

Pure

Scotland's Rural College

Mite community composition across a European transect and its relationships to variation in other components of soil biodiversity

Dirilgen, T; Arroyo, J; Dimmer, WJ; Faber, J; Stone, D; Martins da Silva, P; Carvalho, F; Schmelz, R; Griffiths, BS; Francisco, R; Creamer, RE; Sousa, JP; Bolger, T

Published in:
Applied Soil Ecology

DOI:
[10.1016/j.apsoil.2015.06.008](https://doi.org/10.1016/j.apsoil.2015.06.008)

First published: 01/01/2016

Document Version
Peer reviewed version

[Link to publication](#)

Citation for published version (APA):

Dirilgen, T., Arroyo, J., Dimmer, WJ., Faber, J., Stone, D., Martins da Silva, P., ... Bolger, T. (2016). Mite community composition across a European transect and its relationships to variation in other components of soil biodiversity. *Applied Soil Ecology*, 97, 86 - 97. <https://doi.org/10.1016/j.apsoil.2015.06.008>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Elsevier Editorial System(tm) for Applied Soil Ecology
Manuscript Draft

Manuscript Number: APSOIL-D-15-00159R2

Title: Mite community composition across a European transect and its relationships to variation in other components of soil biodiversity.

Article Type: SI: Soil Biodiversity

Section/Category: Invertebrate-related Submissions

Keywords: mites, soil biodiversity assessment, cross-taxon congruence

Corresponding Author: Ms. Tara Dirilgen,

Corresponding Author's Institution: University College Dublin

First Author: Tara Dirilgen

Order of Authors: Tara Dirilgen; Julio Arroyo; Wim J Dimmers; Jack Faber; Dorothy Stone; Pedro Martins da Silva; Rudiger Schmelz; Bryan S Griffiths; Romeu Francisco; Rachel E Creamer; Jose Paulo Sousa; Thomas Bolger; Filipe Carvalho

Abstract: The sustainable use of soils requires the protection of soil biodiversity because of its importance in the delivery of ecosystems services. However, no effective indicator exists which would allow assessment of the current state of biodiversity and is sensitive to change. This study, which is a component of the EcoFINDERS project, examines the use of mites (Acari) as a possible biological indicator of soil community composition. Thirty-six sites were sampled across 10 European countries spanning four bio-climatic zones (Alpine, Atlantic, Continental and Mediterranean) and 3 land uses (arable, grassland and forestry) for both biotic and abiotic variables. Results show a significant effect of bio-climatic zone on mite communities; in particular, the Mediterranean region had a rather distinct composition. Land use type significantly affected mite community composition and there was a distinct association with forestry. Cross-taxon congruence among soil taxa was variable and generally weak. Procrustes analysis showed that there was little similarity between the patterns of variation in mite community composition and those of other taxonomic groups (Collembola, Enchytraeidae, Nematoda and microbes). Mite and Collembola communities had the strongest correlation ($r=0.4316$, $p<0.001$). There was also variation in the indicator values of individual mite groups. Mesostigmata were correlated with soil microbial activity, as assessed using Multiple Substrate Induced Respiration, and Prostigmata with Collembola.

Highlights

Used extensive transect on which multiple aspects of soil biodiversity were measured.

Composition of mite community varied with bio-climatic zone, land-use type.

Mite community primarily related to extent of fungal dominance of microbial biomass.

Composition of Mesostigmata community correlated with microbial activity (MSIR).

At this spatial scale mites do not appear to be a good indicator of overall soil biodiversity.

1

2 Mite community composition across a European transect and its relationships
3 to variation in other components of soil biodiversity.

4

5

6 T. Dirilgen¹, J. Arroyo¹, W. J. Dimmers², J. Faber², D. Stone³, P. Martins da Silva⁴, F. Carvalho⁴
7 R. Schmelz⁵, B. S. Griffiths⁶, R. Francisco⁴, R. E. Creamer³, J.-P. Sousa⁴, T. Bolger¹

8

9

10 ¹ School of Biology and Environmental Science, UCD, Dublin, Ireland, ² ALTErrA -
11 Wageningen-UR, Research Instituut voor de Groene Leefomgeving, Wageningen, The
12 Netherlands, ³ Teagasc, Johnstown Castle Research Centre, Co. Wexford, Ireland, ⁴ Dep.
13 Ciências da Vida, Universidade de Coimbra, Coimbra, Portugal, ⁵ECT Oekotoxikologie,
14 Flörsheim, Hesse, Germany ⁶ Crop and Soils Systems, SRUC King's Buildings, West Mains
15 Road, Edinburgh, Scotland.

16

17 *Corresponding author: Tara Dirilgen, tara.dirilgen@ucdconnect.ie, +35317162340

18

19 **Abstract**

20 The sustainable use of soils requires the protection of soil biodiversity because of its
21 importance in the delivery of ecosystems services. However, no effective indicator exists
22 which would allow assessment of the current state of biodiversity and is sensitive to change.
23 This study, which is a component of the EcoFINDERS project, examines the use of mites
24 (Acari) as a possible biological indicator of soil community composition. Thirty-six sites were
25 sampled across 10 European countries spanning four bio-climatic zones (Alpine, Atlantic,
26 Continental and Mediterranean) and 3 land uses (arable, grassland and forestry) for both
27 biotic and abiotic variables. Results show a significant effect of bio-climatic zone on mite
28 communities; in particular, the Mediterranean region had a rather distinct composition.
29 Land use type significantly affected mite community composition and there was a distinct
30 association with forestry. Cross-taxon congruence among soil taxa was variable and
31 generally weak. Procrustes analysis showed that there was little similarity between the
32 patterns of variation in mite community composition and those of other taxonomic groups
33 (Collembola, Enchytraeidae, Nematoda and microbes). Mite and Collembola communities
34 had the strongest correlation ($r=0.4316$, $p<0.001$). There was also variation in the indicator
35 values of individual mite groups. Mesostigmata were correlated with soil microbial activity,
36 as assessed using Multiple Substrate Induced Respiration, and Prostigmata with Collembola.

37

38 **Keywords:** mites, soil biodiversity assessment, cross-taxon congruence

39

40 **1. Introduction**

41 The sustainable use of soils in a world where, at the current rate of human impact, demand
42 for their services will inevitably outweigh the supply, is of major concern. Given the
43 importance of soil biodiversity in maintaining the provision of ecosystem services (Decaëns
44 et al., 2006; Mulder et al., 2011) and the fact that human activities are amongst the main
45 current threats to this biodiversity through soil degradation, land use management, climate
46 change, chemical pollution and invasive species (Lavelle et al., 1997; Bohlen et al., 2004;
47 Decaëns et al., 2006; Feld et al., 2009; Gardi et al., 2009; Straube et al., 2009; Bran Nogueira
48 Cardoso et al., 2013) there has been an increased awareness of the need to protect soil
49 biodiversity.

50 In order to set a baseline and to monitor changes in this biodiversity there is a need to have
51 accurate indicators of the current state of soil biodiversity (Turbé et al., 2010) and to assess
52 the main trends over time rather than simply have a snapshot of its current state (Noss,
53 1990). Such indicators should present complex information in a simple and clear manner
54 (Parisi et al., 2005; Turbé et al., 2010) thus enhancing communication and transparency. The
55 criteria for a good indicator will vary depending on the purpose it hopes to serve. The
56 selection of such indicators and the development of an appropriate monitoring scheme are
57 challenging with the present state of our knowledge as the relationship between
58 biodiversity, ecosystem services and function has yet to be fully disentangled. To date, there
59 has been no single method or indicator which reflects all the different aspects of soil
60 complexity (Turbé et al., 2010).

61 There is a long history of chemical, physical or biological indicators being used in soil science
62 to indicate various aspects of soil health, responses to inputs and management (Bongers,

63 1990; Schoenholtz et al., 2000; Gulvik, 2007; Bastida et al., 2008; Bran Nogueira Cardoso et
64 al., 2013). However, while there may have been an implicit assumption that some of these
65 indicated broader changes in the composition of the soil biota there is still not a universally
66 accepted indicator of soil community assemblage *per se*. Soil biodiversity encompasses a
67 broad range of organisms ranging in size from micrometre to centimetre scale.
68 Microorganisms such as bacteria, fungi, protozoa and algae are thought to be responsible
69 for 60-80% of biological activity within the soil (Petersen and Luxton, 1982). Microfauna
70 such as nematodes, mesofauna such as mites, Collembola, Enchytraeidae and other
71 arthropods are considered to be important for microbial population regulation and nutrient
72 cycling. Lastly, macrofauna including earthworms, isopods, centipedes, millipedes, larger
73 enchytraeids, insects at varying developmental stages, fragment and mix soil components
74 and nutrients and affect overall soil structure (Petersen and Luxton, 1982; Edwards &
75 Bohlen, 1996; McInerney and Bolger, 2000; Sheehan et al., 2006).

76 Many invertebrate taxa such as Nematoda, Enchytraeidae, and Collembola have been
77 proposed as and are being used as indicators (Bongers, 1990; Parisi et al., 2005) and
78 increasingly, attempts are being made to monitor soil biodiversity and/or its loss. Projects
79 such as the Environmental Assessment of Soil for Monitoring (ENVASSO) attempted to
80 identify indicators for monitoring biodiversity loss for example, and the Ecological Function
81 and Biodiversity Indicators in European Soils (EcoFINDERS) project, of which this study is
82 part, aims to identify bioindicators reflective of biodiversity and ecosystem function at a
83 European scale.

84 In order to narrow down the wide diversity of soil biota to a list of potential indicators of soil
85 biodiversity a logical-sieve method (Ritz et al., 2009) was used (see Faber et al., 2013 for

86 summary). Despite the 'taxonomic dilemma of mites' (Gulvik, 2007), Acarina (i.e. mites)
87 were amongst those shortlisted for investigation.

88 Mites (Arachnida, Acari) are a large and functionally important part of the soil mesofauna
89 (Gulvik, 2007). They are one of the most species rich arthropod taxa. Approximately 45,000
90 species have been described to date, but current estimates of the number of extant species
91 range from 500,000 to a million and they are perceived by many to be a hyperdiverse (or
92 "megadiverse") group (Hammond, 1992; Walter and Behan-Pelletier, 1999; Ødegaard,
93 2000). Mites contribute directly and/or indirectly to the provision of ecosystem goods and
94 services through their intricate relationship with their surrounding biotic and abiotic
95 environment (Lavelle et al., 2006) and in particular through their dietary interactions with
96 the microflora and their predatory interactions with other components of the soil fauna
97 (Laakso et al., 2000).

98 It has been suggested that soil mite communities hold good promise as bioindicators of soil
99 biodiversity because of their stability of community composition, interaction with ecological
100 niches (van Straalen, 1998) as well as their high abundance, diversity and wide spread
101 distribution (Gulvik, 2007). For example, they have been proposed as indicators for
102 assessing soil quality (Behan-Pelletier, 1999; Parisi et al., 2005) and have been used in some
103 monitoring programmes in conjunction with other indicator taxa (such as; BISQ 'Biological
104 Indicator System for Soil Quality' in the Netherlands, BBSK 'Biological Soil Classification
105 Scheme' in Germany and BSQ 'Biological Soil Quality' in Italy).

106 This study explores the hypothesis that mite community composition is correlated with
107 those of other taxonomic groups within the soil. To do this, data on mites, microbes,
108 Collembola, Enchytraeidae, Nematoda, and environmental parameters from thirty-six sites

109 spanning four bio-climatic zones (Mediterranean, Continental, Atlantic, Alpine) across ten
110 European countries were analysed.

111 The study assessed the value of mite community composition as an indicator of changes in
112 the structure of other components of the soil biota. This was achieved by assessing the
113 turnover in mite communities over large spatial scales and testing whether such changes
114 reflected those of other components of soil biodiversity. Changes in several sub-groups of
115 mites, often separated in studies of soil fauna (Oribatida, Mesostigmata, Astigmata or
116 Prostigmata), were also examined independently and the effect of taxonomic resolution of
117 mite identification on these relationships was assessed.

118

119 **2. Methods**

120 **2.1 Sampling**

121 A total of 36 sites, representing a subset of the sites described in Stone et al. (2015, this
122 issue) were sampled in spring 2013 across 10 EU countries. These sites encompassed four
123 bio-climatic zones (Mediterranean, Continental, Atlantic and Alpine) and three land use
124 types (grassland, arable and forestry) (Fig. 1). Detailed descriptions of site selection, the
125 sampling strategy and list of the abiotic and biotic variables measured at each site are
126 provided in Stone et al. (2015, this issue). A suite of 22 abiotic measurements (Table 1) were
127 taken at each site in autumn 2012 and pH and SOC (Soil Organic Carbon) were re-sampled in
128 Spring 2013 to check consistency and were found to be the same. A standardised protocol
129 was used to sample various elements of the soil fauna and microflora.

130 Each site was sampled in autumn 2012 for microbial populations, Enchytraeidae and
131 Nematoda following the methods described in Creamer et al. (2015a, this issue). The data
132 for most of the components of biodiversity are derived from that sampling. An additional
133 sampling for microarthropods was carried out in spring 2013. This was necessary because
134 the microarthropod extraction for the 2012 sampling was unsuccessful. Within each site
135 microarthropods (including mites) were sampled using three 5cm diameter plastic cores to a
136 depth of 5cm. These cores were driven into the soil using a rubber mallet and dug out using
137 a spade in a manner which minimised the compaction of the soil in the core (Stone et al.
138 2015, this issue). The samples were transferred by courier mail to the laboratory of the
139 partner institute responsible for microarthropod extraction (IMAR, University of Coimbra,
140 Portugal). Upon arrival samples were stored at 20°C for a couple of days until they were
141 placed in a High-Gradient Macfadyen extractor for 7 days to extract soil microarthropods.
142 After extraction and sorting, mites were stored in 80% ethanol and sent to laboratories at
143 either; University College Dublin, Ireland, or Alterra, The Netherlands, for identification.

144 Mites, Collembola (Martins da Silva et al. 2015, this issue) and Enchytraeidae were identified
145 to species level, the nematodes to functional group (Stone et al. 2015, this issue) and
146 microbial populations were measured using phospholipid-derived fatty acids (PLFA)
147 (Francisco et al., 2015, this issue) and Multiple Substrate Induced Respiration via
148 MicroResp™ (MSIR) (Creamer et al., 2015b, this issue). All mites were slide-mounted in
149 Hoyers medium (Krantz 1978) and identified to species level where possible using the keys
150 of Weigmann (2006), Balogh & Balogh (1992), for oribatids; Karg (1993, 1989), Evans (1977),
151 Evans & Till (1979) and Bhattacharyya (1963) for mesostigmatids; Dindal (1990) for
152 astigmatids; Sig Thor (1933), Gilyarov (1978) and Mahunka (1965) for prostigmatids.

153 **2.2 Statistical analysis**

154 The average abundance in the three samples from each site was used throughout the
155 analyses. Mite data were $\log(Y + 1)$ transformed prior to analysis.

156 Constrained Canonical Correspondence Analysis (CCA) was used to assess the relationships
157 between environmental variables (explanatory variables) and mite community composition
158 (response variable). Bio-climatic zone and land use type were introduced as factors while
159 microbial and environmental parameters were considered to be continuous variables. In the
160 analysis of the abiotic parameters a stepwise variable selection was used based on the
161 Akaike Information Criterion (AIC) to select the five most significant variables and which
162 contributed most to describing the inertia in community composition. At each step, only
163 variables explaining a significant ($P < 0.05$, Monte Carlo test with 999 permutations)
164 proportion of the remaining variation were included.

165 Procrustes analysis was used to investigate the degree of concordance among the variation
166 in mite and the other biotic data sets thus providing an indication of the value of mite
167 community data in predicting biodiversity of community composition of other soil taxa. The
168 first four ordination axes were used as input. These were derived from Detrended
169 Correspondence Analysis (DCA) for mites (species, family and sub-groups), Collembola,
170 Enchytraeidae and from Principle Components Analysis (PCA) for the nematode functional
171 groups and the microbial assessments of community structure. The mite, nematode and
172 enchytraeid data were log transformed and the PLFA was transformed using $\log(1000y+1)$
173 transformation. CCA, DCA and PCA analyses were carried out using Canoco for Windows
174 (version 5) (ter Braak and Šmilauer 2012) and Procrustes analysis was performed using the

175 Protest function in the 'Vegan' package (Oksanen et al., 2012) of the R software v.2.15.0
176 (2012) (R Development Core Team, 2012).

177

178 **3. Results**

179 ***3.1 Variation between Bio-climatic Zones and between Land Use Types***

180 One hundred and eighty six mite taxa were recovered from the 36 sites (Appendix 1). There
181 were 101 Oribatida, 56 Mesostigmata, 26 Prostigmata and 3 Astigmata taxa with an overall
182 β -diversity of 7.3 S.D. units as represented by species turnover in Detrended
183 Correspondence Analysis (DCA). The composition of the mite community varied
184 significantly amongst the bio-climatic zones and land uses. The fauna of the Mediterranean
185 region was most distinct with many Prostigmata and Oribatida taxa occurring most
186 frequently in those sites ($F=1.4$, $p= 0.002$) (Fig. 2) and abundances of over $30 \times 10^3 \text{ m}^{-2}$. A
187 similar pattern was seen when only Oribatida were included in the analysis ($F=1.6$, $p=0.004$).
188 Several species such as *Adelphacarus sellnicki*, *Allogalumna alamellae* and *Passalozetes*
189 *africanus* appear to be highly associated with the Mediterranean, while *Ceratozetes*
190 *laticuspidatus*, *Lucoppia burrowsi* and *Malaconothrus monodactylus* are amongst those
191 associated with the Alpine region and *Dissorhina ornata* and *Phthiracarus compressus*
192 occurred most frequently in the Atlantic Region (Fig. 3a). Although the vast majority of the
193 Mesostigmata did not occur as frequently in the Mediterranean region the effect of bio-
194 climatic zone was not significant ($F=1.2$, $p=0.064$) (Fig. 3b). However, one species,
195 *Dendroseius reticulatus*, did occur exclusively in one of the Mediterranean sites.

196 The fauna also varied significantly between land use types ($F = 1.3$, $P = 0.002$) (Fig. 4) with
197 average abundances in the arable sites of $4.2 \times 10^3 \text{ m}^{-2}$ and of $26 \times 10^3 \text{ m}^{-2}$ in the forest sites.
198 The first and second axes of the ordination show that the communities occurring in forestry
199 were most distinct from those occurring in arable and grassland sites. A large number of
200 oribatid species occurred most regularly in forestry (Fig 5a) while the preferences of the
201 mesostigmatid taxa were more evenly spread across all three land use types (Fig 5b).

202 **3.2 Relationships between mites and microbial populations**

203 The relationship between mites and microflora was analysed by using the microbial
204 parameters as “environmental variables”, these included molecular microbial biomass and
205 summary data from PLFA. This analysis indicated that the oribatid fauna were particularly
206 influenced by fungal to bacterial ratio (F:B) and 16:1 $\omega 5c$, which is an indicator of the
207 abundance of Arbuscular Mycorrhizal Fungi ($p=0.004$), which accounted for 27.93% of the
208 inertia in mite species abundance (Fig. 6a). The other microbial parameters associated with
209 the second axis accounted for a further 22% of the inertia. These microbial parameters are,
210 however, also associated with land use type and therefore it is not clear whether it is land
211 use, or the microbial populations *per se*, which are the drivers of the mite community
212 composition.

213 Mesostigmata, which are predominantly predatory, were not significantly associated with
214 fungal communities ($F=1.2$, $p=0.084$). However, the majority of the species occurred in sites
215 with lower microbial biomass while *Prozercon* sp., *Lysigamasus vagabundus* and *Veigaia*
216 *cerva* do appear to be associated with increased microbial biomass and an increased
217 predominance of fungi but these are also the species which were identified as favouring

218 forest habitats. There are some species such as *Dinychus* sp., *Arctoseius cetratus* and
219 *Lysigamasus parrunciger*, which appear not to be related to microbial biomass (Fig 6b).

220 **3.3 Effects of abiotic variables**

221 Twenty two abiotic variables were measured at each site (Table 1) and the relationship
222 between these and mite community composition was assessed by the forward selection of
223 the variables in CCA (Fig. 7). The factors which explained most of the variation in mite
224 community composition were base saturation (Bsa) (4.5%), exchangeable K (KE) (4.4%),
225 Moisture content of non-sieved sample (MC1) (4.1%), soil Nitrogen content determined by
226 combustion (N) (4.1%) and soil texture as expressed by loamy soils (3.9%). These suggest
227 that pH, bulk density/porosity, water content and quantity and quality of organic matter are
228 critical in determining the mite community structures but it is not clear how exchangeable K
229 might affect the animals.

230 **3.4 Congruence between variations in mite community composition and those of other soil** 231 **taxa**

232 Procrustes analysis shows that there was little similarity between the patterns of variation in
233 mite community composition and those of other taxonomic groups. At the species level
234 there was a significant correlation with Collembola ($r=0.4316$, $p<.001$) (Table 2). The
235 weakest relationship was between mites and Enchytraeidae ($r= 0.2436$) and neither of the
236 microbial community measures (MSIR and PLFA) or the nematode functional group
237 composition were significantly associated with mites (Table 2).

238 The level of taxonomic resolution used for the mite classification (species versus family
239 versus sub- group level identification) had an effect on the levels of congruence (Table 2).

240 The significant relationship with collembolan community composition was lost at family
241 level but at sub-group resolution there was a significant correlation with Collembola,
242 Enchytraeidae and Multiple Substrate Induced Respiration (MSIR).

243 Investigation into whether the use of a single sub-group of mites (Oribatida, Mesostigmata,
244 Astigmata or Prostigmata) would indicate the same congruence as studying mite community
245 as a whole was quite variable (Table 2). The variation in Mesostigmata was correlated with
246 MSIR and Prostigmata were correlated with Collembola.

247

248 **4. Discussion**

249 The data from these transects show that mites are responsive to large scale environmental
250 conditions and that there is a significant turnover in mite community composition between
251 different bio-climatic zones and between land use types. These changes appear to reflect
252 changes in the availability of food sources, such as fungi and soil organic materials, and the
253 physical nature of the soils, such as pH, porosity and water availability. However, in a large
254 scale survey such as this one, they do not appear to respond to environmental variation in
255 the same way as many other taxa which occur in the soil.

256 While mite community composition was not related to the latitude of the sampling sites
257 (results not shown), there were significant differences amongst bio-climatic zones. The
258 Mediterranean fauna were particularly distinct and separated on the first axis of all the
259 ordinations. The separation of this fauna from the others is most likely related to the
260 moisture conditions of these soils which would be exposed to prolonged periods of dryness
261 in the summer months.

262 While many mite species have relatively cosmopolitan distributions there is also significant
263 turnover in species composition between major bio-climatic zones. For example,
264 approximately 50% of the oribatid mites that occur in Europe are confined to this region
265 (Schatz 2004). Similarly, within North America, Behan-Pelletier and Schatz (2010) found a
266 turnover of approximately 50% of the species of Ceratozetoidea between one region and
267 another. Amongst the Mesostigmata the rate of endemism in the major global
268 biogeographic zones is approximately 60% for the Phytoseiidae (Tixier et al., 2008) all of
269 which suggest that such a turnover between bio-climatic zones is to be expected. Indeed,
270 Erdmann et al. (2012) have emphasised the importance of regional differences in
271 determining the mite fauna of forests.

272 Mite communities are known to be influenced by land use and management practices
273 (Behan-Pelletier, 1999) and this was also seen in this study. The preferential occurrence of
274 oribatids in forestry is to be expected as oribatids are a dominant component of the
275 microarthropods in most forest soils (Petersen and Luxton, 1982). The observed difference
276 between the two groups is likely to be reflective of the feeding strategies. Mesostigmata are
277 pre-dominantly predatory; (many Uropodina are nematode feeders (Klarner et al. 2013) but
278 some are omnivores and also feed on detritus and fungi (Gulvik, 2007)) compared to
279 Oribatida which, although they contain a broad range of feeding types (Schneider et al.,
280 2004) are mainly fungal and bacterial feeders (Laakso et al., 2000, Maraun et al., 2011).

281 The use of any single taxon as an indicator of biodiversity assumes that there is cross-taxon
282 congruence in the patterns of variation between different taxa. Such congruence can arise
283 because there is (i) similar responses of different taxonomic groups to the same
284 environmental gradient(s), (ii) responses to different but correlated environmental

285 gradients, (iii) biotic interactions (iv) a random draw of species from regional species pool,
286 and (v) inconsistent sampling effort (where some sites may be sampled more efficiently for
287 multiple taxa) (Gaston, 1996). The variation in the composition of the mite and Collembola
288 communities was correlated which would imply that these taxa either respond to
289 environmental factors in a similar manner or respond to correlated environmental
290 parameters (Table 2). Despite the fact that mites and Collembola may have differing life-
291 history strategies, both groups are arthropods which live within the soil pore space, use
292 organic matter and microbial tissue as sources of food or feed on each other, and respond in
293 similar fashions to factors such as soil moisture content. Therefore it is not unexpected that
294 their community compositions would be correlated.

295 At low levels of taxonomic resolution there is a significant relationship between mites and
296 some properties of the microfloral community (Fig. 6, Table 2). This is presumably related to
297 the biotic interactions between these groups, as many of the mites are microbivores.
298 However, the fact that this is seen only at low levels of taxonomic resolution may reflect a
299 prevalence of non-selective feeding and significant dietary niche overlap amongst the mites.
300 There is also considerable evidence for some degree of dietary specialisation (Shaw, 1988;
301 Walsh and Bolger, 1990; Maraun et al., 2011;) which would appear to contradict this idea;
302 however, it is also known that soil food webs are characterised by the presence of many
303 omnivorous species (Digel et al., 2014). The significant relationship between Mesostigmata
304 and MSIR may be a reflection of a trophic cascade as the presence of Mesostigmata affects
305 the abundance of microbivores which would in turn affect the microbial biomass (Hendrix et
306 al., 1986).

307 The relationship with Enchytraeids is perhaps also to be expected as enchytraeid
308 distribution is largely determined by soil water content, pH and organic matter content
309 (Didden, 1993) all of which also affect the abundance of mites. The fact that the relationship
310 was only seen at sub-group level again suggests that the relationship exists because of
311 related effects of environmental conditions rather than interspecific interactions.

312 Although several comparisons showed significant correlations it should be noted that
313 randomization tests can lead to elevated levels of significance and that therefore the value
314 of the correlations should also be taken into account (Heino, 2010). In this study, the highest
315 correlation achieved was 0.4316 which would indicate disagreement value of greater than
316 80%. Thus even where there is significant correlation, the value of any single taxon in
317 predicting the response of another is very weak.

318 It is obvious from this study that it is highly unlikely that a single taxon indicator of soil
319 biodiversity is going to be found which is applicable across a large spatial scale. This study
320 was carried out to test whether variations in mite community composition could be used as
321 an indicator of change in other components of soil biodiversity. The results suggest that, at
322 this large scale, limited relationships exist and that therefore they may not be good
323 indicators. This is in contrast to the many studies which suggest that mites are useful
324 indicators. Two aspects of the methods used here may explain this. Firstly, the spatial extent
325 of this study is greater than most studies from the past which concentrated on either single
326 experimental setups or single geographical areas. The larger scale means that altered
327 variations in relationships between taxa in different climatic and bio-climatic zones and land
328 uses are likely to affect potential relationships. This scaling effect can be seen in
329 comparisons of several studies. For example, in the case of oribatid mites, Zaitsev et al.

330 (2013) have shown that at large spatial scales post-glacial age is important in determining
331 the community composition while at a smaller scale regional factors become important
332 (Erdmann et al., 2012) but at a more local scale relationships with vegetation type and
333 management become important (Bolger et al., 2014). Shevtsov et al. (2013) found that even
334 within a relatively local gradient, the only guild pairs that exhibited higher than expected
335 similarities in species turnover were plants–fungi, fungi–Collembola and Collembola–
336 Mesostigmata all of which are adjacent in the food chain and would be expected to interact
337 directly. Indeed, even within a site that the effect of management can vary between the
338 litter layer and bulk soil and interacts with litter chemistry and climate during
339 decomposition to determine the composition of arthropod communities (Wickings and
340 Grandy, 2013). Secondly, the mites were sampled at a different time to some of the other
341 biota used. This may affect the relationships because the abundance and activity patterns of
342 virtually all components of the soil biota are seasonal (Petersen and Luxton, 1982 *inter alia*).
343 However, on a large scale such as used in this study, such differences would have to be
344 overcome by any method employed. Seasonality and climatic features are always going to
345 vary across the area of the study.

346 In conclusion, strong correlations between mites and other soil taxa would have facilitated
347 the use of a single taxonomic group for predictive purposes. However, as frequently
348 emphasised in the literature, for better resolution, we still need information on the entire
349 soil biological community (van Straalen, 1998) as well as alpha, beta and gamma diversity
350 (Whittaker, 1960). It therefore appears that with our current knowledge, the search for one
351 bioindicator of soil biological diversity is some way away as no single taxon can be expected

352 to adequately indicate patterns for all other taxa at the spatial scale examined in this study
353 (Pearson, 1994).

354

355 **Acknowledgements**

356 This work was supported by the European Commission within the EcoFINDERS project (FP7-
357 264465)

358 **References**

- 359 Bhattacharyya, S.K., 1963. *A revision of the British mites of the genus Pergamasus Berlese s.*
360 *lat. (Acari: Mesostigmata)*. Trustees of the British Museum (Natural History).
- 361 Balogh, J. and Balogh, P., 1992 The oribatid mite genera of the world. 1 and 2. Hungarian
362 Natural History Museum, Budapest.
- 363 Bastida, F., Zsolnay, A., Hernandez, T., Garcia, C., 2008. Past, present and future of soil
364 quality indices: A biological perspective. *Geoderma* 147, 159-171.
- 365 Behan-Pelletier, V., Schatz, H., 2010. Patterns of diversity in the Ceratozetoidea (Acari:
366 Oribatida): a North American assessment. *Trends in acarology. Proceedings of the 12th*
367 *International Congress.*, 97-104.
- 368 Behan-Pelletier, V.M., 1999. Oribatid mite biodiversity in agroecosystems: role for
369 bioindication. *Agriculture Ecosystems & Environment* 74, 411-423.
- 370 Bohlen, P.J., Scheu, S., Hale, C.M., McLean, M.A., Migge, S., Groffman, P.M., Parkinson, D.,
371 2004. Non-native invasive earthworms as agents of change in northern temperate forests.
372 *Frontiers in Ecology and the Environment* 2, 427-435.
- 373 Bolger, T., Arroyo, J., Kenny, J., Capliceu, M., 2014. Hierarchical analysis of mite community
374 structures in Irish forests-A study of the relative contribution of location, forest type and
375 microhabitat. *Applied Soil Ecology* 83, 39-43.
- 376 Bongers, T., 1990. The maturity index - an ecological measure of environmental disturbance
377 based on nematode species composition. *Oecologia* 83, 14-19.

378 Bran Nogueira Cardoso, E.J., Figueiredo Vasconcellos, R.L., Bini, D., Horta Miyauchi, M.Y.,
379 dos Santos, C.A., Lopes Alves, P.R., de Paula, A.M., Nakatani, A.S., Pereira, J.d.M., Nogueira,
380 M.A., 2013. Soil health: looking for suitable indicators. What should be considered to assess
381 the effects of use and management on soil health? *Scientia Agricola* 70, 274-289.

382 Creamer, R.E., Hannula, S.E., van Leeuwen, J.P., Stone, D., Rutgers, M., Schmelz, R.M., de
383 Ruiten, P.C., Bohse Hendriksen, N., Bolger, T., Bouffaud, M.L., Buee, M., Carvalho, F., Costa,
384 D.1, Dirilgen, T., Francisco, R., Griffiths, B.S., Griffiths, R., Martin, F., Martins da Silva, P.,
385 Mendes, S., Morais, P.V., Pereira, C., Plassart, P., Philippot, L., Redecker, D., Römbke, J.,
386 Sousa, J.P., Wouterse, M., and Lemanceau, P., 2015(a). Ecological network analysis reveals
387 the inter-connection between soil biodiversity and ecosystem function as affected by land
388 use across Europe. *Applied Soil Ecology*, (this issue).

389 Creamer R.E., Stone, D., Berry, P., Kuiper, I., 2015(b). Measuring respiration profiles of soil
390 microbial communities across Europe using MicroResp™ method. *Applied Soil Ecology*, (this
391 issue).

392 Decaëns, T., Jimenez, J.J., Gioia, C., Measey, G.J., Lavelle, P., 2006. The values of soil animals
393 for conservation biology. *European Journal of Soil Biology* 42, S23-S38.

394 Didden, W.A.M., 1993. Ecology of Terrestrial Enchytraeidae. *Pedobiologia* 37, 2-29.

395 Digel, C., Curtsdotter, A., Riede, J., Klarner, B., Brose, U., 2014. Unravelling the complex
396 structure of forest soil food webs: higher omnivory and more trophic levels. *Oikos* 123,
397 1157-1172.

398 Dindal, D.L., 1990. Soil Biology Guide. John Wiley & Sons, New York.

399 Edwards, C.A., Bohlen P.J., 1996. Biology and ecology of earthworms, Third ed. Chapman
400 and Hall.

401 Erdmann, G., Scheu, S., Maraun, M., 2012. Regional factors rather than forest type drive the
402 community structure of soil living oribatid mites (Acari, Oribatida). Experimental and
403 Applied Acarology 57, 157-169.

404 Faber, J.H., Creamer, R.E., Mulder, C., Roembke, J., Rutgers, M., Sousa, J.P., Stone, D.,
405 Griffiths, B.S., 2013. The practicalities and pitfalls of establishing a policy-relevant and cost-
406 effective soil biological monitoring scheme. Integrated Environmental Assessment and
407 Management 9, 276-284.

408 Feld, C.K., da Silva, P.M., Sousa, J.P., de Bello, F., Bugter, R., Grandin, U., Hering, D., Lavorel,
409 S., Mountford, O., Pardo, I., Paertel, M., Roembke, J., Sandin, L., Jones, K.B., Harrison, P.,
410 2009. Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and
411 spatial scales. Oikos 118, 1862-1871.

412 Francisco, R., de Abreu, P., Creamer, R., da Costa, M.S., Sousa, J.P. and Morais, P.V., 2015.
413 Methodological improvements of the Simple phospholipid-derived fatty acids (PLFA)
414 Extraction method applied to a comparative analysis of European soils. Applied Soil Ecology,
415 (this issue).

416 Gardi, C., Montanarella, L., Arrouays, D., Bispo, A., Lemanceau, P., Jolivet, C., Mulder, C.,
417 Ranjard, L., Roembke, J., Rutgers, M., Menta, C., 2009. Soil biodiversity monitoring in
418 Europe: ongoing activities and challenges. *European Journal of Soil Science* 60, 807-819.

419 Gaston, K.J., 1996. Biodiversity - Congruence. *Progress in Physical Geography* 20, 105-112.

420 Gilyarov, M.S., 1978. A key to the soil inhabiting mites. Trombidiformes. Zoological Institute
421 of the Academy of Sciences, SSSR, Moscow, 491 pp.

422 Gulvik, M.E., 2007. Mites (Acari) as indicators of soil biodiversity and land use monitoring: A
423 review. *Polish Journal of Ecology* 55, 415-440.

424 Hammond, P., 1992. Species inventory. In *Global Biodiversity: Status of the Earth's Living*
425 *Resources. A report.*, B. Groombridge ed. London: Chapman & Hall.

426 Heino, J., 2010. Are indicator groups and cross-taxon congruence useful for predicting
427 biodiversity in aquatic ecosystems? *Ecological Indicators* 10, 112-117.

428 Hendrix, P.F., Parmelee, R.W., Crossley, D.A., Coleman, D.C., Odum, E.P., Groffman, P.M.,
429 1986. Detritus food webs in conventional and no-tillage agroecosystems. *Bioscience* 36,
430 374-380.

431 Karg, W., 1993. Acari (Acarina), Milben—Parasitiformes (Anactino- chaeta). *Cohors Gamasina*
432 *Leach—Raubmilben. Die Tierwelt Deutschlands*, vol. 59. G. Fischer-Verlag, Jena, 523 pp.

433 Krantz, G.W., 1978. A manual of acarology. Second edition. Oregon State University Book
434 Stores, Corvallis, Oregon.

435 Karg, W., 1989. Acari (Acarina) Milben, Parasitiformes (Anactinochaeta), Uropodina Kramer
436 Schildkrötenmilben. In: Die Tierwelt Deutschlands, 67. Teil. G. Fischer, Jena, 203 pp.

437 Klarner B., Maraun M., Scheu S., 2013. Trophic diversity and niche partitioning in a species
438 rich predator guild—natural variations in stable isotope ratios ($^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$) of
439 mesostigmatid mites (Acari, Mesostigmata) from Central European beech forests. Soil
440 Biology & Biochemistry 57, 327–333.

441 Laakso, J., Setälä, H., Palojarvi, A., 2000. Influence of decomposer food web structure and
442 nitrogen availability on plant growth. Plant and Soil 225, 153-165.

443 Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W., Dhillon, S.,
444 1997. Soil function in a changing world: the role of invertebrate ecosystem engineers.
445 European Journal of Soil Biology 33, 159-193.

446 Lavelle, P., Decaens, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P.,
447 Rossi, J.P., 2006. Soil invertebrates and ecosystem services. European Journal of Soil Biology
448 42, S3-S15.

449 Mahunka, S. 1965. Identification key for the species of the family Scutacaridae (Acari:
450 Tarsonemini). Acta Zoologica Academiae Scientiarum Hungaricae, 11, 353-401.

451 Maraun, M., Erdmann, G., Fischer, B.M., Pollierer, M.M., Norton, R.A., Schneider, K., Scheu,
452 S., 2011. Stable isotopes revisited: Their use and limits for oribatid mite trophic ecology. Soil
453 Biology & Biochemistry 43, 877-882.

454 Martins da Silva, P., Carvalho, F., Dirilgen T., Stone, D., Creamer, R.E., Bolger, T., Sousa, J.P.,
455 2015. Adding traits to the shopping basket: Collembola biodiversity as indicators of land use
456 types across europe. *Applied Soil Ecology*, (this issue).

457 McInerney, M., Bolger, T., 2000. Decomposition of *Quercus petraea* litter: influence of
458 burial, comminution and earthworms. *Soil Biology & Biochemistry* 32, 1989-2000.

459 Mulder, C., Boit, A., Bonkowski, M., De Ruiter, P.C., Mancinelli, G., Van der Heijden, M.G.A.,
460 Van Wijnen, H.J., Vonk, J.A., Rutgers, M., 2011. A Belowground Perspective on Dutch
461 Agroecosystems: How Soil Organisms Interact to Support Ecosystem Services. *Advances in*
462 *Ecological Research* 44, 277-357.

463 Noss, R.F., 1990. Indicators for monitoring biodiversity - a hierarchical approach.
464 *Conservation Biology* 4, 355-364.

465 Ødegaard, F., 2000. How many species of arthropods? Erwin's estimate revised. *Biological*
466 *Journal of the Linnean Society* 71, 583-597.

467 Oksanen J, Blanchet F.G., Kindt R., Legendre P, Minchin P.R., O'Hara R.B., Simpson G.L.,
468 Solymos P., Henry M., Stevens H. and Wagner H., 2012. vegan: Community Ecology Package.
469 R package version 2.0-3. <http://CRAN.R-project.org/package=vegan>Parisi, V., Menta, C.,
470 Gardi, C., Jacomini, C., Mozzanica, E., 2005. Microarthropod communities as a tool to assess
471 soil quality and biodiversity: a new approach in Italy. *Agriculture Ecosystems & Environment*
472 105, 323-333.

473 Pearson, D.L., 1994. Selecting indicator taxa for the quantitative assessment of biodiversity.
474 Philosophical Transactions of the Royal Society of London Series B-Biological Sciences 345,
475 75-79.

476 Petersen, H., Luxton, M., 1982. A comparative analysis of soil fauna populations and their
477 role in decomposition. *Oikos* 39, 288-388.

478 R Development Core Team, 2012. R: A language and environment for statistical computing.
479 R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL
480 <http://www.R-project.org/>

481 Ritz, K., Black, H.I.J., Campbell, C.D., Harris, J.A., Wood, C., 2009. Selecting biological
482 indicators for monitoring soils: A framework for balancing scientific and technical opinion to
483 assist policy development. *Ecological Indicators* 9, 1212-1221.

484 Schatz, H. 2004. Diversity and global distribution of oribatid mites (Acari, Oribatida) –
485 evaluation of the present state of knowledge. *Phytophaga* 14, 485-500.

486 Schoenholtz, S.H., Van Miegroet, H., Burger, J.A., 2000. A review of chemical and physical
487 properties as indicators of forest soil quality: challenges and opportunities. *Forest Ecology*
488 *and Management* 138, 335-356.

489 Shaw, P.J.A., 1988. A consistent hierarchy in the fungal feeding preferences of the
490 collembola *onychiurus-armatus*. *Pedobiologia* 31, 179-187.

491 Sheehan, C., Kirwan, L., Connolly, J., Bolger, T., 2006. The effects of earthworm functional
492 group diversity on nitrogen dynamics in soils. *Soil Biology & Biochemistry* 38, 2629-2636.

493 Shevtsov, J., Wickings, K., Patten, B.C., 2013. Evaluating the role of biotic interactions in
494 structuring communities using a gradient analysis of multiple interacting guilds. *Oikos* 122,
495 1594-1605.

496 Thor, S., 1933. Tydeidae, Ereyneidae, *Das Tierreich* 60, xi, 84pp.

497 Stone, D., Costa, D., Daniell, T.J, Griffiths, B.S., 2015. Rationalising a European scale soil
498 biological monitoring programme for European policy development: Using nematode
499 communities as an example. *Applied Soil Ecology*. (this issue).

500 Stone, D., Blomkvist, P., Bohse Hendriksen, N., Bonkowski, M., Bracht Jørgensen, H.,
501 Carvalho, F., Dunbar, M.B., Gardi, C., Geisen, S., Griffiths, R., Hug, A.S., Jensen, J., Mendes,
502 S., Morais, P.V., Plassart, P., Römbke, J., Rutgers, M., Schmelz, R. M., Sousa, J.P., Suhadolc,
503 M., Winding, A., Lemanceau, P., Creamer, R.E. 2015 (this issue). Establishing a Transect for
504 Biodiversity and Ecosystem Function Monitoring Across Europe. *Applied Soil Ecology*, (this
505 issue).

506 Straube, D., Johnson, E.A., Parkinson, D., Scheu, S., Eisenhauer, N., 2009. Nonlinearity of
507 effects of invasive ecosystem engineers on abiotic soil properties and soil biota. *Oikos* 118,
508 885-896.

509 ter Braak, C. J. F. & Šmilauer, P., 2012. *CANOCO Reference Manual and User's Guide to*
510 *Canoco for Windows: Software for Ordination (version 5.0)*.

511 Tixier, M.-S., Kreiter, S., De Moraes, G.J., 2008. Biogeographic distribution of the
512 phytoseiidae (Acari : Mesostigmata). *Biological Journal of the Linnean Society* 93, 845-856.

513 Turbé A., De Toni A., Benito P., Lavelle P., Lavelle P., Ruiz N., Van der Putten W.H., Labouze
514 E., and Mudgal S., 2010. Soil biodiversity: functions, threats and tools for policy makers. Bio
515 Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment).

516 van Straalen, N.M., 1998. Evaluation of bioindicator systems derived from soil arthropod
517 communities. *Applied Soil Ecology* 9, 429-437.

518 Walsh, M.I., Bolger, T., 1990. Effects of diet on the growth and reproduction of some
519 collembola in laboratory cultures. *Pedobiologia* 34, 161-171.

520 Walter, D.E., Behan-Pelletier, V., 1999. Mites in forest canopies: Filling the size distribution
521 shortfall? *Annual Review of Entomology* 44, 1-19.

522 Weigmann, G., 2006. Hornmilben (Oribatida). In: Dahl, F. (Ed.), *Die Tierwelt Deutschlands*,
523 76. Goecke & Evers, Keltern, pp. 1–520.

524 Whittaker, R.H., 1960. Vegetation of the Siskiyou Mountains, Oregon and California.
525 *Ecological Monographs* 30, 279-338.

526 Wickings, K., Grandy, A.S., 2013. Management intensity interacts with litter chemistry and
527 climate to drive temporal patterns in arthropod communities during decomposition.
528 *Pedobiologia* 56, 105-112.

529 Zaitsev, A.S., van Straalen, N.M., Berg, M.P., 2013. Landscape geological age explains large
530 scale spatial trends in oribatid mite diversity. *Landscape Ecology* 28, 285-296.

531 **Tables**

532 **Table 1.** Soil chemical/physical variables measured at each site

533

Moisture Content of non-sieved sample (ml g^{-1})
Moisture Content of 2 mm sieved sample (ml g^{-1})
Average mass of soil in 98 cm^3 core Fresh Weight (g)
WHC ($\text{ml } 100 \text{ g fresh soil}^{-1}$)
Total N by combustion (%)
Total C by combustion (%)
Organic C by combustion (%)
pH
Clay %
Silt %
Sand %
Texture
CEC ($\text{cmol } +\text{charge kg}^{-1}$)
Exchangable Ca (cmol kg soil^{-1})
Exchangable Mg (cmol kg soil^{-1})
Exchangable Na (cmol kg soil^{-1})
Exchangable K (cmol kg soil^{-1})
Base saturation (%)
Average Fresh Weight (g) in core SPRING (g)
Moisture Content of non-sieved sample SPRING (ml g^{-1})
Amount of $\text{NO}_2\text{-N}$ released (ng/g soil dm/h)
% moisture

534

535

536 **Table 2.** Procrustes analyses of congruence in community composition among mites at varying levels
 537 of taxonomic resolution and other taxonomic groups (where 'MSIR', Multiple Substrate Induced
 538 Respiration measured using MicroResp™ and 'PLFA', phospholipid-derived fatty acids represent
 539 differing microbial population measurement techniques). The values presented are the correlations
 540 in a symmetric Procrustes rotation.

541

Component	<u>MSIR</u>	<u>PLFA</u>	<u>Collembola</u>	<u>Enchytraeidae</u>	<u>Nematoda</u>
mite species	0.3434	0.2872	0.4316***	0.2436	0.3475
mite family	0.2532	0.2658	0.2616	0.3325	0.322
mite sub-group	0.3883*	0.2213	0.369*	0.4018**	0.2863
Oribatida	0.3203	0.3136	0.1922	0.2799	0.2855
Mesostigmata	0.3944**	0.211	0.2293	0.2171	0.2743
Prostigmata	0.3127	0.2482	0.3871*	0.3056	0.2593

542

543

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level. 544

***Significant at the 0.001 probability level.

545

546

547

548

549

Figures

550 **Fig. 1** Map of Europe showing locations of sites across the different bio-climatic zones

551

552 **Fig. 2** Canonical correspondence analysis (CCA) of log transformed mite taxa across four bio-climatic
553 zones. The first two axes account for 11.7% of the taxa bio-climatic region relationship and the first
554 and trace are significant ($F=1.4$, $p= 0.002$). Only the twenty species whose best fit the model are
555 illustrated and labels were adjusted to improve the graph. (Species abbreviations as in Appendix 1)

556

557 **Fig.3** Canonical correspondence analysis (CCA) of mite taxa **(a)** Oribatida and **(b)** Mesostigmata
558 across four bio-climatic zones. The first two axes account for 14.2% and 12.7% respectively of the
559 taxa bio-climatic zone relationship ($F= 1.6$, $p=0.004$; $F= 1.2$, $p= 0.064$ respectively). Only the thirty
560 species whose best fit the model are illustrated and labels were adjusted to improve the graph.
561 (Species abbreviations as in Appendix 1)

562

563 **Fig. 4** Canonical correspondence analysis (CCA) of mite taxa across land use type. The first two axes
564 account for 7.4% of the species land use relationship and the first axis and trace are significant
565 ($F=1.3$, $p=0.002$). Only the thirty species whose best fit the model are illustrated and labels were
566 adjusted to improve the graph. (Species abbreviations as in Appendix 1)

567

568 **Fig. 5** Canonical correspondence analysis (CCA) of mite taxa **(a)** Oribatida and **(b)** Mesostigmata
569 across land use type. The first two axes account for 9.2% and 8.3% respectively of the species land
570 use relationship and the first axis and trace are significant ($F=1.5$, $p=0.002$; $F=1.2$, $p=0.034$)

571 respectively). Only the thirty species whose best fit the model are illustrated and labels were
572 adjusted to improve the graph. (Species abbreviations as in Appendix 1)

573

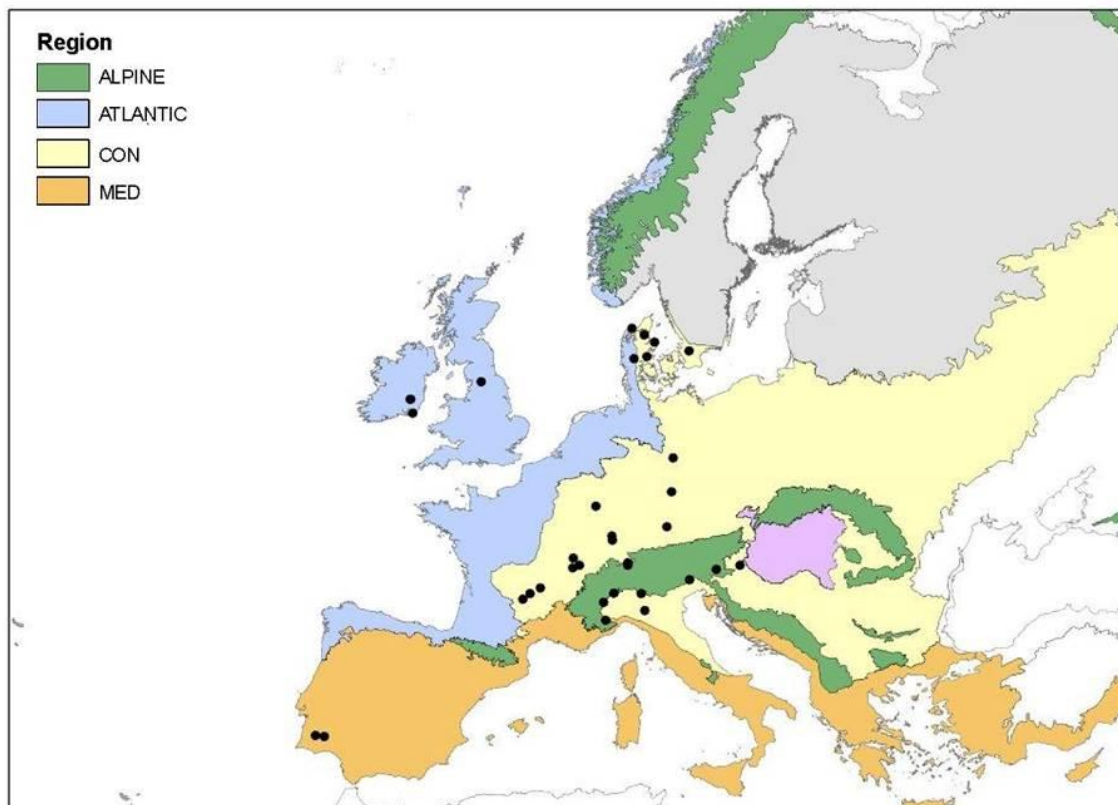
574 **Fig. 6** Canonical correspondence analysis (CCA) of mite taxa **(a)** Oribatida and **(b)** Mesostigmata with
575 microbial parameters. The first two axes account for 22.5% and 20.6% respectively of the mite taxa –
576 microbial relationship ($F=1.6$, $p=0.002$; $F=1.2$, $=0.084$). Only the fifty and thirty species respectively
577 whose best fit the model are illustrated and labels were adjusted to improve the graph. (Species
578 abbreviations as in Appendix 1)

579

580 **Fig. 7** Canonical correspondence analysis (CCA) of log transformed mite taxa against abiotic
581 characteristics of site. The environmental parameters listed were forward selected and the first five
582 are illustrated. Only the forty species whose best fit the model are illustrated and labels were
583 adjusted to improve the graph. (Species abbreviations as in Appendix 1, Environmental parameters
584 are Bsa -base saturation, KE- exchangeable K, MC1 – Moisture content of non-sieved sample, N – soil
585 Nitrogen content determined by combustion and soil texture as expressed by loamy soils).

586

587 **Figure 1**

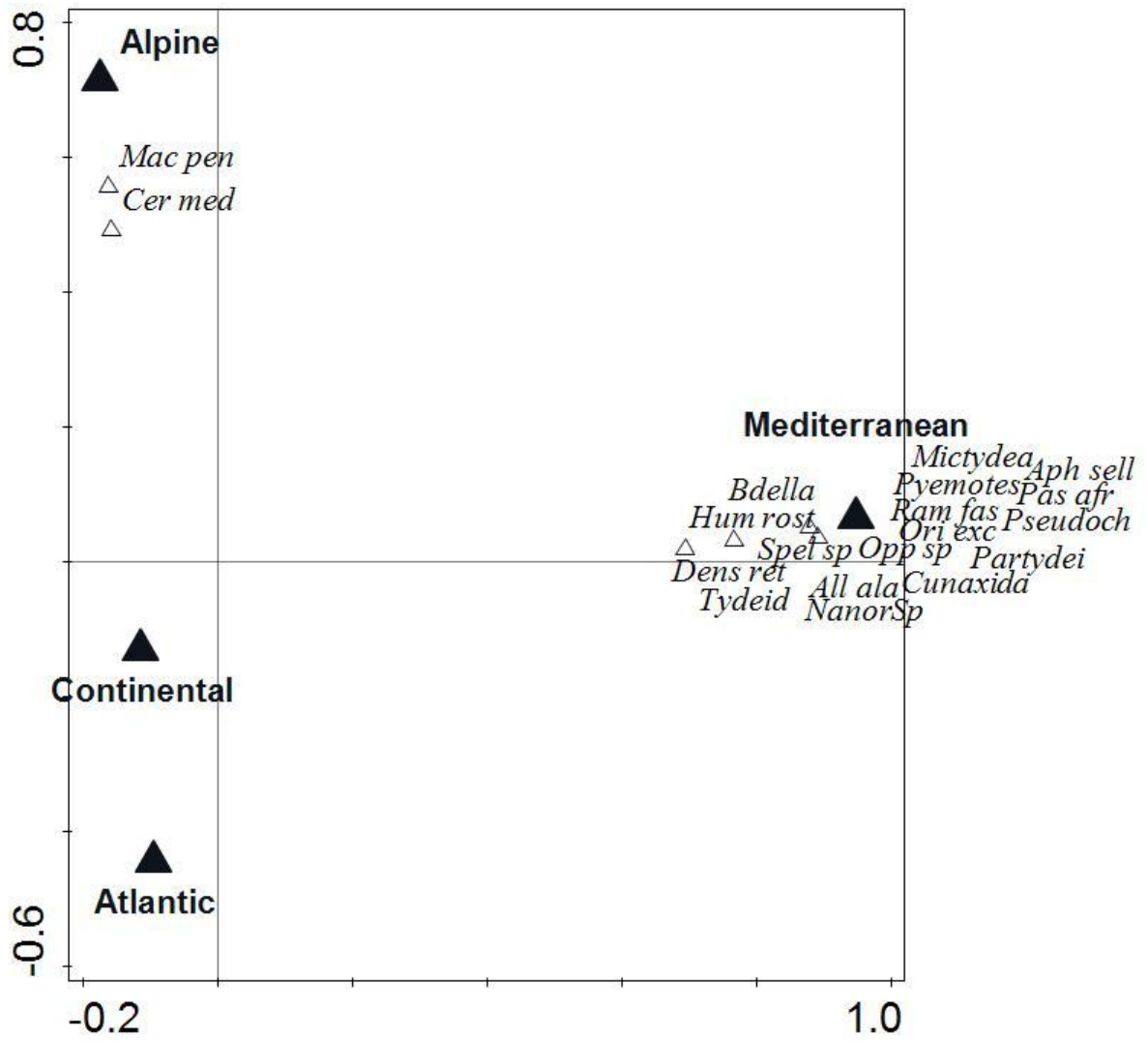


588

589

590

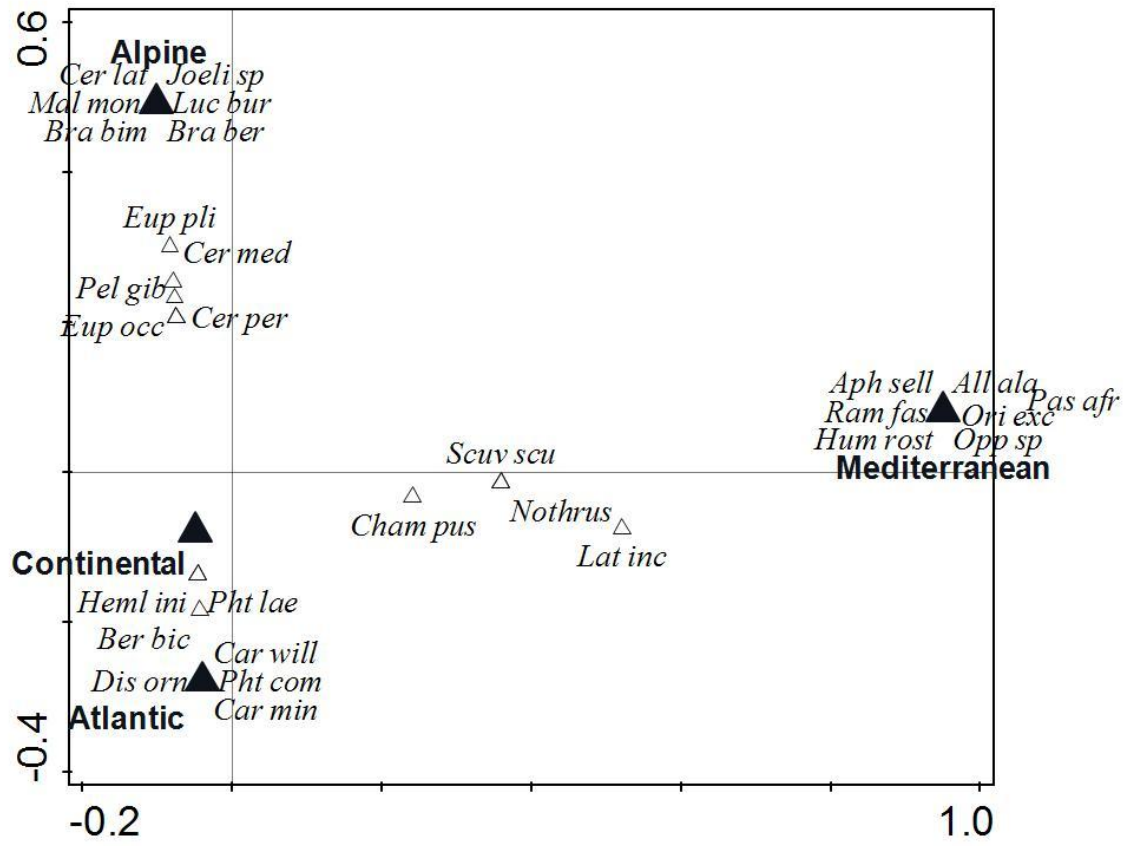
591 Figure 2



592

593

594 **Figure 3a**

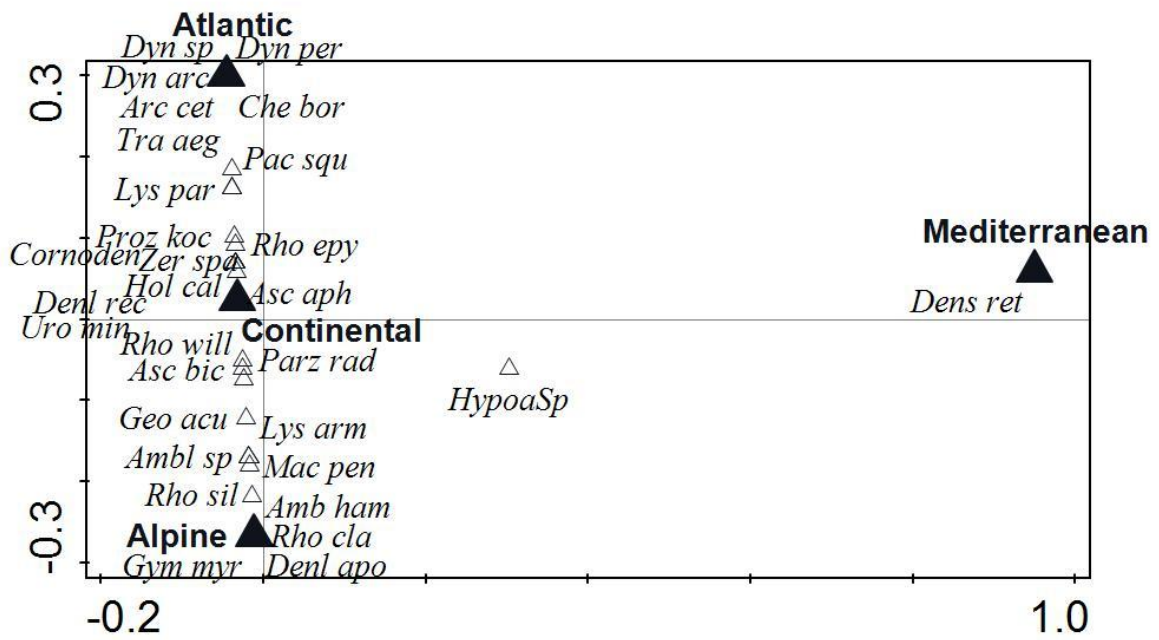


595

596

597 **Figure 3b**

598

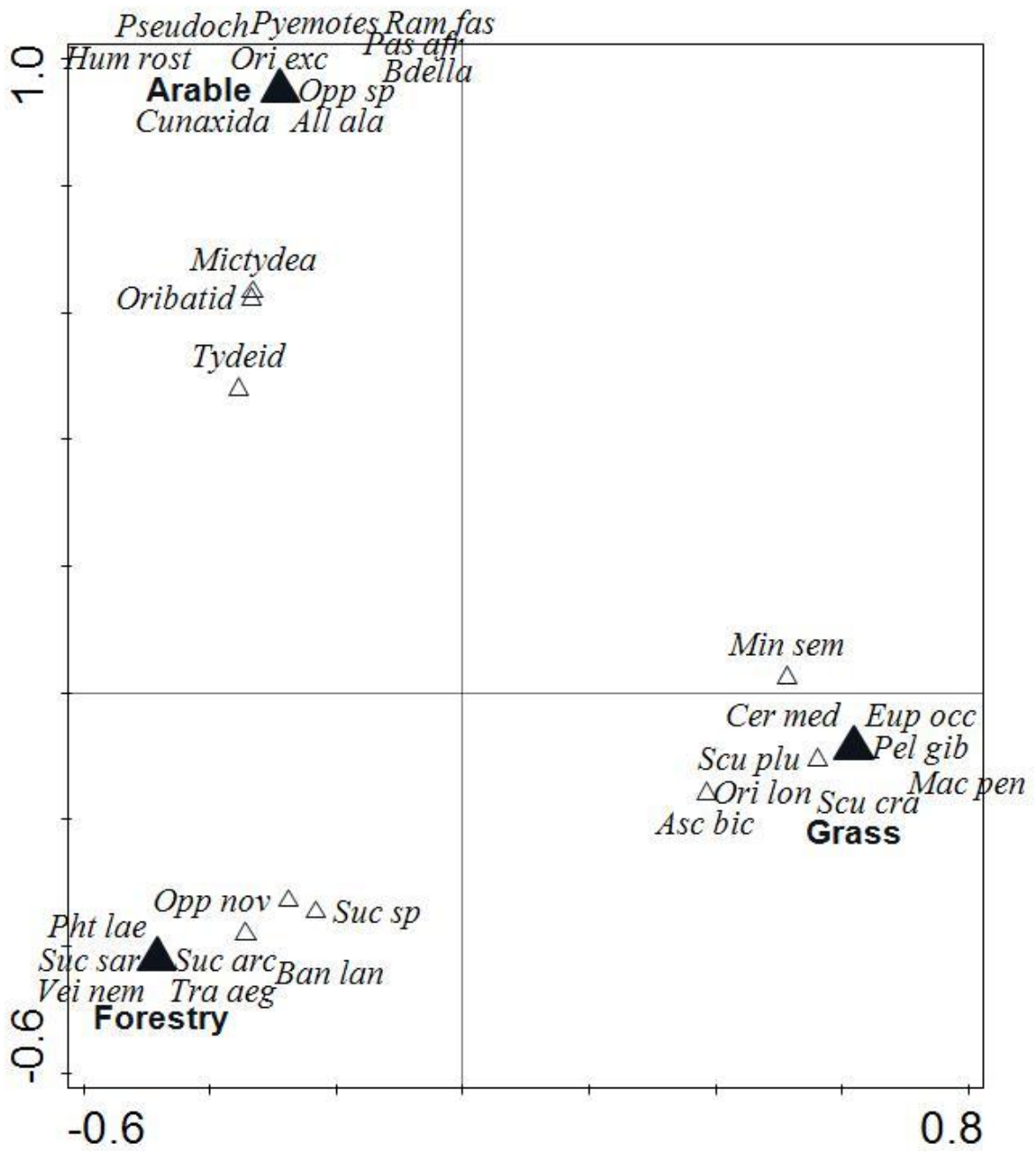


599

600

601 Figure 4

602

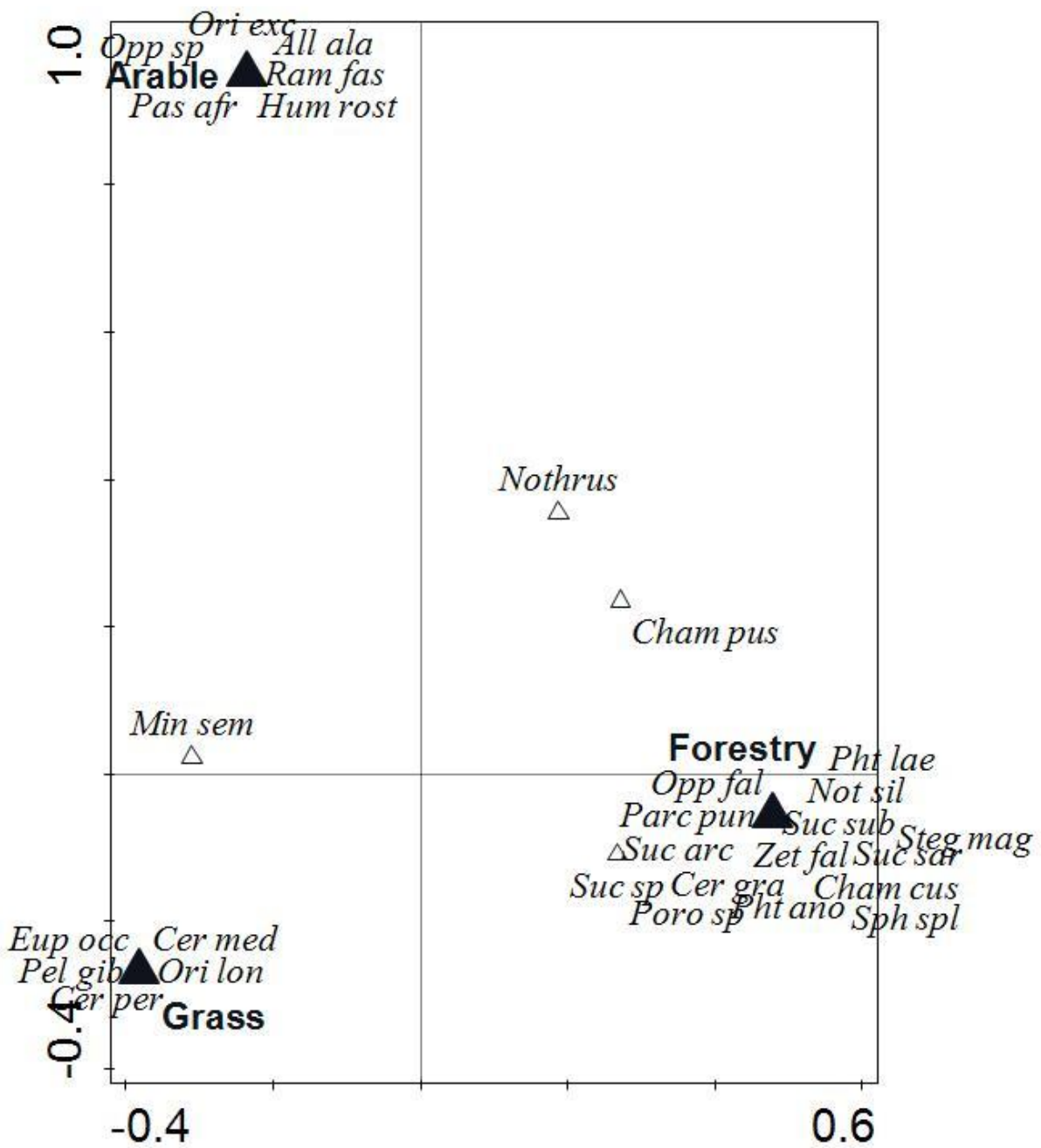


603

604

605 Figure 5a

606

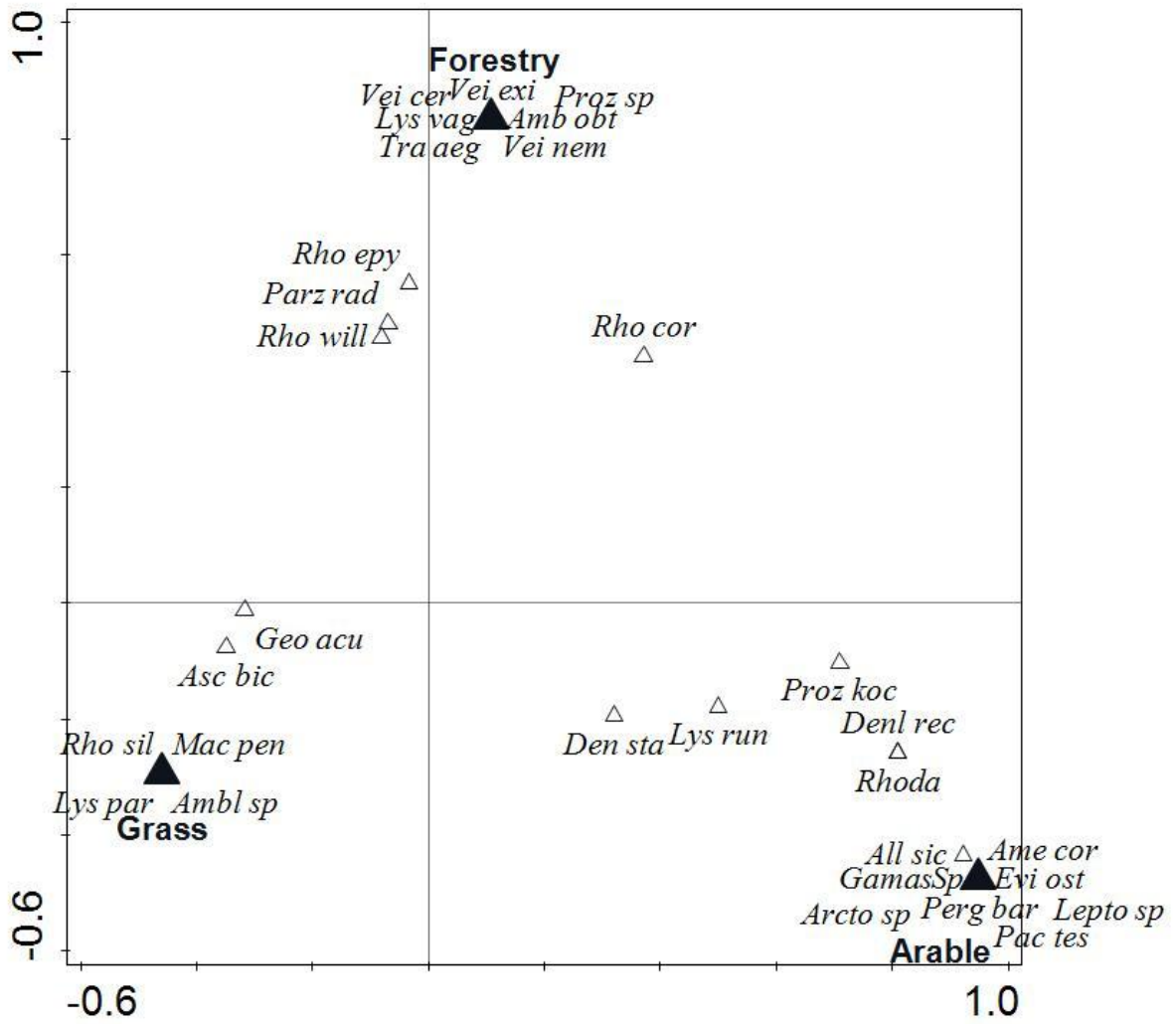


607

608

609 **Figure 5b**

610

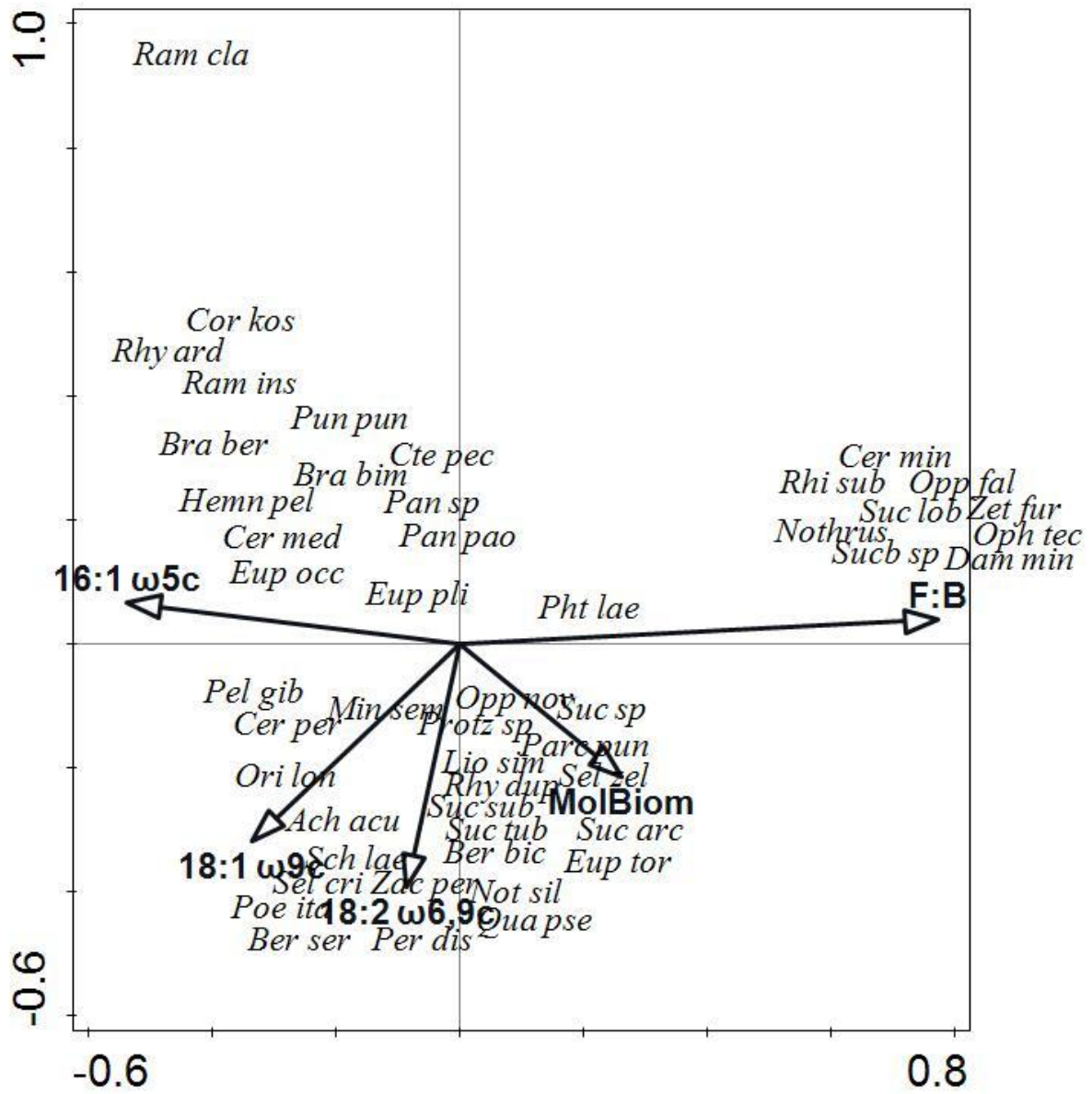


611

612

613 Figure 6a

614

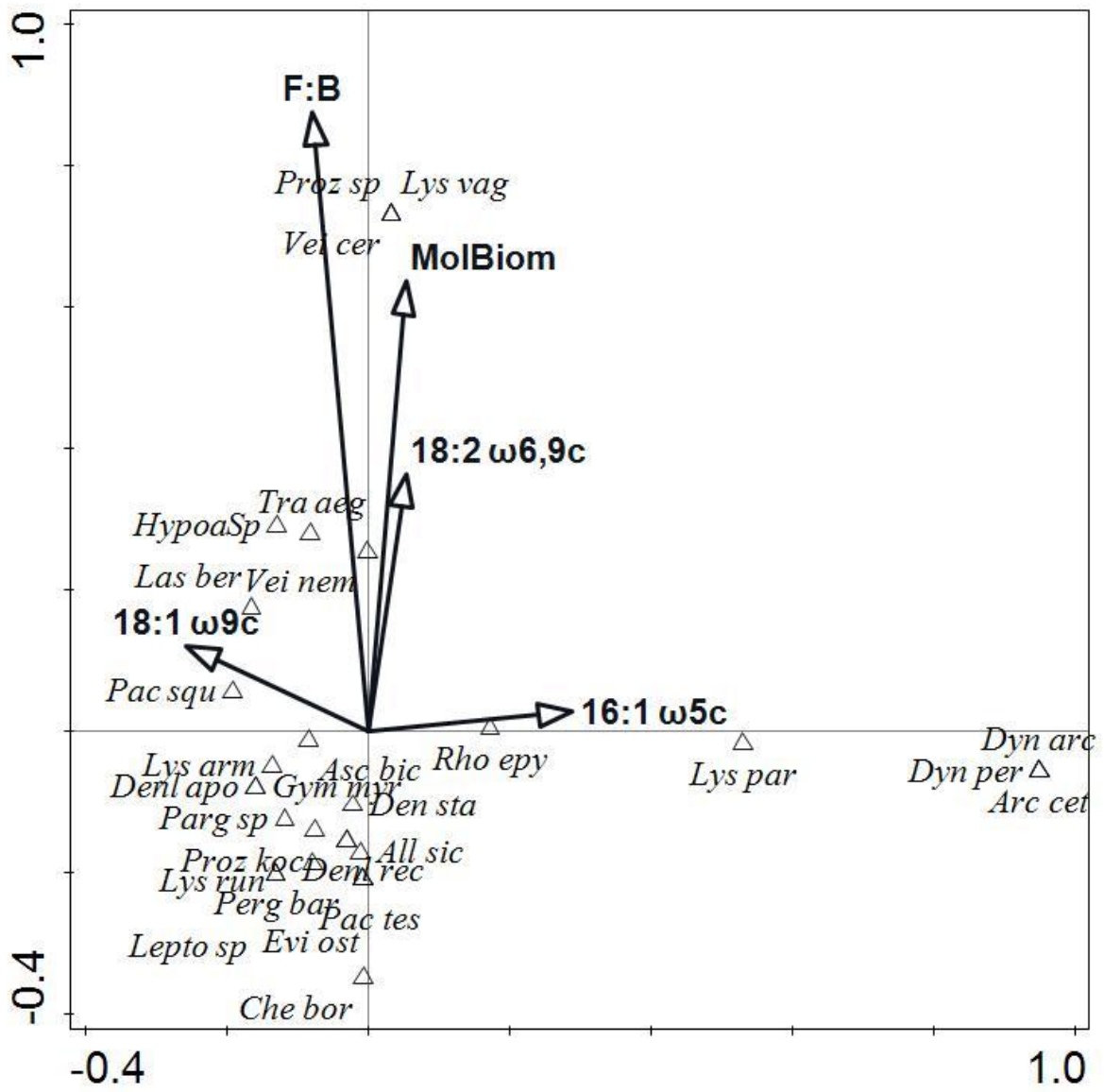


615

616

617 Figure 6b

618

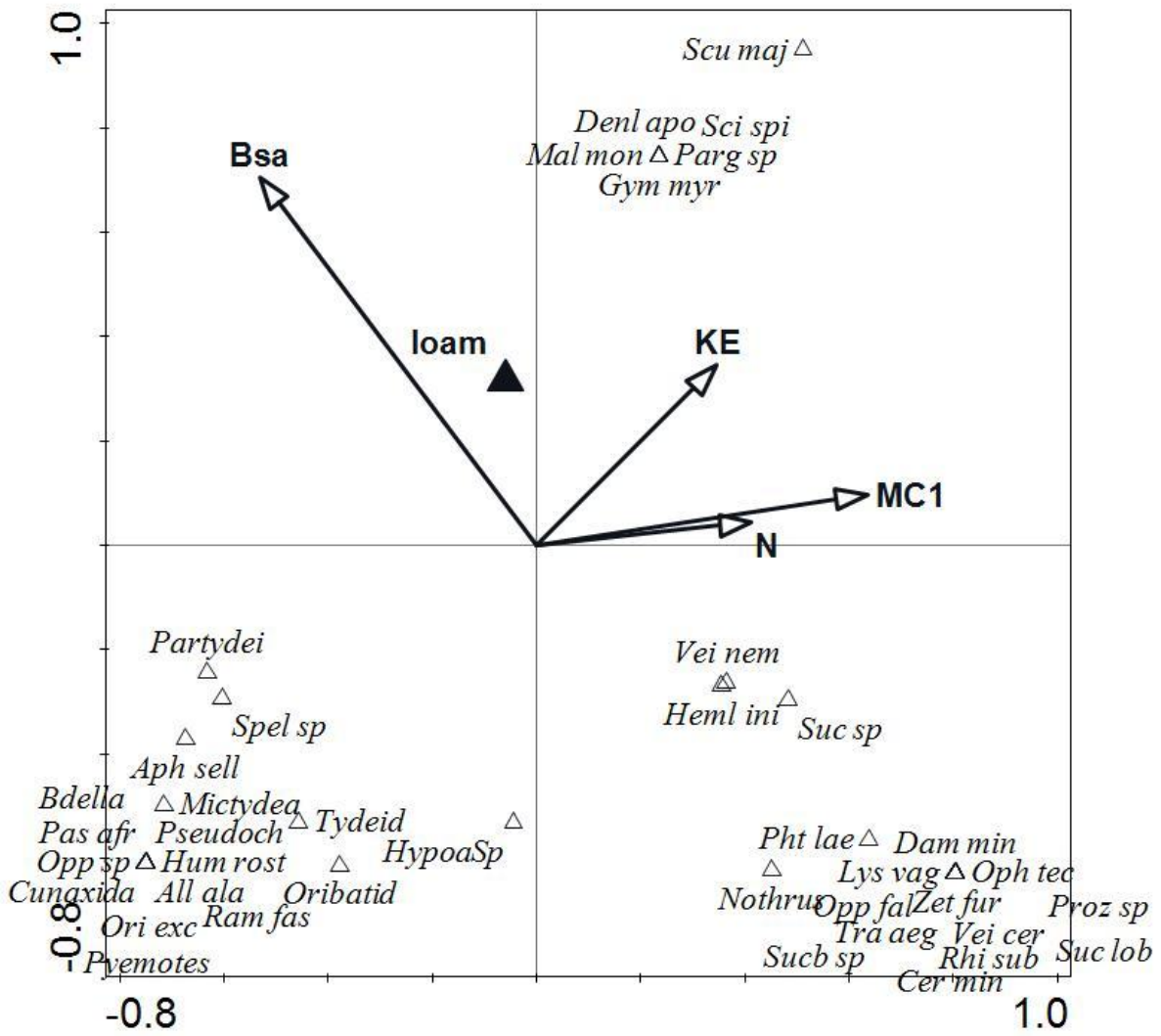


619

620

621 Figure 7

622



623

624

625

626

627

Appendix 1

Species found in each of the bio-climatic zones and land use types.

Abbreviations; Al: Alpine, Con: Continental, Med: Mediterranean, At: Atlantic, Gr: Grassland, For: Forestry, Ara: Arable

Taxon	Abbreviation	Al Gr	Con For	Con Ara	Con Gr	Med For	Med Ara	At For	At Ara	At Gr
Oribatida										
Oribatida	Oribatid		+				+			
Achipteriidae										
<i>Achipteria acuta</i> Berlese, 1908	Ach acu		+		+				+	
<i>Achipteria coleoprata</i> Linnaeus, 1758	Ach col	+	+		+					+
<i>Parachipteria punctata</i> Nicolet, 1855	Parc pun		+					+		
Brachychthoniidae										
<i>Brachychthonius berlesei</i> Willmann, 1928	Bra ber	+								
<i>Brachychthonius bimaculatus</i> Willmann, 1936	Bra bim	+								
<i>Liochthonius brevis</i> (Michael, 1888)	Lio bre				+			+		
<i>Liochthonius sellnicki</i> (Thor, 1930)	Lio sel				+			+		
<i>Liochthonius simplex</i> (Forsslund, 1942)	Lio sim		+		+					
<i>Poecilochthonius italicus</i> Berlese, 1910	Poe ita				+					
<i>Sellnickochthonius cricoides</i> (Weis-Fogh, 1948)	Sel cri				+					
<i>Sellnickochthonius zelawaiensis</i> (Sellnick, 1928)	Sel zel		+							
Camisiidae										
<i>Heminothrus (P.) peltifer</i> (C. L. Koch, 1839)	Hemn pel		+							+
Carabodidae										
<i>Carabodes minusculus</i> Berlese, 1923 (C.)	Car min							+		
<i>Carabodes willmanni</i> Bernini, 1975 (C.)	Car will							+		
Ceratozetidae										
<i>Ceratozetes gracilis</i> (Michael, 1884)	Cer gra		+							

<i>Ceratozetes laticuspidatus</i> Menke, 1964	Cer lat	+						
<i>Ceratozetes mediocris</i> Berlese, 1908	Cer med	+				+		
<i>Ceratozetes minimus</i> Sellnick, 1928	Cer min			+				
<i>Ceratozetes peritus</i> Grandjean, 1951	Cer per	+					+	
<i>Protozetomimus</i> sp. Pérez- Íñigo, 1990	Protz sp			+			+	
<i>Latilamellobates incisellus</i> (Kramer, 1897)	Lat inc							+
<i>Trichoribates novus</i> (Sellnick, 1928)	Tri nov			+	+	+		+
Chamobatidae								
<i>Chamobates cuspidatus</i> (Michael, 1884)	Cham cus			+				
<i>Chamobates pusillus</i> (Berlese, 1895)	Cham pus			+				+
Ctenacaridae								
<i>Adelphacarus sellnicki</i> Grandjean, 1952	Aph sell					+		+
Ctenobelbidae								
<i>Ctenobelba pectinigera</i> (Berlese, 1908)	Cte pec					+		
Damaeidae								
<i>Damaeobelba minutissima</i> (Sellnick, 1929)	Dam min			+				
<i>Porobelba</i> sp. Grandjean, 1936	Poro sp			+				
Galumnidae								
<i>Allogalumna alamellae</i> (Jacot, 1935)	All ala							+
<i>Galumna lanceata</i> Oudemans, 1900	Gal lan			+		+		+
Hemileiidae								
<i>Hemileius initialis</i> (Berlese, 1908)	Heml ini			+		+		+
								+
Humerobatidae								
<i>Humerobates rostromellatus</i> Grandjean, 1936	Hum rost						+	
Liebstadiidae								
<i>Liebstadia similis</i> (Michael, 1888) (<i>Notaspis</i>)	Lie sim				+	+		
Malaconothridae								
<i>Malaconothrus monodactylus</i> (Michael, 1888)	Mal mon	+						
Nanhermanniidae								

<i>Nanhermannia dorsalis</i> (Banks, 1896)	Nna dor	+					
<i>Nanhermannia nana</i> Nicolet, 1855	Nan nan	+	+				
Nothridae							
<i>Nothrus</i> sp.Koch, 1836	Nothrus			+		+	
<i>Nothrus silvestris</i> Nicolet, 1855	Not sil			+			+
Oppiidae							
<i>Berniniella bicarinata</i> (Paoli, 1908)	Ber bic				+		+
<i>Berniniella nr serratirostris</i> (Golosoova, 1970) (<i>Oppia</i>)	Ber ser				+		
<i>Corynoppia kosarovi</i> Jeleva, 1962	Cor kos	+			+		
<i>Dissorhina ornata</i> (Oudemans, 1900)	Dis orn						+
<i>Lauroppia (Oppiella) falcata</i> (Paoli, 1908)	Opp fal			+			+
<i>Medioppia subpectinata</i> (Oudemans, 1900)	Med sub			+	+	+	
<i>Microppia minus</i> Paoli, 1908	Mic min	+	+	+	+		
<i>Oppiella</i> sp.Jacot, 1937	Opp sp						+
<i>Oppiella (Rhinoppia) subpectinata</i> (Oudemans, 1900)	Rhi sub			+			+
<i>Oppiella falcata</i> (Paoli, 1908)	Opp fal			+			
<i>Oppiella nova</i> (Oudemans, 1902)	Opp nov	+	+	+	+		+
<i>Ramusella (l.) elliptica</i> (Berlese, 1908)	Ram ell				+		
<i>Ramusella (l.) insculpta</i> (Paoli, 1908)	Ram ins	+				+	
<i>Ramusella (R.) clavipectinata</i> (Michael, 1885)	Ram cla					+	
<i>Ramusella fasciata</i> (Paoli, 1908)	Ram fas						+
Oribatellidae							
<i>Joelia</i> sp.Oudemans, 1906	Joeli sp	+					
<i>Ophidiotrichus tectus</i> (Michael, 1884)	Oph tec			+			
Oribatulidae							
<i>Lucoppia burrowsi</i> (Michael, 1890)	Luc bur	+					
<i>Oribatula cognata</i> (Oudemans, 1902)	Ori cog				+	+	
<i>Oribatula connexa</i> Berlese, 1904	Ori con				+	+	
<i>Oribatulaⁱ excavata</i> Berlese, 1916	Ori exc						+

<i>Oribatula longelamellata</i> Schweizer, 1956	Ori lon	+			+			
<i>Oribatula undulata</i> (Berlese, 1916)	Ori und			+		+		
Oribotritiidae								
<i>Rhysotritia ardua</i> (C. L. Koch, 1841)	Rhy ard	+				+		
<i>Rhysotritia duplicata</i> (Grandjean, 1953)	Rhy dup			+				
Passalozetidae								
<i>Passalozetes africanus</i> (Grandjean, 1939)	Pas afr							+
Perlohmanniidae								
<i>Perlohmannia dissimilis</i> (Hewitt, 1908)	Per dis							+
Phenopelopidae								
<i>Eupelops occultus</i> (Koch, 1835)	Eup occ	+						+
<i>Eupelops plicatus</i> (Koch, 1836)	Eup pli	+		+				
<i>Eupelops torulosus</i> (Koch, 1840)	Eup tor				+			
<i>Peloptulus gibbus</i> Mihelčič, 1957	Pel gib	+						+
Phthiracaridae								
<i>Phthiracarusc f. anonymus</i> Grandjean, 1934	Pht ano				+			
<i>Phthiracarusc f. compressus</i> Jacot, 1930	Pht com							+
<i>Phthiracarusc f. laevigatus</i> Koch, 1844	Pht lae				+			+
<i>Steganacarus magnus</i> (Nicolet, 1855)	Steg mag				+			
<i>Atropacarus striculus</i> (Koch, 1835)	Atr str	+		+				+
Haplozetidae								
<i>Protoribates capucinus</i> Berlese, 1908	Protb ca	+				+		
Mycobatidae								
<i>Minunthozetes semirufus</i> (Koch, 1841)	Min sem	+				+	+	+
<i>Punctoribates n. hexagonus</i> Berlese, 1908	Pun hex					+		
<i>Punctoribates punctum</i> (Koch, 1839)	Pun pun	+				+	+	
<i>Zachvatkinibates perlongus</i> (Balogh, 1959)	Zac per							+
Quadropiidae								
<i>Quadropia pseudocircumita</i> Minguez et al., 1985	Qua pse				+			

Scheloribatidae

Scheloribates laevigatus (Koch, 1835)

Sch lae + +

Scutoverticidae*Scutovertex sculptus* Michael, 1879

Scuv scu + +

Sphaerochthoniidae*Sphaerochthonius splendidus* (Berlese, 1904)

Sph spl +

Suctobelbidae*Suctobelba* sp.(Paoli, 1908)

Sucb sp +

Suctobelbellanr arcana Moritz, 1970

Suc arc + +

Suctobelbella acutidens (Forsslund, 1941)

Suc acu + +

Suctobelbella falcata (Forsslund, 1941)

Suc fal + + +

Suctobelbella lobata (Strenzke, 1951)

Suc lob +

Suctobelbellanr latirostris (Strenzke, 1950)

Suc lat +

Suctobelbellanr tuberculata (Strenzke, 1950)

Suc tub +

Suctobelbella sarekensis (Forsslund, 1941)

Suc sar +

Suctobelbella similis (Forsslund, 1941)

Suc sim + + +

Suctobelbella sp.Jacot, 1937

Suc sp + + +

Suctobelbella subtrigona (Oudemans, 1916)

Suc sub + +

Tectocepheidae*Tectocepheus velatus* (Michael, 1880)

Tec vel + + + + + + + +

Thyrisomidae*Banksinoma lanceolata* (Michael, 1885)

Ban lan + + +

Pantelozetes paolii (Oudemans, 1913)

Pan pao + +

Pantelozetes sp.(Grandjean, 1953)

Pan sp +

Zetomimidae*Zetomimus furcatus* (Pearce & Warburton, 1906)

Zet fur +

Zetorchestidae*Zetorchestes falzonii* (Coggi, 1898)

Zet fal +

Mesostigmata

Ameroseiidae

Ameroseius corbiculus (Sowerby, 1806)

Ame cor

+

Ascidae

Arctoseius sp. Sig Thor, 1930

Arc to sp

+

Arctoseius cetratus (Sellnick, 1940)

Arc cet

Asca aphidioides (Linné, 1758)

Asc aph

+

+

Asca bicornis (Canestrini et Fanz., 1887)

Asc bic

+

+

+

+

Cheiroseius borealis (Berelese, 1904)

Che bor

Zercoseius spathuliger (Leonardi, 1899)

Zer spa

+

+

Eviphididae

Alliphis sículus (G. et R. Canestrini, 1881)

All sic

+

+

+

Eviphis ostrinus (Koch, 1836)

Evi ost

+

Hypoaspidae

Geolaelaps aculeifer (Canestrini, 1883)

Geo acu

+

+

+

Gymnolaelaps myrmecophilus (Berlese, 1892)

Gym myr

+

Hypoaspis sp. (Canestrini, 1885)

Hypoas sp

+

+

+

Macrochelidae

Macrocheles penicilliger (Berlese, 1904)

Mac pen

+

+

Pachylaelapidae

Pachylaelaps squamifer Berlese, 1920

Pac squ

+

+

Pachylaelaps tessellatus Berlese, 1920

Pac tes

+

Parasitidae

Amblygamasus nr hamatus (C.L. Koch, 1839)

Amb ham

+

Gamasodes sp. (Oudemans, 1939)

Gamaso sp

+

Holoparasitus calcaratus (C. L. Koch, 1839)

Hol cal

+

+

Leptogamasus sp. Trägårdh, 1939

Lepto sp

+

+

Lysigamasus misellus Berlese, 1904

Lys mis

+

Lysigamasus nr armatus Halbert, 1915

Lys arm

+

+

<i>Dinychus arcuatus</i> (Trägårdh, 1943)	Dyn arc								
<i>Dinychus perforatus</i> Krammer, 1882	Dyn per								
<i>Dinychus</i> sp. Kramer, 1882	Dyn sp								+
Uropodidae									
<i>Uropoda minima</i> Kramer, 1882	Uro min		+		+			+	
Veigaiaidae									
<i>Veigaia cerva</i> (Kramer, 1876)	Vei cer		+						
<i>Veigaia exigua</i> (Berlese, 1917)	Vei exi		+						
<i>Veigaia nemorensis</i> (C. L. Koch, 1839)	Vei nem		+						
<i>Veigaia planicola</i> (Berlese, 1892)	Vei pla		+		+				
Zerconidae									
<i>Parazercon radiatus</i> (Berlese, 1914)	Parz rad	+	+					+	
<i>Prozercon kochi</i> (Sellnick, 1943)	Proz koc				+			+	
<i>Prozercon</i> sp. (Trägårdh, 1931)	Proz sp		+						
Prostigmata									
Prostigmata (others)	Prostig				+			+	
Bdellidae									
<i>Bdella</i> sp. Latreille, 1795	Bdella							+	
Cunaxidae									
<i>Cunaxa taurus</i> (Kramer, 1881)	Cun tau				+	+		+	+
Cunaxidae Thor, 1902	Cunaxida							+	
Eupodidae									
<i>Cocceupodes nr paradoxus</i> (Weis-Fogh, 1948)	Cocceupo				+				
<i>Eupodes</i> sp. Koch, 1836	Eupo sp	+	+	+	+	+	+	+	+
<i>Prottereunetes</i> sp. cf Berlese, 1923	Prote sp	+			+				
Eutrombidiidae									
Eutrombidium sp	Eutro sp	+	+						
Nanorchestidae									

<i>Nanorchestes</i> sp. Topsent et Trauessar, 1890	Nanorc sp					+			+
Paratydeidae									
Paratydeidae Baker, 1949	Partydei					+		+	
Pseudocheylidae									
Pseudocheylidae Oudemans, 1909	Pseudoch								+
Pyemotidae									
<i>Pyemotes</i> sp. Amerling, 1861	Pyemotes								+
Pygmephoridae									
<i>Bakerdania</i> sp. Sasa, 1961	Bake sp	+	+	+					+
Rhagidiidae									
<i>Poecilophysis</i> sp. Cambridge, 1876	Poe sp	+	+						
Scutacaridae									
<i>Scutacarus brevipes</i> Mahunka, 1963	Scu brev						+	+	
<i>Scutacarus crassisetus</i> (Paoli, 1911)	Scu cra	+						+	
<i>Scutacarus eucomus</i> (Berlese, 1908)	Scu euc						+		+
<i>Scutacarus lapponicus</i> (Willmann, 1943)	Scu lap						+		+
<i>Scutacarus major</i> (Paoli, 1911)	Scu maj	+							
<i>Scutacarus plumosus</i> (Paoli, 1911)	Scu plu	+						+	+
<i>Scutacarus quadrangularis</i> (Paoli, 1911)	Scu qua	+					+	+	+
<i>Scutacarus spinosus</i> Storkán, 1936	Sci spi	+							
Tarsonemidae									
<i>Steneotarsonemus</i> sp. Beer, 1954	Sten sp								+
<i>Tarsonemus</i> sp. Can. et Fan., 1876	Tar sp	+					+	+	+
Trombidiidae									
<i>Speleorchestes</i> sp. Trägårdh, 1909	Spel sp						+		+
Tydeidae									
<i>Microtydeus</i> sp. Sig Thor, 1931	Mictydea						+		+
Tydeidae P. Kramer, 1877	Tydeid						+		+

Astigmata

Astigmata (others)

Astig

+

+

+

Acaridae

Schwiebea sp. Oudemans, 1916

Schw sp

+

+

+

Tyrophagus sp. Oudemans, 1924

Tyro sp

+

+

+

+

+

+

+

+

628

ⁱ Some species from this genus are considered to be a separate genus, *Zygoribatula*, in Weigmann (2006)