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Species diversity of Coccoidea parasitoids wasps (Hym.: Chalcidoidea) in the northern parts of East-Azarbaijan province, Iran

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Abstract. Various species belongs to the superfamily Chalcidoidea of Hymenoptera are parasitoids on different stages of Hemiptera especially on Coccoidea and Aleyrodoidea. These parasitoid wasps were found emerged from soft scales (*Didesmococcus unifasciatus* and *Sphaerolecanium prunastri*), armored scales (*Chilaspis asiatica*, *Lepidosaphes malicola* and *L. ulmi*) on different trees in East-Azerbaijan province, Iran. A total of 11 parasitic wasps were collected and identified. These parasitoid wasps were collected from different locations of northern East-Azerbaijan province during 2010-2011. Species diversity and Sorensen similarity index between locations were calculated. *Coccobius annulicornis* (Ratzeburg) species with the highest amount of parasitic activity was gathered from four types of pests. The highest Shannon index (1.36) was recorded in Norduz and the lowest Shannon index (0.71) was recorded in Marazad, Komarsofla, and Jolfa areas. The highest Sorenson index (80%) was estimated for Siahrud and Duzal areas.

Key words: Shannon index, Sorenson index, diversity, Hymenoptera, Hemiptera.

Introduction

The superfamily Coccoidea (Hemiptera) are serious pests of different host plants, especially in agricultural ecosystems. These superfamily includes several families where two of those i.e. Diaspididae (Armored scales) and Coccidae (Soft scales) are the most economically important. In most cases, they become economically important only when they form dense aggregations as a result of being tended by ants (Hymenoptera: Formicidae) (Kapranas et al. 2007). Beside the direct damage by sucking the sap of plants, they also inflict cosmetic damages and cause the sooty mold fungi that develop on the scale's honeydew excretions (Lotfalizadeh & Ahmadi 2001).

These pests are mostly under effective natural control by many parasitoid species. The most important parasitoids of the coccoid pests belong to the superfamily Chalcidoidea (Hymenoptera). Although this superfamily is an important group among the insects, its fauna is poorly known in Iran (Mahdavi and Madjdzadeh 2013). Faunistic study of coccoids parasitoids in East-Azarbaijan is only partly studied and some new records has been mentioned for Iranian fauna (Ebrahimi et al. 2012a, 2012b). These parasitoids are among numerically the largest, biologically the most diverse and geologically the oldest of the Parasitica (Gordh 1979, Gibson 1986). These biocontrol agents have been studied widely (Japoshvili et al. 2008). Experiments have shown that augmentative biological control of citricola scale with parasitoids is a potential solution to its current re-emergence as a pest in California's San Joaquin Valley, if such releases can be shown to be economic (Bernal et al. 1999, 2001, Schweizer et al. 2002, 2003).

Biological diversity is usually considered at three different levels: genetic diversity, species diversity and ecosystem diversity. In a stable environment, as much greater diversity as possible, and sustainable environment with more regulatory conditions must exist. Thus, biodiversity in each region should be a key factor of health and environmental sustainability of the region (Schowalter 1996, Speight et al. 2008). Species diversity refers to the variety of species. Aspects of species diversity can be measured in different ways, which can be classified into three groups of measurement: species richness, species abundance and taxonomic or phylogenetic diversity (Magurran, 1988). Measurement on the beta diversity of important indicators such as Sorensen are used to show the variation trends in different localities (Schowalter 1996). Recently, parasitism rate, similarity index and Simpson's index of Aphelinidae (Hym.: Chalcidoidea) for different regions of Markazi and Lorestan provinces in Iran were calculated and discussed (Abolmasoumi et al. 2009).

The objective of this study was to identify the important parasitoids of the coccoid pests belong to the superfamily Chalcidoidea while determin-

Table 1. Sampling localities in the north of East-Azerbaijan province.

Climate	Altitude (m)	Geographical situation (UTM)		Sampling sites
		Longitude	Latitude	
Semi-arid cold desert	750	4308246	38s0565449	Jolfa
Semi-arid cold desert	700	4305911	38s0570610	Marazad
Semi-arid cold	650	4304314	38s0583935	Siahrud
Semi-arid cold	800	4291738	38s586294	Komarsofla
Semi-arid cold	590	4300842	38s0603871	Norduz
Semi-arid cold	500	4302061	38s0606277	Duzal
Semi-arid temperate	350	4336561	38s0675302	Khomarlo
Semi-arid cold	200	4353207	38s0690778	Larijan

ing species diversity and similarity between locations in the north of East-Azerbaijan province, Iran.

Materials and methods

Sampling

The investigations and collection of material was conducted in different localities (Fig. 1), between April-October 2010-2011 on different infested deciduous fruit trees, i.e. pome (such as apple, pear and quince) and stone fruits (peach, nectarine, plum and cherry) in northern parts of East-Azerbaijan, West of Iran. Eight locations were selected to assess the parasitoid species exploiting Coccoidea (Table 1). Sampling were made weekly and each samples consisted of 10 cm of infested branches. The branches were transferred to plastic containers and were then reared in laboratory conditions of 25±2ºC, 70±5% HD.

Species identification

We inspected the plastic containers with the developing parasitoids every 1–2 days for parasitoid emergence. The containers were covered with a fine mesh. The emerged adult wasps were collected by an aspirator and then transferred into a screw top vial containing 95% alcohol for storage. The species and sex of each wasp comprising the brood was identified and counted.

Identification of specimens to genus and species level was based on keys of Ben-Dov & Hodgson (1997), Guerrieri (2006), Guerrieri & Noyes (2000, 2002), Hanson & LaSalle (1995), Japoshvili & Noyes (2006), Lotfalizadeh (2010), Medvedev (1988), Myartseva (1988), Nikol'skaya (1963), Prinsloo (1980) and Trjapitzin (1974, 1989, 2008).

Statistical analysis

The Shannon-Weiner diversity index was calculated using the following formula:

Shannon's H': $$H' = -\sum_{i=1}^{N_o} [p_i * \log p_i]$$

where p_i is the proportion of the total number of individuals belonging to a morphotype, and N_o is the total number of morphotypes seen in that sample. Also, The Simpson's diversity index was calculated using the following formula:

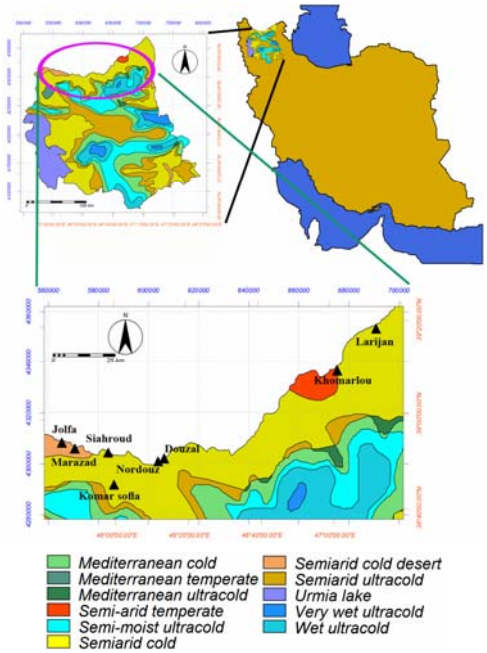

Figure 1. Map of sampling areas and their climatic conditions.

Simpson's D: $$D = 1 - \sum_{i=1}^{N} \frac{n_i(n_i - 1)}{N(N-1)}$$

where n_i is the number of individuals of a particular morphotype and N is the total number seen in the sample (Magurran 2004).

Diversity indices like the Shannon's entropy ("Shannon-Wiener index") and the Gini-Simpson index are not in themselves diversities. The number of equally-common species required to impact a particular value to an index is called the "effective number of species". This is the true diversity of the community. Converting indices to true diversities gives them a set of common behaviors and properties. After conversion, diversity is always measured in units of the number of species (Jost 2006). Conversion of common indices to true diversities can be achieved as described in the following term:

Index x	Diversity in terms of x	Diversity in terms of p_i
Shannon entropy: $x \equiv -\sum_{i=1}^{S} p_i \ln p_i$	exp(x)	$\exp(-\sum_{i=1}^{S} p_i \ln p_i)$
Gini-Simpson index: $x \equiv 1-\sum_{i=1}^{S} p_i^2$	1/ (1-x)	$1/\sum_{i=1}^{S} p_i^2$

Evenness, the other information-statistical index, is affected by both the number of species and their equitability or evenness compared to a community's actual diversity, and the value of E is constrained to 0- 1.0. Shannon's evenness is calculated by the formula: H'/ Hmax.

Beta diversity is generally thought of as the change in diversity among various alpha diversities (variation in species composition among sites in a geographic region) (Koleff et al. 2003, Magurran 2004). The classical Sorensen index is based on both the number of species present in the total sample and numbers only seen in each individual sample (Koleff et al. 2003). Sorenson's measure is regarded as one of the most effective presence/absence similarity measures. The Sorensen similarity index is calculated by C_s= 2a/(2a+b+c), where *a* is the number of species common to both sites, *b* is the number of species at site B but not at A, and *c* is the number of species at site A but not in B (Magurran 2004).

Results and Discussion

In this study three Diaspididae species (*Diaspidiotus slavonicus* (Green), *Lepidosaphes malicola* Borchsenius and *Lepidosaphes ulmi* (Linnaeus)) and two Coccidae species (*Didesmococcus unifasciatus* (Archangelskaya) and *Sphaerolecanium prunastri* (Fonscolombe)) were found on different host plants. Eleven parasitoid wasp species were collected (Table 2). These species include four families of chalcidoids wasps in 11 genera. *Pachyneuron muscarum* (L.) was mentioned as hyperparasitoid of scale insects (Lotfalizadeh & Ahmadi 2001). It was reared on *Lepidosaphes malicola* and *Sphaerolecanium prunastri* because of attack by several parasitic species that may be primary host of *P. muscarum*.

Ablerus chrysomphali (Ghesquiere, 1960)
This species is known from Iran (OILB 1971) and reported from the Palaearctic and Nearctic regions (Noyes 2012). *Ablerus chrysomphali* was reared on *Diaspiditus slavonicus* and *Lepidosaphes malicola.* It has been reported on different species of Diaspididae (Noyes 2012) but *Diaspiditus slavonicus* is a new host for this parasitoid.

Aphytis chrysomphali (Mercet, 1912)
This widely distributed species in the world (Noyes 2012), has been reported by Kiriukhin (1946), Herting (1972) and DeBach (1962) from Iran but is new for East-Azarbaijan province. Different species of armored and soft scales are host of this parasitoids (Noyes 2012) while *Sphaerolecanium prunastri* is new host report.

Coccobius annulicornis (Ratzeburg,1852)
Coccobius annulicornis has been reported from Iran (OILB 1971) and most of European countries (Noyes 2012), while it is new record for East-Azarbaijan province. Biological association of this species with *Sphaerolecanium prunastri, Didesmococcus unifasciatus* and *Lepidosaphes ulmi* is new.

Coccophagus lycimnia Walker, 1939
This species has been reported from several Iranian provinces: Fars, Guilan, Isfahan, Kermanshah, Markazi, Mazandaran and Tehran (Farahbakhsh 1961, Radjabi 1989) but not from East-Azarbaijan province. Soft scales *Eulecanium coryli and Palaeolecanium bitubercalatum* are host of this species in Iran (Radjabi 1989), therefore, *S. prunastr* is a new host record.

Pteroptrix macropedicellata (Malac, 1974)
This parasitoid recently reported by Ebrahimi et al. (2012b) from Iran. It is known in Azarbaijan, Czech Republic and Slovakia (Noyes 2012). *Pteroptrix macropedicellata* reared for the first time on *Sphaerolecanium prunastri* (Hem.: Coccidae), while it has been reported on *Aulacaspis rosae* (Bouché) (Hem.: Disapididae) (Noyes 2012).

Blastothrix sp.
All of reared specimens were male individuals so their identification was unaccommodated.

Epitetracnemus intersectus (Fonscolombe, 1832)
Epitetracnemus intersectus was reported from Iran, Lorestan province (Golpayegani et al. 2010) but this is the first report of this species from East-Azarbaijan province. It is widely distributed in Europe (Noyes 2012). This species was reared on *Lepidosaphes ulmi* and *L. malicola.*

Metaphycus zebratus (Fonscolombe, 1832)
This species is known from Iran (OILB 1971, Lotfalizadeh 2010) and Europe (Noyes 2012). It is

Table 2. Parasitoid wasps collected from the northern parts of East-Azerbaijan province.

Family	Genus	Species	Sampling locality	Hosts
Aphelinidae	*Ablerus*	*Ab. chrysomphali* (Ghesquiere, 1960)	Siahrud	*Lepidosaphes malicola*
			Duzal	*L. malicola*
			Marazad	*Diaspidiotus slavonicus*
	Aphytis	*Ap. chrysomphali* (Mercet, 1912)	Siahrud	*Lepidosaphes malicola*
			Duzal	*L. malicola*
			Marazad	*Diaspidiotus slavonicus*
	Coccobius	*Cb. annulicornis* (Ratzeburg,1852)	Siahrud	*Lepidosaphes malicola*
			Larijan	*L. malicola*
			Duzal	*L. malicola , L. ulmi*
			Norduz	*Didesmococcus unifastiacus, Sphaerolecanium prunastri*
			Jolfa	*L. malicola*
	Coccophagus	*Cp. lycimnia* Walker, 1939	Khomarlo	*Sphaerolecanium prunastri*
			Norduz	*Didesmococcus unifastiacus, S. prunastri*
	Pteroptrix	*P. macropedicellata* (Malac, 1974)	Norduz	*Sphaerolecanium prunastri*
Encyrtidae	*Blastothrix*	*Blastothrix* sp.	Norduz	*Sphaerolecanium prunastri*
	Epitetracnemus	*E. intersectus* (Fonscolombe, 1832)	Duzal	*Lepidosaphes ulmi*
			Larijan	*L. malicola*
	Metaphycus	*M. zebratus* (Fonscolombe, 1832)	Norduz	*Didesmococcus unifastiacus*
			Siahrud	*Lepidosaphes malicola*
	Zaomma	*Z. lambinus* (Walker, 1838)	Norduz	*Didesmococcus unifastiacus*
			Siahrud	*Lepidosaphes malicola*
Pteromalidae	*Pachyneuron*	*P. muscarum* (L., 1758)	Jolfa	*Lepidosaphes malicola*
			Norduz	*Didesmococcus unifastiacus, Sphaerolecanium prunastri*
Signiphoridae	*Thysanus*	*T. ater* (Walker,1840)	Komarsofla	*Lepidosaphes malicola*

parasitoid of several coccoids (Noyes 2012) but for the first time it was reared on *Lepidosaphes malicola* (on spruce) and *Sphaerolecanium prunastri* (on plum).

Zaomma lambinus (Walker, 1838)
This species is known from Iran: Isfahan, Fars, Chahar Mahal-o-Bakhtiari, Markazi, Semnan and Tehran provinces (Radjabi 1989) but it is new for East-Azarbaijan province. This species was reared on *Didesmococcus unifastiacus* and *Lepidosaphes malicola.*

Pachyneuron muscarum (L., 1758)
This pteromalid species has known as hyperparasitoid of Coccoidea. It is widely distributed in Iran (Lotfalizadeh & Gharali 2008) but is new for East-Azarbaijan province. Its association with *Didesmococcus unifasciatus* is new.

Thysanus ater (Walker, 1840)
This species is recently reported from Iran (Ebrahimi et al. 2012a) and is widely distributed in the Holarctic and Oriental regions as parasitoid of different diaspidids and coccids (Noyes 2012). In this research, it was reared on *Lepidosaphes malicola* that is a new host record.

Within these species, *Coccobius annulicornis* (Ratzeburg) and *Aphytis chrysomphali* (Mercet), which have a wide range of hosts, are the most polyphagous (Fig. 2). These two species with their presence in five regions showed a high dispersion rate in the areas under study (Fig. 3).

Among the 11 parasitoid wasp species, the highest number of parasitoid (8 species) were found on *Lepidosaphes malicola* and the least number (2 species) were found on *Didesmococcus slavonicus* and it was observed that they had parasitic activities. On species richness, the highest number (7 species) was found in Norduz area and the least number (1 species) was collected from Khomarlo area (Fig. 2). Considering the inequality of parasitoid species, it is evident that cold semi-arid climate in Larijan, Duzal, Norduz, Komarsofla, and Siahrud regions has been negative effect on the number of collected parasitoid species and Shannon diversity index. Records of the highest Shan-

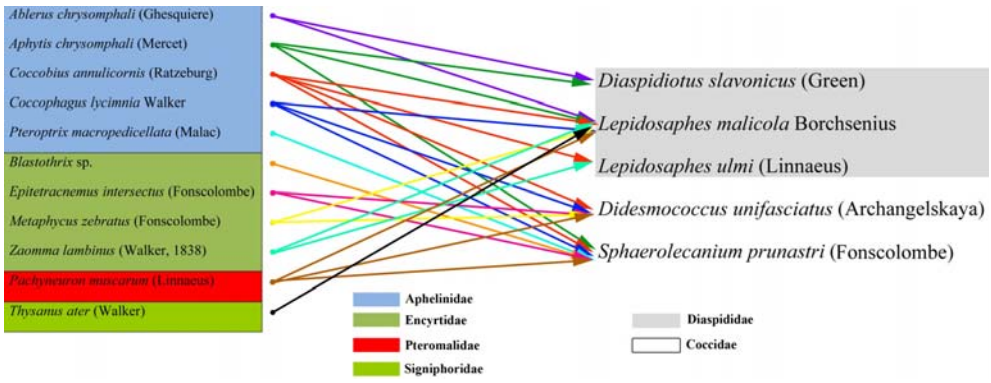

Figure 2. Hymenopterous parasitoids and their host associations in the northern parts of East-Azarbaijan province, Iran (2010-2011).

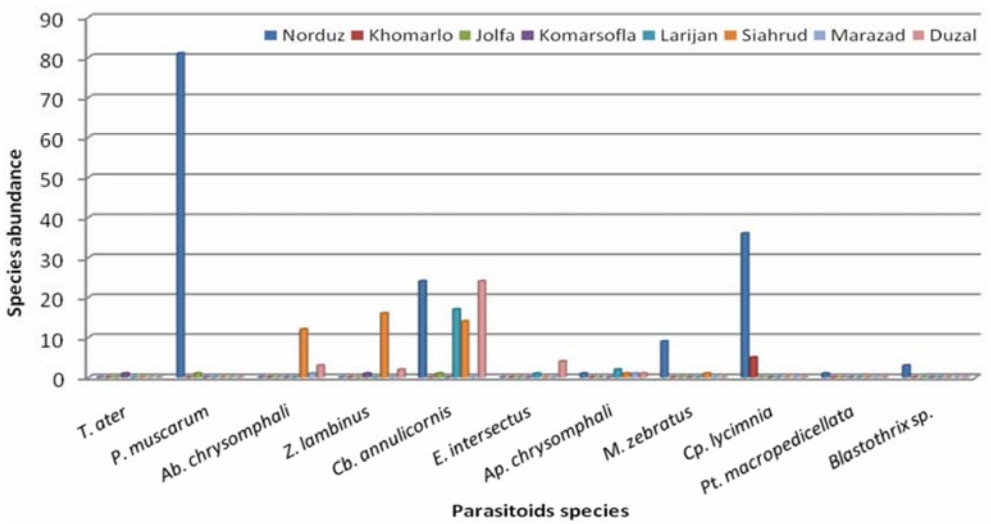

Figure 3. Distribution of parasitoid wasps in different locations of East-Azerbaijan province.

non index and species richness of parasitoids in Norduz is most likely related to the infestation of plum trees by the *S. prunastri* pest and also of almond trees by *D. unifastiacus* pest which has led to greater parasitoid activity of these pests in this region. *Thysanus ater* (Walker) species was only collected from one pest (*Lepidosaphes malicola*) in Komarsofla area while other parasitoid species had parasitic activity on at least two types of pests (Table 2). At an altitude of 800 meters above sea level and in the cold semi-arid climate, *T. ater* species has only been collected from Komarsofla region. This species has parasitoid activity on *L. malicola*. Regarding the fact that other regions have also semi-arid climate and the presence of *L. malicola* as the host for *T. ater* in most of the studied regions, the distribution of this parasitoid species in relation to altitude is only predictable in Komarsofla region. In the current study, *Coccobius annulicornis* species with the highest amount of parasitic activity was gathered from four species.

The highest Shannon index (1.36) was recorded in Norduz and the lowest Shannon index (0.71) was recorded in Marazad, Komarsofla, and Jolfa (Table 3 & Fig. 4). Due to the presence of only one species (*Coccophagus lycimnia*) in Khomarlo estimating diversity and evenness indices was not possible. The highest amount of true diversity index of Shannon was registered in Norduz which proves the high levels of species richness of parasitoids compared with other regions (Fig. 3). Due to the presence of two species with the same fre-

Table 3. Species diversity indices of Coccoidea parasitoids in different locations of the northern part of East Azerbaijan province, 2010-2011.

Sampling sites	Heterogeneity			
	Simpson's index	Shannon's H'	True diversity	Shannon's evenness
Duzal	0.51	0.98	3.51	0.61
Marazad	1.00	0.71	1.66	1.00
Siahrud	0.72	1.26	2.77	0.78
Larijan	0.28	0.52	2.56	0.47
Komarsofla	1.00	0.71	1.66	1.00
Jolfa	1.00	0.71	1.66	1.00
Khomarlo	Not calculated (only one species was collected)			
Norduz	0.68	1.36	5.08	0.51

Table 4. Sorensen similarity quotient between pair wise locations about Coccoidea parasitoid wasps' presence in different locations of East-Azerbaijan province, 2010-2011.

Sites	Duzal	Marazad	Siahrud	Larijan	Komarsofla	Jolfa	Khomarlo	Norduz
Duzal	-	0.58	0.80	0.75	0.28	0.28	0.00	0.30
Marazad		-	0.58	0.40	0.00	0.00	0.00	0.22
Siahrud			-	0.50	0.28	0.28	0.00	0.46
Larijan				-	0.00	0.40	0.00	0.36
Komarsofla					-	0.0	0.00	0.00
Jolfa						-	0.00	0.40
Khomarlo							-	0.22
Norduz								-

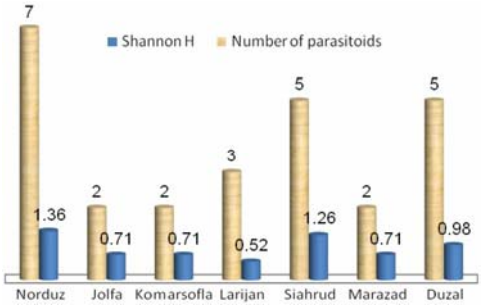

Figure 4. Number of parasitoid wasps with Shannon diversity index in different locations of East-Azerbaijan province, 2010-2011.

quency in Marazad, Komarsofla, and Jolfa, the highest amount of Shannon evenness index (1) was registered in these 3 areas. Also, the lowest amount of the same index (0.47) was found in Larijan. *Thysanus ater*, *Pteroptrix macropedicellata* (Malac), and *Blastothrix* sp. species were collected in only one area, while other species were present in at least two areas. One species was only found in Khomarlo area and because of the presence of only one species in this region, Sorenson index of similarity of Khomarlo and other regions (else Norduz) was calculated to be zero % (no similarity was found). The highest amount of Sorenson index (80%) was estimated for Siahrud and Duzal areas (Table 4). These two areas have five species of parasitoid wasps that four of them are shared between the two regions.

In general, it was observed that in most of the cases the region's climate was ineffective on the distribution of parasitoid crab louses' species such as *P. muscarum* (present in two cold semi-arid climates in Norduz region and cold semi-arid and desert climate in Jolfa region) and *C. lycimnia* species (existing in two semi-arid climates in Khomarlo region and also in cold semi-arid climate in Norduz region) and the presence of this parasitoid species can be studied under the influence of other factors. However, the greatest amount of Sorenson similarity index between Siahrud and Duzal regions can be attributed to their identical climate.

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