

Pseudoscorpions (Arachnida: Pseudoscorpiones) in Strict Forest Reserves in Hesse (Germany)

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Abstract. In 1990 the Federal State of Hesse (Germany) started a long-term faunistic research programme in selected Strict Forest Reserves. Here we report the results of the inventory of pseudoscorpions from seven reserves: Goldbachs- und Ziebachsrück, Hasenblick, Hohestein, Kinzigau, Niddahänge east of Rudingshain, Schönbuche and Stirnberg. A total of 4567 specimens (315-1314 per site) belonging to 13 species (4-9 per site) were recorded using a broad spectrum of methods. The bulk of material comes from pitfall traps (83 %), followed by various types of stem eclectors (16 %). The structure and quality of the species assemblage in the oak-dominated flood plain forest of the Kinzigau differs strongly from those of the remaining reserves, which are all dominated by beech. In the Kinzigau a species-rich community (9 species) with balanced dominance structure (Shannon-Index 1.67) has been recorded. At this site, rare or moderately common species reach abundance proportions of more than 50 %. Most importantly, two species with strong affinities to pristine forests, *Dendrochernes cyrneus* and *Chernes cimicoides*, were exclusively recorded from this reserve. In contrast, the beech-dominated reserves were strongly dominated by a single species, *Neobisium carcinoides* (59-91 % of the specimens, Shannon-Index < 1), and the abundance proportion of the very common species exceeded 90 % in each of these areas. Temperature and altitude determine the composition of the species communities significantly. Of the recorded species, two will be categorized in the forthcoming Red Lists of pseudoscorpions of Germany and Hesse. *Dendrochernes cyrneus* (cat. 3 "vulnerable") reached an abundance proportion of 20 % in the reserve Kinzigau. *Dinocheirus panzeri* (cat. G "indeterminate risk") has been recorded in single specimens from the reserves Hasenblick, Stirnberg and Niddahänge. The preferred habitat for most of the species is the forest. Species with strong affinities to forests make up more than 95 % of the specimens in all reserves except for Kinzigau, where this proportion was 89 %. Species richness and abundances were not different between the Strict Forest Reserves (management was stopped at the end of the 1980's) and the reference areas with continued forestry. However, the proportions of rare and moderately common species were higher in the Strict Reserves as compared to the reference areas.

Keywords: Central Europe, *Fagus sylvatica*, nature conservation, old growth forests

Zusammenfassung. Pseudoskorpione (Arachnida: Pseudoscorpiones) aus hessischen Naturwaldreservaten. In ausgewählten hessischen Naturwaldreservaten (NWR) werden seit 1990 zoologische Langzeituntersuchungen durchgeführt. Es werden die Ergebnisse zu den Pseudoskorpionen aus sieben hessischen NWR vorgestellt: Goldbachs- und Ziebachsrück, Hasenblick, Hohestein, Kinzigau, Niddahänge östlich Rudingshain, Schönbuche und Stirnberg. Insgesamt wurden 4567 Individuen (315-1314 pro Gebiet) aus 13 Arten (4-9 pro Gebiet) mit einem breiten Methodenspektrum erfasst. Der Großteil des Materials stammt aus Bodenfallen (83 %) und verschiedenen Typen von Stammeklektoren (16 %). Die Struktur und Qualität der Artengemeinschaften unterscheidet sich sehr stark zwischen dem Stieleichen-dominierten Hartholzauwald der Kinzigau und den Buchenwald-Naturwaldreservaten (alle übrigen Gebiete). Im NWR Kinzigau wurde eine artenreiche Zönose (9 Arten) mit ausgeglichener Dominanzstruktur angetroffen (Shannon-Index 1,67). Seltene und mäßig häufige Arten erreichen hier Individuenanteile von mehr als 50 %, vor allem aber wurden die an ursprüngliche Wälder gebundenen Arten *Dendrochernes cyrneus* und *Chernes cimicoides* ausschließlich hier festgestellt. Im Gegensatz dazu werden die Buchenwald-NWR sehr stark von *Neobisium carcinoides* dominiert (59-91 % der Individuen, Shannon-Index < 1) und der Individuenanteil sehr häufiger Arten liegt in diesen sechs Gebieten bei > 90 %. Temperatur und Höhenlage der Gebiete zeigen signifikanten Einfluss auf die Zusammensetzung der Artengemeinschaften. Zwei der nachgewiesenen Pseudoskorpion-Arten werden in den Roten Listen Deutschlands und Hessens (Arbeitsversion) gelistet sein. *Dendrochernes cyrneus* (Kat. 3 „gefährdet“) erreicht im NWR Kinzigau einen Individuenanteil von 20 %. *Dinocheirus panzeri* (Kat. G „Gefährdung unbekanntes Ausmaßes“) wurde in Einzelexemplaren in den NWR Hasenblick, Stirnberg und Niddahänge erfasst. Die Mehrzahl der nachgewiesenen Pseudoskorpion-Arten besitzt ihren Verbreitungsschwerpunkt im Wald. Waldarten im engeren Sinne erreichen in allen Untersuchungsgebieten Individuenanteile von > 95 %, außer im NWR Kinzigau, wo der Anteil bei 89 % liegt. Die Ende der 1980er aus der Nutzung genommen Totalreservate unterscheiden sich von weiterhin bewirtschafteten Vergleichsflächen hinsichtlich der Arten- und Individuenzahlen kaum. Die Arten- und Individuenanteile seltener und mäßig häufiger Arten sind jedoch in den Totalreservaten deutlich höher als in den Vergleichsflächen.

The knowledge on the distribution and the preferred habitats of pseudoscorpions in Germany is lower than in other arachnid groups, i.e. spiders and harvestmen (Muster & Blick in press). This is reflected in the comparatively low numbers of grid squares with records per species, which is on average 21 for pseudoscorpions, 105 for harvestmen and 141 for spiders (Staudt 2014, based on 1:25000 maps with a total of 3000 grid squares in Germany). The group is still rarely used in applied studies, biodiversity projects, etc. Nevertheless, the group contains a fairly high number of specialized species of certain endangered habitats (e.g. bogs, nearly natural forests), but in particular of specific habitat structures (bark, rotten wood, nests of birds or ants, compost heaps or barns), resulting in a high potential value for bioindication in nature conservation. This was considered when *Anthrenochernes stellae* Lohmander, 1939 was included in Annex 2 of the Habitats Directive, where it represents (together with several species of beetles) the communities of decomposition stages in old growth forests (Drogla 2003).

This contribution presents results of faunistic and ecological research in Strict Forest Reserves in Hesse (Germany). Currently 27 species of pseudoscorpions are known from Hesse (Muster & Blick in prep.). Systematic surveys in the county were rare (e.g., Helversen 1966, Jost 1982) until 1990, when the Federal State of Hesse started a faunistic inventory in the Strict Forest Reserves, which is unique and has no parallel in any federal state of Germany. In Hesse 31 Strict Forest Reserves have been established since 1988, with a total area of 1228 ha. In the long term not only every single reserve shall be investigated intensively, but also the succession shall be documented by repeated inventories (Dorow et al. 1992). The Senckenberg Research Institute executes this zoological research program. The quality of this project is increased through the investigation of managed reference areas (with continued forestry) in 22 sites.

Pseudoscorpions are not included in the standard set of 7 animal groups that are analysed at all levels of the project (see Dorow et al. 2010, Dorow & Blick 2013), but were added in the sense of an „all-taxa-bio-

diversity-inventory“ approach (Muster 2009, 2013). Here we present the results from 7 reserves (5 of them have an adjacent managed site = reference area). With a total of 4567 specimens this is the second most comprehensive faunistic and ecological study on pseudoscorpions in Germany, outnumbered only by Drogla & Lippold (2004, ca. 23000 specimens).

Material and methods

Study sites. Pseudoscorpions were determined from seven Strict Forest Reserves in Hesse. Data for the sites are listed in Tab. 1, the geographical position within Hesse is shown in Fig. 1.

GZ – Goldbachs- und Ziebachsrück (with managed reference area)

HB – Hasenblick (with managed reference area)

HO – Hohestein (with managed reference area)

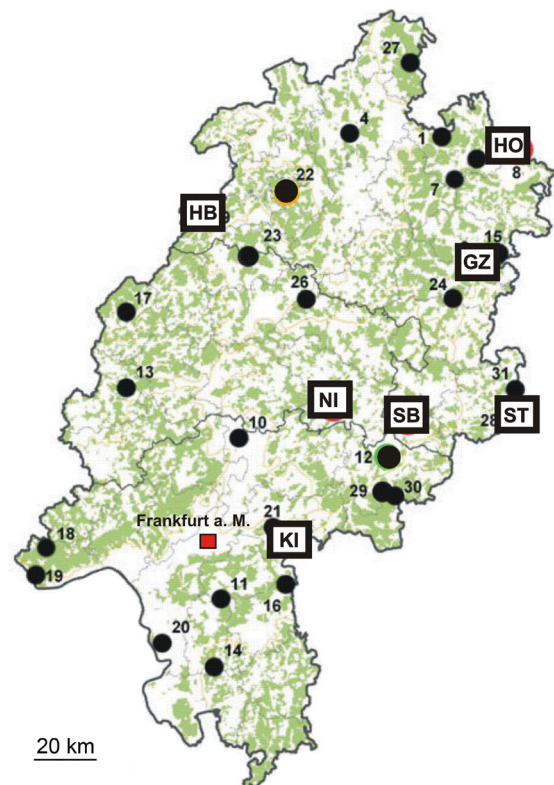


Fig. 1: Geographical position of the investigated Strict Forest Reserves in Hesse/Germany (acronyms in rectangles); the remaining sites of the 31 Strict Forest Reserves in Hesse are marked as black dots (after Dorow et al. 2010a). Shaded areas: forest
Abb. 1: Lage der bearbeiteten hessischen Naturwaldreservate (Kürzel in Quadraten); die übrigen der 31 in Hessen ausgewiesenen Naturwaldreservate sind mit schwarzen Punkten dargestellt (nach Dorow et al. 2010a). Schattierte Fläche: Wälder

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KI – Kinzigau
 NI – Niddahänge E Rudingshain (with managed reference area)
 SB – Schönbuche (with managed reference area)
 ST – Störnberg

Field work. In the seven reserves the fauna has been recorded with a broad set of trap types and trapping methods over two entire years (incl. winter) in a standardized way (Dorow et al. 1992, 2010a). Pitfall traps (generally as groups of three = triplets), window traps (different types, see Tab. 2), colour pans (free, not at the bark) and trunk eclectors at the dominating tree species as well on living trees as on standing and lying trunks (with total contact to the ground and partly without) were used. The applied trunk eclectors were open at the bottom, thus the fauna running up the trunks is captured (for details

see Behre 1989, Blick 2011). All trunk eclectors were installed on common beech (*Fagus sylvatica*), except for the Kinzigau, where one eclector was on a living ash tree (*Fraxinus excelsior*) and the others on oak (*Quercus robur*). Furthermore tent eclectors on stumps and tent eclectors covering dead wood (thick branches) were used (details see Tab. 2 and Dorow et al. 1992).

Determination and nomenclature. The determination was conducted by CM using the keys of Beier (1963), Legg & Jones (1988), Devore-Scribante (1999), Mahnert (2004) and Christophoryová et al. (2011b). Nomenclature and affiliation to families follows Muster & Blick (in press).

Statistics. The similarity of the species assemblages of the seven forest sites has been examined using the non-metric multidimensional scaling method (NMDS), based on Bray-Curtis dissimilarities. This

Tab. 1: Short characterization of the seven investigated Strict Forest Reserves in Hesse. For abbreviations of sites see text above
Tab. 1: Kurzcharakterisierung der sieben untersuchten hessischen Naturwaldreservate. Flächenkürzel wie oben im Text

	GZ	HB	HO	KI	NI	SB	ST
Year of constitution	1988	1988	1989	1993	1988	1988	1997
Size of reserve (ha)	31.3	46.0	26.7	18.1	42.0	27.9	71.1
Size of reference area (ha)	36.8	40.3	24.4	none	31.7	26.5	none
German Grid number (TK25)	5025	4917	4726	5819	5421	5523	5526
°N (WGS84, Centre of the reserve)	50.9301	51.0586	51.2490	50.1427	50.5239	50.4824	50.4897
°E (ditto)	9.8750	8.6356	10.0468	8.9824	9.2036	9.5397	10.0272
Macrochore	East Hesse Highlands, Vogelsberg and Rhön Mountains	Bergisches Land, Sauerland	East Hesse Highlands, Vogelsberg and Rhön Mountains	Upper Rhine Plain and Rhine-Main area	East Hesse Highlands, Vogelsberg and Rhön Mountains	East Hesse Highlands, Vogelsberg and Rhön Mountains	East Hesse Highlands, Vogelsberg and Rhön Mountains
Altitude (m a.s.l.)	300-365	370-486	455-565	110-115	530-690	370-455	690-910
Mean temperature (°C)	8.0	7.2	8.0	9.6	6.7	7.8	6.3
Mean precipitation (mm)	748	868	759	712	1175	776	976
Dominating vegetation	beech forests on acidic soils	beech forests on acidic soils	beech forests on basic and calcareous soils	common oak-ash floodplain forest	beech forests on basic and calcareous soils	beech forests on acidic soils	beech forests on basic and calcareous soils
References for zoological data	Dorow et al. (2009, 2010b)	unpubl.	Flechtner et al. (2006), Dorow & Kopelke (2007)	Blick et al. (2012, 2014)	Flechtner et al. (1999, 2000)	Dorow et al. (2001, 2004a, 2004b)	unpubl.

Tab. 2: Overview of the trapping methods and trap numbers (in brackets: numbers in reserve/reference site) . For abbreviations of sites see text above.

Tab. 2: Übersicht zur Fangmethodik und den Fallenzahlen (in Klammern: Anzahl in Totalreservat/Vergleichsfläche). Flächenkürzel wie oben im Text.

	GZ	HB	HO	KI	NI	SB	ST
Period of investigation	1994-1996	1999-2001	1994-1996	1999-2001	1990-1992	1990-1992	2004-2006
Pitfall trap triplets	16 (8/8)	29 (18/11)	12 (6/6)	12	15 (8/7)	12 (6/6)	23
Additional single pitfalls traps	8 (3/5)		9 (6/3)		7 (3/4)	1 (0/1)	
Electors on living trees	4 (2/2)	4 (2/2)	4 (2/2)	2	4 (2/2)	4 (2/2)	2
Electors on standing dead trees	4 (2/2)	4 (2/2)	4 (2/2)	2	4 (2/2)	2 (2/0)	2
Electors on lying trunks (with total contact to the ground)	1 (1/0)	3 (1/2)	1 (1/0)	1	4 (2/2)	1 (1/0)	1
Electors on free lying trunks (only in smaller parts with contact to the ground)	1 (1/0)	1 (1/0)	1 (1/0)	1	2 (2/0)	2 (2/0)	1
Tent electors on stumps	2 (0/2)		2 (0/2)		1 (0/1)	1 (0/1)	
Tent electors filled with dead wood	2 (1/1)	2 (1/1)	2 (1/1)	1	2 (1/1)	2 (1/1)	1
Tent electors on the floor					2 (1/1)	2 (1/1)	
Colour pan combinations (white, blue, yellow)	2 (1/1)	2 (1/1)	2 (1/1)	1	2 (1/1)	2 (1/1)	2
Window traps (1 m ²)		2 (1/1)		1	2 (1/1)	2 (1/1)	1
Smaller windows traps („Kreuzfensterfallen“)	2 (1/1)		2 (1/1)		2 (1/1)	2 (1/1)	
Window traps at the bark		3 (3/0)		7			

ranking ordination method projects the distances into two dimensions, with minimisation of the distortion. The analysis was conducted with the function "metaMDS" (2 dimensions, 20 start configurations) in the package "Vegan" (Oksanen et al. 2011) with the program "R, version 2.13.1" (R Development Core Team 2011). The *stress* value reports the quality of the ordination. Values <1 represent the true relationships precisely. To interpret the axes and as a test of the relevance of environmental variables (see Tab. 7) the Vegan function "envfit" was used. Only variables (factors), which correlate significantly with the data (1000 permutations) are shown as vectors in the ordination diagram.

Association with forest habitats. The association of individual species with forest habitats was classified with reference to the system proposed for the German vascular plants and mosses by Schmidt et

al. (2011). The allocation of individual species to categories was based on literature data and our own experience (not restricted to this study). The following categories were distinguished (Tab. 3, compare also Blick et al. 2012, 2014, Blick & Dorow 2014):

- F – largely restricted to forest
- fc – largely restricted to closed forest
- fl – prefers forest edges and clearings
- M – occurs in forest and open land (with the focus not in the forest)
- mm – occurs in forests as well as in open land
- mo – may occur in forests, but prefers open land
- O – largely restricted to open land (or any other type of non-forest habitat)

Note that this system reflects exclusively the relationship with forest, not with other environmental factors, such as moisture etc.

Results

A total of 4567 pseudoscorpions were determined from the seven reserves: 1791 males, 1596 females and 1180 juveniles. They belong to 13 species and 3 families (Tab. 3): Neobisiidae: 4 species, 94 % of the specimens; Cheliferidae: 1 species, 0.05 % of the specimens; Chernetidae: 8 species, 6 % of the specimens. The most numerous species, *Neobisium carcinoides*, accounts for 86 % of the specimens. In single forest sites 4 to 9 species (5.5 ± 1.6) and 251 to 1314 specimens (652 ± 332) were recorded.

Trapping methods. The large majority of the pseudoscorpions was caught by pitfall traps (3787 specimens, 82.9 %), followed by the different types of trunk eclectors (734 specimens, 16.0 %) and the window traps on the bark (27 specimens, 0.6 %). With other methods only single specimens were trapped, with a maximum of 5 specimens per method (Tab. 4).

A few species were trapped exclusively by a single method: *Neobisium simoni* with pitfall traps, *Al-*

lochernes wideri in trunk eclectors on dead standing trees and *Lamprochernes nodosus* with window traps. The remaining species were trapped with up to 10 different methods. These methods, however, show quite different efficiencies for the recording of individual species: *Neobisium carcinoides* and *N. simile* were trapped principally with pitfall traps, *N. sylvaticum* and *Pselaphochernes dubius* mostly in eclectors on living trees, *Chernes cimicoides*, *Dendrochernes cyrneus* and *Lamprochernes chyzeri* mainly in eclectors on dead standing trees, *Pselaphochernes scorpioides* predominantly in eclectors on lying trunks (only partly with contact to the ground) and *Dinocheirus panzeri* mainly with window traps near the bark. Furthermore, specific life cycle stages may prefer different vegetation strata. In *Neobisium sylvaticum*, 53 % of the specimens in pitfall traps were adults, while in trunk eclectors 79 % belonged to nymph stages. This illustrates the importance of using a broad set of methods to register the species assemblages as rep-

Tab. 3: Total numbers of specimens in the seven reserves in Hesse including information on association with forests and rarity category (RC) according to Muster & Blick (in press): vc = very common, c = common, mc = moderately common, r = rare. See Material and methods for abbreviations of forest association and site names

Tab. 3: Anzahl erfasster Individuen in sieben hessischen Naturwaldreservaten und Einstufung hinsichtlich Waldbindung und Bestandskategorien (RC) nach Muster & Blick (in press): vc = sehr häufig, c = häufig, mc = mäßig häufig, r = selten. Erklärung der Abkürzungen für Waldbindung und Flächenkürzel in Material und Methoden

Taxon	GZ	HB	HO	KI	NI	SB	ST	Σ	Association with forests	RC
Neobisiidae										
<i>Neobisium carcinoides</i> (Hermann, 1804)	750	1134	547	46	439	278	372	3566	F	vc
<i>Neobisium simile</i> (L. Koch, 1873)	22	149	.	.	114	15		300	F	vc
<i>Neobisium simoni</i> (L. Koch, 1873)	.	.	.	.	.	.	40	40	F	c
<i>Neobisium sylvaticum</i> (C.L. Koch, 1835)	.	12	50	32	187	5	98	384	F	vc
Cheliferidae										
<i>Mesochelifer resslii</i> Mahnert, 1981	.	.	1	1	.	.	.	2	F	c
Chernetidae										
<i>Allochernes wideri</i> (C.L. Koch, 1843)	.	.	.	1	.	.	.	1	F	c
<i>Chernes cimicoides</i> (Fabricius, 1793)	.	.	.	87	.	.	.	87	F	mc
<i>Dendrochernes cyrneus</i> (L. Koch, 1873)	.	.	.	49	.	.	.	49	F	r
<i>Dinocheirus panzeri</i> (C.L. Koch, 1837)	.	8	.	.	1	.	4	13	mm	c
<i>Lamprochernes chyzeri</i> (Tömösváry, 1882)	.	1	.	3	.	.	.	4	fl	r
<i>Lamprochernes nodosus</i> (Schränk, 1803)	.	.	.	.	1	1	.	2	mo	c
<i>Pselaphochernes dubius</i> (O. P.-Cambridge, 1892)	37	.	2	5	.	16	.	60	fl	mc
<i>Pselaphochernes scorpioides</i> (Hermann, 1804)	18	10	.	27	1	.	3	59	mo	c
Specimens	827	1314	600	251	743	315	517	4567	.	.
Species	4	6	4	9	6	5	5	13	.	.
Shannon-diversity	0.41	0.49	0.32	1.67	0.97	0.49	0.81	.	.	.

representatively and completely as possible (see Dorow et al. 2010a).

Comparison of the reserves with their managed reference areas. The quality of this research program is increased through the inclusion of 22 adjacent managed sites/reference areas, where forestry is continued. Five of the seven reserves included in this study have such reference areas (not present in Kinzigau and Stirnberg).

Neither the species numbers nor the numbers of pseudoscorpion individuals were significantly different between the reserves and the reference areas (Mann-Whitney U-Tests, $p > 0.05$). In Hohestein and Niddahänge the species number was

higher in the unmanaged areas (reserves), whereas in Hasenblick and Schönbuche it was higher in the managed reference areas, while no differences were observed in Goldbachs- und Ziebachsrück (Fig. 2). A higher number of individuals were trapped in the reserves of Hasenblick and Hohestein compared to their reference areas, and lower numbers in Goldbachs- und Ziebachsrück, Schönbuche and Niddahänge (Fig. 3). Note that the recording scheme was not completely identical in the reserves and the corresponding reference areas (see Tab. 2). The number of pitfall trap sites reflects the number of different structures in the reserves and the reference areas.

Fig. 2: Comparison of the species numbers of the pseudoscorpions in the 7 Strict Forest Reserves (SFR) and the 5 reference sites (REF) in Hesse

Abb. 2: Vergleich der Artenzahlen von Pseudoskorpionen in Totalreservaten (SFR) und deren Vergleichsflächen (REF) von 7 hessischen Naturwaldreservaten

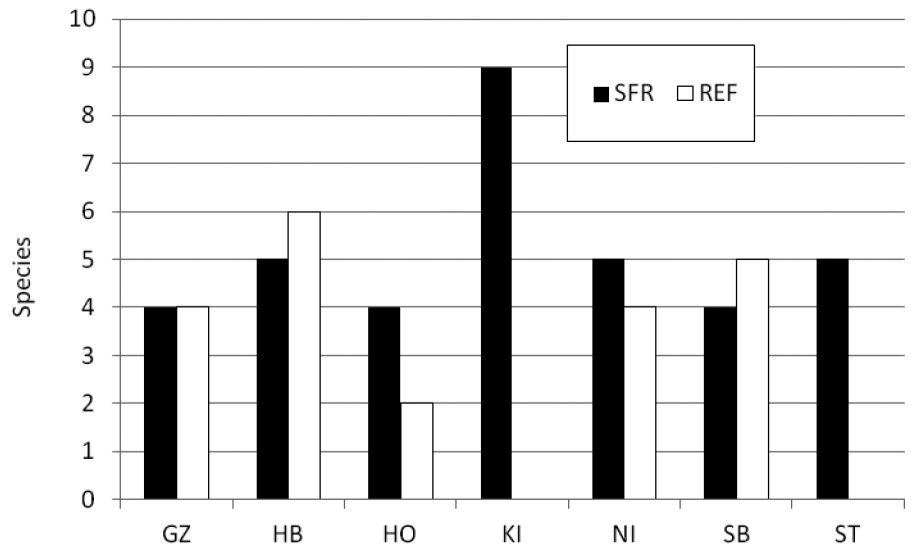
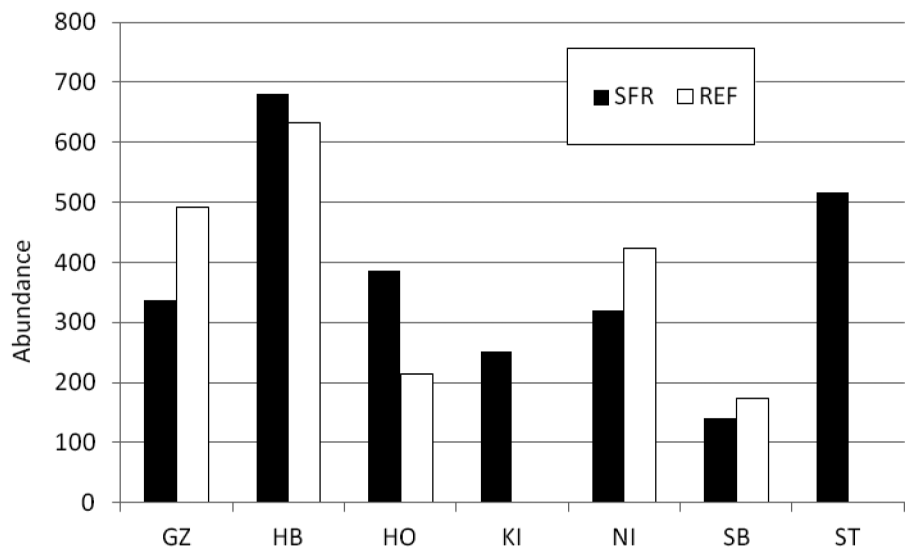


Fig. 3: Comparison of the specimen numbers of the pseudoscorpions in the 7 Strict Forest Reserves (SFR) and the 5 reference sites (REF) in Hesse

Abb. 3: Vergleich der Anzahl erfasster Individuen von Pseudoskorpionen in Totalreservaten (SFR) und deren Vergleichsflächen (REF) von 7 hessischen Naturwaldreservaten



Tab. 5: Abundance (standardized to individuals/pitfall trap) of pseudoscorpion species from pitfall traps in strict forest reserves as compared to managed reference sites (KI and ST omitted due to lack of reference sites). For abbreviations of sites see text above

Tab. 5: Vergleich der standardisierten Abundanz von Pseudoskorpionen (Individuen/Bodenfalle) aus Bodenfallen in Totalreservaten (SFR) und deren Vergleichsflächen (REF) in 5 hessischen Naturwaldreservaten (in KI und ST wurden keine Vergleichsflächen beprobt). Flächenkürzel wie oben im Text

	Strict forest reserves (SFR)					Reference sites (REF)					all SFR	all REF	% SFR
	GZ	HB	HO	NI	SB	GZ	HB	HO	NI	SB			
<i>Dinocheirus panzeri</i>	.	0,09	.	.	.	.	0,09	.	0,04	.	0,033	0,031	51,4
<i>Lamprochernes chyzeri</i>	.	.	.	.	.	.	0,03	.	.	.	0	0,008	0,0
<i>Lamprochernes nodosus</i>	.	.	.	0,04	.	.	.	.	.	0,05	0,007	0,008	45,8
<i>Mesochelifer reszli</i>	.	.	0,04	.	.	.	.	.	.	.	0,007	0	100,0
<i>Neobisium carcinoides</i>	10,7	10,3	14	6,81	6,56	15,9	17,6	10	10,2	8,42	9,887	13,11	43,0
<i>Neobisium simile</i>	0,37	2,13	.	2,22	0,78	0,41	1,03	.	2,16	0,05	1,327	0,795	62,5
<i>Neobisium sylvaticum</i>	.	0,11	1,92	2,74	0,17	.	0,18	0,19	4,52	0,11	0,86	0,984	46,6
<i>Pselaphochernes dubius</i>	0,74	.	0,08	.	0,33	0,59	.	.	.	0,53	0,187	0,213	46,8
<i>Pselaphochernes scorpioides</i>	0,59	0,02	.	0,04	.	0,07	0,27	.	.	.	0,12	0,087	58,1

At the species level, however, some differences are recognisable. *Neobisium carcinoides* was trapped more numerously in almost all reference areas, which indicates a preference for more open forest stands, whereas for *N. simile* the reverse pattern emerged (Tab. 5).

Qualitative characteristics of the assemblages. The assemblages of four beech forest reserves (Goldbachs- und Ziebachsrück, Hasenblick, Hohestein and Schönbuche) show a similar structure, as they are strongly dominated by *Neobisium carcinoides* (> 85 %) and contain a relatively low number of species (max. 6). This is furthermore reflected in low values of the Shannon-diversity (< 0.5, see Tab. 3). The two beech reserves in the higher low mountain range (Niddahänge, Störnberg) have a comparable number of species. But the structure of the communities is more balanced, with other *Neobisium* species reaching high percentages, resulting in higher Shannon-values (0.8–1.0). Totally different is the situation in the lowland floodplain forest, dominated by common oak (Kinzigau). Here, the structure of dominance is balanced, the species number is considerably higher and a higher value of Shannon-diversity is reached (1.67).

In the Red Data List of the German pseudoscorpions (Muster & Blick in press) two species from the Strict Forest Reserves in Hesse are listed. *Dendrochernes cyrneus* is classified as vulnerable (German category „3“), while the degree of endangerment of *Dinocheirus panzeri* could not be classified in detail

(German category „G“). In each of the reserves Hasenblick, Kinzigau, Niddahänge and Störnberg one of these two species has been recorded. The reserve Kinzigau has the highest proportionate abundance (24.3 %) of Red Data List species (< 1 % in all other reserves).

Figs. 4 and 5 show the proportions of species and individuals of rarity categories, as included in the latest Red Data List (Muster & Blick in press). The species were classified into seven criteria-classes (from extremely rare to very abundant) based on records on the 1:25000 grid squares of Germany (mean value about 129 km² per grid) (Staudt 2014). Extremely rare and very rare species have not been found in the reserves. The very common species reach about 50%, with the exception of Kinzigau, where the percentage was rather lower (Fig. 4). This is even more obvious regarding the abundance proportion (Fig. 5): whereas the percentage of the individuals of the very common species was higher than 90 % in all other reserves, it was about 1/3 in the Kinzigau. Here, the relative abundance of the moderately common and rare species reaches more than 50 %.

The analysis of the pseudoscorpion assemblages with respect to their relationship to forest habitats results in the (unsurprising) insight, that all recorded species are typical forest dwellers (categories W and M including their subcategories) (Tab. 3). More than 98 % of the specimens belong to species which are strongly associated with forest habitats (Tab. 6: F and fl). Again there is one exception, the Kinzigau,

where 10.8 % of the specimens belong to *Pselapho- chernes scorpioides*, a species that can be found regularly in forests, but has its focus outside of forests.

Relationships of the species communities. The relationships of the species communities of the seven reserves (incl. their reference areas) and the influence of abiotic variables was examined by means of non-metrical multidimensional scaling (NMDS). The NMDS-ordination (stress < 0.1) shows the area Hasenblick in the centre of the diagram (Fig. 6), in nearly equal distance to the other beech forests. Along axis 1 of the NMDS the oak dominated reser-

ve Kinzigau has a separated position. Axis 2 divides the beech forests on acidic soils (GZ, HB, SB) from those on basic and calcareous soils (HO, NI, ST), which are, at the same time, the three with the highest elevation. Of the tested abiotic factors, altitude and the average temperature correlate significantly with the position of the reserves in the ordination (Tab. 7, Fig. 6). In contrast, an influence of precipitation or geographical position is not detectable. The species *Allochernes wideri*, *Chernes cimicoides*, *Dendrochernes cyrneus* and *Lamprochernes chyzeri* are associated with the lower sites with higher temperature,

Fig. 4: Percentage of the species of the pseudoscorpions of seven Hessian Strict Forest Reserves (reference areas included), categorised after their frequency in Germany. vc = very common, c = common, mc = moderately common, r = rare

Abb. 4: Artenanteile der Häufigkeitsklassen von Pseudoskorpionen in sieben hessischen Naturwaldreservaten. vc = sehr häufig, c = häufig, mc = mäßig häufig, r = selten

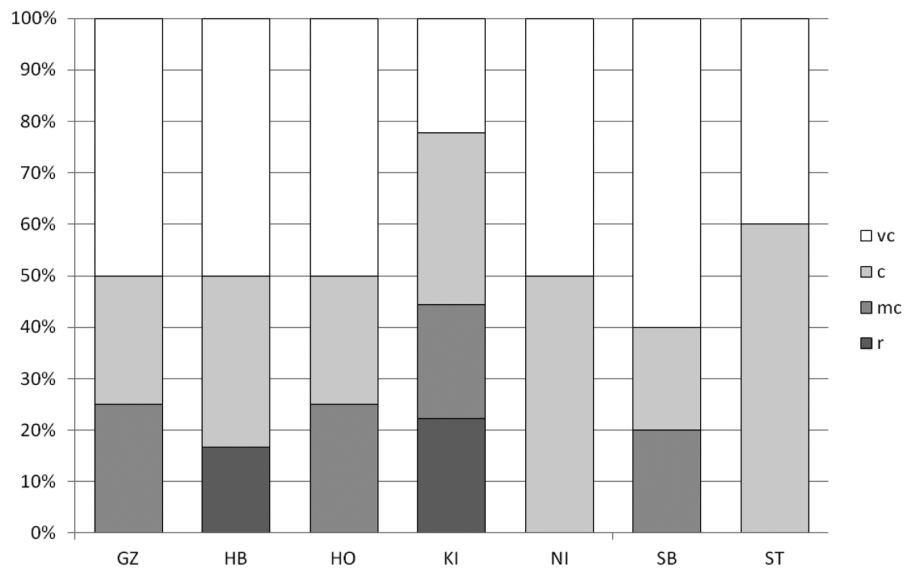
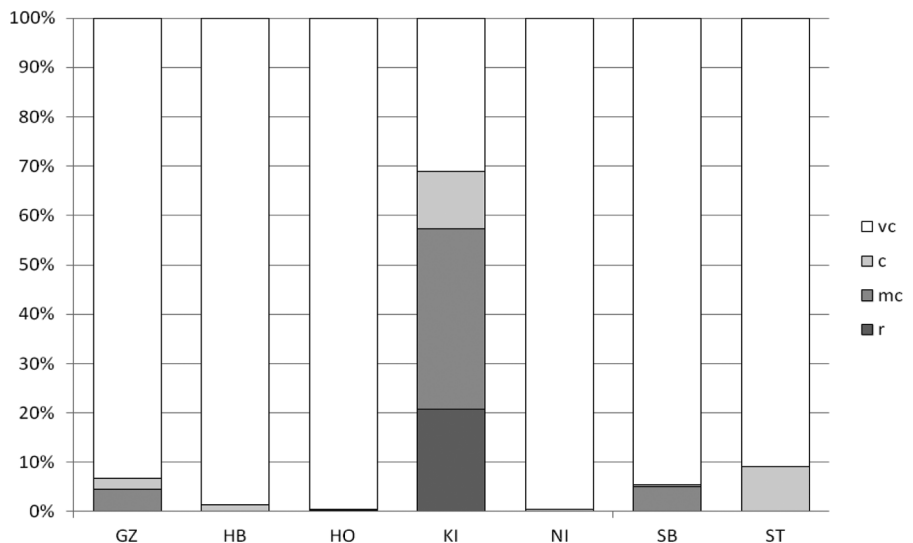


Fig. 5: Percentage of the individuals of the pseudoscorpions of seven Hessian Strict Forest Reserves (reference areas included), categorised after their frequency in Germany. vc – very common, c – common, mc – moderately common, r – rare

Abb. 5: Individuenanteile der Häufigkeitsklassen von Pseudoskorpionen in sieben hessischen Naturwaldreservaten. vc – sehr häufig, c – häufig, mc – mäßig häufig, r – selten



Tab. 6: Association of the species assemblages with forests in the seven reserves (see text and Tab. 3)**Tab. 6:** Waldbindung der Artengemeinschaften in den einzelnen Naturwaldreservaten (vgl. Text und Tab. 3)

Relationship to forests	GZ	HB	HO	KI	NI	SB	ST
F - largely restricted to forest	93.3 %	98.6 %	99.7 %	86.1 %	99.6 %	94.6 %	98.6 %
fl - prefers forest edges and clearings	4.5 %	0.1 %	0.3 %	3.2 %	.	5.1 %	.
mm - occurs in forests and open land	.	0.6 %	.	.	0.1 %	.	0.8 %
mo - may occur in forests	2.2 %	0.8 %	.	10.8 %	0.3 %	0.3 %	0.6 %

while *Neobisium simoni* shows a relationship with sites of higher elevation. As expected, the ubiquitous *Neobisium carcinoides* is positioned in the centre of the ordination (Fig. 6).

Discussion

This study of seven Strict Forest Reserves in Hesse (including five reference areas) resulted in records of 13 species of pseudoscorpions. This is equivalent to 26 % of the 50 species known from Germany (Muster & Blick in press) and 50 % of the 26 species known from Hesse (Muster & Blick in prep.). These ratios are higher than the average in other groups of animals (23 % resp. 32 %, Dorow et al. 2010a). There are great differences in the representation of the more species-rich families among the pseudoscorpions. Whilst 33 % of the German and 80 % of the Hessian Neobisiidae and 53 % of the German and 73 % of the Hessian Chernetidae have been found, the species-rich family Chthoniidae (14 species in Germany, 5 species in Hesse) was lacking completely in the collections from the Strict Forest Reserves in Hesse. With regard to the high intensity of trapping and the broad spectrum of survey methods this lack of Chthoniidae remains unexplainable. In fact, it is known that some species of Chthoniidae show aggregated distributions (sometimes with high local abundances, see Droglá & Lippold 2004, Muster et

al. 2008). Several species of Chthoniidae are regularly trapped with pitfalls, and the most common species, *Chthonius (Ephippiochthonius) tetrachelatus*, has been collected with this method in the course of biospelling surveys in Hesse (Zaenker 2001, Reiss et al. 2009). In the forest of Ettlingen (Baden-Württemberg) *C. tetrachelatus* made up 24 % of the specimens caught with pitfalls (Braun & Beck 1986) and in the Luxembourgian forest “Schnellert” even four species of *Chthonius* have been found (Groh 2007).

Due to the low overall number of species we refrained from using rarefaction methods to assess the completeness of the inventory. But the intensity of the sampling and the broad spectrum of applied methods imply a rather comprehensive survey. There exist only few regional faunistic studies on Central European pseudoscorpions of similar magnitude. Compared to other sites, the nine species in the Kinzigau is a fairly high number, and even four to six species in the other reserves are not unusually low. Some examples are given to illustrate this: Strebel (1961) collected four species in the “Siebengebirge” (North Rhine-Westphalia), Helversen & Martens (1971) listed nine species from the gorge of the “Wutach” (Baden-Württemberg), Droglá (1977) recorded five species in a mixed deciduous forest in the low mountain range of the nature reserve “Tiefental bei Königsbrück” (Saxony), an intensive inventory in nearly natural forests in Luxembourg revealed the presence of five or six species (Groh 2007, Köhler et al. 2011), the collections by Jost (1982) in the nature park “Hoher Vogelsberg” (Hesse) yielded eleven species; the same number as found by Štáhlavský & Krásný (2007) in the valley of the lower Vltava (Czech Rep.). On the other hand, Droglá (1988) found in a forest near “Deutsch Paulsdorf” (Upper Lusatia, Saxony) only a single species (*Neobisium carcinoides*) and 587 specimens from a floodplain forest at the river Rhine (Rhineland-Palatinate) (Marx et al. 2008) as well as 3777 specimens in the forest

Tab. 7: Correlation of the variables/factors with the NMDS ordination, significant factors are in bold**Tab. 7:** Korrelation von Einflussvariablen mit der NMDS Ordination, signifikante Umweltvariablen sind fett hervorgehoben

Variable/Factor	Axis 1	Axis 2	r ²	p (>r)
Altitude (m)	0.66598	-0.74597	0.8936	0.008**
Temperature	-0.88388	0.46772	0.8638	0.013*
Precipitation	0.85473	-0.51907	0.6253	0.139
°East	0.20875	-0.97797	0.1286	0.758
°North	0.47475	-0.88012	0.0572	0.875

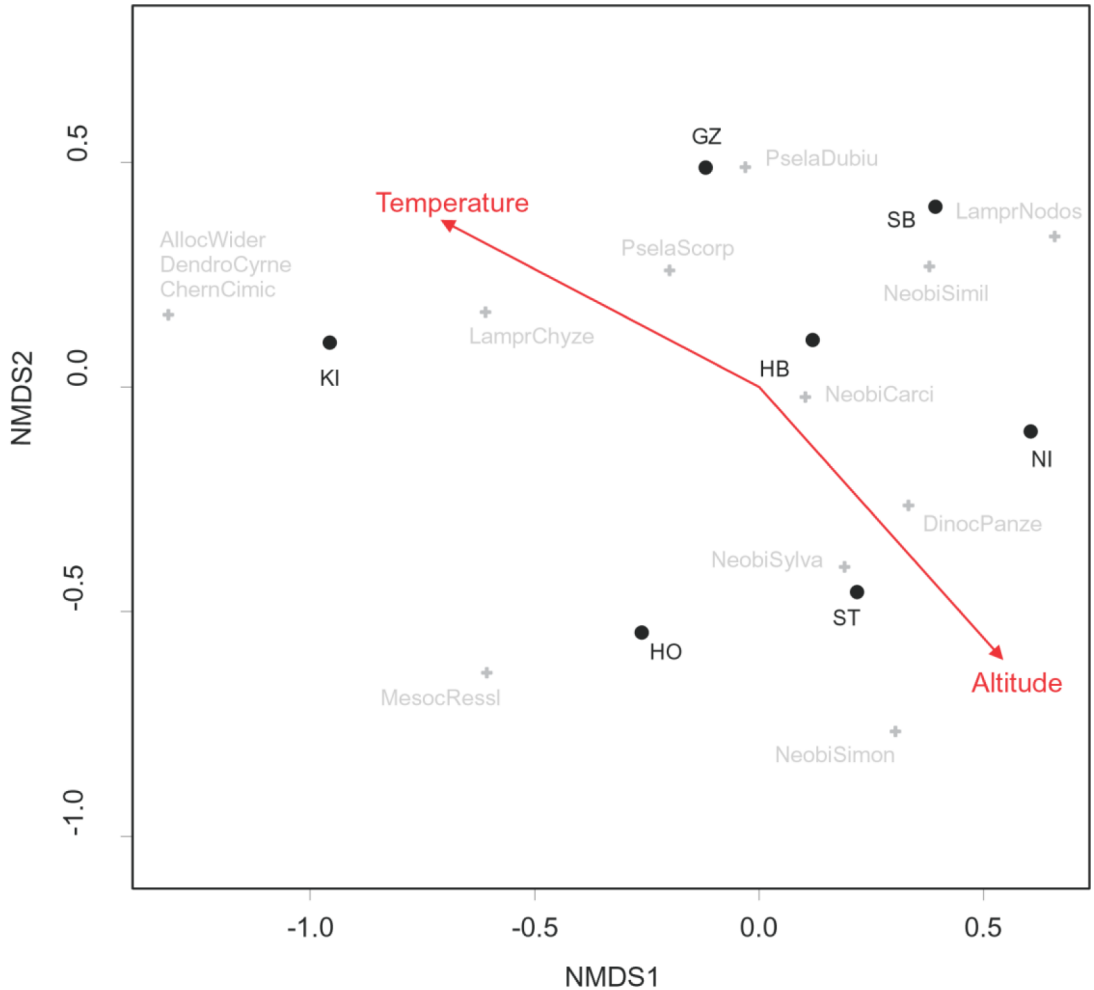


Fig. 6: NMDS ordination of the pseudoscorpions of seven Hessian Strict Forest Reserves (reference areas included) (black dots), based on the Bray Curtis dissimilarity matrix. The abiotic factors temperature and altitude correlate significantly with the ordinated data. Positions of the species in grey

Abb. 6: NMDS-Ordination der hessischen Naturwaldreservate (schwarze Punkte) basierend auf der Bray-Curtis-Unähnlichkeitsmatrix der Pseudoskorpion-Artabundanzen. Die Umweltvariablen Temperatur und Höhe korrelieren signifikant mit den ordinierten Daten. Positionen der Arten in grau

of Ettlingen (Baden-Württemberg) (Braun & Beck 1986) belonged to not more than two species. Surely one has to consider different sampling intensities in such quantitative comparisons. Especially eclectors have been used only rarely. In local studies in south-eastern parts of Central Europe, Štáhlavský (2011) and Štáhlavský & Chytil (2013) detected very high species numbers; respectively 20 and 23 species. The comparably low numbers of species and individuals in trunk eclectors of the beech-dominated Hessian reserves are surely not a result of methodology. Corticolous taxa may de facto avoid the bark of beeches,

which is poorly structured compared to other tree species. In line with our results, Ressler & Beier (1958) reported records of corticolous pseudoscorpions from 36 species of trees and shrubs, but none from common beech (*Fagus sylvatica*).

The comparison of the reserve areas with reference areas (where forestry is continued) showed no distinct quantitative differences in the assemblages of pseudoscorpions. This fits with the results of other analysed groups of animals (e.g. Dorow et al. 2010b, Blick et al. 2014). However, in the pseudoscorpions (in contrast to, e.g. spiders, see Blick 2012) a clear

tendency to higher presence and dominance of less abundant species in the reserves was detectable, as compared to the reference areas. That the respectable efforts for process conservation in the Strict Forest reserves in Hesse have not yet resulted in a more clear distinctiveness, may have several reasons. The most important is the time. A period of 15 years is simply too short to achieve a final balance. The development of natural dynamics in forest ecosystems is a long-lasting process, which needs much more time to be reflected in the species composition of predator guilds.

An evaluation of the conservation value of the seven Hessian reserves results in the extraordinary status of the Kinzigaue. Here, not only the biodiversity reaches its maximum, but the qualitative criteria also underline the distinctiveness of the area. The proportion of Red Listed species was 24.3 % (in the other areas < 1 %!), and the abundance proportions of rare and moderately common species reached > 50 % (in the other areas < 10 %). Remarkable are the exclusive records of two species in the Kinzigaue, which are attached to “primary” forests, *Chernes cimicoides* and *Dendrochernes cyrneus*. On the contrary, the beech forest reserves are collectively inhabited by a very similar, species-poor and unspectacular assemblage of species. Besides climatic parameters and influences of the structures of the forests, other factors, like forest continuity (i.e., long-term persistence of forest habitats at a given site), may play a role (Wulf 1994). For example, the pseudoscorpion species *Dendrochernes cyrneus* may be restricted to ancient woodland (Muster 1998, Droglá & Lippold 2004, but see Esser 2011). Future investigations in Hessian forest reserves should include forest types other than beech forest (Dorow et al. 2010a, Blick et al. 2014). Sifting of mould in cavities of old trees may eventually result in records of the FFH pseudoscorpion species *Anthrenochernes stellae* (see Droglá 2003), which is definitely to be expected in Hesse.

The investigation of the pseudoscorpions of the Strict Forest Reserves increased the knowledge on pseudoscorpiones in Hesse considerably. The hitherto most thorough studies from Hesse comprised 554 individuals (Helversen 1966) and 428 individuals (Jost 1982). The inventory of the forest reserves, with a total of 4567 specimens, is an important basis for a Red Data List for Hesse (Muster & Blick in prep.). As compared to other groups of animals (including spiders and harvestmen), the knowledge about pre-

ferred habitats, microhabitats and ecological preferences of the German pseudoscorpions is still limited. Therefore, the results of this study have also national relevance.

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