shafee (1985)
Tineophoctonus *armatus* (Ashmead, 1888)	NEA, PAL	Anobiidae	Trjapitzin (1989)
Zaommoencyrtus *brachytarsus* Xu & He, 1998	ORL	Cerambycidae	Xu & He (1998)
emetzi Khlopunov, 1981	PAL	Cerambycidae	Khlopunov (1981)
Zdenekiella *deon* Guerrieri & Noyes, 2005	PAL	Bostrychidae	Guerrieri & Noyes (2005)
Eulophidae			
Aprostocetus *crypturgus* Yang, 1996	PAL	Scolytidae	Yang (1996)
dendroctoni Yang, 1996	ORL	Cerambycidae	Yang (1996)
lamiicidus Kerrich, 1963	AFT	Cerambycidae	Herting (1973)
Baryscapus *agrilorum* (Ratzeburg, 1844)	PAL	Buprestidae	Graham, 1991
holbeini (Girault, 1917)	PAL	Buprestidae	Herting (1973), Peck (1963)
nordi (Burks, 1963)	NEA	Buprestidae	Burks (1963)
Boučekastichus *leileri* (Hedqvist, 1974)	PAL	Anobiidae	Hedqvist (1974a)
Entedon *broussonetiae* Yang, 1996	PAL	Scolytidae	Yang (1996)
confinis Ratzeburg, 1848	PAL	Anobiidae	Bouček & Askew (1968)
ergias Walker, 1839	NEA, PAL	Cerambycidae, Scolytidae	Gumovsky (1999), Lotfalizadeh & Khalghani (2008)
methion Walker, 1839	NEA, PAL	Anobiidae	Thampson (1955)
tibialis (Nees, 1834)	PAL	Anobiidae, Scolytidae	Markovic & Stojanovic (1996)
stephanopachi Heqvist, 1959	NEA, PAL	Bostrychidae	Schauff (1988)
zanara Walker, 1839	PAL	Buprestidae	Bouček & Askew (1968)
Euderus *agrili* Bouček, 1963	PAL	Buprestidae	Bouček & Askew (1968)
caudatus Thomson, 1878	NEA, PAL	Cerambycidae	Bouček & Askew (1968)
regiae Yang, 1996	PAL	Scolytidae	Yang (1996)
jezoensis Ishii, 1938	PAL	Scolytidae	Herting (1973)
Tetrastichus *agrilocidus* Graham, 1991	PAL	Buprestidae	Graham, 1991
heeringi Delucchi, 1954	PAL	Buprestidae	Herting (1973), Graham

			(1991)
telon (Graham, 1961)	PAL	Buprestidae	Graham (1991)
clavicornis Yang, 1996	PAL	Scolytidae	Yang (1996)
clavatus Yang, 1996	PAL	Scolytidae	Yang (1996)
xylebororum Domenichini, 1960	ORL	Scolytidae	Herting (1973)
taibaishanensis Yang, 1996	PAL	Scolytidae	Yang (1996)
ulmi Erdös, 1954	PAL	Buprestidae, Scolytidae, Cerambycidae	Herting (1973), Graham, (1991), Stojanovic & Markovic (2007)
Planotetrastichus			
scolyti Yang, 1996	PAL	Scolytidae	Yang (1996)
Pnigalio			
minio (Walker, 1847)	NEA	Buprestidae	Burks (1979)
Phymastichus			
coffea LaSalle, 1990	AFT, NET	Scolytidae	Lopez Vaamonde & Moore (1998)
Wichmannia			
pictipennis Bouček , 1972	PAL	Scolytidae	Bouček (1972)
decorata Ruschka, 1916	PAL	Scolytidae	Bouček (1972)
Eurytomidae			
Endobia			
donacis Erdös, 1964	NEA, ORL, PAL	Bostrychidae	Farooqi & Subba Rao (1986)
Eurytoma			
arctica Thomson, 1876	PAL	Scolytidae	Lotfalizadeh & Khalghani (2008)
blastophagi Hedqvist, 1963	PAL	Scolytidae	Lotfalizadeh & Khalghani (2008)
conica Provancher, 1887	NEA	Scolytidae	Berisford et al. (1970)
elistae Zerova, 1995	PAL	Buprestidae	Zerova & Seryogina (2006)
flaviventris Zerova, 1977	PAL	Buprestidae	Zerova & Seryogina (2006)
gyorfii Erdös, 1957	PAL	Anobiidae	Zerova & Seryogina (2006)
graminicola Zerova, 1981	PAL	Buprestidae	Zerova & Seryogina (2006)
iranicola Zerova, 2007	PAL	Cerambycidae	Zerova & Seryogina (2006), Lotfalizadeh & Khalghani (2008)
kondarica Zerova, 1994	PAL	Buprestidae	Zerova & Seryogina (2006)
morio Boheman, 1836	PAL	Scolytidae	Stojanovic & Markovic (2007), Lotfalizadeh & Khalghani (2008)
nova Zerova, 2001	PAL	Anobiidae	Zerova & Seryogina (2006)
pedicellata Yang, 1996	PAL	Scolytidae	Yang (1996)
pini Bugbee, 1958	NEA, NET	Scolytidae	Herting (1973)
polygraphi (Ashmead, 1894)	NEA, PAL	Scolytidae	Zerova, 1978
pyrrhidii Erdös, 1969	PAL	Buprestidae, Cerambycidae	Zerova & Seryogina (2006)
tilicola Hedqvist, 1966	PAL	Buprestidae, Cerambycidae	Zerova & Seryogina (2006)
tomici Ashmead, 1894	NEA	Scolytidae	Peck (1963)
turkomanica Zerova, 1995	PAL	Buprestidae	Zerova & Seryogina (2006)
wachtli Mayr, 1878	PAL	Cerambycidae	Zerova & Seryogina (2006); Zerova,1978
zykovi Zerova, 1995	PAL	Buprestidae	Zerova & Seryogina (2006)
Eupelmidae			
Balcha			
indica (Mani & Kaul, 1973)	NEA, ORL	Scolytidae, Cerambycidae	Gibson (2005)
levicollis (Cameron, 1908)	ORL	Buprestidae	Gibson (2005)
Calosota			
aestivalis Curtis,1836	PAL	Scolytidae, Buprestidae, Anobiidae	Trjapitzin (1978), Mendel (1986)

agrili Nikol'skaya, 1952	PAL	Buprestidae	Trjapitzin (1978)
yanglingensis Yang, 1996	PAL	Scolytidae	Yang (1996)
qilianshanensis Yang, 1996	PAL	Scolytidae	Yang (1996)
Eusandalum			
acmaeoderae Rohwer, 1917	NEA	Buprestidae	Peck (1963)
alfierii (Bolivar y Pieltain, 1925)	PAL	Buprestidae	Bouček (1967)
coronatum (Thomson, 1876)	PAL	Buprestidae	Trjapitzin (1978)
inerme (Ratzeburg, 1848)	PAL	Anobiidae, Bostrichidae, Buprestidae, Cerambycidae, Scolytidae	Lotfalizadeh & Khalghani (2008)
flavipenne Ruschka, 1921	PAL	Buprestidae	Trjapitzin (1978)
lindemani Kalina, 1984	PAL	Buprestidae	Kalina (1984)
Eupelmus			
carinifrons Yang, 1996	ORL, PAL	Scolytidae	Yang (1996)
kashmiricus Narendran, 2001	ORL	Scolytidae	Narendran et al. (2001)
sculpturatus Nikol'skaya, 1952	PAL	Scolytidae	Herting (1973), Markovic & Stojanovic (2003)
muellneri Ruschka, 1921	PAL	Buprestidae, Scolytidae	Lotfalizadeh & Khalghani (2008)
valsus Narendran, 2001	ORL	Scolytidae	Narendran et al. (2001)
vindex Erdös, 1955	PAL	Scolytidae	Narendran et al. (2001)
Metapelma			
compressipes Cameron, 1909	ORL	Cerambycidae	Herting (1973)
indica (Girault, 1920)	ORL	Bostrychidae	Thompson (1955)
zhangi Yang, 1996	PAL	Scolytidae	Yang (1996)
Pentacladia			
eques (Haliday, 1862)	AFT, PAL	Buprestidae	Delvare (2001)
mateui Delvare, 2001	PAL	Buprestidae	Delvare (2001)
Leucospidae			
Leucospis			
dorsigera Fabricius, 1775	PAL	Bostrichidae, Cerambycidae	Herting (1973), Baur (2005)
Mymaridae			
Anaphes			
sp.	PAL	Cerambycidae	Lakatos & Thuroczy (2002)
Prionaphes			
sp.	AUS	Cerambycidae	Lin et al. (2007)
Pteromalidae			
Ablaxia			
squamifera (Thomson, 1878)	PAL	Cerambycidae, Scolytidae	Bouček (1961), Meduna (1986)
Acerocephala			
atroviolacea (Crawford, 1913)	NEA	Scolytidae	Dzhanokmen (1991)
Acrocormus			
semifasciatus Thomson, 1878	PAL	Scolytidae	Bouček (1961), Graham (1969), Hertig (1973), Stojanovic & Markovic (2007)
Aggelma			
agrili Bouček, 1965	PAL	Buprestidae	Dzhanokmen (1991)
Agrilocida			
ferrierei Steffan, 1964	PAL	Buprestidae, Scolytidae	Steffan (1964), Mendel (1986), Gibson (2003)
Amotura			
caelata Grissell, 1991	NEA, NET	Buprestidae, Bostrychidae	Grissell (1991)
Anisopteromalus			
calandrae (Howard, 1881)	AFT, AUS, NEA, NET,	Anobiidae	Dzhanokmen (1991)

	ORL, PAL		
Callimomoides *ovivorus* (Ferrière, 1936)	ORL	Cerambycidae	Bouček (1988)
Callocleonymus *Bimaculae* Yang, 1996	PAL	Scolytidae, Buprestidae	Dzhanokmen (1991), Yang (1996)
pulcher Masi, 1940	AFT, PAL	Bostrychidae, Scolytidae, Buprestidae	Dzhanokmen (1991), Lotfalizadeh & Khalghani (2008)
Cerocephala *aquila* (Girault, 1920)	AUS, NET, ORL	Bostrychidae, Buprestidae, Scolytidae	Dzhanokmen (1991)
eccoptogastri Masi, 1921	AFT, PAL	Scolytidae	Herting (1973), Mendel (1986), Lozano & Campos (1993), Stojanovic & Markovic (2007)
rufa (Walker, 1833)	NEA, PAL	Buprestidae, Anobiidae, Scolytidae	Dzhanokmen (1991)
Chalcedectus *balachowskyi* Steffan, 1968	PAL	Bostrychidae, Buprestidae, Cerambycidae	Gibson (2003), Lotfalizadeh & Khalghani (2008)
Cheiropachus *obscuripes* Brues, 1910	NEA, PAL	Scolytidae, Buprestidae	Dzhanokmen (1991)
quadrum (Fabricius, 1787)	NEA, PAL, ORL, NET	Bostrychidae, Cerambycidae, Scolytidae	Dzhanokmen (1991), Lotfalizadeh & Khalghani (2008), Stojanovic & Markovic (2007)
Cleonymus *laticornis* Walker, 1837	PAL	Anobiidae, Bostrychidae, Buprestidae, Cerambycidae, Scolytidae	Dzhanokmen (1991), Gibson (2003)
Dibrachys *boarmiae* (Walker, 1863)	AUS, PAL, NET	Anobiidae	Dzhanokmen (1978)
Dinotiscus *aponius* (Walker, 1848)	PAL	Scolytidae	Dzhanokmen (1991), Stojanovic & Markovic (2007)
colon (Linnaeus, 1758)	NEA, PAL, NET	Scolytidae	Dzhanokmen (1991), Lakatos & Thuroczy (2002)
eupterus (Walker, 1836)	NEA, PAL	Scolytidae	Dzhanokmen (1991), Lakatos & Thuroczy (2002)
dendroctoni (Ashmead, 1894)	NEA	Scolytidae	Dzhanokmen (1991)
tenebricus Walker, 1834	PAL	Scolytidae, Cerambycidae	Graham (1969)
Dorcatomophaga *westi* Kryger, 1951	PAL	Anobiidae	Dzhanokmen (1991)
Euderus *lividus* (Ashmead, 1886)	ORL, NEA	Cerambycidae	Peck (1963), Grimble et al. (1971), Gibson (2003)
Habritys *brevocornis* (Ratzeburg, 1844)	NEA, PAL	Scolytidae	Thompson, 1958
Heydenia *pretiosa* Förster, 1856	PAL	Buprestidae, Scolytidae, Cerambycidae	Dzhanokmen (1991), Lotfalizadeh & Khalghani (2008), Lakatos & Thuroczy (2002), Gibson (2003)
indica Narendran, 2001	ORL	Scolytidae	Buhroo et al. (2002), Sureshan & Narendran (2003)

unica Cook & Davis,1891	NEA	Scolytidae	Dzhanokmen (1991)
Kaleva			
microps Bouček, 1993	NEA	Anobiidae	Bouček (1993)
Tomicobia			
pityophthori (Bouček, 1955)	PAL	Scolytidae	Dzhanokmen (1991), Lakatos & Thuroczy (2002)
Lariophagus			
puncticollis (Möller, 1882)	NET, PAL	Anobiidae	Dzhanokmen (1991)
Macromesus		Scolytidae	Dzhanokmen (1991),
amphiretus Walker, 1848	PAL		Stojanovic & Markovic (2007)
cryphali Yang, 1996	PAL	Scolytidae	Yang (1996)
huanglongnicus Yang, 1996		Scolytidae	Yang (1996)
harithus Narendran, 2001	ORL	Scolytidae	Narendran et al. (2001), Buhroo et al. (2002)
Mesopolobus			
typographi (Ruschka, 1924)	PAL	Scolytidae	Thompson (1958) Herting (1973), Stojanovic & Markovic (2007)
Metacolus			
azureus (Ratzeburg, 1844)	PAL	Scolytidae	Thompson (1958), Graham (1969), Herting (1973), Lakatos & Thuroczy (2002)
sinicus Yang, 1996	PAL	Scolytidae	Dzhanokmen (1991), Yang (1996)
unifasciatus Förster, 1856	PAL, ORL	Scolytidae	Thompson (1958), Graham (1969), Dzhanokmen (1991), Lakatos & Thuroczy (2002)
Nasonia			
vitripennis (Walker, 1836)	AFT, AUS, NEA, NET, ORL, PAL	Scolytidae	Pettersen (1976)
Nikolskayana			
mirabilis Bouček, 1965	PAL	Scolytidae	Graham (1969), Dzhanokmen (1991)
Norbanus			
scabriculus (Nees, 1834)	NEA, PAL	Cerambycidae	Bin (1973)
Notanisus		Buprestidae,	Delucchi (1962), Mitroiu &
oulmesiensis (Delucchi, 1962)	PAL	Scolytidae	Andriescu (2008)
Oodera			
ahoma (Mani & Kaul, 1973)	ORL	Buprestidae	Farooqi et al. (1986), Dzhanokmen (1991)
formosa (Giraud, 1863)	PAL	Buprestidae, Scolytidae	Dzhanokmen (1991), Gibson (2003)
regiae Yang, 1996	PAL	Buprestidae	Dzhanokmen (1991), Yang (1996)
Oxysychus			
convexus Yang 1996	PAL	Scolytidae	Yang (1996)
grandis Yang, 1996	PAL	Scolytidae	Yang (1996)
pini Yang,1996	PAL	Scolytidae	Yang (1996)
mori Yang, 1996	PAL	Scolytidae	Yang (1996)
scolyti Yang, 1996	PAL	Scolytidae	Yang (1996)
Pandelus			
flavipes (Förster, 1841)	PAL	Anobiidae	Dzhanokmen (1991)
Perniphora			Graham (1969);
robusta Ruschka, 1923	PAL	Scolytidae	Dzhanokmen (1991)
Platygerrhus			Dzhanokmen (1991), Yang
scutellatus Yang, 1996	PAL	Scolytidae	(1996)
ductilis (Walker, 1836)	PAL	Anobiidae, Scolytidae	Dzhanokmen (1991)
Plutothrix			
coelius (Walker, 1839)	PAL	Anobiidae	Dzhanokmen (1991)
glareosa Heydon, 1997			Dzhanokmen (1991),

	NEA	Anobiidae	Heydon, 1997
Rhaphitelus maculatus Walker, 1834	PAL	Bostrychidae, Scolytidae	Dzhanokmen (1991), Stojanovic & Markovic (2007), Lotfalizadeh & Khalghani (2008)
Rhopalicus brevicornis (Thomson, 1878)	PAL	Scolytidae	Graham (1969), Herting (1973), Lakatos & Thuroczy (2002)
quadratus (Ratzeburg, 1844)	PAL	Scolytidae	Kamijo (1981), Dzhanokmen (1991)
guttatus (Ratzeburg, 1844)	PAL	Buprestidae, Scolytidae	Herting (1973), Dzhanokmen (1991), Yang (1996), Lakatos & Thuroczy (2002)
zolae Grissell, 1983	NEA	Scolytidae	Dzhanokmen (1991)
pulchripennis (Crawford, 1912)	NEA	Scolytidae	Dzhanokmen (1991)
tutela (Walker, 1836)	PAL, ORL, NEA	Bostrychidae, Scolytidae	Dzhanokmen (1991), Lakatos & Thuroczy (2002)
pulchripennis (Crawford, 1912)	NEA	Scolytidae	Dzhanokmen (1991)
Roptrocerus brevicornis (Thomson, 1878)	PAL	Scolytidae	Graham (1969), Herting (1973), Lakatos & Thuroczy (2002)
cryphalus Yang, 1996	PAL	Scolytidae	Dzhanokmen (1991), Bouček & Rasplus (1991), Yang (1996)
mirus (Walker, 1834)	PAL	Scolytidae	Graham (1969), Herting (1973), Lakatos & Thuroczy (2002)
xylophagorum (Ratzeburg, 1844)	AUS, NEA, NET, ORL, PAL	Scolytidae	Dzhanokmen (1991), Lakatos & Thuroczy (2002)
Rhaphitelus maculatus Walker, 1834	AUS, NEA, NET, ORL, PAL	Scolytidae	Dzhanokmen (1991)
Stenoselma nigrum Delucchi,1956	PAL	Buprestidae	Garrido Torres & Nieves-Aldrey (1999)
Solenura ania (Walker, 1846)	ORL, PAL	Buprestidae, Cerambycidae	Yang (1991)
Theocolax elegans (Westwood, 1874)	AFT, AUS, NEA, NET, ORL, PAL	Bostrychidae Scolytidae Anobiidae	Dzhanokmen (1991), Prinsloo (1980)
formiciformis Westwood, 1832	AUS, NEA, NET, PAL	Anobiidae	Dzhanokmen (1991)
Tomicobia seitneri (Ruschka, 1924)	PAL	Scolytidae	Dzhanokmen (1991), Lakatos & Thuroczy (2002)
tibialis Ashmead, 1904	NEA	Scolytidae	Peck (1963), Burks (1979), Dzhanokmen (1991)
Tricolas xylocleptis Bouček, 1967	PAL	Anobiidae	Graham (1969)
Trychnosoma ernobii Hedqvist, 1974	PAL	Anobiidae	Hedqvist (1974b), Dzhanokmen (1991)
Zdenekiana plana (Huggert, 1976)	PAL	Buprestidae	Bouček & Rasplus (1991)
yui Yang, 1996	PAL	Buprestidae, Scolytidae	Yang (1996)
Zolotarewskya longicostalia Yang, 1996	PAL	Anobiidae, Scolytidae	Yang (1996), Gibson (2003)
robusta Yang, 1996	PAL	Buprestidae, Scolytidae	Yang (1996)

Trichogrammatidae			
Trichogramma minutum Riley, 1871	AUS, NEA, NET, ORL, PAL	Cerambycidae Scolytidae	Hayat & Viggiani (1984)
semblidis (Aurivillius, 1898)	NEA, ORL, PAL	Scolytidae	Michalski & Seniczak (1974)
Torymidae			
Ecdamua nambui Kamijo, 1979	PAL	Anobiidae, Buprestidae, Scolytidae	Zavada (2005), Zerova & Seryogina (2007)
Microdontomerus mysticus Grissell, 2005	NET	Cerambycidae	Grissell (2005)
westcotti Grissell, 2005	NEA	Buprestidae	Grissell (2005)

The abbreviations of zoogeographic regions are as follow: AFT, Afrotropical region; AUS, Australian region; NEA, Nearctic; NET, Neotropical region; ORL, Oriental region; PAL, Palaearctic region.

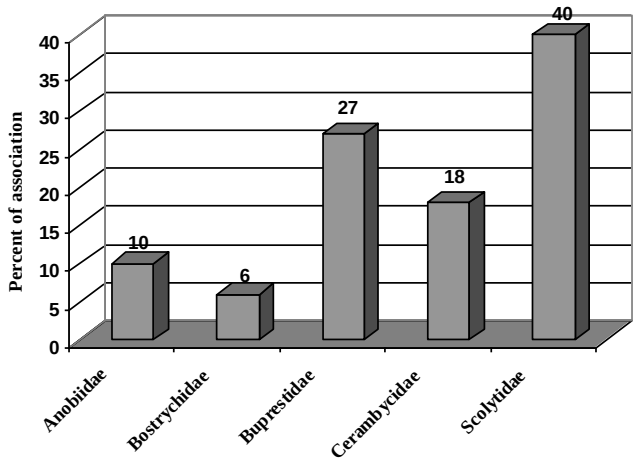

Figure 1. Percent of associations of each XB family with hymenopterous families.

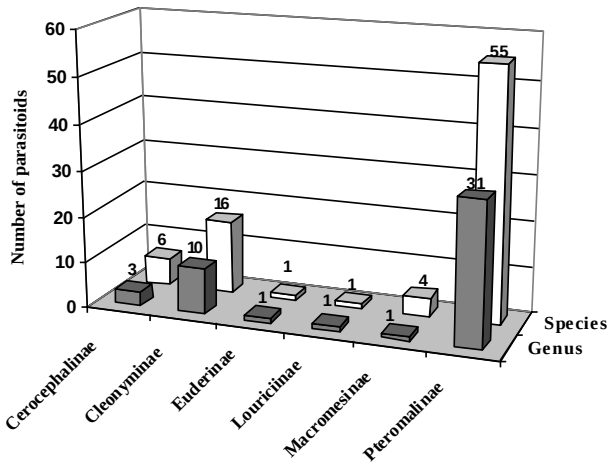

Figure 2. Numbers of the pteromalid's subfamilies taxa associated with XBs.

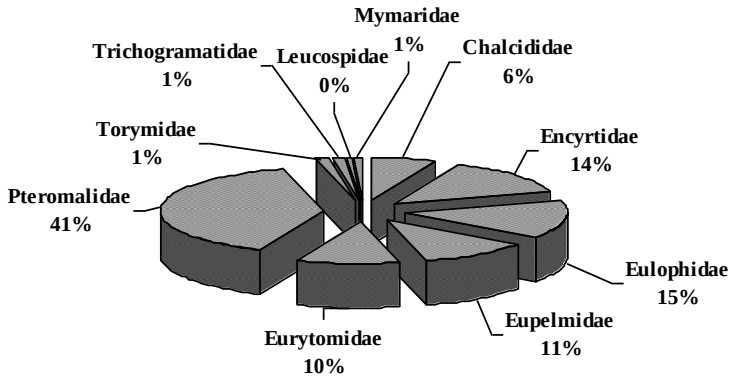

Figure 3. Percent of each chalcidoid parasitoid families reported XBs.

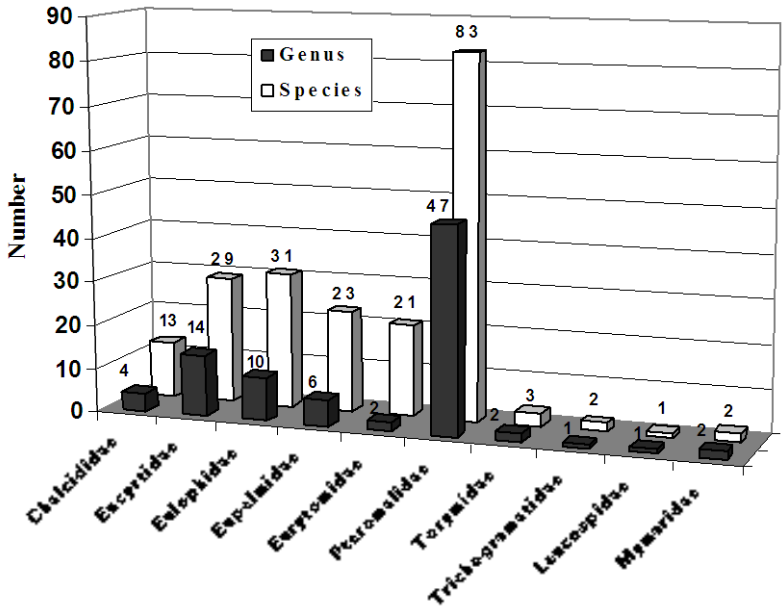

Figure 4. Numbers of chalcidoids taxa with known chalcidoid-XBs parasitoid-host associations.

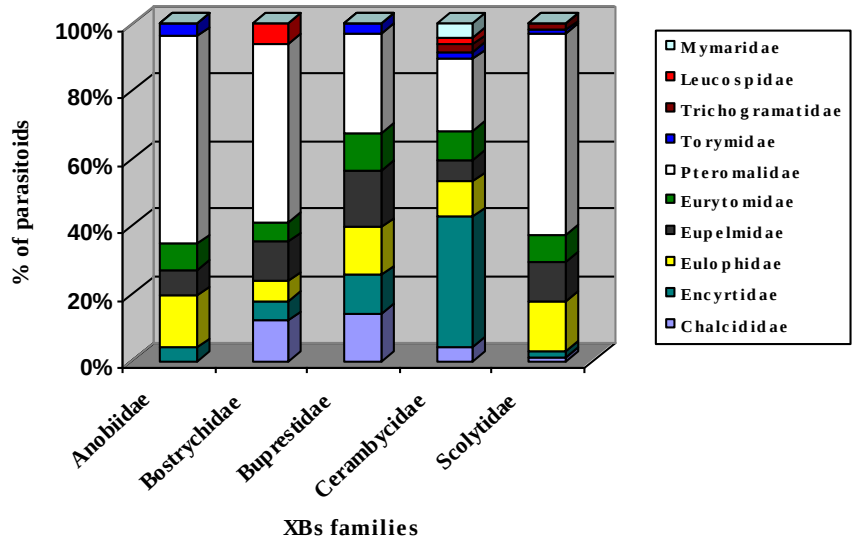

Figure 5. Percent of chalcidoids taxa on each XB families.

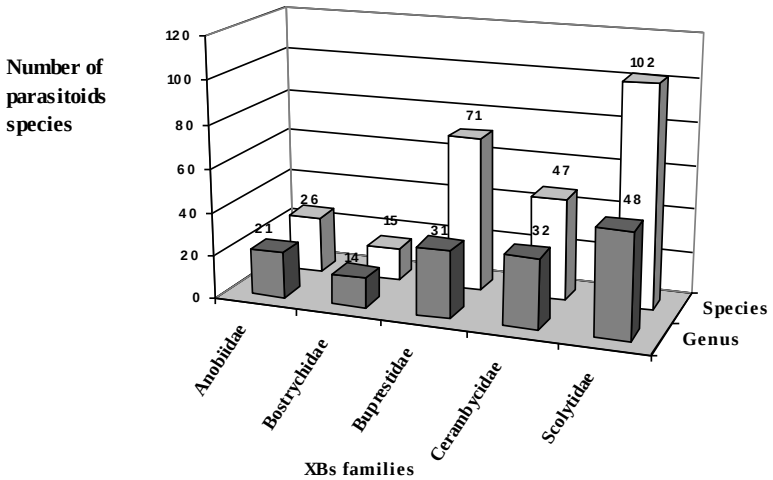

Figure 6. Numbers of chalcidoids genera and species on each XB families.

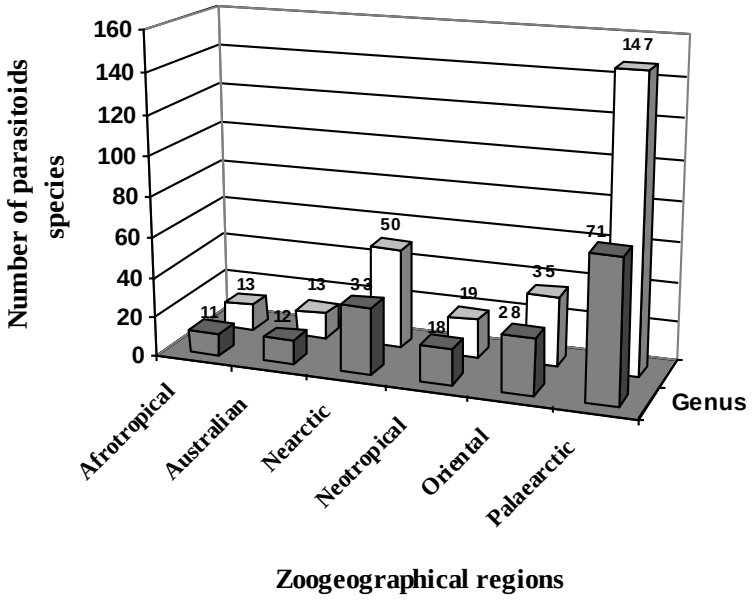

Figure 7. Numbers of chalcidoids genera and species associated with XB families in each zoogeographical regions.