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Spatio-temporal heterogeneity differently drives the diversity of various trophic guilds of mesofauna in semiarid oak forests

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# Spatio-temporal heterogeneity differently drive the diversity of various trophic guilds of 28 mesofauna in semi-arid oak forests 29

#### Abstract

30

Despite the importance of mesofauna in soil formation, litter decomposition, biological cycles 31 and growth of plants in semi-arid forest ecosystems, the effects of different woody species 32 and seasonality on the abundance, diversity and distribution of mesofauna invertebrates have 33 been little studied. This study has evaluated the effects of different woody species (trees and 34 shrubs) on trophic guilds of soil mesofauna (detritivores vs. predators) composition, 35 abundance and diversity during spring and winter seasons. Moreover, the basic drivers 36 including microclimatic characteristics and soil properties of soil biota abundance, 37 composition and diversity have been identified in semi-arid deciduous broadleaved forests. 38 Woody species types and seasonality affected soil mesofauna abundance, composition and 39 diversity. All the species were present during spring and winter and in all types of woody 40 species, but the mesofauna was differently affected by season and woody cover. Predator 41 abundance was affected by species and seasonality, whereas detritivore abundance was only 42 influenced by woody species. In relation to the season, mesofauna abundance is generally 43 higher in winter compared to spring. Detritivore and predation diversity in soil mesofauna was 44 affected by woody species and seasonality, but not by the interaction of both factors. It has 45 been also demonstrated that the trees understory is a more important biodiversity hotspot 46 compared to shrubs for mesofauna activity; moreover, the detritivores vs. predators 47 mesofauna composition are driven by the seasonality and woody species. Overall, this work 48 has demonstrated that aboveground and belowground relationship (that is, plant and soil 49 organisms) have reciprocal ecological linkages and that aboveground and belowground 50 communities can be powerful mutual drivers. 51

Keywords: shrub; tree; soil detritivores; abundance; evenness.

#### 1. Introduction

The living soil (soil biota) contains a very high diversity of organisms, including 54 microorganisms (i.e., bacteria, fungi) and microscopic and macroscopic fauna (Bardgett and 55 Van Der Putten, 2014; Balestrini et al., 2015). The soil fauna includes macrofauna (having a 56 body size > 2 mm), mesofauna (body size between 100  $\mu$ m and 2 mm) and microfauna (< 100 57  $\mu$ m) (Whalen and Sampedro, 2010). The mesofauna consists of small invertebrates that live 58 in soil or litter with different diets such as predators and detritivores (Whalen and Sampedro, 59 2010). These organisms plays an important role in ecosystems multifunctionality and soil 60 quality (Lavelle et al., 2006) playing a vital role in the functioning of terrestrial ecosystems 61 (Wolters et al., 2000; Hossain and Sugiyama, 2019).

Soil mesofauna interact with plants and these relationships form the soil's food chain and 63 sustain the services and functions of natural ecosystems, such as carbon and nutrient cycling 64 or water cycle regulation (Motiejūnaitė et al., 2019). Thus, interactions between soil 65 mesofauna and plant are certainly important for growth and establishment of various plant 66 species including trees and shrubs species. In many ecosystems, changes in the diversity and 67 abundance of soil organisms can have significant effects on plant-soil interactions and 68 ecosystem production and functions (Ponge, 2013; Zhao et al., 2013; Agapit et al., 2018). 69 However, soil organisms are sensitive to abiotic and biotic factors both above and below 70 ground, such as climatic conditions, management measures, plant cover and different 71 chemical and physical soil properties (Pritchard, 2011; Wissuwa et al., 2012; Wu and Wang, 72 2019). Mesofauna invertebrates (both mesofauna detritivores and predators) diversity may be 73 affected by several ecosystem features, such as plant cover and biodiversity, which in turn 74 may be directly affected by soil nutrient deficiencies, climate change, forest fires and other 75 biological factors (such as pests and diseases) (Ahmadi et al., 2014; Lieutier and Paine, 2016; 76

Torres- Muros et al., 2017). Moreover, forest characteristics, including forest structure, tree 77

canopy cover, vegetative form (shrub or tree species), abundance and spatial distribution of 78 woody species may alter composition of mesofauna invertebrates through for example the 79

quantity or quality of plant debris (Morán- López et al., 2015; Brygadyrenko, 2016). Many 80

studies have examined the effects of tree species, silvicultural operations or shrubs 81 composition on soil fauna (Kataja-aho et al., 2016; Čuchta et al., 2019). For instance, Heydari 82 et al. (2017 a) showed that Shannon-Wiener diversity and Margalef indices of mesofauna 83 richness in soil were significantly related to stand structural indices in a mixed oak (*Quercus* 84 *brantii* Lindl.) forest. Different characteristics of tree and shrub species - canopy architecture 85 and size, and consequently different amount of litter input and root development - can be 86 effective on their effects on soil properties (Vetaas, 1992; Muraoka and Koizumi, 2005; Yao 87 et al., 2017). However, recognizing the effects of different woody species on the abundance, 88 diversity and distribution of mesofauna invertebrates can provide valuable information on the 89 factors contributing to the conservation and enhancement of soil biodiversity at different 90 trophic levels in threaten ecosystems.

The different characteristics of soil organisms (such as composition, abundance and diversity) 92 are not randomly distributed, but organise horizontally, following patchy patterns at landscape 93 scale, and vertically, along the soil profile (Frey, 2015). These specific patterns can be largely 94 dependent on site microhabitats (Bayranvand et al., 2017; Heydari et al., 2017 a) and climate 95 seasonal variations (including differences on soil moisture and temperature) (Görres et al., 96 1998; Campuzano et al., 2019). On this context, the role of plant ecosystems or microclimatic 97 characteristics influence on soil mesofauna density is still not completely known (Briones, 98 2018). For instance, a deeper understanding of the effects of forest species on mesofauna 99

detritivores and predators communities may be useful as ecosystems quality indicators, 100 particularly in semi-arid ecosystems in which soil degradation processes are important under 101 the climate change context. 102 Zagros forests are one of the oldest and unique oak habitats in the world. The Zagros forest 103 cover an area of approximately 5 million hectares with highly scattered and occasionally 104 denser oak trees (mostly Brant's oak, Quercus brantii var. Persica) associated with different 105 shrub and tree species (Sagheb-Talebi et al., 2014). In these oak forests, the effect of individual 106 tree and shrub species on different soil biological and chemical properties throughout the 107 seasons has been little investigated, since most studies have focused on forest stands (Hosseini 108 et al., 2017; Mirzaei et al., 2020). Although one of the major determinants of the spatial 109 distribution of soil fauna diversity in forest ecosystems can be related to the overstory, the 110 current knowledge about the relationships between mesofauna invertebrates and tree species 111 is scarce (Gholami, et al., 2017). This makes difficult for ecologists the application of models 112 describing the structure of soil organism's communities and the comprehension of the 113 distribution of diversity of soil organisms at different scales (Barrios, 2007; Da Silva et al., 114 2015; Kuznetsova et al., 2019). To fill these gaps, this study aims to investigate the spatio-115 temporal dynamics of soil mesofauna in semi-arid oak forest ecosystems of western Iran. In 116 more detail, the specific objectives of the study were: (i) to analyze the effects of different 117 woody species (trees and shrubs) on trophic guilds of soil mesofauna (detritivores vs. 118 predators) composition, abundance and diversity during spring and winter seasons; and (ii) to 119 identify the basic drivers including microclimatic characteristics and soil properties of soil 120 biota abundance, composition and diversity in semi-arid deciduous broadleaved forests. On 121 this regard, we hypothesized that: (i) the variation of soil mesofauna abundance, composition 122 and diversity are affected by woody species types and season changes; (ii) the trees understory 123 is a more important biodiversity hotspot compared to shrubs for soil biota activity; and (iii) 124 the contribution of mesofauna trophic guilds (detritivores vs. predators) in soil mesofauna 125 composition can be explained by the interaction of season and growth form types (tree vs. 126 shrub). 127

#### 2. Material and methods

## 2.1. Study area

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The study site (covering 60 ha) is the Zagros forests in the Bankol forest region (Sirvan city, 133 western Iran) (Fig. 1). This deciduous forest include broadleaved species dominated by 134 Persian oak (Quercus brantii L.) with some associated species, such as Acer monspessulanum 135 L. subsp. cinerascens (Boiss.), Pistacia atlantica Desf., Crataegus puntica C. Koch., 136 Amygdalus scoparia Spach., and Lonicera nummularifolia Jaub & spach. The presence of 137 individuals or groups of trees/shrubs of small to medium sizes with average overstory canopy 138 cover 35-50 % is recorded. The ground vegetation includes a relatively dense cover of annual 139 and perennial grasses and forbs, such as Bromus tectorum L., Astragalus adscendens Boiss., 140 Gundelia turneffortii L., Geranium lucidum L., Hordeum bulbosum L., Alyssum marginatum 141 Steud. ex Boiss., Avena wiestii Steud, Medicago radiata L., Valerianella vesicaria Moench 142 and Neslia apiculata Fisch. The studied site shows the very similar physiographic conditions 143 (slope < 10% and altitude 1900-2000 m a.s.l.). In the study area, climatic data of the period 144 2006 to 2017 were collected at the nearest meteorological station (Lomar, 33° 56' N, 46°82' 145 E, 850 m a.s.l.). The average annual precipitation was 384 mm and the average annual 146 temperature was 20.6 °C; the dry season is between May and October (Fig. 2). The prevalent 147 soil type (according to the FAO classification) is lithosols with low depth and fertility (Jazirehi 148 and Ebrahimi Rastaghi, 2003) and a sandy clay loam texture. 149

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#### 2.2. Experimental design

A flat area in the studied forest was selected in this study. Soil was sampled under three tree 153 species, including *Quercus brantii* (hereinafter indicated as QU), *Acer monspessulanum* L. 154 (AC) and *Pistacia atlantica* Desf. (PI), and three shrub species, i.e. *Crataegus puntica* C. 155 Koch. (CR), *Amygdalus scoparia* Spach. (AM) and *Lonicera nummularifolia* Jaub & spach. 156 (LO) in mid-spring and in winter 2018. For each tree and shrub species, five individuals within 157 the same diameter class were randomly selected. Individuals of the same species always 158 surrounded selected trees and shrubs species. Thirty individuals were considered for each of 159 the two seasons for a total of 60.

Soil was sampled at a depth between 0 and 0.25 m including litterfall at three points, randomly 161 chosen under each species. Soil samples were extracted using a cylindrical extractor with an 162 area of 0.0314 m<sup>2</sup> and a depth of 0.25 m. The three soil cores were mixed into a composite 163 sample. Immediately after sampling, the samples were stored in plastic bags and brought to 164 the laboratory. Then, the samples were placed into a Berlese funnel to remove the terrestrial 165 arthropods. The species level of the arthropods was identified using standard taxonomic keys 166 and reference slides (Mirab-balou et al., 2011; Ramroodi et al., 2014; Nassirkhani et al., 2017). 167 Richness (*SR*<sub>mg</sub>, Margalef, 1958), diversity (*H*', Shannon and Weaver, 1949) and evenness 168 (*J*', Pielou, 1966) of mesofauna invertebrates were calculated using the following equations: 169

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$SRmg = (S-1)/\ln N$	(	(1	.)	1	7	1
$SRmg = (S-1)/\ln N$	(	(1	.)		1	17

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$
 (2) 172

- $E = H' / \ln(S)$  (3) 173
  - 174

where  $p_i$  is the proportion of cover of species '*i*', *N* is the total number of individuals and *S* is 175 the total number of mesofauna species. 176

In addition, three composite soil samples of about 0.5 kg were randomly collected from the 178 soil horizon to a depth of 0.25 m under each species, in order to evaluate the chemical and 179 microbial properties of the soil. The soils were sieved through a 2-mm mesh and split into two 180 sub-samples, of which one was stored at 4 °C at its water content, to measure later soil 181 microbial activity (soil microbial biomass carbon, soil microbial biomass nitrogen, soil basal 182 respiration and substrate induced respiration), and a second sub-sample was air-dried, to 183 measure soil chemical properties (soil pH and electrical conductivity and soil organic carbon). 184 The soil water content was determined using the gravimetric method (Famiglietti et al., 1998). 185 Soil organic carbon (SOC) was measured by dichromate oxidation followed by rapid titration 186 (Walkley and Black, 1934). Soil pH and electrical conductivity (EC) were measured in filtered 187 extracts with a glass electrode and a conductivity probe, respectively (Kalra and Maynard, 188 1991). Soil microbial biomass carbon (SMC) was evaluated by determining organic carbon 189 by dichromate digestion in both chloroform-sprayed and non-fumigated samples (Vance et 190 al., 1987). Soil SMC was estimated from the carbon concentration ( $\mu$ gC g<sup>-1</sup> of dried soil) of 191 0.5 M of K<sub>2</sub>SO<sub>4</sub> soil extracts using the equation (Vance et al., 1987): 192

193

$$SMC = 2.64 (A)$$
 (4) 194

195

where A is the difference in carbon from fumigated and non-fumigated soils. Soil basal 196 respiration (BR) was determined by trapping and measuring emitted CO<sub>2</sub> over a 5-day period 197 (Alef and Nannipieri, 1995). Substrate-induced respiration (SIR) was measured using glucose 198 (1%) as substrate and evolved CO<sub>2</sub> was measured after eight hours of incubation. Evolved 199 CO<sub>2</sub> was adsorbed by 1 M NaOH and measured by titration of 0.1 M HCl (Anderson and 200 Domsch, 1978). The soil microbial biomass nitrogen (SMN) was determined as total Kjeldahl 201 nitrogen in the same K<sub>2</sub>SO<sub>4</sub>extracts (Brookes et al., 1985). The total N discharge (N extracted 202

by the  $K_2SO_4$  from the non-fumigated soil subtracted from the fumigated soil) was divided by 203 the KN value (N fraction of the biomass extracted after chloroform fumigation) of 0.54 204 (Brookes et al., 1985). 205

#### 2.3. Statistical analysis

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General linear models (GLM) were used to assess the effects of woody species, seasons and 209 their interaction on the soil mesofauna abundance, composition and diversity, including both 210 detritivores and predators. Variables were transformed when necessary to satisfy assumptions 211 of normality and homoscedascity of residues. Duncan's post-hoc tests were used to compare 212 the means of soil mesofauna abundance, composition and diversity among different woody 213 species in the understory. A principal component analysis (PCA) was used to evaluate the 214 relationships between soil mesofauna abundance of various trophic guilds (Detritivore vs. 215 Predator) and the chemical and biological properties of the soil under different species 216 throughout the two seasons (TerBraak and bmilauer, 1998). Moreover, a hierarchical grouping 217 and heat mapping of the 30 soil samples were carried out. A two-way clustering dendrogram 218 was obtained using Euclidean distance with the Ward clustering algorithm and coupled with 219 the heat map relative to the abundances of the nine mesofauna taxa. Differences in soil 220 mesofauna composition between different tree and shrub species were explored using non- 221 metric multidimensional scaling (NMS) as part of the 'vegan' package in R (Oksanen et al., 222 2018). This sorting method, which projects multivariate data in a space with fewer 223 dimensions, was performed on each data set using Bray-Curtis dissimilarity. Unidirectional 224 analysis of variance (ANOVA) was used to identify significant differences in sample plot 225 scores on the NMS axis. All statistical analyses were performed using R 3.5.2 (Main Team R, 226 2018) and CANOCO 5 software. 227

#### 3. Results

# 3.1. Soil mesofauna species and composition

Nine mesofauna species were found under the tree and shrub species, belonging to two trophic 233 guilds, detritivores (*Pseudosinella octopunctata* Börner, *Folsomides marchicus* (Frenzel) and 234 *Oribatula sp.*) and predators (*Macrocheles glaber* (Müller), *Gaeolaelaps aculeifer* 235 (Canestrini), *Arctoseius cetratus* (Sellnick), *Tyrophagus sp.*, *Acanthocreagris iranica* Beier 236 and *Aleochara sp.*) (Fig. 3a and 3b). The heat map splits the six species analysed in two 237 clusters (one for each season), based on mesofauna abundance. However, since soil mesofauna 238 composition was similar, the tree and shrub species were not separated. *Oribatula sp.* (spring), 239 as well as *Tyrophagus sp.* and *Oribatula sp.* (winter) were the most abundant soil mesofauna 240 invertebrates. More specifically, in spring, the most abundant species was *Oribatula sp.* under 241 *Acer monspessulanum* L. subsp. cinerascens (Boiss.), and *Pistacia atlantica* Desf. (Fig. 3a). 242 In winter, *Tyrophagus sp.* and *Oribatula sp.* showed a high abundance under all species. 243 Moreover, *Folsomides marchicus* (Frenzel) and *Pseudosinella octopunctata* Börner were 244 more abundant under shrub species (*Crataegus puntica* C. Koch., *Amygdalus scoparia* Spach., 245 and *Lonicera nummularifolia* Jaub & spach) (Fig. 3b)

The NMS shows significant differences in mesofauna composition in spring (F-value = 10.46248 and P-value < 0.0001 on NMDS axys 1, and F-value = 12.73 and P-value < 0.0001 on NMDS 249 axys 2) (Fig. 4 b, c) and winter (F-value = 23.70 and P-value < 0.0001 on NMDS axis 1, and 250 F-value = 4.82 and P-value < 0.05 on NMDS axis 2) among species (Fig. 4 f, g). The 251 mesofauna composition under QU was, as expected, different from the composition detected 252

in other species in both seasons. Mesofauna composition was very similar under AM, PI and 253 CR (in spring), and CR and AM (in winter), as shown by the clear overlapping (Fig. 4 a, e). 254 The contribution of trophic guilds of soil mesofauna in composition under each species was 255 influenced by the interaction of season with vegetative form (tree and shrub), as in spring 256 predators contributes more in mesofauna composition under tree species (Fig. 4 d), while in 257 winter detritivores have a greater contribution in composition beneath shrubs (Fig. 4 h).

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## *3.2. Soil mesofauna abundance and diversity*

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The total abundance of mesofauna was significantly different between the two seasons under 262 all species (Fig. 5). Compared to spring, Lower values were detected under QU and AC in 263 winter, while, in the same season, the abundance was higher under LO and PI . Detritivore 264 abundance was significantly higher in winter compared to spring, except for QU and CR (for 265 the latter the same values were detected in spring and winter). The maximum abundance of 266 detritivores was found under CR in spring (135  $\pm$  32) and winter (138  $\pm$  32), while and the 267 minimum value was detected under LO (32  $\pm$  9) and PI (32  $\pm$  6) in spring. Predator abundance 268 was higher under QU, AC, CR and AM, and lower under PI and LO in spring. The highest 269 abundance of predators was recorded under QU (124  $\pm$  13) and AC (132  $\pm$  15) in spring, while 270 the lowest abundance was surveyed under AM (19.2  $\pm$  4) in winter (Fig. 5).

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The tree and shrub species significantly affected the soil mesofauna diversity indices and 273 abundance of their trophic guilds (i.e., detritivores and predators). Pielou's evenness was an 274 exception, since it was not affected by species. The sampling season had a significant effect 275 on Shannon–Wiener diversity, Margalef's richness and Pielou's evenness of both detritivores 276 and predators diversity. Also in this case, the total mesofauna diversity indices were not 277

significantly affected by season. As regards the trophic guild abundance, only predator 278 abundance was significantly affected by the sampling season (Table 1). The interaction 279 between species and season significantly affected the total mesofauna diversity and evenness, 280 the detritivore diversity and richness, the total mesofauna abundance and the predator 281 abundance (Table 1). No significant differences were detected in the total mesofauna diversity 282 indices between the two sampling seasons. All diversity indices of detritivores were 283 significantly higher in winter compared to spring; conversely, these indices were significantly 284 higher in spring for predators. The comparison of diversity indices between species in spring 285 indicates that diversity and richness indices of total mesofauna, detritivores and predators 286 were the highest under QU and AC and the lowest under shrubs (especially for AM and LO). 287 In spring, only evenness of detritivores got the highest and the lowest values under QU and 288 LO, respectively (Table 2).

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# 3.3. Spatio-temporal variation in mesofauna abundance in relation to soil properties 291 292

PCA provided two main principal components (PCs), explaining more than 49% (PC1) and 293 19% (PC2) of the total variance in soil properties and mesofauna diversity indices under the 294 six species in the sampling seasons (Fig. 6). PC1 indicated that, under soil conditions with 295 higher pH, water content and organic carbon (i.e., under QU and AC in both spring and 296 winter), the activity of predators and microorganisms (higher SMC, MBN, BR and SIR) is 297 higher (see upper left quarter of the chart); moreover, both PC1 and PC2 showed that 298 decreasing organic carbon, water content, pH and microbial activity, and increasing EC 299 (decrease soil fertility) affect a higher activity of detritivores and lower activity of predators 300 under shrubs (CR, AM and LO) in winter. Along the negative direction of PC2 (indicating 301 higher EC, and lower nutrient content and microbial activity) the conditions of understory of 302

CR, AM, LO and PI in spring are represented by an intermediate presence of both trophic 303 guilds (detritivores and predators) (Fig. 6 and Table 3). 304

All soil properties (except for EC, P = 0.056) showed statistically significant differences 305 among different woody species: pH (P < 0.001), soil organic carbon (P < 0.001), WC (P < 306 0.001), basal respiration (P < 0.001), substrate-induced respiration (P < 0.001), soil microbial 307 biomass nitrogen (P = 0.004), soil microbial biomass carbon (P < 0.001). Soil water content 308 beneath trees was significantly higher than beneath shrubs. It was also significantly higher in 309 spring compared t winter only for *Acer monspessulanum*, *Quercus brantii*, and *Crataegus* 310 *pontica*. In addition, soil organic carbon was higher under trees compared to shrubs. Soil pH 311 was higher in spring compared to winter for trees (*Acer monspessulanum* and *Pistacia* 312 *atlantica*) and shrub (*Crataegus pontica* and *Lonicera nummularifolia*). Soil biological 313 attributes (i.e. SIR, BR, SMC, SMN) were significantly higher under tree species compared 314 to shrubs; these attributes were also higher in spring compared to winter (Table 4).

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## 4. Discussions

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Little information about the effects of different woody species (trees and shrubs) on soil 319 mesofauna detritivores and predators composition, abundance and diversity is available. 320 Therefore, these effects have been evaluated during spring and winter seasons in semi-arid 321 deciduous broadleaved forests in Zagros forest. Moreover, we also try to identify the basic 322 drivers (microclimatic characteristics and soil properties) of soil biota abundance (detritivores 323 and predators), composition and diversity in the semi-aridforest of the study area. Among the soil 324 organisms, mesofauna is one of the most important biological components of soil, since it can 325 play an important role in determining soil multifunctionality (Koehler, 1992; Morais et al., 326 2010; Wu and Wang, 2019). However, its role and relationships in many natural ecosystems 327

including trees and shrubs are still poorly understood, especially in arid or semi-arid 328 environments (Taylor and Wolters, 2005; Young et al., 2018). Understanding the different 329 aspects of plant-soil interactions in arid and semi-arid forest ecosystems is very important, 330 because of resource constraints and higher environmental stresses (Schlesinger and Pilmanis, 331 1998; Karmakar et al., 2016). 332

Through this study, the first working hypothesis of our study is confirmed, since woody 333 species types and seasonality affected soil mesofauna abundance, composition and diversity. 334 In more detail, as shown in the abundance heat maps of soil mesofauna invertebrates, all the 335 species were present during spring and winter and in all types of woody species, but the 336 mesofauna was differently affected by season and woody species cover. Oribatula sp. and 337 Tyrophagus sp. found in Pistacia atlantica and Acer monspessulanum plots were the most 338 abundant mesofauna species in spring (higher than 60 individuals per m<sup>2</sup>). Oribatula sp., 339 Tyrophagus sp., Pseudosinella octopunctata and Folsomides marchicus species were the most 340 abundant species, but with weak differences among woody species plots, in winter. As regards 341 the mesofauna abundance, GLMs (Table 1) showed statistically significant effects of tree and 342 shrub species and season. Predator abundance was affected by species and seasonality, 343 whereas detritivore abundance was only influenced by woody species. The positive effect of 344 the wet season is shown by the heat map of figure 3, where it is evident that mesofauna 345 abundance is generally higher in winter compared to spring. Water content in soil is an 346 important regulator of soil life, since most biochemical processes, such as the enzymatic 347 activity and reproduction, strictly depend on soil temperature and humidity (Lucas-Borja, 348 2016). Higher soil humidity of wet seasons under plant cover promotes higher availability of 349 chemical nutrients in soil solution, which enhances plant growth, and organic matter inputs to 350 soil, which feed soil mesofauna (Zagatto et al, 2017). As exposed by different authors and in 351 addition to the characteristics of woody species canopy, changes in biological and abiotic 352

factors due to seasonal changes can have directly (e.g., by humidity and temperature changes) 353 or indirectly (production rates) effects on the dynamics of biological activity, including the 354 diversity and richness of soil detritivores and predators (Anslan et al., 2018; Nascimento et 355 al., 2019; Kooch and Noghre, (2019). 356

The highest total mesofauna abundance was found under CR (shrubs species) and in QU, AC 357 (trees species) plots, detritivores species being higher in CR shrubs, and predator species 358 being higher in QU and AC trees, compared to the other woody species plots. Overall, our 359 results are in accordance with previous research about mesofauna abundance. Some studies 360 pointed out that tree canopy abundance and woody species significantly affect soil mesofauna 361 abundance (e.g., Vanbergen et al., 2007). Higher enrichment of carbon and nutrients beneath 362 the canopy of individual woody species with larger canopy size (trees vs. shrubs) can be 363 probably due to higher litter input per unit area and differentiated microclimate conditions 364 along seasons (Yao et al., 2017; Heydari et al., 2017 b; Bayranvand et al., 2017; Salazar et al., 365 2019). These characteristics can differently affect the diversity and composition of fauna 366 invertebrates (Negrete-Yankelevich et al., 2008). Soil invertebrates can benefit from woody 367 species cover, because a litter depth under a deciduous canopy or a dense shrub layer may 368 generate a thick litters (otherwise being thin), which may sustain mesofauna species (Ferguson 369 and Berube, 2004; Schuldt et al. 2008). In addition, Jiménez-Chacón et al. (2018) found that 370 light availability is a main determinant of soil fauna, although the sign of the light effect varied 371 among studies. It is worth to note that in water-limited ecosystems, mesofauna benefits from 372 the higher moisture found in darker microsites (Dhooria, 2016). As Jiménez-Chacón et al. 373 (2018) demonstrated, environmental predictors including light and soil humidity accounted 374 mostly for variation in the abundance of many different mesofauna species (i.e. Diplopoda, 375 *Pscoptera*, *Oribatida*, *Diptera*, and *Poduromorpha*). 376

In more detail, mesofauna predators were significantly influenced by SMN, WC, SIR, SOC 377 and BR, whereas detritivores by EC. As demonstrated by Liu et al. (2011), soil fauna 378 abundance and richness is highly affected by soil properties and shrubs characteristics. On 379 this context, litter coming from woody species may play a key role on the mesofauna 380 dynamics, since it is the main input of C, N and many other elements to bulk soil. As Thoms 381 et al. (2010) stated, there are direct interactions between soil fauna and plant communities and 382 different vegetal inputs generate variations in initial nutrient concentration and physico- 383 chemical properties of soil. According to Lucas-Borja et al. (2012), plant diversity influences 384 physico-chemical and microbiological soil properties of forest ecosystems. Therefore, the 385 spatial distribution of different wood species on the horizontal surface makes the forest floor 386 conditions heterogeneous in terms of different environmental factors, such as moisture, 387 temperature and litter depth. These agents create various microhabitats (Prescott and 388 Grayston, 2013) that can affect nesting, diversity and activity of organisms within and on soil 389 surface (Tedersoo et al., 2016; Gallé et al., 2017) beside the physical, chemical and biological 390 soil properties (Waring et al., 2016; Hammer, 2019). Thus, the differences related to tree 391 diversity, such as the litter composition, and the variations only indirectly related to woody 392 species composition or tree diversity, such as pH, soil organic matter and EC, might explain 393 the described patterns of soil mesofauna. 394

Our results indicated that detritivore and predation diversity in soil mesofauna was affected 395 by woody species and seasonality, but not by the interaction of both factors. This means that 396 both woody species and season alter at the same extent diversity indexes. For instance, the 397 higher detritivore and predation diversity was generally found in QU and AC (trees species 398 plots) plots, whereas the lowest values were detected in CR (shrubs species plots) plots in 399 spring and winter. This fact seems to corroborate our second and third working hypothesis, 400 which pointed that: (i) the trees understory is a more important biodiversity hotspot compared 401 to shrubs for mesofauna activity; and (ii) the detritivores vs. predators mesofauna composition 402 could be explained by the seasonality and woody species factors. Overall, our result confirm 403 that differences in mesofauna diversity and richness might be related to the characteristics of 404 woody species and the shelters plant species provide. In addition, mesofauna may be also 405 affected by soil properties under shrub and tree species (Liu et al., 2011). Korboulewsky et al. 406 (2016) indicated that mesofauna abundance and diversity is strongly affected by certain tree 407 species; the soil organism community structure is, in most cases, significantly affected by an 408 increase in tree richness or by a mixing effect. Studies developed in the same region as this 409 study demonstrated that soil fauna diversity and abundance were spatially correlated to tree 410 species abundance, diversity. This, highlights that soil properties, tree abundance and plant 411 composition are key driver factors for soil fauna diversity distribution (Gholami et al., 2017). 412 Moreover, our results are in accordance with the findings of the latter authors as we found that 413 different microhabitats generated under different woody species (trees and shrubs) provided 414 the suitable conditions (light, moisture and litter quality) for establishing the mesofauna 415 abundance, composition and diversity. In general, changes in environmental conditions can 416 affect both the composition and the abundance of soil mesofauna, which makes mesofauna a 417 suitable indicator to evaluate the degree of change in site conditions (Davis et al., 2001). 418

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Finally, a correspondence in composition, abundance and diversity of mesofauna and 420 aboveground woody species exists depending on both the nature of the biological interactions 421 between mesofauna and woody species themselves and the spatial and temporal scales of the 422 ecological factors influencing the biology of the organisms (Adeduntan, 2009;). This work 423 has demonstrated that aboveground and belowground relationship (that is, plant and soil 424 organisms) have reciprocal ecological linkages and that aboveground and belowground 425

communities can be powerful mutual drivers (Battigelli et al., 2004; Harrison and Bardgett 426 2010; Wu and Wang, 2019).

## 5. Conclusions

Arid and semi-arid forests, including Zagros forests in western Iran, have high heterogeneity 430 in terms of species composition and canopy structure of woody species. This heterogeneity 431 complicates the study and the comprehension of soil-plant interactions in these ecosystems. 432 However, different conclusions can be derived from this study. This work addresses how the 433 signs and strength of the local determinants of mesofauna abundance, composition and 434 diversity change across woody species gradients. Differences in mesofauna composition, 435 abundance and diversity should be related to the characteristics of woody species and 436 seasonality, in addition to soil conditions mediated by the different shrub and tree species. The 437 high spatial heterogeneity of the forest in the horizontal dimension (such as the different 438 branch and canopy abundance and, as a consequence, the variable forest light and temperature) 439 and vertical variations in the quantity and quality of leaves and woody texture can create 440 different microclimates for the studied mesofauna.

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## References

Adeduntan, S.A., 2009. Diversity and abundance of soil mesofauna and microbial population 448 in South-Western Nigeria. African Journal of Plant Science, 3(9), pp.210-216. 449 Agapit, C., Gigon, A., Puga-Freitas, R., Zeller, B. and Blouin, M., 2018. Plant-earthworm 450 interactions: influence of age and proportion of casts in the soil on plant growth, morphology 451 and nitrogen uptake. Plant and soil, 424(1-2), pp.49-61.

Ahmadi, R., Kiadaliri, H., Mataji, A. and Kafaki, S., 2014. Annual ring analysis of Persian 453 oak (*Quercus brantii*) to determine periods of stress and tensions on Zagros forests (Case 454 study: forests of Ilam county). Journal of Biodiversity and Environmental Science, 5, pp.378-455 384.

Alef, K. and Nannipieri, P., 1995. Methods in applied soil microbiology and biochemistry 457 (No. 631.46 M592ma). Academic Press. 458

Anderson, J.P.E. and Domsch, K.H., 1978. A physiological method for the quantitative 459 measurement of microbial biomass in soils. Soil biology and biochemistry, 10(3), pp.215-221.460 Anslan, S., Bahram, M. and Tedersoo, L., 2018. Seasonal and annual variation in fungal 461 communities associated with epigeic springtails (Collembola spp.) in boreal forests. Soil 462 Biology and Biochemistry, 116, pp.245-252.

Balestrini, R., Lumini, E., Borriello, R. and Bianciotto, V., 2015. Plant-soil biota interactions. 464Soil Microbiol. Ecol. Biochem, pp.311-338.465

Bardgett, R.D. and Van Der Putten, W.H., 2014. Belowground biodiversity and ecosystem 466 functioning. Nature, 515(7528), pp.505-511.
Bargrios, E., 2007. Soil biota, ecosystem services and land productivity. Ecological 468

469

economics, 64(2), pp.269-285.

Battigelli, J.P., Spence, J.R., Langor, D.W. and Berch, S.M., 2004. Short-term impact of forest 470 soil compaction and organic matter removal on soil mesofauna density and oribatid mite 471 diversity. Canadian Journal of Forest Research, 34(5), pp.1136-1149.

Bayranvand, M., Kooch, Y. and Rey, A., 2017. Earthworm population and microbial activity 473 temporal dynamics in a Caspian Hyrcanian mixed forest. European Journal of Forest 474 Research, 136(3), pp.447-456.

Briones, M.J., 2018. The serendipitous value of soil fauna in ecosystem functioning: The 476 unexplained explained. Frontiers in Environmental Science, 6, p.149.
Brookes, P.C., Landman, A., Pruden, G. and Jenkinson, D.S., 1985. Chloroform fumigation 478 and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass 479 nitrogen in soil. Soil biology and biochemistry, 17(6), pp.837-842.
Brooks, P.D., Stark, J.M., McInteer, B.B. and Preston, T., 1989. Diffusion method to prepare 481 soil extracts for automated nitrogen-15 analysis. Soil Science Society of America Journal, 482

53(6), pp.1707-1711. 483

Brygadyrenko, V.V., 2016. Effect of canopy density on litter invertebrate community 484 structure in pine forests. Ekológia (Bratislava), 35(1), pp.90-102.

Campuzano, E.F., Ibarra- Núñez, G., Machkour- M' Rabet, S., Morón- Ríos, A. and 486

Jiménez, M.L., 2019. Diversity and seasonal variation of ground and understory spiders from 487 a tropical mountain cloud forest. Insect science. 488

Correia, M.E.F., de Souza, R.C., dos Reis Ferreira, C., de Resende, A.S., dos Anjos, L.H.C. 489 and Pereira, M.G., 2018. Soil fauna changes across Atlantic Forest succession. Comunicata 490 Scientiae, 9(2), pp.162-174.

Čuchta, P., Miklisová, D. and Kováč, Ľ., 2019. The succession of soil Collembola 492 communities in spruce forests of the High Tatra Mountains five years after a windthrow and 493 clear–cut logging. Forest ecology and management, 433, pp.504-513.

Cunha, L., Brown, G.G., Stanton, D.W., Da Silva, E., Hansel, F.A., Jorge, G., McKey, D., 495

Vidal-Torrado, P., Macedo, R.S., Velasquez, E. and James, S.W., 2016. Soil animals and 496

pedogenesis: the role of earthworms in anthropogenic soils. Soil Science, 181(3/4), pp.110-497 125. 498

Da Silva, P.M., Berg, M.P., Da Silva, A.A., Dias, S., Leitão, P.J., Chamberlain, D., Niemelä, 499 J., Serrano, A.R. and Sousa, J.P., 2015. Soil fauna through the landscape window: factors 500 shaping surface-and soil-dwelling communities across spatial scales in cork-oak mosaics. 501 Landscape ecology, 30(8), pp.1511-1526. 502

Davis, A.J., Holloway, J.D., Huijbregts, H., Krikken, J., Kirk- Spriggs, A.H. and Sutton, S.L., 503

2001. Dung beetles as indicators of change in the forests of northern Borneo. Journal of 504 Applied Ecology, 38(3), pp.593-616. 505 Dhooria, M.S., 2016. Fundamentals of applied acarology. Springer. 506 Elie, F., Vincenot, L., Berthe, T., Quibel, E., Zeller, B., Saint-André, L., Normand, M., 507 Chauvat, M. and Aubert, M., 2018. Soil fauna as bioindicators of organic matter export in 508 temperate forests. Forest ecology and management, 429, pp.549-557. 509 Famiglietti, J.S., Rudnicki, J.W. and Rodell, M., 1998. Variability in surface moisture content 510 along a hillslope transect: Rattlesnake Hill, Texas. Journal of Hydrology, 210(1-4), pp.259-511 281. 512 Ferguson, S.H. and Berube, D.K., 2004. Invertebrate diversity under artificial cover in relation 513 to boreal forest habitat characteristics. The Canadian Field-Naturalist, 118(3), pp.386-394. 514 Frey, S.D., 2015. The spatial distribution of soil biota. Soil Microbiology, Ecology and 515

Frouz, J., 2018. Effects of soil macro-and mesofauna on litter decomposition and soil organic 517

516

Biochemistry, pp.223-244.

Gholami, S., Sheikhmohamadi, B. and Sayad, E., 2017. Spatial relationship between soil 521
macrofauna biodiversity and trees in Zagros forests, Iran. Catena, 159, pp.1-8.
Görres, J.H., Dichiaro, M.J., Lyons, J.B. and Amador, J.A., 1998. Spatial and temporal 523
patterns of soil biological activity in a forest and an old field. Soil Biology and Biochemistry, 524
30(2), pp.219-230.

Hammer, R.L., 2019. Soil Respiration and Related Abiotic and Remotely Sensed Variables in 526
Different Overstories and Understories in a High Elevation Southern Appalachian Forest 527
(Doctoral dissertation, Virginia Tech).

Hedlund, K. and Öhrn, M.S., 2000. Tritrophic interactions in a soil community enhance 529 decomposition rates. Oikos, 88(3), pp.585-591. 530

Heydari, M., Prévosto, B., Abdi, T., Mirzaei, J., Mirab-Balou, M., Rostami, N., Khosravi, M. 531 and Pothier, D., 2017 a. Establishment of oak seedlings in historically disturbed sites: 532 Regeneration success as a function of stand structure and soil characteristics. Ecological 533 Engineering, 107, pp.172-182.

Heydari, M., Prévosto, B., Naji, H.R., Mehrabi, A.A. and Pothier, D., 2017 b. Influence of 535 soil properties and burial depth on Persian oak (Quercus brantii Lindl.) establishment in 536 different microhabitats resulting from traditional forest practices. European Journal of Forest 537 Research, 136(2), pp.287-305.

Hopkin, S.P. 1997. Biology of the springtails (Insecta: Collembola). Oxford University Press, 539 New York. 540

Hossain, M.Z. and Sugiyama, S.I., 2019. Structural and Functional Relationships Between 541 Plant and Soil Microbial Communities for the Management of Grasslands. Trends in Applied 542 Sciences Research, 14, pp.160-169. 543

Hosseini, A., Hosseini, S.M. and Calderón, J.C.L., 2017. Site factors and stand conditions 544 associated with Persian oak decline in Zagros mountain forests. Forest systems, 26(3), p.3. 545

Jazirehi, M.H. and Ebrahimi Rastaghi, M., 2003. Silviculture in Zagros. Tehran: University 546 of Tehran. 547

Jiménez-Chacón, A., Homet, P., Matías, L., Gómez-Aparicio, L. and Godoy, O., 2018. Fine 548 Scale Determinants of Soil Litter Fauna on a Mediterranean Mixed Oak Forest Invaded by the 549 Exotic Soil-Borne Pathogen Phytophthora cinnamomi. Forests, 9(4), p.218. 550 Kalra, Y.P. and Maynard, D.G., 1991. Methods manual for forest soil and plant analysis (Vol. 551 319). 552

Karmakar, R., Das, I., Dutta, D. and Rakshit, A., 2016. Potential effects of climate change on 553 soil properties: a review. Science international, 4(2), pp.51-73.

Kataja-aho, S., Hannonen, P., Liukkonen, T., Rosten, H., Koivula, M.J., Koponen, S. and 555 Haimi, J., 2016. The arthropod community of boreal Norway spruce forests responds variably 556 to stump harvesting. Forest Ecology and Management, 371, pp.75-83.

Koehler, H.H., 1992. The use of soil mesofauna for the judgement of chemical impact on 558 ecosystems. Agriculture, Ecosystems & Environment, 40(1-4), pp.193-205. 559

Kooch, Y. and Noghre, N., 2019. The effect of shrubland and grassland vegetation types on 560 soil fauna and flora activities in a mountainous semi-arid landscape of Iran. Science of The 561 Total Environment, p.135497.

Korboulewsky, N., Perez, G. and Chauvat, M., 2016. How tree diversity affects soil fauna 563 diversity: a review. Soil Biology and Biochemistry, 94, pp.94-106.

Kuznetsova, N.A., Bokova, A.I., Saraeva, A.K. and Shveenkova, Y.B., 2019. Structure of the 565 Species Diversity of Soil Springtails (Hexapoda, Collembola) in Pine Forests of the Caucasus 566 and the Russian Plain: a Multi-Scale Approach. Entomological Review, 99(2), pp.143-157. 567 Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P. 568 and Rossi, J.P., 2006. Soil invertebrates and ecosystem services. European journal of soil 569 biology, 42, pp.S3-S15. 570 Lieutier, F. and Paine, T.D., 2016. Responses of mediterranean forest phytophagous insects 571 to climate change. In Insects and Diseases of Mediterranean Forest Systems (pp. 801-858). 572 Springer, Cham. 573

Liu, R., Zhao, H., Zhao, X. and Drake, S., 2011. Facilitative effects of shrubs in shifting sand 574 on soil macro-faunal community in Horqin Sand Land of Inner Mongolia, Northern China. 575 European journal of soil biology, 47(5), pp.316-321. 576

Lucas-Borja, M.E., Candel, D., Jindo, K., Moreno, J.L., Andrés, M. and Bastida, F., 2012. 577 Soil microbial community structure and activity in monospecific and mixed forest stands, 578 under Mediterranean humid conditions. Plant and soil, 354(1-2), pp.359-370. 579 Lucas-Borja, M.E., Hedo, J., Cerdá, A., Candel-Pérez, D. and Viñegla, B., 2016. Unravelling 580 the importance of forest age stand and forest structure driving microbiological soil properties, 581 enzymatic activities and soil nutrients content in Mediterranean Spanish black pine (Pinus 582 nigra Ar. ssp. salzmannii) Forest. Science of the Total Environment, 562, pp.145-154. 583 Margalef, R., 1958. Temporal succession and spatial heterogeneity inphytoplankton. In: 584 Buzzati-Traverso (Ed.), Perspectives in Marine Biology.Univ. Calif. Press, Berkeley, pp. 323–585 347. 586

Mirab-balou, M., Tang, P. and Chen, X.X., 2011. The grass-living genus Aptinothrips 587 Haliday, 1836 (Thysanoptera: Thripidae) from China. Far Eastern Entomologist, (232), pp.1-588 10. 589

Mirzaei, J., Heydari, M., Moradi, M. and Daniel, C.D., 2020. Arbuscular Mycorrhizal Fungi 590 as a Bio-Indicator for Monitoring Soil Attributes in Zagros Semi-Arid Woodlands. Ecopersia, 591 8(1), pp.23-31. 592

Morais, J.W.D., Oliveira, S.V., Dambros, S.C., Tapia-Coral, S.C. and Acioli, A.N., 2010. Soil 593 mesofauna in differents systems of land use soil in Upper River Solimões, AM, Brazil. 594 Neotropical entomology, 39(2), pp.145-152. 595 Morán- López, T., Fernández, M., Alonso, C.L., Flores- Rentería, D., Valladares, F. and 596

Díaz, M., 2015. Effects of forest fragmentation on the oak–rodent mutualism. Oikos, 124(11), 597 pp.1482-1491.

Motiejūnaitė, J., Børja, I., Ostonen, I., Bakker, M.R., Bjarnadottir, B., Brunner, I., Iršėnaitė, 599 R., Mrak, T., Oddsdóttir, E.S. and Lehto, T., 2019. Cultural ecosystem services provided by 600 the biodiversity of forest soils: A European review. Geoderma, 343, pp.19-30. 601 Muraoka, H. and Koizumi, H., 2005. Photosynthetic and structural characteristics of canopy 602 and shrub trees in a cool-temperate deciduous broadleaved forest: implication to the 603 ecosystem carbon gain. Agricultural and Forest Meteorology, 134(1-4), pp.39-59. 604 Nascimento, M.D.S., Barreto-Garcia, P.A.B., Scoriza, R.N. and Pereira, J.E.S., 2019. Edaphic 605 Macrofauna as Indicator of Edge Effect in Semi-deciduous Forest Fragments. Floresta e 606 Ambiente, 26(3). 607

Nassirkhani, M., Mirab-balou, M., Bazgir, M., Zamani, M., 2017. A redescription 608 ofAcanthocreagris iranica Beier (Pseudoscorpiones: neobisiidae) inhabiting soilunder oak 609 trees in Zagros forests, western Iran. Vestn. Zool. 51 (2), pp.143–150. 610

Negrete-Yankelevich, S., Fragoso, C., Newton, A.C., Russell, G. and Heal, O.W., 2008. 611 Species-specific characteristics of trees can determine the litter macroinvertebrate community 612 and decomposition process below their canopies. Plant and Soil, 307(1-2), pp.83-97. 613 Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'hara, R.B., Simpson, 614 G.L., Solymos, P., Stevens, M.H.H. and Wagner, H., 2018. Package 'vegan'community 615 ecology package. See https://cran. r-project. org/web/packages/vegan/index. html. 616 Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. 617

Journal of theoretical biology, 13, pp.131-144.	618
Ponge, J.F., 2013. Plant-soil feedbacks mediated by humus forms: a review. Soil E	Siology and 619
Biochemistry, 57, pp.1048-1060.	620

Prescott, C.E. and Grayston, S.J., 2013. Tree species influence on microbial communities in 622	L
litter and soil: current knowledge and research needs. Forest Ecology and Management, 309, 622	2
pp.19-27. 623	3
Pritchard, S.G., 2011. Soil organisms and global climate change. Plant Pathology, 60(1), 624	ŀ
pp.82-99. 625	5
Ramroodi, S., Joharchi, O., Hajizadeh, J., 2014. A new species of Laelaspis Berlese (Acari: 626	<b>;</b>
laelapidae) from Iran and a key to Iranian species. Acarologia, 54 (2), pp.177–182.	7
Sagheb-Talebi, K., Pourhashemi, M. and Sajedi, T., 2014. Forests of Iran: A Treasure from 628	}
the Past, a Hope for the Future. springer. 629	)
Salazar, P.C., Navarro-Cerrillo, R.M., Grados, N., Cruz, G., Barrón, V. and Villar, R., 2019. 630	)
Tree size and leaf traits determine the fertility island effect in Prosopis pallida dryland forest 631	L
in Northern Peru. Plant and soil, 437(1-2), pp.117-135.	2
Sardans, J. and Peñuelas, J., 2013. Plant-soil interactions in Mediterranean forest and 633	}
shrublands: impacts of climatic change. Plant and soil, 365(1-2), pp.1-33.	ł
Schlesinger, W.H. and Pilmanis, A.M., 1998. Plant-soil interactions in deserts. 635	5
Biogeochemistry, 42(1-2), pp.169-187.	5
Schuldt, A., Fahrenholz, N., Brauns, M., Migge-Kleian, S., Platner, C. and Schaefer, M., 2008. 637	7
Communities of ground-living spiders in deciduous forests: Does tree species diversity 638	3
matter?. Biodiversity and conservation, 17(5), pp.1267-1284.	)
Shannon, C.E., Wiener, W., 1949. The Mathematical Theory of Communication.University 640	)
of Illinois Press, Urbana. 641	L

Soltani, A., Angelsen, A., Eid, T., Naieni, M.S.N. and Shamekhi, T., 2012. Poverty, 642 sustainability, and household livelihood strategies in Zagros, Iran. Ecological Economics, 79, 643 pp.60-70.

Taylor, A.R. and Wolters, V., 2005. Responses of oribatid mite communities to summer 645 drought: The influence of litter type and quality. Soil Biology and Biochemistry, 37(11), 646 pp.2117-2130.

Tedersoo, L., Bahram, M., Cajthaml, T., Põlme, S., Hiiesalu, I., Anslan, S., Harend, H., 648 Buegger, F., Pritsch, K., Koricheva, J. and Abarenkov, K., 2016. Tree diversity and species 649 identity effects on soil fungi, protists and animals are context dependent. The ISME journal, 650 10(2), pp.346-362.

Ter Braak, C.J.F., P. þmilauer, 1998. CANOCO Reference Manual and User's Guide to 652 Canoco for Windows: Software for Canonical Community Ordination (version 4). 653 Microcomputer Power, Ithaca, NY, USA.

Torres- Muros, L., Hódar, J.A. and Zamora, R., 2017. Effect of habitat type and soil moisture 655

on pupal stage of a M editerranean forest pest (T haumetopoea pityocampa). Agricultural and 656 forest entomology, 19(2), pp.130-138.

Vanbergen, A.J., Watt, A.D., Mitchell, R., Truscott, A.M., Palmer, S.C., Ivits, E., Eggleton, 658 P., Jones, T.H. and Sousa, J.P., 2007. Scale-specific correlations between habitat 659 heterogeneity and soil fauna diversity along a landscape structure gradient. Oecologia, 153(3), 660 pp.713-725.

Vance, E.D., Brookes, P.C. and Jenkinson, D.S., 1987. An extraction method for measuring 662 soil microbial biomass C. Soil biology and Biochemistry, 19(6), pp.703-707.

Vetaas, O.R., 1992. Micro- site effects of trees and shrubs in dry savannas. Journal of 664

Walkley, A. and Black, I.A., 1934. An examination of the Degtjareff method for determining 666 soil organic matter, and a proposed modification of the chromic acid titration method. Soil 667 science, 37(1), pp.29-38.

Waring, B.G., Adams, R., Branco, S. and Powers, J.S., 2016. Scale- dependent variation in 669

nitrogen cycling and soil fungal communities along gradients of forest composition and age 670 in regenerating tropical dry forests. New Phytologist, 209(2), pp.845-854. 671

Whalen, J.K. and Sampedro, L., 2010. Soil ecology and management. CABI. 672

Wissuwa, J., Salamon, J.A. and Frank, T., 2012. Effects of habitat age and plant species on 673
predatory mites (Acari, Mesostigmata) in grassy arable fallows in Eastern Austria. Soil 674
Biology and Biochemistry, 50, pp.96-107.

Wolters, V., Silver, W.L., Bignell, D.E., Coleman, D.C., Lavelle, P., Van Der Putten, W.H., 676 De Ruiter, P., Rusek, J., Wall, D.H., Wardle, D.A. and Brussard, L., 2000. Effects of Global 677 Changes on Above-and Belowground Biodiversity in Terrestrial Ecosystems: Implications for 678 Ecosystem Functioning: We identify the basic types of interaction between vascular plants 679 and soil biota; describe the sensitivity of each type to changes in species composition; and, 680 within this framework, evaluate the potential consequences of global change drivers on 681 ecosystem processes. Bioscience, 50(12), pp.1089-1098.

Wu, P. and Wang, C., 2019. Differences in spatiotemporal dynamics between soil macrofauna 683
and mesofauna communities in forest ecosystems: the significance for soil fauna diversity 684
monitoring. Geoderma, 337, pp.266-272.

Wu, P. and Wang, C., 2019. Differences in spatiotemporal dynamics between soil macrofauna 686
and mesofauna communities in forest ecosystems: the significance for soil fauna diversity 687
monitoring. Geoderma, 337, pp.266-272.

Yao, Y., Shao, M.A., Jia, Y. and Li, T., 2017. Distribution of soil nutrients under and outside 689 tree and shrub canopies on a revegetated loessial slope. Canadian Journal of Soil Science, 690

Young, A.R., Miller, J.E., Villella, J., Carey, G. and Miller, W.R., 2018. Epiphyte type and 692 sampling height impact mesofauna communities in Douglas-fir trees. PeerJ, 6, p.e5699. 693

Zagatto, M.R.G., Niva, C.C., Thomazini, M.J., Baretta, D., Santos, A., Nadolny, H., Cardoso, 694 G.B.X. and Brown, G.G., 2017. Soil invertebrates in different land use systems: how 695 integrated production systems and seasonality affect soil mesofauna communities. Embrapa 696 Cerrados-Artigo em periódico indexado (ALICE). 697

Zagatto, M.R.G., Zanão Júnior, L.A., Pereira, A.P.D.A., Estrada-Bonilla, G. and Cardoso, 698 E.J.B.N., 2019. Soil mesofauna in consolidated land use systems: how management affects 699 soil and litter invertebrates. Scientia Agricola, 76(2), pp.165-171.

Zhao, C., Griffin, J.N., Wu, X. and Sun, S., 2013. Predatory beetles facilitate plant growth by 701 driving earthworms to lower soil layers. Journal of Animal Ecology, 82(4), pp.749-758. 702

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Fig. 1 The study site is located in the Southern Zagros forests in western Iran (a) and Sirvan County (b). For each woody species [QU: Quercus brantii), AC: Acer monspessulanum L. and PI: Pistacia atlantica Desf. and three shrub species, CR: Crataegus puntica C. Koch., AM: Amygdalus scoparia Spach. And LO: Lonicera nummularifolia Ja ub & spach.] five patches (colored squares) were selected in the study site (c and d). Soil sampling was done in spring and winter 2018 in each patch under the canopy of a central woody species (e) at 0-25 cm depth with a sampling area of  $314 \text{ cm}^2$ . 





Fig. 2 Ombrothermic diagram of the study site (Southern Zagros forests, western Iran).

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Fig. 3 Abundance heat map of soil mesofauna invertebrates under different tree and shrub species in spring (a) and winter (b) in Southern Zagros forest (western Iran). Que: Quercus brantii, Ace: Acer monspessulanum, Pis: Pistacia atlantica, Cra: Crataegus pontica, Amy: Amygdalus scoparia, Lon: Lonicera nummularifolia. The colour spectrum represents the

normalized values of relative abundance. 





Fig. 4 Non-metric multidimensional scaling (NMS) ordination (a and e) based on BrayCurtis similarity matrix to identify differences in the mesofauna composition between
different tree and shrub species in Southern Zagros forest (western Iran). QU: *Quercus*

44	brantii, AC: Acer monspessulanum, PI: Pistacia atlantica, CR: Crataegus pontica, AM:
45	Amygdalus scoparia, LO: Lonicera nummularifolia) in spring (A) and winter (B); b and c
46	compare means on axis 1 and 2 in spring; f and g compare means on axis 1 and 2 in winter;
47	d and h report the contribution of trophic guilds of soil mesofauna to composition under
48	each species in spring and winter, respectively.
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Fig. 5 Differences in the abundance (mean  $\pm$  standard error, individuals/m<sup>2</sup>) of total mesofauna, detritivores and predators for tree and shrub species (QU: Quercus brantii, AC: Acer monspessulanum, PI: Pistacia atlantica, CR: Crataegus pontica, AM: Amygdalus scoparia, LO: *Lonicera nummularifolia*) in two sampling seasons (
 spring and 
 winter) in Southern Zagros forest (western Iran). Different lowercase and capital letters indicate significant differences (P < 0.05) among species and seasons, respectively, after Duncan's test; means and standard errors are calculated on 5 individuals for 6 species (total N = 30)) and 30 individuals for two seasons (total N = 60).



103 induced respiration, Soil microbial biomass nitrogen (SMN), Soil microbial biomass carbon (SMC).

# 1 TABLES

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3 Table 1 - Results of GLMs evaluating the effects of tree and shrub species and season on diversity indices.

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Diversity and abundance of mesofauna	Tree or shr	ub species	Sea	son	Species × Season		
Diversity and abundance of mesofauna	F	p-value	F	p-value	F	p-value	
Total mesofauna diversity							
Shannon-Wiener diversity	17.270	<u>0.000</u>	0.400	0.530	1.943	0.104	
Margalef's richness	62.337	<u>0.000</u>	0.250	0.620	5.292	0.001	
Pielou's evenness	1.637	0.168	0.922	0.342	2.501	0.043	
Detritivore diversity							
Shannon-Wiener diversity	6.283	<u>0.000</u>	37.447	0.000	4.377	0.002	
Margalef's richness	8.6328	<u>0.000</u>	38.604	0.000	2.610	0.036	
Pielou's evenness	2.728	<u>0.030</u>	11.221	<u>0.002</u>	1.629	0.170	
Predator diversity							
Shannon-Wiener diversity	10.343	<u>0.000</u>	24.156	0.000	1.317	0.273	
Margalef's richness	11.713	<u>0.000</u>	10.513	0.000	1.547	0.185	
Pielou's evenness	2.548	<u>0.040</u>	23.657	<u>0.000</u>	0.157	0.977	
Mesofauna abundance (individuals/m <sup>2</sup> )							
Total mesofauna abundance	4.184	<u>0.003</u>	0.142	0.708	3.935	0.005	
Detritivore abundance	5.460	<u>0.000</u>	3.284	0.076	1.340	0.264	
Predator abundance	10.661	<u>0.000</u>	12.206	<u>0.001</u>	6.813	<u>0.000</u>	

5 Note: Underlined p-values indicate significant statistical differences at p<0.05.

6 Table 2- Soil mesofauna diversity (mean ± SE) under different tree and shrub species (QU: Quercus brantii, AC: Acer monspessulanum, PI: Pistacia

7 atlantica, CR: Crataegus pontica, AM Amygdalus scoparia, LO: Lonicera nummularifolia) and seasons (spring and winter) in the topsoil (0-25 cm) in

- 8 Southern Zagros forest (western Iran).
- 9 Notes: Different lowercase and capital letters indicate significant differences (P < 0.05) among species and seasons, respectively, after Duncan's test; means and standard errors are

C	<b>G</b> •	T	otal mesofaun	a	Detritivores		Predators				
Season	Species _	SH	MR	РЕ	SH	MR	PE	SH	MR	РЕ	
	QU	2.03± 0.11 a	$2.08 \pm 0.09$ a	$0.92 \pm 0.03$ a	$0.94 \pm 0.03a$	0.70± 0.04 a	0.85± 0.10 a	1.65± 0.14a	1.47± 0.17 a	0.92± 0.12 a	
Spring	AC	$1.64\pm0.13$ b	$1.52{\pm}~0.07~b$	$0.84{\pm}0.02~b$	$0.51{\pm}0.03~b$	$0.45{\pm}0.01~b$	$0.62{\pm}0.12~b$	$1.22\pm0.10$ bc	$0.98{\pm}0.15~b$	$0.85{\pm}0.10$ a	
	PI	$1.11{\pm}0.05~\text{c}$	$1.16{\pm}~0.04~{\rm c}$	$0.82{\pm}~0.04~b$	$0.36{\pm}~0.03~{\rm c}$	$0.42{\pm}~0.05~b$	$0.52 \pm 0.11 \text{ c}$	$0.66{\pm}~0.04~de$	$0.63{\pm}0.10~\text{bc}$	$0.73{\pm}~0.13~b$	
	CR	$1.21{\pm}0.09~c$	$0.96{\pm}0.08~\text{cd}$	$0.80{\pm}~0.01~b$	$0.45{\pm}~0.03~\mathrm{c}$	$0.45{\pm}0.06~b$	$0.50\pm0.11~\mathrm{c}$	$0.91{\pm}~0.04~cd$	$0.71{\pm}0.12~bc$	$0.71{\pm}0.14~b$	
	AM	$1.10\pm0.07~\mathrm{c}$	$0.72{\pm}\:0.05\;d$	$0.89{\pm}0.07$ a	$0.40\pm0.03~\mathrm{c}$	$0.28{\pm}0.02~\mathrm{c}$	$0.57{\pm}~0.10~{\rm c}$	$0.43{\pm}0.04~de$	$0.35{\pm}0.07~\mathrm{c}$	$0.56 \pm 0.11 \text{ c}$	
	LO	$0.97{\pm}\:0.03~c$	$0.73{\pm}0.06~d$	$0.93{\pm}0.08~a$	$0.22 \pm 0.03 \ d$	$0.15{\pm}~0.03~{\rm c}$	$0.31 \pm 0.11 \ d$	$0.37{\pm}0.04~d$	$0.25{\pm}~0.04~\mathrm{c}$	$0.54{\pm}~0.14~{\rm c}$	
	Mean	1.34± 0.17 A	1.19± 0.17 A	$0.87{\pm}~0.04~\mathrm{A}$	0.48± 0.06 B	0.39± 0.03 B	0.56± 0.08 B	$0.87{\pm}~0.14~\mathrm{A}$	$0.73{\pm}~0.03~\mathrm{A}$	0.72±0.11 A	
	QU	$1.80 \pm 0.12$ a	2.33± 0.16 a	$0.82 \pm 0.06 \text{ ab}$	$0.85 \pm 0.07$ a	$0.86 \pm 0.02$ a	$0.77 \pm 0.13$	$1.08 \pm 0.12$ a	$1.34 \pm 0.07$ a	$0.60 \pm 0.02$ a	
	AC	$1.27{\pm}0.08~\mathrm{c}$	$0.97{\pm}~0.05~{\rm c}$	$0.88{\pm}0.08~ab$	$0.69{\pm}~0.02~b$	$0.74{\pm}~0.05~b$	$0.76 \pm 0.11$	$0.27{\pm}~0.07~b$	$0.14{\pm}~0.07~{\rm c}$	$0.39 \pm 0.01 \text{ bc}$	
	PI	$1.18{\pm}0.08~\mathrm{c}$	$1.30{\pm}~0.118~b$	$0.75{\pm}\:0.07\:b$	$0.58{\pm}~0.05~{\rm c}$	$0.50\pm0.06~\mathrm{c}$	$0.71 \pm 0.10$	$0.28{\pm}~0.05~b$	$0.43{\pm}0.07~b$	$0.32 \pm 0.01$ bc	
Winter	CR	$1.16{\pm}~0.05~\text{c}$	$0.71{\pm}0.06~\text{cd}$	$0.92{\pm}0.03~a$	$0.49 \pm 0.02$ c	$0.62 \pm 0.04 \ \mathrm{bc}$	$0.74 \pm 0.12$	$0.207{\pm}\:0.07\:b$	$0.14{\pm}0.07~\mathrm{c}$	$0.18 \pm 0.01 \text{ bc}$	
	AM	$1.24{\pm}~0.09~{\rm c}$	$0.91{\pm}\:0.08~cd$	$0.80{\pm}0.05$ ab	$0.53 \pm 0.04$ c	$0.58 \pm 0.01 \; \text{bc}$	$0.78{\pm}0.12$	$0.00{\pm}~0.00~\mathrm{c}$	$0.00{\pm}~0.07~{\rm c}$	$0.00{\pm}~0.00~\mathrm{c}$	
	LO	$1.06{\pm}~0.05~{\rm c}$	$0.78{\pm}0.03~\text{cd}$	$0.89{\pm}~0.04~ab$	$0.52{\pm}~0.03~\mathrm{c}$	$0.61{\pm}~0.07~bc$	$0.79{\pm}0.14$	$0.24{\pm}~0.09~b$	$0.30{\pm}0.07~b$	$0.139{\pm}0.07~bc$	
	Mean	1.30± 0.15 A	1.17± 0.15 A	$0.84{\pm}~0.07~{\rm A}$	0.61± 0.06 A	0.64± 0.06 A	0.74± 0.05 A	0.34± 0.05 B	0.39± 0.08 B	$0.27{\pm}~0.08~\mathrm{B}$	

10 calculated on five individuals for six species (total N = 30)) and 30 individuals for two seasons (total N = 60); SH: Shannon–Wiener diversity, MR: Margalef's richness: and PE: Pielou's

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18 Table 3 - PCA applied to the Pearson's correlation coefficient of the soil attributes in the study area

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Soil attributes	Axys 1	Axys 2
Detritivores abundance (individuals m <sup>-2</sup> )	0.300 <sup>ns</sup>	0.341 *
Predators abundance (individuals m <sup>-2</sup> )	- 0.746 **	0.213 <sup>ns</sup>
pH	- 0.517 *	- 0.385 *
EC (dS/m)	0.430 *	0.696 **
WC (%)	- 0.860 **	0.081
BR $(\operatorname{mg} \operatorname{kg}^{(\%)})$ day <sup>-1</sup> )	- 0.690 ** - 0.683 **	0.398 <sup>*</sup> * - 0.616 <sup>*</sup>
SIR (mg kg <sup>sol-1</sup> day <sup>-1</sup> )	- 0.929 **	- 0.151 <sup>ns</sup>
SMC $(mg^{soll}g^{-1})$	- 0.692 **	0.622 **
$SMN (mg kg_{soil}^{soil-1})$	- 0.876 **	0.207 <sup>ns</sup>

20 Notes: pH: Soil acidity, EC: electrical conductivity, SOC: soil organic carbon, WC: water content, BR: basal respiration,

21 SIR: substrate-induced respiration, Soil microbial biomass nitrogen (SMN), Soil microbial biomass carbon (SMC); ns: No

significant, \* Significant ( $\alpha = 5\%$ ), \*\* Significant ( $\alpha = 1\%$ )

Table 4- Mean (± standard error) soil properties under different woody species (QU: *Quercus brantii*, AC: *Acer monspessulanum*, PI: *Pistacia atlantica, CR: Crataegus pontica*, AM: *Amygdalus scoparia*, LO: *Lonicera nummularifolia*) and seasons (spring and winter). Lowercase letters

indicate significant differences between woody species based on Duncan's multiple range test (p < 0.05).

Soil properties	Q	QU		AC		PI		CR		AM		0
	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter
pH	$7.56 \pm 0.02$ ab	7.60± 0.02 a	$7.47{\pm}~0.03~bc$	7.32± 0.03 d	$7.47{\pm}~0.03~bc$	7.33± 0.03 d	$7.55 \pm 0.04$ ab	$7.44 \pm 0.02$ c	7.50± 0.05 abc	7.54± 0.04 abc	7.48± 0.01 bc	$7.42\pm0.02$ c
EC (dS/m)	$0.33{\pm}~0.01~ab$	$0.31{\pm}~0.01~b$	$0.24{\pm}~0.02~cd$	$0.35{\pm}~0.04~ab$	$0.25{\pm}~0.01~\text{cd}$	$0.35{\pm}\ 0.03\ ab$	$0.22{\pm}~0.02cde$	$0.19{\pm}~0.01~e$	$0.21{\pm}~0.01~de$	$0.19{\pm}~0.01~e$	$0.27{\pm}~0.05~{\rm c}$	$0.36{\pm}~0.02~a$
SOC (g/kg dry soil)	$5.24{\pm}~0.60$ a	$4.48{\pm}~0.30~\text{bc}$	$4.37{\pm}~0.02~bc$	$3.94{\pm}~0.04~{\rm c}$	$2.20{\pm}~0.74~e$	$1.94{\pm}~0.34~e$	$4.27{\pm}~0.42~bc$	$4.04{\pm}~0.19~c$	$3.10\pm0.50~d$	$2.80{\pm}~0.40~d$	2.11± 0.11 e	1.98± 0.25 e
WC (%)	69.51± 4.20 a	$51.06{\pm}~3.28~c$	69.57± 5.11 a	44.12± 3.32 d	$50.92 \pm 3.15 \text{ c}$	$50.80{\pm}~5.35~\text{c}$	60.79± 3.42 b	44.86± 2.12 d	$40.40{\pm}~4.14~e$	$38.53{\pm}4.00~e$	38.20± 5.00 e	40.72± 3.18 e
BR (mg kg <sub>soil</sub> <sup>-1</sup> day <sup>-1</sup> )	53.22± 3.11 a	$26.00{\pm}\ 2.50\ e$	$46.00{\pm}\ 2.60\ b$	$24.32{\pm}~3.00~e$	40.34±3.70 c	$23.10{\pm}~1.80~e$	$39.30{\pm}~3.50~\text{c}$	$16.65{\pm}\ 2.00\ f$	$41.17{\pm}~3.20~c$	$17.46{\pm}\ 2.40\ f$	36.11± 2.50 d	$18.07{\pm}\;3.61~f$
SMC (mg kg <sub>soil-1</sub> )	748.14±74.20 a	662.79±45.20a	540.91±70.11bc	538.00±30.18bc	521.53±41.32bc	502.00±53.18bc	551.12±49.18b	322.32±36.32e	370.46±31.30d	269.66±29.15e	372.34±30.01d	320.00±28.17e
$SMN (mg kg_{soil})$	57.92± 6.10 a	$48.76{\pm}~4.10~b$	$44.79{\pm}~3.45~bc$	$43.86{\pm}~3.45~bcd$	$46.22{\pm}~3.35~b$	31.06± 3.92 e	31.80±2.23 e	34.18± 3.00 e	36.40± 2.81 de	29.91± 2.10 e	37.01±2.79cde	32.40± 2.34 e
$SIR (mg kg_{soil_1} day_1)$	60.00± 3.10a	$41.97{\pm}\ 2.80b$	55.17± 3.12 a	$36.60{\pm}\ 2.60\ c$	57.75±1.92 a	$33.03{\pm}~1.30~\text{c}$	$43.00\pm2.41$ bc	28.63± 2.10 d	$35.00{\pm}~1.46~\text{c}$	$31.06 \pm 1.50 \text{ c}$	31.60±1.12c	$28.47{\pm}~1.09~{\rm c}$

27 Notes: pH: Soil acidity, EC: electrical conductivity, SOC: soil organic carbon, WC: water content, BR: basal respiration, SIR: substrate-induced respiration, Soil microbial biomass

28 nitrogen (SMN), Soil microbial biomass carbon (SMC).