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The maturity index applied to soil gamasine mites from five natural forests in Austria

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Abstract

In this study, we tested the performance of the gamasine mites maturity index of (Ruf, A., 1998. A maturity index for gamasid soil mites (Mesostigmata: Gamsina) as an indicator of environmental impacts of pollution on forest soils. Appl. Soil Ecol. 9, 447–452) in five natural forest reserves in eastern Austria. These sites were assumed to be stable and undisturbed reference habitats. The maturity indices of the gamasine communities were near their maximum in the investigated stands, and thus performed well towards the ''high end'' of the total range of the index. An occasionally inundated floodplain forest yielded much lower values. However, the correlation of the index with humus type, as proposed by Ruf et al. (Ruf, A., Beck, L., Dreher, P., Hund-Rienke, K., Römbke, J., Spelda, J., 2003. A biological classification concept for the assessment of soil quality: ''biological soil classification scheme'' (BBSK). Agric. Ecosyst. Environ. 98, 263–271) for managed forests, was not found. This indicates that the humus form is not a good predictor of the index over its entire range and is inappropriate to assess the fit of test communities. Fourteen percent of the species in this study were omitted from index calculation because adequate data for their families are lacking. They partly belonged to frequent and abundant soil families which urgently need to be included in the scheme. Our results indicate that the gamasine mites maturity index is a promising bioindicative tool, since data collection is comparatively inexpensive and fail-save (individuals must be sorted but not identified, presence/absence data are sufficient) and the results are easily understood and communicated.

Keywords: Maturity index; Gamasine mites; Bioindication; Natural forest reserve; Humus type

1. Introduction

Soil indication and monitoring tools have been traditionally based on chemical and physical site parameters. Currently, they are supplemented by a more ecological approach which considers characteristics of the soil organisms and the composition of their communities.

Gamasine mites meet many of the biological and ecological demands for faunal bioindicators (AK Bioindikation, 1996; Dunger, 1982; Koehler, 1996; Schick, 2000) as do other soil faunal groups such as nematodes (Bongers, 1990, 1999; Bongers and Ferris, 1999) and enchytraeids (Graefe, 1993; Graefe and Belotti, 1999; Graefe and Schmelz, 1999). Gamasina occur in relatively high abundances, however with modest numbers of species (Petersen and Luxton, 1982). Their distribution is worldwide, and as predators, they are at the end of the mesofaunal energy chain (Larink, 1997), thus encompassing the environmental demands of their prey. Gamasine mites are highly susceptible to anthropogenic and natural disturbances and perturbations (Koehler, 1999). The European species are taxonomically well-documented (Karg, 1993).

In an early attempt to use gamasine mites for indication, Karg (1961, 1967, 1968, 1982) tried to

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associate single species with biotope types. However, since most gamasine species are eurytopic, the correlation between biotope type and occurrence of species was generally poor. Thus, current bioindication concepts focus rather on the community features of taxocoenoses. One established example is Bongers' nematode maturity index (Bongers, 1990, 1999; Bongers and Ferris, 1999) which is based on the *r*–*K*-values of families and their frequency at study sites. A related approach has been suggested for gamasine mites by Ruf (1997, 1998, 2000a) and Ruf and Römbke (1999). On the one hand, *K* strategists exhibit a slow life cycle, low egg deposition rate, and small numbers of offspring. They inhabit stable habitats and exhibit almost no seasonal fluctuations in abundance. They are susceptible to disturbance and their potential to colonise new sites is limited. On the other hand, *r* strategists have rapid juvenile development, high egg deposition rates and high numbers of offspring. They reproduce quickly under favourable conditions and have a short life cycle. *r* strategists often inhabit ephemeral and disturbed substrates in high abundance.

According to the position of gamasine families in this *r*–*K* continuum, Ruf (1997, 2000b) assigned them *r*- or *K*-values (3*K*, 2*K*, 1*K* and 4*r*, 3*r*, 2*r*, 1*r*) on an ordinal scale. The gamasine maturity index expresses the proportion of *K*-values to the sum of the *r*- and *K*-values of all species of a sampled community. The minimum index value is zero (no *K* strategists at the site), the maximum is 1 (all species are *K* strategists). In a heavily or frequently disturbed ecosystem the index is expected to be low since *r* strategists prevail, and high in undisturbed ecosystems. The index portrays anthropogenic disturbance in the same way as natural disturbance.

In a recent attempt to adopt a limnological bioindication scheme (Wright et al., 2000) for soil fauna, German scientists developed the "Biological Soil Classification Scheme" (Römbke et al., 2000; Ruf et al., 2003) which groups sites into biotope types. A characteristic faunal community is described for each soil type, which subsequently serves as a reference for assessment of the soil quality of test sites. A range of expected values may be given for structural parameters (e.g. species number) of the reference communities, and sites falling outside this range are easily identified and their deviations quantified.

Ruf and co-workers determined reference ranges of the gamasine maturity index for a number of sites in Baden-Württemberg (Germany) (Ruf and Römbke, 1999; Ruf et al., 1999, 2003). They discovered that for forests the values formed groups and that the humus type could serve as the key clustering parameter. Maturity index values for mull humus ranged from 0.58 to 0.75, for mor from 0.73 to 0.81, and for raw humus from 0.81 to 0.82. It was assumed that the decomposition processes of the humus forms impose different levels of disturbance for the fauna, which are reflected in the maturity index.

In the present study, we analysed the community of gamasine mites in five natural forests in Eastern Austria. These stands have a very low level of anthropogenic influence, form a gradient of humus types from mull to acidic mor, and are thus excellent test sites for the calculation of the maturity index. We show here that the index performs well with respect to the disturbance level (hemeroby – a measure of unnaturalness of human impact, Hill et al., 2002) of the stands; however, it is not related to humus type.

2. Materials and methods

We report on the analysis of the soil gamasine fauna from five natural forest stands (Table 1) as part of a recent project (Hackl et al., 2004a, 2004b; Hackl et al., 2005; Zechmeister-Boltenstern et al., 2005). Each forest stand represents one of the major forest types of Eastern Austria (Kilian et al., 1993). The sites are included in the Austrian Natural Forests Program which selected forests for development without human intervention (Parviainen and Frank, 2003). Two of the stands (Rothwald and Merkenstein) are true primeval forests.

All study sites were sampled once in the autumn of 2001. At each stand, 100 samples were taken from a 100×30 m area on a regular grid with a soil corer

Table 1
Characteristics of the investigated natural forests in Eastern Austria (data partly after Hackl, 2005)

Site	Forest community	Forest type	Elevation (m above sea level)	Humus type	pH
Rothwald (47°46′N, 15°07′E)	Adenostylo glabrae-Fagetum	Spruce-fir-beech	1035	Mull/mor	4.9 ± 0.4
Saubrunn (48°32′N, 15°33′E)	Luzulo-Fagenion	Acidophilous beech	540	Acid mor	4.0 ± 0.0
Kolmberg (47°58′N, 16°41′E)	Carici pilosae-Carpinetum	Oak-hornbeam	345	Mor/mull	5.4 ± 0.3
Merkenstein (47°59′N, 16°07′E)	Euphorbio saxatilis-Pinetum nigrae	Austrian pine	620	Eroded mull	7.2 ± 0.0
Müllerboden (48°00′N, 16°42′E)	Pruno-Fraxinetum	Floodplain	160	Typical mull	7.4 ± 0.0

Table 2
Soil gamasine mite species from five natural forest stands in Austria with their *r*–*K*-values, abundance and frequency

Species	*r*–*K*-values	Rothwald	Saubrunn	Kolmberg	Merkenstein	Müllerboden
		Abundance [Ind m^{-2}] (Frequency in aliquots (%))				
Amblygamasus galeatellus (Parasitidae), ATHIAS-HENRIOT, 1967	2*K*	–	–	–	338.2 (53.3)	–
Amblygamasus longispinosus (Parasitidae), HOLZMANN, 1969	2*K*	–	–	56.4 (13.3)	–	–
Amblygamasus mirabilis (Parasitidae), WILLMANN, 1951	2*K*	28.2 (6.7)	–	140.9 (13.3)	–	–
Cheiroseius furcatus (Ascidae), KARG, 1973	1*r*	112.7 (13.3)	–	–	–	–
Eugamasus berlesei (Parasitidae), (WILLMANN, 1935)	4*r*	–	–	–	–	56.4 (13.3)
Euryparasitus sp. (Rhodacaridae)	2*K*	–	–	169.1 (30.8)	28.2 (6.7)	–
Epicrius stellatus (Epicriidae), BALLOGH, 1959	–	366.4 (46.7)	–	–	–	–
Eviphis ostrinus (Eviphididae), (KOCH, 1836)	–	28.2 (6.7)	–	28.2 (6.7)	–	253.7 (33.3)
Gamasellus montanus (Rhodacaridae), (WILLMANN, 1936)	2*K*	–	338.2 (53.3)	–	–	–
Geholaspis berlesei (Machrochelidae), VALLE, 1953	–	–	–	56.4 (13.3)	–	–
Geholaspis longispinosus (Machrochelidae), (KRAMER, 1876)	–	–	–	–	–	28.2 (6.7)
Geholaspis mandibularis (Machrochelidae), (BERLESE, 1904)	–	28.2 (6.7)	–	–	28.2 (6.7)	56.4 (13.3)
Geholaspis pauperior (Machrochelidae), (BERLESE, 1918)	–	394.6 (53.3)	–	–	–	–
Geholaspis sp. (Machrochelidae)	–	–	56.4 (13.3)	–	–	–
Holoparasitus coronarius (Parasitidae), KARG, 1971	2*K*	–	84.6 (13.3)	366.4 (46.7)	–	–
Holoparasitus tirolensis (Parasitidae), (SELLNICK, 1968)	2*K*	–	28.2 (6.7)	84.6 (20.0)	–	–
Holostaspella sp. (Machrochelidae)	–	–	–	–	–	84.6 (20.0)
Hypoasis angusticutata (Hypoaspididae), WILLMANN, 1951	1*r*	–	–	–	–	140.9 (26.7)
Hypoaspis helianthi (Hypoaspididae), SAMŠINAK, 1958	1*r*	–	–	–	28.2 (6.7)	–
Hypoaspis nolli (Hypoaspididae), KARG, 1962	1*r*	–	–	–	–	28.2 (6.7)
Hypoaspis praesternalis (Hypoaspididae), WILLMANN, 1949	1*r*	–	–	–	197.3 (26.7)	–
Hypoaspis sp. (Hypoaspididae)	1*r*	–	253.7 (33.3)	225.5 (53.3)	–	–
Leptogamasus afobeus (Parasitidae), (ATHIAS-HENRIOT, 1970)	2*K*	84.6 (6.7)	–	–	–	–
Leptogamasus bidens (Parasitidae), (SELLNICK, 1951)	2*K*	28.2 (6.7)	–	56.4 (13.3)	–	–
Leptogamasus callicrus (Parasitidae), (ATHIAS-HENRIOT, 1967)	2*K*	–	56.4 (13.3)	–	–	–
Leptogamasus drassus (Parasitidae), (ATHIAS-HENRIOT, 1970)	2*K*	–	–	–	56.4 (6.7)	–
Leptogamasus lobatus (Parasitidae), (WILLMAN, 1951)	2*K*	–	28.2 (6.7)	–	–	–
Leptogamasus notigius (Parasitidae), ATHIAS-HENRIOT, 1970	2*K*	253.7 (60.0)	–	–	–	–
Leptogamasus oxalis (Parasitidae), KARG, 1968	2*K*	140.9 (20.0)	–	–	–	–
Leptogamasus oxygynelloides (Parasitidae), (KARG, 1968)	2*K*	–	197.3 (40.0)	620.1 (60.0)	394.6 (60.0)	197.3 (33.3)

Table 2 (*Continued*)

Species	*r–K*-values	Rothwald	Saubrunn	Kolmberg	Merkenstein	Müllerboden
Leptogamasus pannonicus (Parasitidae), (WILLMAN, 1951)	2*K*	56.4 (6.7)	873.8 (70.0)	338.2 (46.7)	197.3 (46.7)	–
Leptogamasus pertelicrus (Parasitidae), ATHIAS-HENRIOT, 1967	2*K*	–	930.2 (73.3)	394.6 (60.0)	28.2 (6.7)	–
Leptogamaus tectegynellus (Parasitidae), (ATHIAS-HENRIOT, 1967)	2*K*	648.3 (60.0)	–	–	–	–
Lysigamasus crassicornutus (Parasitidae), WILLMANN, 1954	2*K*	310.1 (53.3)	253.7 (40.0)	–	–	–
Lysigamasus cuneatus (Parasitidae), KARG, 1968	2*K*	–	–	–	–	28.2 (6.7)
Lysigamasus resinae (Parasitidae), KARG, 1968	2*K*	–	–	281.9 (40.0)	–	–
Lysigamasus runcatellus (Parasitidae), (BERLESE, 1903)	2*K*	–	84.6 (13.3)	–	–	–
Lysigamasus truncellus (Parasitidae), ATHIAS-HENRIOT, 1967	2*K*	–	761.0 (86.7)	–	–	–
Lysigamasus vagabundus (Parasitidae), KARG, 1968	2*K*	–	169.1 (33.3)	–	225.5 (40.0)	84.6 (13.3)
Machrochelidae sp. (Machrochelidae)	–	–	–	–	28.2 (6.7)	–
Pachylaelaps pectinifer (Pachylaelapidae), (G.et R. CANESTRINI, 1882)	1*K*	–	–	–	–	28.2 (6.7)
Pachylaelaps sp. (Pachylaelapidae)	1*K*	–	28.2 (6.7)	–	–	–
Pachyseius humeralis (Machrochelidae), BERLESE, 1910	–	–	28.2 (6.7)	–	–	169.1 (26.7)
Pergamasus barbarus (Parasitidae), BERLESE, 1904	2*K*	–	–	–	56.4 (13.3)	–
Pergamasus crassipes (Parasitidae), (LINNÉ, 1758)	2*K*	–	28.2 (6.7)	28.2 (6.7)	–	–
Pergamasus giganteus (Parasitidae), WILLMANN, 1932	2*K*	–	–	112.7 (13.3)	–	–
Pergamasus mediocris (Parasitidae), BERLESE, 1904	2*K*	169.1 (26.7)	–	–	–	–
Pergamasus rühmi (Parasitidae), WILLMANN, 1938	2*K*	–	169.1 (33.3)	281.9 (53.3)	28.2 (6.7)	–
Prozercon halaskovae (Zerconidae), PETROVA, 1977	3*K*	–	–	28.2 (6.7)	–	–
Prozercon ornatus (Zerconidae), (BERLESE, 1904)	3*K*	–	–	–	28.2 (6.7)	–
Prozercon traegardhi (Zerconidae), (HALBERT, 1923)	3*K*	310.1 (60.0)	112.7 (20.0)	563.7 (60.0)	451.0 (60.0)	–
Pseudoparasitus centralis (Hypoaspididae), (BERLESE, 1921)	1*r*	–	–	–	–	28.2 (6.7)
Pseudoparasitus myrmophilus (Hypoaspididae),(MICHAEL, 1891)	1*r*	169.1 (20.0)	–	–	–	–
Pseudoparasitus myrmecophilus (Hypoaspididae), (BERLESE, 1892)	1*r*	84.6 (20.0)	–	197.3 (33.3)	28.2 (6.7)	–
Rhodacarus aequalis (Rhodacaridae), KARG, 1971	2*K*	84.6 (20.0)	–	84.6 (6.7)	–	–
Rhodacarus clavulatus (Rhodacaridae), ATHIAS-HENRIOT, 1961	2*K*	–	–	394.6 (60.0)	–	–
Rhodacarus coronatus (Rhodacaridae), BERLESE, 1921	2*K*	–	281.9 (46.7)	–	–	–
Rhodacarus longisetosus (Rhodacaridae), SHCHERBAK, 1980	2*K*	–	–	–	338.2 (46.7)	–
Rhodacarellus epigynalis (Rhodacaridae), SHEALS, 1956	2*K*	–	140.9 (20.0)	–	–	–
Rhodacarellus subterraneus (Rhodacaridae), WILLMANN, 1935	2*K*	–	–	–	169.1 (26.7)	28.2 (6.7)

Table 2 (*Continued*)

Species	*r–K*-values	Rothwald	Saubrunn	Kolmberg	Merkenstein	Müllerboden
Veigaia nemorensis (Veigaiaidae), (C.L. KOCH, 1839)	2*K*	1691.2 (93.3)	1099.3 (80.0)	902.0 (66.7)	479.2 (66.7)	394.6 (46.7)
Veigaia sp. (Veigaiaidae)	2*K*	761.0 (60.0)	140.9 (26.7)	–	–	–
Zercon echinatus (Zerconidae), SCHWEIZER, 1922	3*K*	169.1 (26.7)	–	–	–	–
Zercon fageticola (Zerconidae), HALAŚKOVÁ, 1970	3*K*	–	56.4 (13.3)	28.2 (6.7)	56.4 (13.3)	–
Zercon peltatus (Zerconidae), C.L. KOCH, 1836	3*K*	–	112.7 (20.0)	–	–	–
Zercon montanus (Zerconidae), WILLMANN, 1953	3*K*	–	–	–	56.4 (13.3)	–
Zercon polonicus (Zerconidae), BLASZAK, 1970	3*K*	–	84.6 (20.0)	–	–	–
Zercon triangularis (Zerconidae), C.L. KOCH, 1836	3*K*	–	–	28.2 (6.7)	140.9 (26.7)	
Zercon vacuus (Zerconidae), C.L. KOCH, 1839	3*K*	–	–	281.9 (40.0)	–	–
Zercon vitiosus (Zerconidae), MIHELCIC, 1962	3*K*	–	–	–	28.2 (6.7)	–
Zercon sp. (Zerconidae)	3*K*	–	–	–	56.4 (13.3)	–

(5 cm × 5 cm × 10 cm deep). The cores were extracted with a modified Macfadyen High-Gradient Canister Extractor into 10% aqueous sodium benzoate solution (Zehetner, 2002). The arthropods in the 100 extracts were bulked into one sample, from which 15 aliquots were taken for mite enumeration (Bruckner et al., 2000). Gamasine mites were identified with the key of Karg (1993).

The gamasine maturity index of each study site was calculated as the proportion of *K*-values to the sum of the *r* and *K*-values of all species of a sampled community.

$$\mathrm{MI} = \frac{\sum_{i=1}^{s} K_i}{\sum_{i=1}^{s} K_i + \sum_{i=1}^{s} r_i}$$

where S is the species number, *K* the *K*-value, and *r* the *r*-value for the family of species *i* (Ruf, 1997).

In order to assess how many of the species of the communities were effectively found in the samples, species saturation plots (extrapolations of species accumulation curves) were computed by EstimateS 7.5 (Colwell, 2005). The abundance-based coverage estimator (ACE) was applied and 10,000 randomizations were conducted.

3. Results

Altogether, 71 gamasine species were identified, 21 of them new to the fauna of Austria (Table 2).

The species saturation plot (Fig. 1) shows that 59–79% of the species predicted at the sites were found in the aliquots. Thus, the sampling procedure was adequate and provided reliable information on the species‘ diversity and correctly estimated the maturity index. The probability of inducing bias by missing species is especially high in stands with low species richness and when the proportion of rare species is high. In our study this danger was not great, because species richness was high and the fraction of *r* strategists in the communities may reasonably be considered low in old growth forests.

The maturity index was as high as ≥0.90 for four of the sites (Table 3), this value far exceeds the range expected from the respective humus types (Ruf and Römbke, 1999; Ruf et al., 1999, 2003). The floodplain

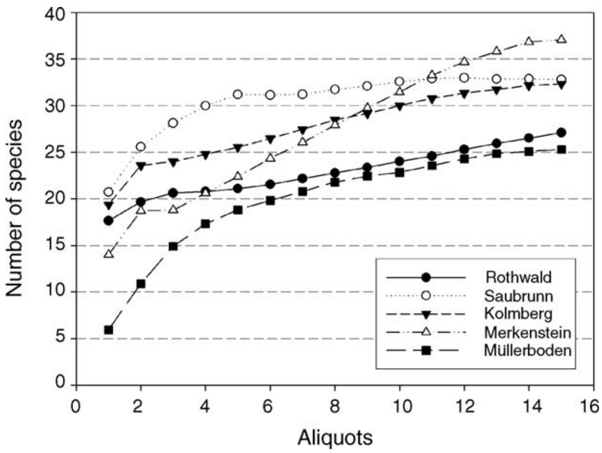

Fig. 1. Sample-based species accumulation plots of soil gamasine mite species in five natural forest stands in Austria.

Table 3
Predicted (from Ruf et al., 2003) and observed values of the gamasine maturity index for five natural forest stands in Austria

Sites	Species number	Predicted MI values	Observed MI values	Evaluation	Range of possible MI[a]	MI values if frequency included	Not assigned
Rothwald	21 (5)	0.58–0.75	0.90	[b]	0.61–0.93	0.96	4
Saubrunn	26 (8)	0.73–0.81	0.98	[b]	0.84–0.98	0.98	2
Kolmberg	25 (7)	0.73–0.81	0.96	[b]	0.82–0.96	0.96	2
Merkenstein	24 (5)	0.58–0.75	0.94	[b]	0.80–0.94	0.97	2
Müllerboden	15 (5)	0.58–0.75	0.63	[c]	0.34–0.77	0.80	4

() = new for Austria.
[a] If the missing species are calculated either as extreme values 3*K* or 4*r*.
[b] = Not in agreement with Ruf.
[c] = In agreement with Ruf; MI: Maturity Index (Ruf, 1998); not assigned = number of species for which *r* - *K*-values are still missing.

forest Müllerboden scored lower (0.63) and was well within the reported range for mull humus (Table 3). Including the species' frequency in the calculations yielded the same ordering of sites (Table 3) although the absolute index values became more similar.

The vast majority of species were *K* strategists, most of them 2*K* (Fig. 2). The life history classes 2*r* and 3*r* were not detected in the material and only one 4*r* species was recorded in the floodplain forest Müllerboden.

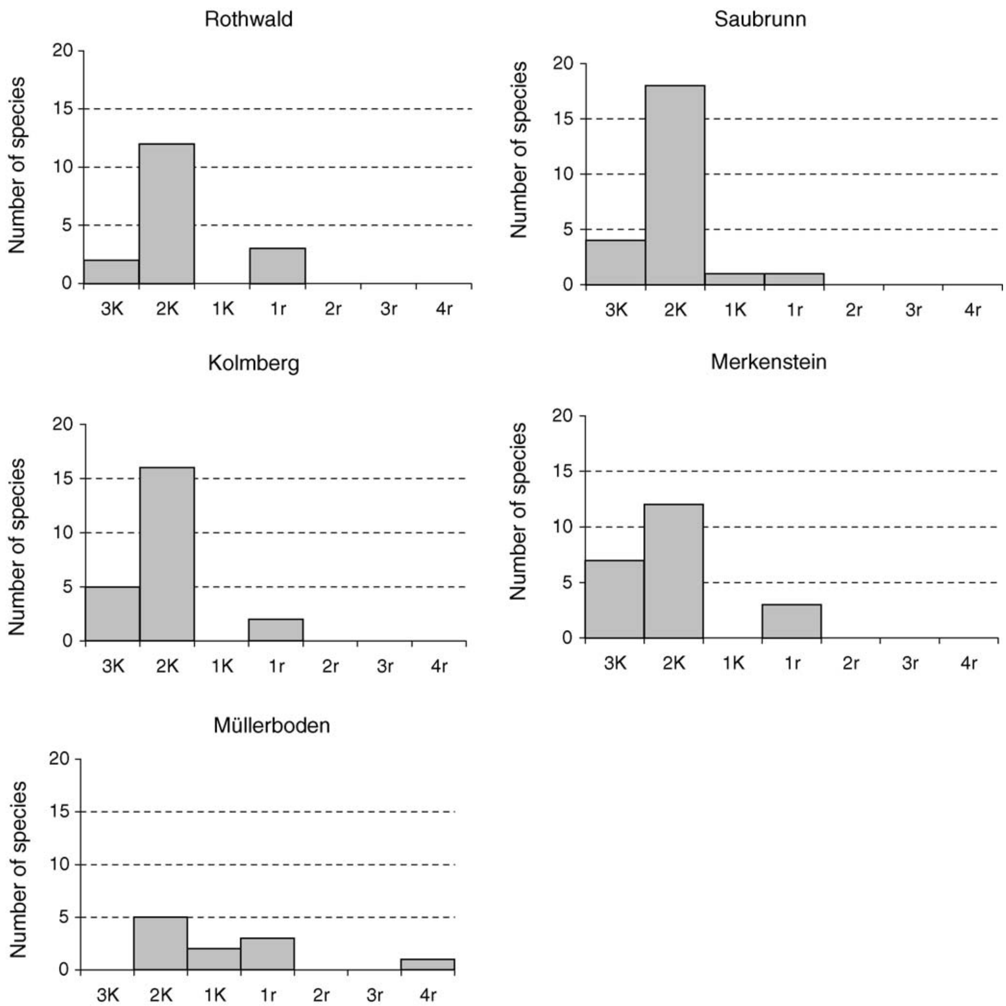

Fig. 2. Frequency distribution of life history classes of soil gamasine mite species in five natural forests stands in Austria.

About 14% of the sampled species could not be assigned *r* or *K*-values (Table 3) because their families are not classified in Ruf (1997, 2000b). This did not affect the performance of the index: if the species without assignment were all either treated as 3*K* or 4*r* (that is, the extreme ends of the scale), the sites remained ranked in the same order.

4. Discussion and conclusion

The maturity index of the gamasine communities of the four natural forests ranged near the maximum value of 1. This suggests that our study sites are very stable and undisturbed habitats, as may be expected for old growth forests without significant human intervention for considerable time. Thus, the maturity index performed well towards the ''high end'' of its range. At one location, Müllerboden, the gamasine maturity index was much lower (0.63). Müllerboden is a floodplain forest, which is dammed from the river nearby, but occasionally inundated by rising groundwater. Such events can set back the successional stage of soil communities (Russell et al., 2002) and lower the gamasine maturity index.

The maturity indices of the terrestrial natural forests were far from the values expected from the humus type (Ruf and Römbke, 1999; Ruf et al., 1999, 2003). This indicates that humus type is not a good predictor of the index over its entire range and may not be suited to categorise site parameters to assess the deviations of test communities from the ''norm''. If the index value is near 1, the maturity of gamasine communities is seemingly more influenced by parameters other than humus type and does not follow the ''humus gradient'' that Ruf and co-workers found for managed forests.

The threshold values (Table 3) for the maturity index in Ruf et al. (2003) were based on 15 previously published species lists and 10 additionally evaluated stands (Ruf et al., 1999; Ruf et al., 2003). This number is obviously too limited to allow a reliable assessment scheme. For example, the biological classification of British running waters (Wright et al., 2000) is currently based on 614 sampled sites. Thus, for the future development of the index, many more sites should be investigated to formulate a technically mature assessment scheme.

Another obstacle for the practical use of the index is that *r*- *K*-values are still missing for several families, because their life-history traits are not sufficiently known. Among these are the Epicriidae, Eviphididae and Machrochelidae that are biologically too heterogeneous to receive a single index value. The genus *Macrocheles*, for example, includes both phoretic species with rapid development and other pronounced *r* features and predominantly forest inhabiting species that are best assigned a high *K* value (Ruf, pers. comm.). Species of the Epicriidae and Eviphididae rarely appear in soil and disregarding them if occasionally encountered should not significantly bias the index.

However, despite all shortcomings and data gaps, the maturity index for gamasine mites is promising for the assessment of soil quality and monitoring. In contrast to other bioindication schemes for soil animals (e.g. for Oligochaeta, Graefe, 1993; Graefe and Belotti, 1999; Graefe and Schmelz, 1999), individuals must be sorted, but not identified to species. It is sufficient to classify them in taxonomic groups at species level (i.e. morphospecies that do not have to be assigned to a known species name but can just be numbered consecutively). This saves time and decreases the danger of misidentification. Critical identification need only be performed at the family level, since (with few exceptions) the *r*–*K*-values do not vary within families. Another advantage is that presence/absence data are sufficient for calculating the index. Nevertheless, to avoid biasing the index by the low probability of recovering rare species, the sampling has to be as comprehensive as possible, for example by compositing large numbers of cores (Bruckner et al., 2000). To counteract the influence of rare species, the maturity index for nematodes (Bongers, 1990, 1999; Bongers and Ferris, 1999) weighs species occurrences by their frequencies in the sample. Ruf (1997, 1998) did not consider this when developing the gamasine index. The abundances of the mites are two to three orders of magnitude lower than those of nematodes and many species are found only as single specimens. Thus, the differences in frequency between dominant and rare species are much lower than for nematodes, and the effects of weighing are considered insignificant (Ruf, per. comm.). The data from this study support these assumptions: we recalculated the maturity index including the frequencies and this yielded the same ordering of sites. However, the absolute index values became more similar, that is, the gamasine index better discriminated among sites.

Finally, the index has a strong appeal for the broader public, because its message is easy to understand and communicate. ''Maturity'' is a familiar concept for everybody, therefore study results do not have to be interpreted or translated to be comprehended by policy makers and other lay persons.

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References

Bioindikation, A.K., 1996. Begriffsdefinitionen zur Bioindikation. UWSF – Z. Umweltchem. Ökotox. 8 (3), 169–171.

Bongers, T., 1990. The maturity index: an ecological measure of environmental disturbance based on nematode species composition. Oecologia 83, 14–19.

Bongers, T., 1999. The maturity index, the evolution of nematode life-history traits, adaptive radiation and cp-scaling. Plant Soil 212, 13–22.

Bongers, T., Ferris, H., 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends Ecol. Evol. 14, 224–228.

Bruckner, A., Barth, G., Scheibengraf, M., 2000. Composite sampling enhances the confidence of soil microarthropod abundance and species richness estimates. Pedobiologia 44, 63–74.

Colwell, R. K., 2005. Estimates: statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application published at: http://purl.oclc.org/estimates.

Dunger, W., 1982. Die Tiere als Leitformen für anthropogene Umweltveränderungen. Decheniana Beihefte 26, 151–157.

Graefe, U., 1993. Die Gliederung von Zersetzergesellschaften für die standortökologische Ansprache. Mitt. Dtsch. Bodenkundl. Gesellsch. 69, 95–98.

Graefe, U., Belotti, E., 1999. Strukturmerkmale der Bodenbiozönose als Grundlage für ein natürliches System der Humusformen. Mitt. Dtsch. Bodenkundl. Gesellsch. 89, 181–184.

Graefe, U., Schmelz, R.M., 1999. Indicator values, strategy types and life forms of terrestrial Enchytraeidae and other microannelids. Newslett. Enchytraeidae 6, 59–67.

Hackl, E., Bachmann, G., Zechmeister-Boltenstern, S., 2004a. Microbial nitrogen turnover in soils under different types of natural forest. Forest Ecol. Manage. 188, 101–112.

Hackl, E., Zechmeister-Boltenstern, S., Bodrossy, L., Sessitsch, A., 2004b. Comparative diversity and composition of bacteria inhabiting natural forest soils. Appl. Environ. Microb. 70 (9), 5057–5065.

Hackl, E., Pfeffer, M., Donat, C., Bachmann, G., Zechmeister-Boltenstern, S., 2005. Composition of the microbial communities in the mineral soil under different types of natural forest. Soil Biol. Biochem 37, 661–671.

Hill, M.O., Roy, D.B., Thompson, K., 2002. Hemeroby, urbanity and ruderality: bioindicators of disturbance and human impact. J. Appl. Ecol. 39, 708–720.

Karg, W., 1961. Ökologische Untersuchungen an edaphischen Gamasiden (Acari, Parasitiformes). Pedobiologia 1, 53–98.

Karg, W., 1967. Synökologische Untersuchungen von Bodenmilben aus forstwirtschaftlich und landwirtschaftlich genutzten Böden. Pedobiologia 7, 198–214.

Karg, W., 1968. Bodenbiologische Untersuchungen über die Eignung von Milben, insbesondere von parasitiformen Raubmilben, als Indikatoren. Pedobiologia 8, 30–39.

Karg, W., 1982. Untersuchungen über Habitatansprüche, geographische Verbreitung und Entstehung von Raubmilbengattungen der Cohors Gamasina für ihre Nutzung als Bioindikatoren. Pedobiologia 24, 241–247.

Karg, W., 1993. Acari (Acarina), Milben Parasitiformes (Anactinochaeta) Cohors Gamasina Leach. Die Tierwelt Deutschlands 59, 523.

Koehler, H.H., 1996. Soil animals and bioindication. In: Van Straalen, N.M., Krivolutsky, D.A. (Eds.), Bioindicator Systems for Soil Pollution. Kluwer Academic Publishers, London, pp. 179–188.

Koehler, H., 1999. Predatory mites (*Gamasina*, Mesostigmata). Agric, Ecosyst. Environ. 74, 394–410.

Kilian, W., Müller, F., Starlinger, F., 1993. Die forstlichen Wuchsgebiete Österreichs. Eine Naturraumgliederung nach waldökologischen Gesichtspunkten. FBVA-Berichte 82, 1–60.

Larink, O., 1997. Springtails and mites: important knots in the food web of soils. In: Benckiser, G. (Ed.), Fauna in Soil Ecosystems. Dekker Inc.,, New York, pp. 225–264.

Parviainen, J., Frank, G., 2003. Protected forests in Europe approaches harmonising the definitions for international comparison and forest policy making. J. Environ. Manage. 67, 27–36.

Petersen, H., Luxton, M., 1982. A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos 39, 287–388.

Römbke, J., Dreher, P., Beck, L., Hammel, W., Hund, K., Knoche, H., Kördel, W., Kratz, W., Moser, T., Pieper, S., Ruf, A., Spelda, J., Woas, S., 2000. Bodenbiologische Bodengüte-Klassen. UBA-Texte 6/00, 276.

Ruf, A., 1997. Fortpflanzungsbiologie von Raubmilben und Charakerisierung von Böden – Ein Konzept zur Indikation von Belastungszuständen von Böden. Abh. Ber. Naturkundemus. Görlitz 69 (2), 209–216.

Ruf, A., 1998. A maturity index for gamasid soil mites (Mesostigmata: Gamsina) as an indicator of environmental impacts of pollution on forest soils. Appl. Soil Ecol. 9, 447–452.

Ruf, A., 2000a. Die Raubmilbenfauna als Indikator für Bodenqualität – was zeigen Milben an, das Regenwürmer nicht können? Abh. Ber. Naturkundemus. Görlitz 72 (I), 121–133.

Ruf, A., 2000b. Die Raubmilben des Hardtwaldes bei Bruchsal – Beobachtungen an verschiedenen Experimentalflächen über zwei Jahre. Carolinea 58, 183–193.

Ruf, A., Römbke, J., 1999. Beurteilung von Bodenqualität mit Hilfe von Bodentieren. In: Köehler, H., Mathes, K. (Eds.), Bodenökologie interdisziplinär. Springer, Berlin, pp. 119–132.

Ruf, A., Beck, L., Hammel, W., Hund, K., Kratz, W., Römbke, J., Spelda, J., 1999. Grundlagen zur Erarbeitung eines Bewertungsrahmens für die Bodenfunktion ''Lebensraum für Bodenorganismen''. Teil II: Erste Ergebnisse zur Anwendung von bodenkundlich/bodenbiologisch definierten Standorttypen. Mitt. Dtsch. Bodenkundl. Gesellsch. 89, 177–180.

Ruf, A., Beck, L., Dreher, P., Hund-Rienke, K., Römbke, J., Spelda, J., 2003. A biological classification concept for the assessment of soil quality: ''biological soil classification scheme'' (BBSK). Agric. Ecosyst. Environ. 98, 263–271.

Russell, D.J., Schick, H., Nährig, D., 2002. Reaction of soil Collembolan communities to inundation in floodplain ecosystems of the

Upper Rhine Valley. In: Broll, G., Merbach, W., Pfeiffer, E. (Eds.), Wetlands in Central Europe. Springer-Verlag, Berlin, pp. 35–68.

Schick, H., 2000. Biomonitoring im Boden – Anmerkung zur Bewertung bodenfaunistischer Untersuchungen. Ber. Nat. -Med. Verein Innsbruck 87, 381–388.

Wright, J.F., Sutcliffe, D.W., Furse, M.T. (Eds.), 2000. Assessing the biological quality of fresh waters: RIVPACS and other techniques. Freshwater Biological Association, Ambleside, UK, p. 397.

Zehetner, K., 2002. Optimierung des Extraktionsapparates für Bodentiere nach Macfadyen. Diploma thesis, Univ. Vienna, 60 pp.

Zechmeister-Boltenstern, S., Hackl, E., Bachmann, G., Pfeffer, M., Englisch, M., 2005. Nutrient turnover, greenhouse gas exchange and biodiversity in natural forests of Central Europe. In: Binkley, D., Menyailo, O., (Eds.), Tree Species Effects on Soils: Implications for Global Change. NATO Science Series. IV. Earth and Environmental Sciences, Berlin, vol. 55, pp. 31–49.