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Full Length Research Paper

Distributional record of oak gall wasp (Hymenoptera: Cynipidae) species' diversity in different regions of West-Azerbaijan, Iran

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Among gall–inducing insects, the majority of species are gall wasps (Hymenoptera: Cynipidae) that occur on oak trees (*Quercus* spp.) and produce galls on a certain part of the host. In this survey, oak gall wasp species were collected from the oak forests of Pardanan, Mirabad, Nalas, Sardasht, Hamran and Dar-ghabr in West-Azerbaijan province. The galls occurring on 50 cm sampled branches from four cardinal directions on each tree were counted multiple times throughout the season. Species richness of oak gall wasps was estimated for each region and also species diversity indices such as Simpson's index, Shannon's H', and Sorensen similarity quotient were calculated. In this survey, 40 oak gall wasps species were identified. Most galls were found on *Quercus infectoria*. All of the collected oak gall wasps belonged to seven genera: *Andricus*, *Cynips*, *Neuroterus*, *Chilaspis*, *Pseudoneuroterus*, *Biorhiza* and *Aphelonyx*. Among these species, 28 were related to the *Andricus* genus. The highest Simpson and Shannon indices were recorded in the Dar-ghabr and Pardanan regions in the fall, respectively. The highest Sorensen similarity was recorded in the spring's galls (sexual generation of oak gall wasps) and fall' galls (asexual generation) between Pardanan and Mirabad, and between Pardanan and Dar-ghabr regions, respectively. Differences in the local distribution of oak species, especially their subspecies, and the climate of the locations should be considered as main factors in oak gall wasp species diversity and the distribution of oak gall wasp species.

Key words: Diversity, Similarity index, oak, gall wasps, forest.

INTRODUCTION

The Zagros Mountains in Iran are divided into the northern Zagros and southern Zagros. West-Azerbaijan province is located in the northern Zagros that is the main habitat of *Quercus infectoria* Oliv (Fatahi, 1994; Sabeti, 1998; Saghebtalbi et al., 2004). This region is the focus of our study.

Oak gall wasps select oak trees for gall formation on certain specialized organs (Rokas et al., 2003). About 80% of wasps in the family Cynipidae produce diverse galls on oaks in terms of structure and form (Short and Castner, 1997; Liljeblad and Ronquist, 1998). Cynipid gall formation is an extremely complex interaction between cynipid gall wasps and the host plant, in which the wasp communicates with the host plant to redirect normal plant development to create galls that provide nutrients and protection for the developing larva (Nyman and Julkunen-Tiitto, 2000; Stone et al., 2002; Nylander, 2004). Sexual and asexual generations of oak gall wasps produce galls in the spring and early summer, and in the summer and autumn, respectively (Schonrogge et al., 1999). Biodiversity in each region should be a key health and environmental sustainability of the region (Schowalter, 1996; Ashori and Kheradpir, 2009).

Species diversity refers to the variety of species such as the number and relative abundance in a defined location. Species diversity can be measured in different ways, which can be classified into three groups of measurements: species richness, species abundance and taxonomic or phylogenetic diversity (Magurran, 1988). There are four methods for evaluating species diversity and one of them is general index of diversity. A number of these indices that assess the relative frequency of the species are known as heterogeneity indexes. One indicator is the Shannon diversity index that

involves predicting an individual randomly from a set of S species with N selected individuals (Magurran, 1988, 2004). This index is usually between 1.5 and 4.5 and the low level of this index represents the destruction of the environment (Schowalter, 1996). Another index is Simpson index that is based on abundance and evenness of species. This indicator is strongly related to dominant species, but has little sensitivity to species richness. This index value is between zero and one and the numbers close to one represent a high diversity (Simpson, 1949). Beta diversity is measured by important indicators such as Sorensen which are used to show the variation in trends in different localities (Schowalter, 1996).

Oak gall wasp species have high richness in the West-Azerbaijan province. Shojai (1980) reported 36 oak gall wasp species associated with oak *Q. infectoria* from Iran. Recent surveys were conducted about the cynipids fauna in Iran (Azizkhani, 2006; Tavakoli et al., 2008; Zargaran et al., 2008) and according to the latest results, and 82 species of oak gall wasps have been introduced in the oak forests of Iran whereas 25 species are species that were reported in the world for the first time (Sadeghi et al., 2010). However, few studies have measured oak cynipid gall wasps diversity. Nazemi et al. (2008) reported species richness of oak gall wasps from Kurdistan, Ilam and Kermanshah provinces of Iran. The oak gall wasps species diversity and their distribution in West-Azerbaijan province of Iran were carried out in 2008-2009. The objective of this paper is to measure oak gall wasp diversity in multiple regions in West-Azerbaijan province.

MATERIALS AND METHODS

Sampling was performed in six regions of West-Azerbaijan province, Iran (Table 1), in 2008-2009 where cynipid galls were collected from oak forests. The climates were identified based on Dumarten's climate classification method. In our study area, sampling of cynipid galls took place in the mid and the end of spring, in the end of summer, and in the mid of fall to collect sexual and asexual galls occurring throughout the seasons. The optimal number of samples was determined according to Southwood and Henderson's formula (2000) that is $N=(t\times s / D\times m)^2$, where *t* is student's T-test of standard statistical tables, *D* is the predetermined confidence limit for the estimation of the mean expressed as a decimal (0.2), *m* is preminaliry sampling mean and *s* is the standard deviation. The optimal number of samples was determined to be 30 trees per region. In total, we counted galls on 360 trees in six sites (30 trees per site) in two years. All cynipid galls were counted on randomly selected four branches (each branch length was 50 cm) in four cardinal directions per tree. Also, the trees were selected randomly.

We calculated species diversity using a variety of indices. Species diversity refers to the variety of species. Species richness was measured by counting the number of species in a defined area or site. We also measured the species abundance of each species. Measures of species diversity that simplify information on species richness and relative abundance into a single index are of extensive use (Magurran, 2004). We calculated species richness, Shannon's H', Simpson's index, and Sorensen similarity coefficient for each region in the spring and the fall collections separately using Ecological Methodology 3.0 software (Krebs, 1998).

Shannon-Weiner index: The computation of this diversity index uses the following formula:

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

Where, p_i is the proportion of the total number of individuals, and N_o is the total number of species in a region.

Simpson's index: The diversity index is calculated using the following formula:

$$\text{Simpson's diversity indices} = 1 - \sum_{i=1}^{N} \frac{n_i(n_i-1)}{N(N-1)}$$

Where, n_i is the number of individuals of a particular species in a region, *N* is the total number of individuals of all species in a region.

Similarity coefficients directly compare diversity of different sites and represent the number of species common to all areas. Sørensen similarity index is calculated from this formula as:

$C_s = 2a / (2a + b + c)$

Where, *a* is the number of species common to both sites, *b* is the number of species in site B, but not in A and *c* is the number of species in site A, but not in B.

RESULTS

In the six sites, 40 oak gall wasps species were collected and separated. These species were in the following genera: *Andricus* (28 species), *Cynips* (3 species), *Neuroterus* (4r species), *Pesudoneuroterus* (1 species), *Chilaspis* (1 species), *Biorhiza* (1 species) and *Aphelonyx* (2 species). The genus *Andricus* had the highest species richness. Also, gall wasp species richness was different among the regions. We collected 34 species from Pardanan, 17 species from Mirabad, 15 species from Nalas, 18 species from Hamran, 28 species from Dar-ghabr and 17 species from Sardasht regions. The highest oak gall wasp species' richness was found in the Pardanan region whereas Nalas region had the lowest species richness among the stations. The highest number of species of the genus *Andricus* was observed in the Pardanan region with 25 species and the lowest number of this genus was 8 species in Nalas region. *Cynips* was found in all of the regions and maximum number of 3 species belonging to *Cynips* was collected from Pardanan and Dar-ghabr regions. All species of the genus *Neuroterus* sp. (total 4 species), were obtained from the Nalas region. Meanwhile, only 1 species of the genus *Neuroterus* was observed in Mirabad region. The two genera *Pseudoneuroterus* and *Chilaspis* with 1 species were found only in the Hamran region. *Biorhiza pallida* Olivier was obtained from Pardanan, Mirabad and Sardasht but *Aphelonyx* was observed in all of the study regions.

Table 1. Oak gall wasp species diversity in different regions of West-Azerbaijan, 2008-2009.

Characteristic		Region					
		Pardanan	Mirabad	Hamran	Nalas	Dar-ghabr	Sardasht
Host (*Quercus*)		*Q. infectoria* *Q. brantii* *Q. libani*	*Q. infectoria* *Q. brantii*	*Q. infectoria* *Q. brantii*	*Q. infectoria* *Q. brantii*	*Q. infectoria* *Q. brantii* *Q. libani*	*Q. infectoria* *Q. brantii* *Q. libani*
Latitude		36° 39′N	36° 15′N	36° 01′N	36° 35′N	36° 11′N	36° 25′N
Longitude		45° 28′W	45° 22′W	45° 47′W	45° 11′W	45° 24′W	45° 48′W
Climate		Very humid and cold	Very humid and cold	Humid Mediterranean	Very humid Mediterranean	Humid Mediterranean	Very humid Mediterranean
Diversity index							
Simpson	S	0.721	0.811	0.612	0.659	*	0.524
	F	0.896	0.841	0.875	0.813	0.912	0.835
Shannon's H'	S	2.019	2.322	1.662	1.756	*	1.231
	F	4.117	2.963	3.109	2.735	4.108	3.308
No. of species (Spring+Fall)		34(4+30)	17(5+12)	18(3+15)	15(3+12)	28(1+27)	17(3+14)

S, Spring; **F**, fall; *****, not calculated (only one species was collected).

Table 2. Sorensen similarity quotient (percent) in different regions of West-Azerbaijan.

Region	Pardanan	Mirabad	Nalas	Hamran	Dar-ghbr	Sardasht
Pardanan		* 70.2(max)	*62.2	* Not similar	* Not similar	*65.3
Mirabad	56.2		*66	*41	* Not similar	*61
Nalas	53	45.2		*32(min)	* Not similar	*43.5
Hamran	42	43.1	51.5		*57.6	* Not similar
Dar-ghbr	87.3(max)	44	25.4(min)	55		* Not similar
Sardasht	64.2	60.7	38	33.2	58	

(* means, for the spring's galls and other are the fall's galls).

All species of oak gall wasps were gathered on 3 species of oak *Q. infectoria*, *Q. brantii* and *Q. libani* and Table 3 presents the species-rich fauna of oak gall wasp species in West-Azerbaijan that occurred on *Q. infectoria*. The highest number of the spring' species was found on *Q. brantii*. The lowest value of Simpson index (0.524) was found in the spring collected galls from Sardasht region and the highest value of this index (0.912) was recorded in the summer and fall galls in Dar-ghabr region (Table 1). The only collected species from Dar-ghabr in spring was *Andricus cecconi* Kieffer that produced the galls on *Q. brantii.* Thus, we could not calculate diversity indices for this region. The highest value of Shannon index, for summer-fall galls was recorded in Pardanan and Dar-ghabr regions and the high level of this index in these regions indicate that oak gall wasp species have the highest species richness and abundance in these regions. The lowest of Shannon index in spring's galls was observed in Sardasht (2.231) area.

Beta diversity, which indicates a change in species richness among regions, is measured using Sorensen similarity quotient. Of spring's galls, the highest similarity was between Mirabad and Pardanan and the lowest recorded index of similarity was between two regions, Hamran and Nalas (Table 2). Pair wise regions such as Hamran and Pardanan, Dar-ghabr and Pardanan, Dar-ghabr and Mirabad, Dar-ghabr and Nalas, Sardasht and Hamran do not share any species; therefore, the similarity value was zero. The highest and lowest similarity index of the summer galls was observed between Dar-ghabr and Pardanan (87.3%), and between Nalas and Dar-ghabr (25.4%), respectively (Table 2).

DISCUSSION

40 oak gall wasps species from studied areas in West-Azerbaijan province were identified to belong to seven major genera of the family Cynipidae. *Andricus*, *Cynips* and *Aphelonyx* with 65.7, 11.42 and 5.7 abundance, respectively were distributed in all of the areas. *Andricus* was found on the three oak species, *Cynips* on *Q.*

Table 3. Oak gall wasps species associated with oak trees in West-Azerbaijan, 2008-2009.

Oak gall wasps species		Location of gall formation	Type of generation	Host
Spring gall				
1	*A. burgundus* (Giraud, 1859)	Catkin	Sexual	*Q. libani*
2	*A. cecconii* (Kieffer, 1901)	Catkin	Sexual	*Q. brantii*
3	*A. curvator* (Hartig, 1840)	Leaf	Sexual	*Q. infectoria*
4	*A. grossulariae* (Giraud, 1859)	Catkin	Sexual	*Q. brantii*
5	*A. multiplicatus* (Giraud, 1859)	Leaf	Sexual	*Q. brantii*
6	*Biorhiza pallida* (Olivier, 1791)	Shoot	Sexual	*Q. infectoria*
7	*Chilaspis israeli* (Sternlicht, 1968)	Catkin	Sexual	*Q. brantii*
8	*Andricus pseudoaries* (Melika et al. 2004)	Shoot	Asexual	*Q. infectoria*
9	*A. askewi* (Melika and Stone, 2001)	Shoot	Asexual	*Q. infectoria*
10	*A. caliciformis* (Giraud, 1859)	Shoot	Asexual	*Q. infectoria*
11	*A. caputmedusae* (Hartig, 1843)	Shoot	Asexual	*Q. infectoria*
12	*A. conglomeratus* (Giraud, 1859)	Shoot	Asexual	*Q. infectoria*
13	*A. coriarius* (Hartig, 1843)	Shoot	Asexual	*Q. infectoria*
14	*A. foecundatrix* (Hartig, 1840)	Shoot	Asexual	*Q. infectoria*
15	*A. galeatus* (Giraud, 1859)	Shoot	Asexual	*Q. infectoria*
16	*A. gemmeus* (Giraud, 1859)	Shoot	Asexual	*Q. infectoria*
17	*A. hystrix* (Trotter, 1899)	Shoot	Asexual	*Q. infectoria*
18	*A. kollari* (Hartig, 1843)	Shoot	Asexual	*Q. infectoria*
19	*A. lucidus* (Hartig, 1843)	Shoot	Asexual	*Q. infectoria*
20	*A. mediterraneae* (Trotter, 1901)	Shoot	Asexual	*Q. infectoria*
21	*A. megalucidus* (Melika et al. 2003)	Shoot	Asexual	*Q. infectoria*
22	*A. panteli* (Kieffer, 1901)	Branch	Asexual	*Q. infectoria*
23	*A. polycerus* (Giraud, 1859)	Branch	Asexual	*Q. infectoria*
24	*A. quercuscalicis* (Borgsdorf, 1783)	Fruit	Asexual	*Q. infectoria*
25	*A. quercustozae* (Bosc, 1792)	Shoot	Asexual	*Q. infectoria*
26	*A. seckendorffi* (Wachtl, 1879)	Shoot	Asexual	*Q. infectoria*
27	*A. sternlichtii* (Bellido and Melika, 2003)	Shoot	Asexual	*Q. infectoria*
28	*A. theophrastea* (Trotter, 1901)	Shoot	Asexual	*Q. infectoria*
29	*A. tomentosus* (Trotter, 1901)	Shoot	Asexual	*Q. infectoria*
30	*A. megatruncicolus* Giraud	Shoot	Asexual	*Q. infectoria*
31	*Aphelonyx cerricola* (Giraud, 1859)	Shoot	Asexual	*Q. brantii*
32	*Aphelonyx persica* (Melika et al. 2004)	Shoot	Asexual	*Q. brantii*
33	*Cynips cornifex* (Hartig, 1843)	Leaf	Asexual	*Q. infectoria*
34	*C. quercus* (Fourcroy, 1785)	Leaf	Asexual	*Q. infectoria*
35	*C. quercusfolii* (Linnaeus, 1758)	Leaf	Asexual	*Q. infectoria*
36	*Neuroterus saliens* (Kollar, 1857)	Leaf	Asexual	*Q. brantii*
37	*N. lanoginosus* (Giraud, 1859)	Leaf	Asexual	*Q. brantii*
38	*N. numismalis* (Geoffroy, 1785)	Leaf	Asexual	*Q. infectoria*
39	*N. quercus-baccarum* (Linnaeus, 1758)	Leaf	Asexual	*Q. infectoria*
40	*Pseudoneuroterus macropterus* (Hartig, 1843)	Shoot	Asexual	*Q. brantii*

infectoria and *Q. brantii*, and *Aphelonyx* only on *Q. brantii*. Considering the different studied climatic regions, at the first stage it did not appear that these species' distribution will be affected by climate change. *Q. infectoria* was the most widely distributed oak in all regions, and subsequently the highest number of galls (30 galls) was recorded on this oak species. It was host to the highest gall species richness on *Q. infectoria*. Meanwhile, the numbers of 9 and 1 species of gall wasps were present on *Q. brantii* and *Q. libani*, respectively. Similarly, Azizkhani et al. (2007) found that oak gall wasp fauna of the Lorestan province in Iran was higher on *Q. brantii* compared to *Q. infectoria*. *Pseudoneuroterus* and *Chilaspis* species produced galls on *Q. brantii* and only were collected from the Hamran region. Given that *Q. brantii* was present in both areas and that Hamran and

Dar-ghabr regions have similar climates, which appear to be of other factors involved in the distribution of these 2 species and very possibly the presence of different subspecies of oak trees will be investigated as the first important factor in this relationship. Among 40 of oak gall wasps species, 7 spring galls and 33 summer-fall galls were identified. Most of the spring's galls (4 galls) were created by the sexual generation of oak gall wasp species on *Q. brantii*. In contrast, most summer-fall galls (28 species) were made by asexual generation of oak gall wasps on *Q. infectoria*. Only one species of oak gall wasps in the spring is gall-maker on *Q. libani*. In fact, these oak species have the lowest richness of oak gall wasps. Based on climatic similarity in the Pardanan and Mirabad regions and also the presence of *Q. brantii* as a dominant species, the highest similarity was found in the spring between these two regions. The lowest similarity was registered between Hamran and Nalas regions that contain similar oak species, and different climates. It seems that presence of oak gall wasp species was affected by climate and or oak species and also subspecies. Due to a lower species richness in spring (7 species) and lack of equal distribution in various regions, the rate similarity index was zero in many areas that showed dissimilarity in the desired areas (Table 2). Stone et al. (2002) suggests geographical differences in oak gall wasp fauna is related to oak distribution patterns in different regions. The highest similarity of the asexual generation of oak gall wasp was observed between the Pardanan and Dar-ghabr regions where the plant covering is the same but climates are different from each other. Oak gall wasp species richness might be expected to increase due to the richness of host plant species (Starzomski et al., 2008). Species richness of oak gall wasps in Mexico was reviewed and the results showed that species richness between insects and host plants have positive correlations (Cuevas-Reyes et al., 2004). Galling insects may preferentially select those plant species with characteristics such as chemical toxicity, mechanical strength, or longevity that can be manipulated to benefit the galler (Genimar-reboucas et al., 2003). Gall traits (such as structure, location, and phenology) may play important roles in community diversity, but there is little empirical evidence of this (Hayward and stone, 2005). The lowest similarity was observed between Dar-ghabr and Nalas in summer. Probably the presence of oak species and their subspecies was the cause of this difference and led to different richness of oak gall wasp and a minimum similarity between these two regions has been recorded.

Blanche (2000) in a study concluded that the ambient temperature and rainfall does not have an effect on distribution of galling insects and we cannot conclude that the species richness in warm and dry regions is higher than the cold and humid regions. But, some results in relation to galling-insect distribution showed that the effect of humidity on the distribution of these insects is minor and leads to the lower species richness (Fernandes and Price, 1992).

Price et al. (2004) studied the oak gall wasps demographic population changes and also the relationship between host plant and gall wasps species richness. Gall wasps are specialist and because all of the galling insects are usually host-specific, generation and maintenance of gall wasp species richness is often related to plant species richness (Wright and Samways, 1996; Abrahamson et al., 1998; Price, 2005).

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