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Responses of soil-inhabiting mesostigmatid mites to deforestation and disturbance in oak (*Quercus brontii*) forests of southwestern Iran

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Abstract: The impacts of deforestation on edaphic mesostigmatid mites were investigated in oak forests of Lordegan, southwestern Iran, from April to October. A total of twenty-one species belonging to eighteen genera and ten families were collected and identified. The Shannon-Wiener, Simpson, Jaccard's and Margalef biodiversity indices were used for data analyses. Among the collected species, *Antennoseius bacatus* with 29% and *Sessilunchus hungaricus* with 16% relative abundance were the most abundant and dominant species in human-disturbed and natural forests, respectively. The estimated values were higher in natural oak forest than in disturbed and cultivated habitat. Significant differences were observed in soil nitrogen content and soil organic carbon between the two habitats, but not in pH values. Significant effects of sampling time and habitat were found on all four indices, but the effect of their interactions on these indices was not significant. It can be concluded that the changes in soil quality that resulted from deforestation may have a major role in reducing the soil mite density and related diversity indices in disturbed forests.

Keywords: biodiversity; ecosystem changes; edaphic mites; land use; soil properties; Zagros woodlands

Agricultural practices and intensification generally reduce the abundance of different soil biota, while extensification (the reverse of intensification) does not always lead to restoration and renewal of the original soil biota and their population (Gulvik 2007; Postma-Blaauw et al. 2010, 2012; Banerjee et al. 2019; Plaas et al. 2019). Agricultural land uses have been shown to be responsible for decreased diversity and richness of soil mites, which is attributed to strong disturbance of soils, caused by human activity on crop production systems (Arroyo, Iturrondobeitia 2006; Minor, Cianciolo 2007). In agricultural soils under cropping systems, lower abundance and diversity of mites have been recorded compared to the less manipulated and natural soils under forest ecosystems. For example, ploughing and tillage operations have resulted in undesirable effects on soil mites and can reduce 50%

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of their population in some cases (Hülsmann, Wolters 1998). Uncultivated and natural soils supply the plant residue cover that makes food sources available. This also moderates the effects of extreme soil temperatures and reduces moisture loss from the soil surface (Coleman et al. 2002; Blanco-Canqui, Lal 2009).

Two major factors that could affect the number of species occurring in different habitats are the type and intensity of changes that resulted from different land-use regimes (Odiwe et al. 2012). Comparing natural and disturbed forest habitats, by measuring the changes in habitat characteristics, increases our knowledge of mechanisms leading to diversity changes (Migge-Kleian et al. 2007; Benítez-Malvido et al. 2014; Alroy 2017).

Air/soil temperature and moisture also strongly affect mites and other soil-dwelling communities (Gongalsky et al. 2008; Robinson et al. 2018). Some ecologists have emphasized that the population of edaphic microarthropods such as gamasid mites (Acari, Mesostigmata, Gamasina) depends on abiotic conditions. It was shown that soil relative humidity usually acts as a limiting factor. When the soil atmosphere is humid, the determinative factor is temperature (Salmane 2000).

Soil-dwelling mites are a wide and cosmopolitan distributed group of soil microarthropods, and among them, Gamasids are found in diverse habitats. This group is represented by many genera and species and is widely distributed in the world. Gamasid mites can be considered as suitable indicators of soil conditions since they live in the soil and are dependent on soil ecological conditions (Salmane 2000; Gulvik 2007; Călugăr 2018; Manu et al. 2019).

Lordegan region is located in the southwestern Chaharmahal-Bakhtiari province in Iran with approximately half of the oak (*Quercus brontii*) forest area of the province. These forests have a semi-Mediterranean climate and are classified as semi-arid forests and sometimes referred to as the Zagros woodlands of this province (Salehi et al. 2013). A previous study on the oak forests of Lordegan revealed the impacts of deforestation and tillage on reducing soil quality and productivity (Hajabbasi et al. 1997).

Several researches have been carried out to study the impact of agricultural practices on soil fauna including mites; however, few investigations have compared the mite fauna of agricultural lands with natural soils adjacent to arable lands (Bedano et al. 2005; Wissuwa et al. 2013; De Groot et al. 2016). To achieve insights into the impact of deforestation on the diversity of soil mesostigmatid mites in Lordegan oak forests, we assessed their fauna and diversity at different parts of the forests from April to October 2014. Soil characteristics and weather information were also measured to assess their correlation with diversity indices.

MATERIAL AND METHODS

First, a faunistic survey was carried out as a preliminary step in studying diversity indices, focusing on the entire oak (*Quercus brontii*) forests of Lordegan region [Figure S1 in the Electronic Supplementary Material (ESM)]. To investigate deforestation impacts, study plots were chosen at two adjoining areas: natural oak forest (NF) and disturbed oak forest (DF) 500 m apart from Salehat village near the Khanmirza district (Lordegan, Iran), at 31°32'19''N latitude and 50°57'53''E longitude with mean annual rainfall of about 550 mm. Each site was a square-shaped area of about 2 500 m^2 separated from each other by a five-meter buffer. The disturbed habitat has been ploughed and cropped with dryland cereals (mainly wheat and barley) during the last 35 years. Soil texture was clay-loam in natural forest and clay in disturbed habitat. Land slopes were similar in both habitats.

Soil mites were collected by random sampling from the soil top layer (10 cm) in each habitat/treatment (six samples for each habitat per month, in total 12 samples) from April to October 2014 (7 months). So, in total 84 samples (12 × 7) were considered for mite abundance. The sampling unit (core sampler) was a quadrate 10 cm × 10 cm in size. Extraction of soil mites was carried out by using a modified Berlese-Tullgren funnel (Krantz 1978). After species identification, the mites were counted under a stereomicroscope. Mite density was expressed based on the number of individuals per soil square meter (mite·m^{-2}).

Six samples for each habitat every two months (in total 12 samples for both treatments) and three times during the seven months of experiment were obtained to determine the soil physical and chemical characteristics. So, in total 36 samples (12 × 3) were considered. Soil pH was measured using an electronic pH meter, in a 2 : 5 soil to water dilution. Air temperature and rainfall were recorded using air thermometer and rain cylinder (gauge), respectively. Soil organic matter content was es-

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timated by the Walkley-Black method (Walkley, Black 1934; Hesse 1971) and total nitrogen by the Kjeldahl method as described by Bremner and Mulvaney (1982).

Four diversity indices including diversity index (Shannon and Wiener index), Simpson index, Jaccard index, and species richness index (Margalef index) were calculated to assess the effect of changes caused by deforestation on mesostigmatid mite populations (see details about the calculation of each index in ESM). Analysis of variance was conducted by SAS (Version 9.4, 2013). Data for diversity indices did not follow a normal distribution. Because of this, the *H* test as a non-parametric analysis of variance (ANOVA) method was used. For this, the data were converted to the ranks by the RANK procedure, and then the output was analyzed by the GLIMMIX procedure based on a factorial model. For the other traits, we used parametric ANOVA with a factorial experiment. The correspondence analysis was conducted by Past software (Version 4.03, 2001) as a multivariate method to exhibit the relations between species and environments.

RESULTS

In this study, twenty-one species of mesostigmatid mites were collected and identified throughout our oak forests of Lordegan belonging to eighteen genera and ten families (Table S1 in the ESM). Moreover, 18 species were found in our two oak forest sites (natural and disturbed habitats) of Khanmirza district (Table 1). The species *Androlaelaps schusteri* (Berlese, 1887) and *Allogamasellus castilhoi* (Athias-Henroit, 2016) were reported for the first time and second time for the Iranian mite fauna, respectively. Among the collected species, *Sessiluncus hungaricus* (Karg, 1964) was the most abundant and dominant species in the natural forest with 16% frequency and *Gaeolaelaps oreithyiae* (Walter and Oliver, 1989) and *Pachylaelaps angustus* (Hyatt, 1956) were the least abundant species with 1% frequency. *G. oreithyiae*, *Laelaspis kamalii* (Joharchi and Halliday, 2012), *A. schusteri*, *A. castilhoi* were not found in disturbed forest and *Antennoseius bacatus* (Athias-Henroit, 1961) had the highest relative abundance with 29% frequency in this habitat (Table 1). Also, the similarity between two sites measured by the Jaccard index indicated 31% faunal similarity.

Table 1. Collected species of mesostigmatid mites from Lordegan oak forests with their relative abundance

Species	Family	Relative abundance (%)	
		disturbed forest	natural forest
Gymnolaelaps obscuroides	Laelapidae	4.5	4.6
Gaeolaelaps minor		3	5.2
Gaeolaelaps oreithyiae		0	1
Laelaspis kamalii		0	4.2
Haemolaelaps fenilis		6	6.6
Androlaelaps schusteri		0	3.7
Haemolaelaps shealsi		4.5	5.7
Veigaia planicola	Veigaiidae	9	6.6
Pachylaelaps angustus	Pachylaelapidae	1.5	1
Pachylaelaps imitans		11	4.7
Macrocheles merdarius	Macrochelidae	9.1	8.8
Allogamasellus castilhoi	Ologamasidae	0	2.8
Sessilunchus hungaricus		9	16
Lasioseius youcefi	Blattisociidae	3	2.4
Arctoseius cetratus	Ascidae	4.5	5.2
Gamasellus bicolor		4.5	5.2
Antennoseius masoviae		1.5	2.4
Antennoseius bacatus		29	14
Total		100	100

Sampling date and habitat showed significant effects on all four indices (Table 2). However, the interaction effect of sampling date and habitat was not observed. In general, 43.09% of information was

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Table 2. Analysis of variance for the effects of sampling dates and habitats on soil mesostigmatid mite density and species richness and number of individuals in two habitats, natural oak forest and disturbed oak forest of Lordegan, Iran; detailed method for the calculation of indices is presented in Electronic Supplementary Material (ESM)

Index	Parameters	*df*	*F*	*P*
Shannon-Wiener	sampling date	6	3.65	0.003*
	habitat	1	56.69	< 0.0001*
	date × habitat	6	0.41	0.86
Simpson	sampling date	6	3.56	0.004*
	habitat	1	55.13	< 0.0001*
	date × habitat	6	0.38	0.89
Species richness	sampling date	6	2.86	0.015*
	habitat	1	43.45	< 0.0001*
	date × habitat	6	0.27	0.94
Number of individuals	sampling date	6	6.21	0.0001*
	habitat	1	80.39	< 0.0001*
	date × habitat	6	0.94	0.47

**P* < 0.05; *df* – degrees of freedom

justified by the two-dimensional correspondence analysis graph (Figure 1). The X-axis was consisting of 25% of the information about species and this value was 17.7% for the Y-axis. The species which were involved with the X-axis were *A. schusteri*, *Veigaia planicola*, *P. imitans*, *Macrocheles merdarius*, and *Arctoseius cetratus* with high positive coefficients, and also *Lasioseius youcefi* was there with a negative coefficient. The species for the Y-axis were *Gymnolaelaps obscuroides*, *G. minor*, *P. angustus*, *A. bacatus* positively, and *A. castilhoi*, *Gamasellus bicolor*, *Haemolaelaps shealsi* negatively (Figure 1). Two species *L. kamalii* and *A. masoviae* were presented on both axes. Both of them had a positive and negative coefficient for the X- and Y-axis, respectively. Also, *A. masoviae* was present on the X-axis with positive and on the Y-axis with negative coefficient. The presence of species with positive coefficients implies that the positive amounts on the axis are more valuable for these species. The negative coefficients are vice versa. It means if there is a species with a negative coefficient on the X-axis, this species would be considered for the regions which are seen on the negative side of the X-axis. So, in the first quarter of the graph where both axes are positive, the presence of species with positive coefficients for both axes is more effective in this quarter. Thus, the regions which are presented in this quarter are involved with these species, especially the species *P. angustus*. In this quarter, there are NF4, DF4, DF2, DF3, and NF6, which implies in these regions and times the presence of *P. angustus* was dominant. Furthermore, *V. planicola*, *P. imitans*, *M. merdarius*, and *A. cetratus* are near to DF3 in this quarter, or on the other hand, DF3 has

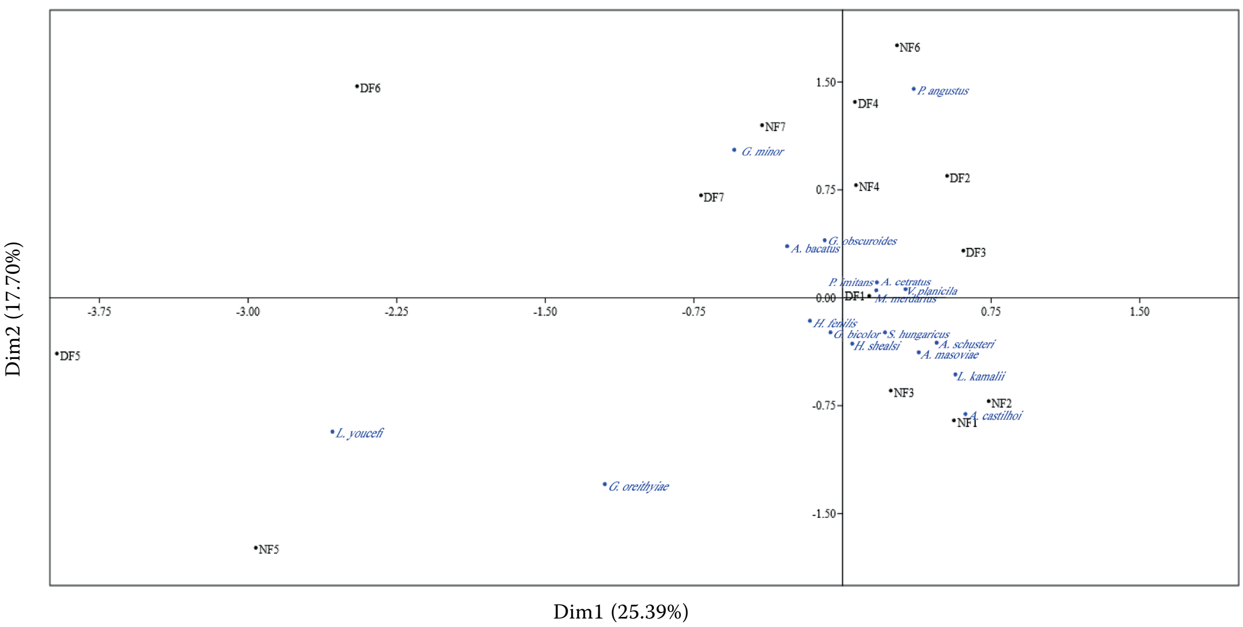

Figure 1. Correspondence analysis between regions in different times and species (for species names see Table 1)
DF – disturbed forest; NF – natural forest; 1–7 – months of April–October; Dim – dimension

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a high positive value on the X-axis. So, these species have a big role in this region.

Mean abundance values were significantly different between the two habitats (Table 3). The average values (mean of seven months) of the measured indices (Shannon-Wiener diversity, Simpson, and species richness) were significantly different between the two habitats (Table 3).

Soil organic matter and soil nitrogen content were significantly higher in natural oak forest compared to disturbed forest (Table 4), but pH did not differ between these two habitats. Soil organic matter (F = 49.2, P < 0.0001), nitrogen content (F = 25.0, P < 0.0001), and pH (F = 12.4, P = 0.007) showed significant temporal variations (Table S2 in the ESM). The interactions of habitat × date were not significant for the measured soil parameters

Table 3. Average biodiversity index values of two studied habitats, natural oak forest (NF) and disturbed oak forest (DF) in Lordegan, Iran; data are means of indices (average of 7 months) with standard error given in parentheses; mite density is expressed based on the number of individuals per soil square meter

Habitat	Index			Number of individuals
	H'	1-D	SR	
NF	1.20 (0.09)^a	0.61 (0.03)^a	1.79 (0.13)^a	0.017 (0.005)^a
DF	0.33 (0.07)^b	0.21 (0.04)^b	0.61 (0.12)^b	0.006 (0.003)^b

^{a,b}significant differences between microhabitats (P < 0.05); H' – Shannon and Wiener index [Equation (S1) in ESM]; 1-D – Simpson index of diversity [Equation (S2) in ESM]; SR – Species richness index [Equation (S4) in ESM]

Table 4. Values of soil parameters in two habitats of oak forests, natural and disturbed oak forest of Lordegan, Iran; data are means of six replicates (for each sampling date) with standard errors given in parentheses

Variable	Habitat	Mean for three sampling dates
Organic carbon (%)	NF	1.29 (0.15)^a
	DF	0.69 (0.07)^b
Nitrogen (%)	NF	0.15 (0.01)^a
	DF	0.11 (0.01)^b
pH	NF	7.76 (0.03)^a
	DF	7.71 (0.01)^a

^{a,b}significant differences (P < 0.05) between treatments; NF – natural oak forest; DF – disturbed oak forest

(Table S2 in the ESM). Mean monthly precipitation and temperature in the study area are shown in Figure S2 in the ESM. The highest temperatures were recorded during July and August, with no rainfall observed from June to September.

DISCUSSION

Generally, biodiversity considers changes in species composition between habitats (Hawksworth, Bull 2006; Lindo, Winchester 2008; Aggemyr et al. 2018; Hillerbrand et al. 2018). In this study, diversity of mite species was compared between natural oak forest and disturbed parts converted to agricultural lands. There are many considerable differences between natural habitats (such as forests) and manipulated habitats in the species abundance and diversity (Holland 2004; Bedano et al. 2005; Bedano et al. 2006; Gulvik et al. 2008; Santorufo et al. 2012). It has been documented that the communities of Uropodina (Acari, Mesostigmata) are more abundant and more diverse in old-protected forests (Napierała et al. 2009). Agricultural practices, such as removing of plant residues and ploughing, generally modify (usually disturb) the soil structure (usually upper layers) and result in soil drought and loss of nutrient accessibility. Consequently, this causes disturbance in the habitat and reduction in the abundance of soil biota and their ecological functions (Gergócs, Hufnagel 2009; Postma-Blaauw et al. 2010).

In this study, we collected some rare species that are reported for the first or second time from Iran such as *A. schusteri*, *L. kamalii*, and *A. castilhoi* only from the natural parts of Lordegan oak forest. The most abundant species in the natural habitat was *S. hungaricus*, which is usually found in humus layer and litter (Bregetova et al. 1977; Fenďa, Ciceková 2005) while in the disturbed habitat *A. bacatus* (a cosmopolitan species) was the dominant species. Considering that more species were collected from natural parts of the Lordegan oak forest highlights the fact that forests act as refuges for soil-dwelling microarthropods, such as mites, and also these less manipulated habitats support a higher biodiversity of soil biota (Paoletti 1999).

Four biodiversity indices were measured in this study. Each index often emphasizes one characteristic more than the others; for example, the Shannon-Wiener index considers abundance while the Simpson index emphasizes the dominant species. Results of our monthly sampling showed

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that the Shannon-Wiener, Simpson, and Margalef indices were much higher in the natural oak forest than in the disturbed habitat. Also, the total abundance of mesostigmatid mites was estimated higher in the natural forest. The lower diversity indices found in the disturbed forest are possibly due to the fact that mites cannot easily tolerate impacts of habitat disturbance. Agricultural activities, such as cultivation, rotations, monoculture, and application of pesticides and fertilizers, may result in the elimination of species susceptible to damage, desiccation and destruction of their habitats (Behan-Pelletier 1999; Banerjee et al. 2019; Plaas et al. 2019). A previous study showed that the range of values of the Shannon-Wiener and Margalef indices was 0.75–1.14 and 5.5–10.1, respectively, and the indices were higher in the habitats containing litter compared to the habitats with litter removal (Wu et al. 2006). Studying the activity and diversity of mites in a degraded Midwestern oak woodland indicated that communities with lower litter mass had lower mite diversities (Steffen et al. 2012).

In this study, we found significant differences between various sampling dates and mite density and estimated diversity indices, most probably as a result of increase or decrease in temperature and also due to a change in rainfall (the decisive factor could be soil temperature). The highest rainfall and the lowest temperature were recorded in April, while the highest temperature and a lack of rainfall occurred in August. This would result in dryness of the top layer of soil (0–10 cm) and subsequently make it unfavourable for soil mesostigmatid mites. It has been reported that when soil conditions are inappropriate and inadequate for soil mites, they begin migrating (vertically) to deeper layers of the soil (Okiwelu et al. 2012; De Groot et al. 2016). Several studies indicated that there is a negative correlation between the increase in air temperature (and thus soil temperature) and density and population of soil mites (Salmane 2000; Bedano et al. 2005, 2006; Călugăr 2018; Manu et al. 2019). We observed a negative significant correlation between temperature and total abundance of the mites and a positive significant correlation between total abundance of soil mites and rainfall. From the above results, it could be concluded that enough moisture is available for the stay of mites in the top layer of soil in April and May due to rainfall and transpiration of crops. When the crops (such as wheat or barley) are harvested in July, the top layer of soil becomes dry, especially when there is no rainfall. In this situation, relative humidity also decreases, which makes conditions unfavourable for soil mites. Therefore, a decline in diversity indices is expected from July to September and indices are rising again in October due to rainfall increase and temperature decrease.

Soil organic matter has a major role as a resource for soil fauna, which subsequently increases mineralization and nutrient availability in the soil and plant nutrient uptake. Enhancing microarthropod density and their grazing activities on soil-dwelling microorganisms may result in increasing the total nitrogen of soil (Cole et al. 2004). It has been suggested that the abundance and density of soil microarthropods are higher under the influence of available food than the soil chemical characters, such as carbon, nitrogen content or pH (Kautz et al. 2006). The increase of organic matter in soil, as an important process in an ecosystem, increases the abundance of bacteria and fungi and consequently the abundance and diversity of soil mites is increased (Vreeken-Buijs et al. 1998). In this study, soil organic matter and nitrogen content were found significantly higher in the natural forest than in the disturbed forest. Hajabbasi et al. (1997) also reported increasing bulk density and decreasing soluble ions in the disturbed forest soil of Lordegan oak forests as well as reduced organic matter and nitrogen content compared to the natural forest.

The changes in other soil parameters caused by deforestation may also have influenced soil mite density and related diversity indices in the disturbed forest. Moreover, pH is another important characteristic of the soil. Our statistical analysis showed that sampling time had a significant effect on pH (time dependent), but the interaction between habitat and sampling date was not significant. The difference in pH between the two habitats was not significant. The density of soil microarthropods has been found to be strongly correlated with the amount of soil organic matter and pH in temperate and tropical rain forests (Illig et al. 2010). It seems that the positive correlation between mesostigmatid mite density and pH indicates a tendency towards a neutral pH in this group. However, the response of a species to soil pH can change with changing environmental factors (Bedano et al. 2005).

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