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Different forest cover and its impact on eco-hydrological traits, invertebrate fauna and biodiversity of spring habitats

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Abstract

Headwater springs in the German Low Mountain Ranges are local ecotone habitats and biogeographical islands embedded in and interlinked with their adjacent landscape. The structure of forests reflects the eco-hydrological conditions in substrate type occurrence, microhabitat richness and biodiversity in forest springs. This study considers effects from different forest land cover by comparing spring habitats in deciduous beech forests and coniferous spruce forests on eco-hydrological structures and biodiversity. Study areas include six different forest landscapes in the Low Mountain Ranges in Central Germany in Hesse and Thuringia. Hydro-morphological structure mapping and invertebrate sampling was executed within a multi-habitat sampling regime, which involves sampling plots being allocated according to the cover ratio of the occurring substrata. Aquatic and terrestrial spring zones are considered with respect to an ecotone approach. Some *in situ* measurements were implemented, such as pH values, to assess the acidity of the spring water. Results show obvious differences in acidity, substrate type cover ratios and biodiversity in deciduous and coniferous forest springs. Conifer forest springs were found tending to acidification while deciduous forest springs were slightly alkaline. Deciduous forest springs had higher cover ratios of organic microhabitats as well as a higher biodiversity in species richness and total number of individuals. Although it was not possible to clearly distinguish one direct key factor of fauna assemblages, negative effects from forest management practices (e.g. monoculture plantations of conifer forest) on spring habitats can be concluded.

Keywords

springhead, headwater, microhabitats, substrate, habitat assessment, crenobionts

Introduction

Mountainous headwater springs are mostly small water bodies where dominant groundwater occurs at the surface to form an intermittent or permanent discharge influenced by subsurface interflow and overland flow (Frisbee et al. 2013). Spring habitats are ecotones in two spatial dimensions. Firstly, springs are vertical aquatic below-above-ground-interfaces between groundwater and surface water. Secondly, springs are above-ground-horizontal terrestrial-aquatic interfaces between different adjacent areas within a continuum of aquatic, semi-aquatic or amphibian to hygrophilous terrestrial spring areas similar to the riparian zone ecotone (Gibert et al. 1990). Therefore, springs are normally nearly constantly cold and wet island habitats without clarifying benchmarks on the delimitation of hot springs (e.g. Pentecost et al. 2003). Glazier (2009) introduces the term "ambient springs" to characterise the water temperature regime with low minimum and maximum amplitudes and an annual mean related to the local yearly mean air temperature (Thienemann 1924). The relative constantly cold water temperature conditions or isothermy (Odum 1971, Teal 1957) lead to specific fauna adaptation of cold-stenothermic specialists and glacial relicts (Nielsen 1950, Ward and Stanford 1982, Fischer 1996). However, fauna composition is much more heterogeneous in springheads and is often explained as a consequence of a high degree of substratum heterogeneity, which can result in high species richness (Bonettini and Cantonati 1996, Lindegaard et al. 1998, Williams and Williams 1999, Staudacher and Füreder 2007, Koperski et al. 2011). The springhead can be built of different substrate types that build heterogeneous mosaic-like structures called patches, hence, springs which can also be termed patchy ecosystems on the micro scale (Pickett and White 1985). The first quantitative approach for analysing the microhabitat-fauna-relationship in springheads and for calculating ratios of invertebrate substrate preferences regarding the ecotone characteristics was completed by Reiss (2011) and considered mountainous headwater springs in Central Germany.

The objective of this study is to determine effects from different forest cover by comparing spring habitats in deciduous and coniferous forests on eco-hydrological structures and biodiversity. This research focuses on impacts from forest types as a determinant of the occurrence of corresponding microhabitat types, its substrate type composition and diversity, as well as its specific colonisation by invertebrates. Here, acidity is also considered, because conifer forests could be contributing to acidification of surface waters (Nisbet 1990, Cannell 1999).

Methods

Study area

Study sites are located in 6 different forested parts of the Low Mountain Ranges in Central Germany (Fig. 1, Tables 1, 2). They were originally chosen to guarantee a wide range of hydro-morphological structures within diverse substrate types as microhabitats for inver-

Figure 1. Study sites in Central Germany.

Table 1. Overview of the study sites within deciduous forest land cover.

Deciduous Forest	Hainich	Krofdorf	Keller-wald	Vogels-berg	Rhön	Burg-wald	Total
Geology	Limestone	Greywacke, Clay Shale		Volcanic rocks		Sandstone	
No. of objects	4	16	27	9	5	0	61
%	7%	26%	44%	15%	8%	–	100%

Table 2. Overview of the study sites within deciduous forest land cover.

Coniferous Forest	Hainich	Krofdorf	Keller-wald	Vogels-berg	Rhön	Burg-wald	Total
Geology	Limestone	Greywacke, Clay Shale		Volcanic rocks		Sandstone	
No. of objects	2	3	3	0	0	17	25
%	8%	12%	12%	–	–	68%	100%

tebrates. In total, 86 springheads were analysed, split amongst 61 springs in deciduous forest land cover dominated by *Fagus sylvatica* (Beech) and 25 springs in coniferous forest land cover dominated by *Picea abies* (Spruce).

Data analysis and field methods

Data analysis was based on a data set from a study on the microhabitat-fauna-relationship and the importance of invertebrate substrate preferences (Reiss 2011). Here,

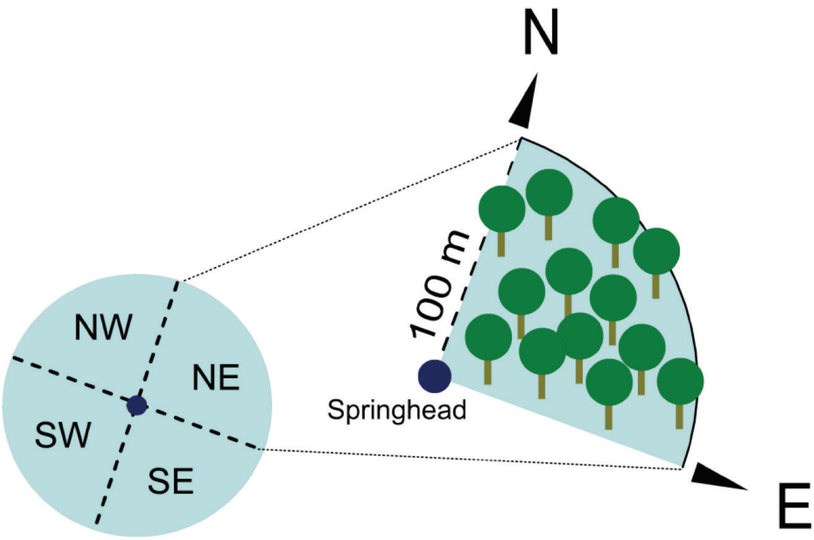

Figure 2. Four-segment approach of adjacent biotope types mapping for springs.

the evaluation of possible effects from different forest cover on abiotic parameters and biodiversity was not an objective of the previous research. However, data regarding adjacent biotope types were mapped. The determination of new taxa was also added.

Adjacent biotope field mapping was done by observing a length of 100 metres from the springhead and by considering four separated quarters, orientated by compass directions (Fig. 2) (Zollhöfer 1997).

In situ measurements of physical-chemical parameters, such as water temperature (°C), pH, electrical conductivity ($\mu S{*}cm^{-1}$), oxygen concentration (mg/l) and oxygen saturation (%), were taken with hand held sensors.

Hydro-morphological structure mapping and invertebrate sampling was conducted using a novel integrated technique for multi-habitat sampling (Reiss 2011, Reiss and Chifflard 2015). The technique was based on a modified approach and substrate type terminology was used similar to the AQEM/STAR procedure (Hering et al. 2003). Here, the substantial difference is the subdivision of mineral and organic substrate types within the determination of the coverage ratios of microhabitats. Mineral and organic layers were considered individually in a 2-layer approach by taking the area of the whole springhead habitat as a reference surface (5-10 m^2). Distribution of sub-sample replicates in each layer should be done according to the estimated share of microhabitats (100 percent coverage means 20 samples in total per layer: 1 sample taken for 5 percent coverage). For example, if the sampling layer of mineral microhabitats consists of 50% psammopelal (mud), 25% microlithal (coarse gravel), 25% macrolithal (coarse blocks and head-sized cobbles) then 10 replicates of benthic macroinvertebrate samples should be taken in the psammopelal, 5 replicates in the microlithal, 5 replicates in the macrolithal. Fauna sampling corresponds with each 5 percent coverage fraction by sampling invertebrates for 2 minutes over a 10 cm x 10 cm reference area for each fraction. Invertebrates were preserved in ethanol alcohol (90%) for transport and subsequent identification in the laboratory.

Data preparation was carried out by filtering and sorting all data related to 100% of the deciduous and coniferous forest cover within the four-segment approach of the adjacent biotope type field mapping procedure. Multiple methods were used to characterise diversity indices: Margalef richness (d) after Margalef (1958), Shannon index (H') after Shannon and Weaver (1949) and Pielou's evenness (J') after Pielou (1966), using the statistical analysis tool PRIMER-E (Clarke and Gorley 2006). Box-Whisker-Plots were generated with BoxPlotR using the online version (shiny.chemgrid.org/boxplotr) (Spitzer et al. 2014).

Results

Hydro-physical-chemical parameters

The results from hydro-physical-chemical *in situ* measurements in springs (Table 3) indicated that there is not much difference between deciduous forest and coniferous forest land cover for water temperature (Wtemp) and electrical conductivity (EC). In contrast, differences are obvious for pH, oxygen concentration (O_2 Conc.) and oxygen saturation (O_2 Satur.).

The acidification of spring water seems to be one major effect in conifer forest springheads, showing that the pH measurements giving a much lower median value in coniferous forest with pH 5.4, than in deciduous forest with pH 7.7 (Fig. 3).

Microhabitats

Microhabitats, which cover ratios for deciduous and coniferous forest springs (Fig. 4), highlight differences within the two dissimilar forest types. Generally, 13 substrate types are equally present in deciduous forest and coniferous forest springs. However, cover ratios of substrate types in coniferous forest springs are obviously rarer, so that most of the microhabitats, especially organic substrate types are under-represented. Otherwise, certain microhabitats, such as coniferous litter and moss cushions, show slightly higher cover ratios in coniferous forest than in deciduous forest springs. Emergent macrophytes in coniferous forest springs are considerably under-represented in comparison to springheads in deciduous forests.

Fauna and Biodiversity

Overall, 52 taxa and 2617 individuals in springs of deciduous forest land cover and 33 taxa and 326 individuals in springs of coniferous forest land cover were found. Tables 4 and 5 show taxa lists of found invertebrates including individuals per taxon,

Table 3. Hydro-physical-chemical measurements of deciduous forest and coniferous forest land cover.

Parameter	Wtemp		pH		EC		O_2 Conc.		O_2 Satur.	
										
	°C				$\mu S{*}cm^{-1}$		mg/l		%	
Max	15.9	13.4	8.5	8.3	960	790	13.0	14.8	134%	142%
75-Q	12.4	11.5	7.9	7.4	320	230	9.7	10.7	107%	102%
Median	10.2	10.3	7.7	5.4	200	180	8.9	7.0	92%	75%
25-Q	8.1	8.1	7.5	4.9	130	140	7.1	4.3	79%	43%
Min	3.1	3.0	6.0	4.0	70	110	3.6	2.4	38%	25%

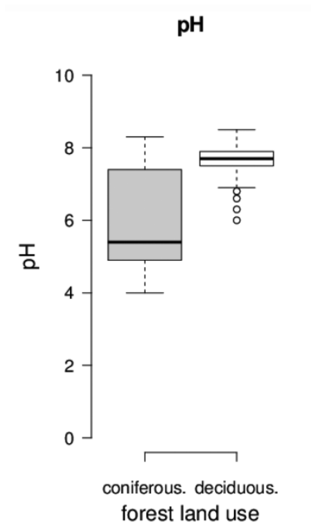

Figure 3. pH of springs of coniferous (left boxplot) and deciduous (right boxplot) forest land cover.

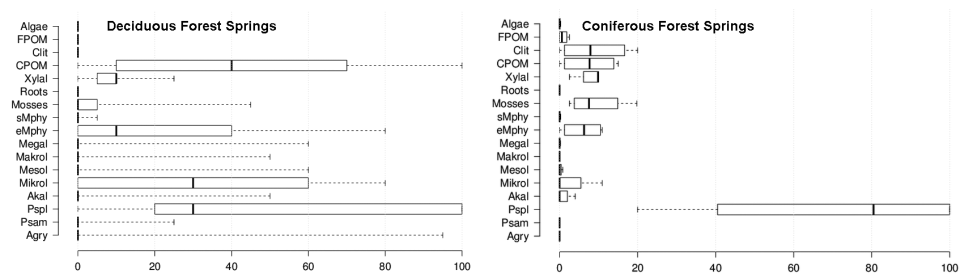

Figure 4. Cover ratio of microhabitats in deciduous (left) and coniferous (right) forest headwater springs. Substrate terminology: Argyllal – Agry; Psammal – Psam; Psammopelal – Pspl; Akal – Akal; Microlithal – Mikrol; Mesolithal – Mesol; Macrolithal – Makrol; Megalithal – Megal; Emergent macrophytes – eMphy; Submerged macrophytes – sMphy; Moss cushions – Mosses; Fine roots – Roots; Xylal (Dead Wood) – Xylal; Coarse particular organic material – CPOM; Coniferous litter – Clit; Fine particular organic material – FPOM; Algae – Algae.

Table 4. Taxa list of springs within deciduous forest land cover. x – good substrate type preference identification; xx – very good substrate type preference identification; m – mosses (spring dwelling taxa are in bold).

Invertebrates – taxa and abundances				Invertebrates – substrate preference					
Taxa	**Individuals (Ind.)**	**Springs**	**Ind./springs**	**Pspl**	**Microl**	**CPOM**	**Xylal**	**eMphy**	**Others**
Bythinella dunkeri	577	26	22.2			x			
Bythinella compressa	198	11	18.0	x					
Gammarus fossarum	402	26	15.5			x			
Gammarus pulex	110	10	11.0	x		x			
Crenobia alpina	112	15	7.5			x			
Niphargus schellenbergi	50	7	7.1			x			
Sericostoma sp.	188	34	5.5		x				
Crunoecia irrorata	177	38	4.7			x			
Pisidium cf. *personatum*	165	36	4.6	xx					
Oniscus asellus	17	4	4.3				xx		
Nemoura sp.	86	29	3.0			x			
Carychium tridentatum	20	7	2.9	x			x		
Niphargus aquilex	16	6	2.7			xx			
Leuctra sp.	71	28	2.5	x		x			
Trichoniscus sp.	58	23	2.5			x	x		
Niphargus sp.	19	8	2.4						
Oligolophus tridens	7	3	2.3					xx	
Monachoides incarnatus	30	13	2.3					xx	
Hydroporinae sp.	17	8	2.1						
Dixa sp.	57	27	2.1					x	
Clinocera sp.	2	1	2.0						
Euconulus fulvus	8	4	2.0			x			
Helophorus sp.	2	1	2.0			x	x		
Anacaena sp.	72	37	1.9			x			m
Galba truncatula	27	15	1.8			x			
Ligidium hypnorum	7	4	1.8						m
Protonemura sp.	7	4	1.8				x		
Eiseniella tetraedra	30	18	1.7			x	x		
Discus rotundatus	13	8	1.6				x		
Velia sp.	8	5	1.6		x	x			
Carychium sp.	17	11	1.5						
Pedicia rivosa	4	3	1.3					xx	
Bezzia sp.	11	10	1.1	xx					
Agabus sp.	4	4	1.0			x			
Amphinemura sp.	1	1	1.0						
Arianta arbustorum	1	1	1.0						
Cicadella viridis	3	3	1.0					xx	
Cochlicopa sp.	1	1	1.0						
Cordulegaster bidentatus	2	2	1.0	x	xx	x			

Glomeris marginata	1	1	1.0						
Habroleptoides confusa	3	3	1.0			xx			
Ixodes sp.	1	1	1.0						
Leiobunum blackwalli	1	1	1.0					xx	
Lithobius sp.	4	4	1.0					x	
Mitopus morio	1	1	1.0						
Nemastoma lugubre	1	1	1.0						
Neobisium sp.	2	2	1.0				x		m
Platybuninae sp.	1	1	1.0						
Polydesmus sp.	1	1	1.0			x	xx		
Radix sp.	1	1	1.0						
Trichia sp.	2	2	1.0						
Trombidium holosericeum	1	1	1.0						
Averages	Ø 50	Ø 10	Ø 3						
Identification of substrate type preferences				7	3	20	9	7	3
Identification of substrate type preferences / total no. of taxa				0.14	0.06	0.38	0.17	0.14	0.06
Identification of substrate type preferences in total				49					

occurrence of a taxon (no. of springs), the ratio of individuals and springs (occurrence of a taxon) and the classification of the substrate preference. Typical spring dwelling taxa are in bold letters. In deciduous forest, the ratio of the total number of individuals in a taxon and their level of occurrence (no. of springs) is 43 individuals per spring and, in coniferous forest, 13 individuals per spring. The average number of springs, colonised by individuals of a taxon, is much higher for deciduous forest springs (Ø 10 no. of springs) than it is for coniferous springs (Ø 3 no. of springs). The identification of substrate preferences is also higher for springs in deciduous forest (49 identified with 12 very good substrate type preference identification), than in springs in coniferous forest (40 identified with 7 very good substrate type preference identification). Taxa, with an organic substrate type preference, are much more dominant in both forest types than taxa with a mineral substrate type preference. A clear decline of cold stenothermal species, such as the two groundwater amphipods *Niphargus schellenbergi*, *Niphargus aquilex* and the spring-dwelling flatworm *Crenobia alpina*, is particularly apparent in coniferous forest springs regarding the individuals per spring ratios. The number of spring dwelling taxa – as a group of well-known crenobionts and crenophilous taxa – is almost equal in both forest types. In deciduous forest springs, 11 spring dwelling taxa and, in conifer forest springs, 10 spring dwelling taxa occur. Certainly, the median of the individuals per spring ratio is different; while in deciduous forest springs, it is 4.7 individuals per spring and in conifer forest springs, it is 2.8 individuals per spring. Overall, the amount of spring dwelling taxa is higher in proportion to the total number of taxa in conifer forest springs than in deciduous forest springs. Characterising biodiversity, using biodiversity indices like Margalef richness (d) and Shannon index (H') with deciduous and coniferous forest cover, shows only marginal differences (Table 6). Overall, biodiversity is slightly

Table 5. Taxa list of springs within coniferous forest land cover. x: good substrate type preference identification; xx: very good substrate type preference identification; m – mosses; Ml – Megalith (spring dwelling taxa are in bold).

Invertebrates – taxa and abundances				**Invertebrates – substrate preference**					
Taxa	**Individuals (Ind.)**	**Springs**	**Ind./springs**	**Pspl**	**Microl**	**CPOM**	**Xylal**	**eMphy**	**Others**
Bythinella dunkeri	77	2	38.5			x			
Leuctra sp.	14	1	14.0	x		x			
Gammarus fossarum	34	3	11.3			x			
Gammarus pulex	5	1	5.0	x		x			
Pisidium cf. *personatum*	24	5	4.8	xx					
Nemoura sp.	32	7	4.6			x			
Crunoecia irrorata	16	4	4.0			x			
Cordulegaster bidentatus	3	1	3.0	x	xx	x			
Sericostoma sp.	11	4	2.8		x				
Anacaena sp.	44	18	2.4			x			
Trichoniscus sp.	18	8	2.3			x	x		
Dixa sp.	6	3	2.0					x	
Euconulus sp.	4	2	2.0			x			
Habroleptoides confusa	4	2	2.0			xx			
Niphargus schellenbergi	2	1	2.0			x			
Polycelis felina	2	1	2.0			x			
Leiobuninae sp.	3	2	1.5						
Agabus sp.	3	3	1.0			x			
Bezzia sp.	3	3	1.0	xx					
Carychium sp.	2	2	1.0	x		x			
Clinocera sp.	1	1	1.0						
Crenobia alpina	1	1	1.0			x			
Eiseniella tetraedra	3	3	1.0			x	x		
Galba truncatula	1	1	1.0			x			
Helophorus sp.	1	1	1.0			x	x		m
Lacinius ephippiatus	1	1	1.0						
Ligidium hypnorum	2	2	1.0						m
Metellina merianae	1	1	1.0						
Neobisium sp.	2	2	1.0				x		m
Niphargus aquilex	1	1	1.0			xx			
Paranemastoma quadripunctatum	3	3	1.0				xx		Ml
Polydesmus sp.	1	1	1.0			x	xx		
Rilaena triangularis	1	1	1.0						
Averages	Ø 10	Ø 3	Ø 4						
Identification of substrate type preferences				6	2	21	6	1	4
Identification of substrate type preferences / total no. of taxa				0.18	0.06	0.64	0.24	0.03	0.12
Identification of substrate type preferences in total				40					

Table 6. Diversity indices in deciduous and coniferous forest headwater springs.

Forest land cover	Margalef richness (d)	Shannon index (H')	Pilou's evenness (J')
Deciduous Forest	6.48	2.78	0.70
Coniferous Forest	5.53	2.65	0.76

higher in deciduous forest springs. The distribution of individuals within occurring invertebrate taxa is more homogenous in coniferous forest springs regarding Pielou's evenness (J').

Discussion

Results show three main forest land cover impacts on eco-hydrological structures and biodiversity in mountainous headwater springs concerning deciduous and coniferous forest: 1) Acidification in conifer forest springs; 2) Higher cover ratios of organic substrate type based microhabitats in deciduous forest springs; 3) Higher biodiversity in species richness and total number of individuals as well as abundances in deciduous forest springs.

Acidification of springs in coniferous forests of the German Low Mountain Ranges is a well-known problem, especially in siliceous springs with poor acid buffer capacities and can causes a decrease in the total number of species and individuals (Klös 1984, Lükewille et al. 1984, Meijering 1984, Mauden 1994, Orendt and Reinhart 1997, Audorff and Beierkuhnlein 1999, Hahn 2000). Therefore, it can be expected that the lower values of the total number of species and individuals in conifer forest springs is mainly a consequence of acidification. This interpretation is congruent with findings from a multivariate statistical analysis to characterise the main components of environmental factors influencing the absent and present data on spring fauna using a principal component analysis in the entire data set (Reiss 2011). It is important to note that only in-situ measurements (on-site pH values) were taken into account and no further investigations could be executed to analyse the dynamics or additional reasons for low pH values in order to deduce more accurate and detailed interpretations about acidification.

Higher cover ratios of organic substrate type based microhabitats in deciduous forest springs compared with springs in coniferous forest can be seen as a higher hydromorphological representation of specific microhabitats (e.g. emergent macrophytes or CPOM). However, conifer forest springs have the same quantitative share of occurring substrate types. CPOM (Coarse particular organic material), mainly composed by leaf litter from deciduous trees, is more important as allochthonous organic material as the most important food source for spring fauna communities with a high proportion of primary consumers in particular like herbivorous shredders (e.g. *Gammarus fossarum*, *Gammarus pulex*) or grazer and scrapers (e.g. *Bythinella dunkeri*, *Bythinella compressa*) (Teal 1957, Mninshall 1967, Whiles and Wallace 1997, Kemp and Boynton 2004). There is no microhabitat preference in coniferous litter, because it is commonly known that the chemical composition of needles tend to retard biological activity in decomposition (Olson 1963). Here, detritus processing takes a much longer time (Sedell et al. 1974, Whiles and Wallace 1997) and can be characterised as a low quality detritivore food resource (Taylor et al. 1989, Klemmedson 1992, Friberg and Jacobsen 1994). Furthermore, comparing deciduous and coniferous spring microhabitats, one main conclusion is that substrate types are more important than substrate heterogeneity in contrast to a more general finding by Kubíková et al. (2012). However, in this study, it is not possible to distinguish between acidification and substrate types for describing a prevailing key factor causing taxa and individuals' richness in forest spring habitats.

Higher biodiversity in species richness, total number of individuals as well as abundances in deciduous forest springs in contrast to conifer forest springs, are the most obvious impacts caused by different forest stands. The result of a higher amount of spring dwelling taxa in conifer forest springs than in deciduous forest springs, in proportion to the total number of all found taxa, is consistent with findings by Hahn (2000). Hahn (2000) concluded that spring dwelling species are more tolerant to low pH-values than rhithrobiontic ones due to their adaptation to special crenal living conditions. However, conifer forest springs in our investigation, with their tendency to acidification, are characterised by considerably less individuals per spring ratios and a total number of individuals considering only spring dwelling taxa. Higher cover ratios of organic substrate type based microhabitats in deciduous forest springs compared with springs in coniferous forest seem to be less crucial for biodiversity. Nevertheless, although organic substrate type based microhabitats are of importance, they are more decisive on taxa composition. Some taxa which are under-represented in deciduous forest springs become more quantitatively relevant in conifer forest springs. The abundance of the shredding plecopteran *Leuctra* spp. is much higher in conifer forest springs, which is in line with the findings in a study about leaf litter decomposition in macroinvertebrate communities in pine and hardwood headwater catchments of the southern Appalachian Mountains in North Carolina, USA (Whiles and Wallace 1997). *Leuctra* spp. is known as an acid-tolerant aquatic invertebrate (Dangles and Guérold 2000), which is an indicator for acidification as an important factor on taxa composition. Otherwise, acid-sensitive amphipod *Gammarus fossarum* is similarly abundant, which means no acidification shift in taxa composition is noticeable. It can be inferred that both factors – acidification and microhabitat – govern fauna assemblages or biodiversity and no strong key variable can be characterised. However, this study indicates impacts from different forest cover when comparing spring habitats in deciduous and coniferous forest on eco-hydrological structures and biodiversity.

Conclusion

Different forest land cover causes considerable contrasts in microhabitat structures; obvious organic substrate type composition and cover ratios; as well as differences in species richness and invertebrate abundance of spring habitats in deciduous and coniferous forest. This means, land cover as an ecological mesoscale, properly determined by different forest types, has an impact on eco-hydrological structures and biodiversity on the micro scale. It implies an essential consideration for adjacent biotope type mapping and is an important integrative parameter for spring habitat assessment approaches. Furthermore, the recognition of substrate preferences of invertebrates, within an ecotone based assessment approach, characterises microhabitats explicitly for all parts of a springhead, regarding aquatic and terrestrial spring habitat zones. Here, the importance of forest land cover and the substrate type diversity relationship is taken into account within an ecological spring habitat assessment methodology and characterises its consequences on invertebrate biodiversity. Therefore, negative effects from forest management practices (e.g. forest conversion) within a nature conservation perspective can be included in decision-making and action plans to realise national or regional strategies on biodiversity.

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