MASTERARBEIT

Titel der Masterarbeit

„Characterization of macroinvertebrate communities in meteogene travertine-depositing headwaters in Austria“

Verfasser

Jean-Pierre Bednar, BSc

angestrebter akademischer Grad

Master of Science (MSc)

Wien, 2015

Studienkennzahl lt. Studienblatt:	A 066 833
Studienrichtung lt. Studienblatt:	Masterstudium Ökologie
Betreuer:	Ao. Univ.-Prof. Dr. Johann Waringer

ACKNOWLEDGEMENT

First of all, I would like to thank my supervisor, Professor Dr. Johann Waringer, who has an excitement in regard to research and teaching. Without his guidance and persistence this thesis wouldn't have been possible.

I would like to express my deepest appreciation to my project partner, Manuela Trobej, BSc, who shared the stress and strains of a double Austrian-wide sampling with me. We spent a lot of hours in field during this study and she was always, through all ups and downs, the best companion, always ready for great discussions and a source of ideas.

In addition, I would like to thank her supervisor and my second mentor, Professor Dr. Michael Schagerl, for his constant enthusiasm about these special habitats, which influenced me by the first moment.

I also thank our great Assistant's Christoph Bstaendig, BSc and Clemens Straganz, who supported us perfectly in field during storms and heat waves – as volunteers!

Weiters möchte ich meiner Mutter, Denise Bednar, danken, die mich seit jeher bei all meinen Ideen und Plänen mehr als unterstützt hat. Ohne deine Hilfe und deinen Zuspruch hätte ich das Studium vermutlich weder begonnen noch beendet. Außerdem möchte ich Frank Müller für seine stetige Unterstützung während des Studiums danken.

I am indebted to my Colleague Mag. Simon Vitecek for his great statistical skills and extensive support. You will always be my first address in further questions about r Studio.

Last but not least, I thank the Department of Limnology and Bio-oceanography for the financial support and for provision with material and equipment, and special thanks to chemist Hubert Kraill for the chemical analysis. I thank also Prof. Dr. Hubert Krisai (University of Salzburg) for identifying the Bryophytes and Ing. Dr. Rudolf Pavuza and Dr. Petra Cech, Museum of Natural History Vienna, for recommendations for ideal sampling sites.

This work was financially supported by a scholarship (Masterthesis-scholarship) of the University of Vienna.

TABLE OF CONTENTS:

LIST OF ABBREVIATIONS

ANOSIM	Analysis of similarity
CCA	Canonical correspondence analysis
cPOM	Coarse particular organic matter
fPOM	Fine particular organic matter
ISA	Indicator species analysis
LSI	Langelier saturation index
MTDH	Meteogene travertine-depositing headwaters
MZB	Macrozoobenthos
nMDS	Nonmetric multidimensional scaling
RCC	River continuum concept
TP	Total phosphorus
uPOM	Ultrafine particular organic matter

ABSTRACT

In order to characterize the macroinvertebrate communities, 14 travertine-depositing springs and headwaters in Austria were classified as active in travertine deposition and therefore selected as sites for further investigations. The aim of this study was to explore taxa associations of macrozoobenthos over a range of travertine-depositing headwaters in Austria and the interactions between communities and environmental conditions, such as different calcium carbonate precipitation rates. To get further information on possible seasonal effects, the sampling campaigns took place in springtime and autumn 2014. The results show that travertine-depositing springs and headwaters in Austria are nearly homogeneous in terms of hydrochemistry, and that differences to similar sites in other countries are minimal and based on geological and catchment factors. The community was predominantly composed of stygobiontic taxa from groundwater refugia and of immigrated generalists that prefer the stable conditions there (e.g., low amplitudes of water temperature and high buffering capacity). Analysis based on the taxa inventories yielded seven site groups, which were seasonally and geographically well-mixed. Further statistics identified the sinter coverage, O_2 and total phosphorus concentration as well as the Langelier saturation index as significantly influencing environmental parameters for macrozoobenthic community composition. The calcium carbonate precipitation rate merely highlighted trends but yielded no significant correlations with macrozoobenthos species sets. Only a few endemic species (e.g., *Bythinella austriaca austriaca, B. opaca opaca, B. bavarica* and *Rhyacophila pubescens*) and specialists separated the study sites geographically, but the majority were well-known spring- and headwater-dwelling species (e.g., from the genera *Gammarus* and *Simulium*) without any known adaptation to carbonate precipitation or association with travertine. Nonetheless, the carbonate precipitation seems to lead to higher structural heterogeneity and provides a range of new niches, which contribute to broader ranges of taxonomic diversity.

1. INTRODUCTION

In a global context, almost 30 % of the water resources consists of groundwater, emerging at springs (Shiklomanov, 1998; Durack, 2015). Worldwide, more than $57{\cdot}10^6$ spring habitats (excluding Antarctica) were estimated by Glazier (2009), serving as interfaces between groundwater and the many types of surface freshwater systems.

The main driving force of stream ecosystems is gravity, resulting in an unidirectional water movement, highly shortened residence times when compared to lentic environments, the permanent downstream transport of a wide spectrum of dissolved organic and inorganic components and redeposition of particles originating from the catchment (Payn, 2005; Lamberti & Gregory, 2007; Newbury & Bates, 2007; Lutz *et al.*, 2012). The physico-chemical, hydrological and biological properties of running water systems highly reflect the catchment characteristics (geology, vegetation and climate; Odum, 1956; Hynes, 1970; Mulholland *et al.*, 1985; Wetzel, 2001; Dodds, 2002; Mulholland *et al.*; 2005; Likens, 2009).

1.1. Springs and headwaters

Springs are geographically isolated running water environments with stable conditions when compared to other freshwater habitats (Hynes, 1970; Sherwood & Sheath, 1998). Hydrogeologically, springs are defined as places where groundwater emerges (Odum, 1971) and often seen as functionally and structurally simple habitats, although environmental heterogeneity may be high at the microhabitat scale (Kløve *et al.*, 2011).

This heterogeneity is due to lotic (spring brooks) and lentic (spring pool) subsystems (Barquin & Scarsbrook, 2008), combined with spatial gradients of wetness within the semi-terrestrial zone (Staudacher & Füreder, 2007), thereby providing highly structured habitats with a multitude of ecological niches (Cantonati *et al.*, 2006; Gerecke *et al.*, 2011).

Due to this transition between terrestrial and aquatic zones, springs can be considered as multiple 3-way ecotones that link aquatic and terrestrial ecosystems: the spring, the ground- and the surface water (Scarsbrook *et al.*, 2007). This mosaic structure of different microhabitats (e.g. mosses, debris; Illies and Botosaneanu, 1963), next to the availability of different substrate types, and the wide range of available nutrients is one of the main reason for the observed high biodiversity of springs (Stanford *et al.*, 1994).

Based on geology, hydrochemistry, water temperature, hydrology and human services, springs and adjacent headwater streams were grouped in different types (Glazier, 2009).
The lithology of the aquifer is one of the main determinants of the hydrochemistry, next to the hydrological regime and the substrate characteristics (van der Kamp, 1995).

1.2. Travertine definition and chemical background of travertine formation

The precipitation of calcium carbonate results in formation of travertine. These highly self-regulating travertine systems produce new kinds of sediments under the influence of flowing freshwater (Sanders *et al.*, 2011). Depending on the origin of CO_2, Pentecost & Viles (1994) distinguished between “meteogene” and “thermogene” travertine:

- **Meteogene travertine** precipitation occurs under conditions were the main CO_2 source originates from soil by root respiration, previously fixed from the atmosphere. Widely distributed, these kinds of travertine usually contain a wide range of bacteria, macroinvertebrates and photoautotrophic micro- and macrophytes. In Austria only this type of travertine exists.
- **Thermogene travertine** formation results from CO_2 produced by hydrolysis and oxidation of carbon. These extreme habitats are mostly hot water springs and inhabited only by highly specialized hyperthermophilic biota such as bacteria and archaea (Ford & Pedley, 1996).

Terraces, cascades, dams and walls can be formed by this process and contribute to the high structural diversity of these systems (Wright, 2000).

Travertine formation underlies the dissociation of carbon. The chemical conditions and reactions, which are necessary for travertine formation, are as follows:

According to Henry's Law, carbon dioxide dissolves in H_2O:

$$[CO_2] = KCO_2 \; pCO_2 \tag{1}$$

where K is the solubility constant and p the partial pressure of CO_2 gas. The gas concentration of a solution is proportional to the ambient partial gas pressure next to the solubility at equilibrium condition

$$pCO_2 \leftrightarrow [\mathrm{CO_2}] \tag{2}$$

The dissolved carbon dioxide reacts with water to

$$[\mathrm{CO_2}] + [\mathrm{H_2O}] \leftrightarrow [\mathrm{H_2CO_3}] \leftrightarrow [\mathrm{H^+}] + [\mathrm{HCO_3^-}] \tag{3}$$

$$[\mathrm{HCO_3^-}] \leftrightarrow [\mathrm{H^+}] + [\mathrm{CO_3^{2-}}] \tag{4}$$

Cold groundwater, supersaturated with CO_2 by metabolism (decomposition and respiration) processes in the soil and aquifer, is acidic and able to dissolve $CaCO_3$. At spring locations the rapid change of temperature and partial pressure leads to outgassing of CO_2 and precipitation of $CaCO_3$ (Barnes, 1965; Stumm, 1995):

$$\mathrm{CaCO_3} + \mathrm{CO_2} + \mathrm{H_2O} \leftrightarrow \mathrm{Ca^{2+}} + 2\mathrm{HCO_3^-}$$

Next to these abiotic processes, photosynthesis is a biotic pathway for precipitation by organismic removal of CO_2 e.g., by calcifying cyanobacteria like *Rivularia* and *Scytonema* (Rott *et al.*, 2012).

Calcium carbonate precipitation is, therefore, a physico-chemical process shifting unidirectionally from abiotic to biogenic along the stream continuum (Merz & Zankle, 1991).

1.3. Macrozoobenthic invertebrates in aquatic ecosystems

Representatives of many taxonomic groups of organisms inhabit aquatic ecosystems. Their interactions with the aquatic system alter water characteristics and execute ecosystem services like nutrient cycling and decomposition. These organisms are serving as sensitive sentinels for identification of pollution. The correct taxonomic identification of plants, animals and microbes in freshwater systems is essential for understanding food webs and is necessary to assess water quality (Dodds, 2002; Carter *et al.*, 2007; Hauer & Resh, 2007; Lencioni *et al.*, 2012), where macrozoobenthos (defined as visible with unaided eye: > 0.5 mm) plays an important role.

The downstream transport of autochthonous/ allochthonous organic material as well as storage and utilization by macroinvertebrate functional feeding groups creates distinct patterns of different community structures. The river continuum concept (RCC) characterizes these functional feeding groups, based on mouthparts morphology. One key aspect of the RCC is the importance of allochthonous input (e.g., leaf litter at sites with high canopy cover), which decreases from springs to higher stream orders. Headwater communities mostly contain high proportions of shredders and collectors, reflecting the dominant particle size Reduction of organic matter size leads to higher proportions of collectors, whereas predators change less in abundance over a high range of orders (Vannote *et al.*, 1980).

1.4. Macrozoobenthic invertebrates in springs and headwaters

The chemical, physical and biological variability of springs and headwaters leads to unique habitats with fluctuating conditions and provides niches for small isolated populations as described in the patch dynamics concept by Townsend (1989). Different ecotypes of species inhabit springs and headwaters, thereby creating a mix of groundwater species with stable water temperature requirements, surface water species and terrestrial or wetland species (Ferrington, 1995; Hahn, 2000; Hoffsten & Malmqvist, 2000).

All of them prefer the buffering capacity benefit of groundwater against aridity and extreme temperature (Kløve *et al.*, 2011). Sets of key parameters for crenal communities were identified by ecologists over the last decades: conductivity and discharge (Roca & Baltanás, 1993), stable discharge, acidity and eutrophication (Verdonschot & Schot, 1987), particle size of substratum and discharge (Bonettini & Cantonati, 1996), and climate and hydrochemistry (Mezquita *et al.*, 1999).

Generally, springs habitats which provide biodiversity hotspots are not included in the European habitat directive. However, certain types of spring habitats (e.g., Cratoneurion; Code * 7220) are seen as habitats with high conservation priority in this directive. On the other hand, data from Schleswig-Holstein (Martin & Wischniowsky, 2014) show no significant differences between macrozoobenthic invertebrate communities of travertine depositing-springs when compared to other spring habitats. Other studies observed that species richness was lower in travertine-depositing habitats (Zollhöfer, 1997).

1.5. Objectives

There is a lack of studies focusing on headwaters and spring-dwelling organisms; therefore the relationships between abiotic variables and crenocoenoses are still poorly understood, although such habitats are considered as highly important in our understanding of many general aspects of freshwater ecology (Botosaneanu, 1998; Hoffsten & Malmqvist, 2000). Therefore, the aim of the present study was to explore taxa associations of macrozoobenthos over a range of travertine-depositing headwaters in Austria and the interactions between communities and environmental conditions, such as different calcium carbonate precipitation rates.

2. MATERIAL AND METHODS

This study is part of a collaboration with Manuela Trobej, BSc., who investigated the structure of algal communities at the same sites (MSc thesis "Characterization of algae communities in spring-associated limestone habitats of Austria").

2.1. Study sites

In order to characterize the macroinvertebrate communities, 25 different travertine-depositing springs and headwaters in Austria were visited, 14 classified as active in travertine deposition and therefore selected as sites for further investigations (**Fig. 1**). The first sampling campaign took place in springtime from April to May 2014. Further samplings were taken in early autumn (September) 2014 to get further information on possible seasonal effects (**Table 1**).

2.2. Overview and description of the sampling sites

Representative reaches with lengths of 5 meters of each active meteogene travertine depositing headwater were selected and marked with metal rods. After photographical documentation of the sampling positions, microhabitats (travertine, cPOM – coarse particular organic matter, fPOM – fine particular organic matter) were mapped and their percentage areas estimated.

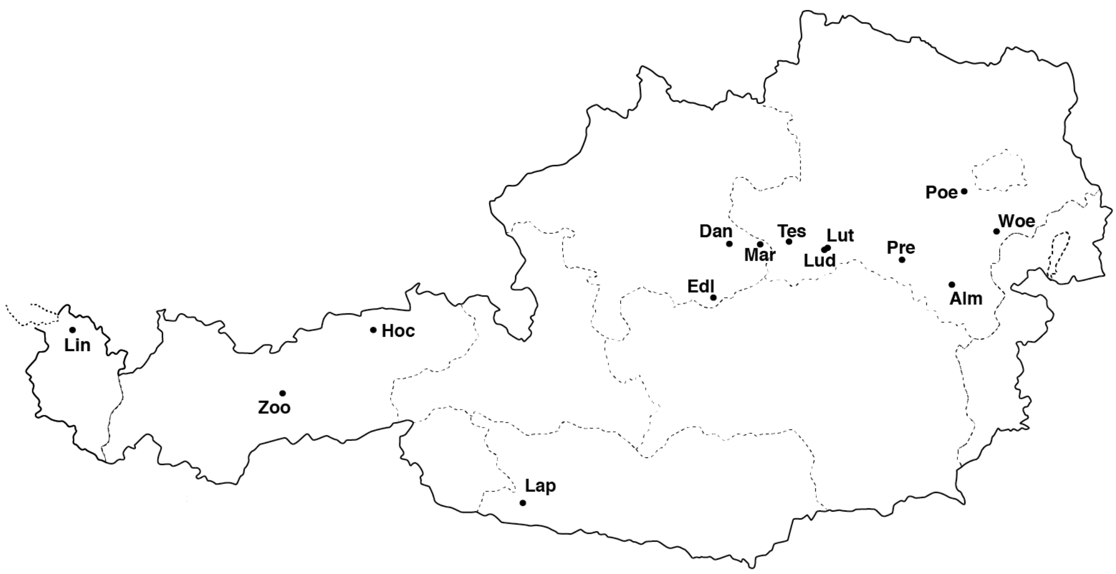


Fig. 1. Map of Austria showing the sampling sites. ID's are explained in detail in **Table 1**.

Table 1. Overview of sampling locations and dates including geographical coordinates of all sites. The ID's will be further used as abbreviation of each site.

Site	ID	Sampling-Date	Coordinates
Woellersdorf, Lower Austria	Woe	Spring 20 May 2014 Autumn 19 September 2014	N 47.8567, E 16.1364
Maiszinken at Lake Lunz (top), Lower Austria	Lut	Spring 22 May 2014 Autumn 15 September 2014	N 47.861343, E 15.067526
Maiszinken at Lake Lunz (down), Lower Austria	Lud	Spring 22 May 2014 Autumn 15 September 2014	N 47.8599, E 15.0666
Side arm of the Poellerbach in Alland, Lower Austria	Poe	Spring 26 May 2014 Autumn 19 September 2014	N 48.055684, E 16.025906
Almassysschloessl next to Schloeglmuehl Gloggnitz, Lower Austria	Alm	Spring 31 May 2014 Autumn 18 September 2014	N 47.699812, E 15.904347
Alpenzoo Innsbruck, Tyrol	Zoo	Spring 22 June 2014 Autumn 09 September 2014	N 47.283133, E 11.398982
Hochtalalm, Tyrol	Hoc	Spring 23 June 2014 Autumn 09 September 2014	N 47.549090, E 11.888078
Lingenau, Vorarlberg	Lin	Spring 24 June 2014 Autumn 09 September 2014	N 47.444036, E 9.907163
Preinmuehle next to Schwarzau/ Preintal Lower Austria	Pre	Spring 01 July 2014 Autumn 18 September 2014	N 47.794759, E 15.660054
Maria Neustift, Upper Austria	Mar	Spring 04 July 2014 Autumn 22 September 2014	N 47.930808, E 14.610769
Dandlgraben next to Maria Neustift Losenstein, Upper Austria	Dan	Spring 04 July 2014 Autumn 22 September 2014	N 47.930454, E 14.451295
Lappenbach next to Stein Drauntal, Carinthia	Lap	Spring 15 July 2014 Autumn 11 September 2014	N 46.727105, E 13.040664
Teschengraben Lower Austria	Tes	Spring 25 July 2014 Autumn 15 September 2014	N 47.926322, E 14.800572
Edlbach next to Spital am Phyrn, Upper Austria	Edl	Spring 25 July 2014 Autumn 22 September 2014	N 47.673229, E 14.35100

2.3. Physical, chemical and structural parameters

At three measuring points (one in every third of the reach) a set of 12 environmental parameters were measured *in situ* (**Table 2**).

Table 2. Summary of *in situ* parameters and procedures.

Parameter	Method
pH	WTW pH 330i/ METROHM combined glass electrode (6.0253.100)
Oxygen concentration [%]/ [mg l^{-1}]	WTW Oxy 197i
Conductivity [µS cm^{-1}] and water temperature [°C]	WTW LF 197i/ DIN EN 27888:1993-11, ISO 7888:1985)
Site openness	NIKON Coolpix 4500, NIKON Fisheye Converter Lens FC-E8 0.21x and the
Slope [%]	Flexible tube water level
Depth, width [m]	Measuring stick
Flow velocity [m s^{-1}]	Tracer method with methylene blue after Pomeisl (1953)
Alkalinity, acidity and free CO_2	Titration after Hütter (1994) with 0,1 N HCl and 0,01 N NaOH to pH values 4,3 / 8,2

For calcium carbonate precipitation measuring, metal washers provided artificial substrates and were mounted randomly at the stream bed (**Fig. 2**) within active travertine zones at each sampling site during the first sampling procedure between April and May 2014. The incrusted washers were recovered with a mobile metal detector in September 2014.

Fig. 2. Artificial substrate used for calcium carbonate precipitation measurements.

Table 3. Overview of the methods and standards for chemical analyses.

Parameter	Method	Device
Major cation and anion concentrations: **(Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO^{3-}, SO_4^{2-}, Cl^{-})** **NO^{3-}**	Ion chromatography: *Cations:* OENORM EN ISO 14911:1999-11-01; *Anions incl. NO^{3-}:* OENORM EN ISO 10304-1:2012-06-01)	Ion chromatography: Metrohm Compact IC 761 Suppressormodul MSM Metrohm 853 CO2-Suppressor Metrohm IC Filtration Sample Processor 788 *Anions:* Metrohm Metrosep A Supp 5 (150 x 4.0 mm ID) with suppression *Cations:* Metrohm Metrosep C2 (150 x 4.0 mm ID)
Total phosphorus **PO_4.P**	Photometric (OENORM EN ISO 6878:2004-09-01), converted into PO_4	HACH-LANGE DR 2800
N-NO^{2-}	Photometric (DIN EN 26777:1993-04), converted into NO^{2-}	HACH-LANGE DR 2800
N-NH^{4+}	Photometric (OENORM ISO 7150-1:1987-12-01), converted into NH^{4+}	HACH-LANGE DR 2800

Subsequently, water subsamples were taken at each measuring site (9 samples á 50 ml). Six samples were filtered with Whatman GFF (Glass microfiber filters, 47 mm Ø) syringe-filters and three were left unfiltered; for further analysis in the laboratory at the Department of Limnology and Bio-oceanography, the samples were transported in a fridge box.
The methods used for the limnochemical analyses are listed in **Table 3**.

Hydrogen carbonate and free carbon dioxide were calculated after Hütter (1994). Discharge was calculated using widht, mean depth and flow velocity at 40 % water depth.

Furthermore, the Langelier Saturation Index was calculated with the online calculator by Lenntech (2015) which indicates the water un-/ saturation with calcium carbonate and the tendency for precipitation or erosion (Tchobanoglous & Burton, 1991).

Geological information was provided by the database of the Federal bureau of geology and the riverine landscape and flow regime typology by Wimmer *et al.* (2000) was used for the site descriptions. Site openness was computed by using the software “gap light analyser” (GLA, v2) after Frazer *et al.* (1999).

2.4. Precipitation rates and disturbance

Calcium carbonate precipitation rates were calculated by measuring the height of the surface deposition of the recovered washers, using a binocular (ZEISS SteREO Lumar.V12). The disks were vertically mounted with paper clips, and the thickness of the incrustations (**Fig. 3**) were measured randomly 5 times using the ZEISS ZEN Software (blue edition, 2011). Arithmetic means of incrustation thickness measurements and the exposition time in the field enabled us to calculate precipitation rates per year [mm a^{-1}].

Fig. 3. Measurement of calcium carbonate precipitation. A binocular was used to measure the thickness of incrustation on field-exposed disks.

The anthropogenic disturbance of each sampling station was estimated in spring and autumn by field surveys and ranked by using the following classes:

0 Not disturbed (near to natural conditions)

1 Rarely disturbed (without any visible anthropogenic impacts)

2 Less disturbed (with possible anthropogenic impacts)

3 Disturbed (with anthropogenic impacts)

4 Highly disturbed

5 Completely disturbed (e.g. human drainage, canalization).

2.5. Sampling and identification of macroinvertebrates

Three subsamples for sinter, cPOM and fPOM were taken at each of the three measuring points at every sampling site:

a) by using a syringe-tube-combination and a bottomless 250 ml bottle, its neck modified by adding a rubber lip (**Fig. 4**) for travertine microhabitats (sampling area = 12.6 cm^2) and

b) by sampling an area of 12.6 cm^2 down to 2 cm depth using the same device (sampling volume = 25.1 cm^3) in fPOM and cPOM substrates.

Fig. 4. 250 ml bottle modified with rubber lip for travertine microhabitat samplings. For fPOM and cPOM samples, the lip was removed and the bottle was used as sediment core (sampling depth = 2 cm).

After preservation in 75 % ethanol, the organisms within cPOM and fPOM substratum were filtered in the laboratory with hand nets (200 µm mesh size), than identified under a binocular (ZEISS SteREO Lumar.V12), sorted and their abundance estimated using six frequency classes (0 = absent; 1 = single; 2 = rare; 3 = medium; 4 = abundant; 5 = very abundant).

For identification the keys of Reynoldson & Young (2000), Nilsson (1996a); Waringer & Graf (2011), Eggers & Martens (2001), Bellmann (2010), Bauernfeind & Humpesch (2001), Janeček (2003), Graf & Schmidt-Kloiber (2002), Glöer (2002) and Glöer & Meier-Brook (2003) were used.

Bryophytes were identified by Prof. Dr. Robert Krisai (University of Salzburg) and the functional feeding groups were identified by using Moog (2002); dominance classification closely follows the classes defined by Schiemenz (in Müller, 1984) : 16-35,9 % of the total sample = dominant, > 36 % = eudominant.

2.6. Statistical analysis and graphics

The statistical analyses were carried out with RStudio (v0.98.1103) for Mac. The packages *vegan, MASS, xlsx, cluster, gclus, pvclust, base, indispecies, labdsv* and *vcd* were used.

Environmental data were z-standardized and the dissimilarity matrix for the function *vegdist* was done by using the Bray-Curtis dissimilarity index. The cophenetic correlation function recommended the *hclust* method "average" for agglomeration and a Mantel test the optimum number of clusters. NMDS was computed with *metaMDS* function and two dimensions. The Bray-Curtis dissimilarity matrix served as input and the number of random starts was 100, the maximum number of iterations was 2000. This procedure was carried out four times.

In order to test for significant differences between groups the function *anosim* was used. The indicator species analysis (ISA) was calculated by the function *indval* and verified by permutations tests (999 permutations). With the functions *cca* and *ordistep* canonical correspondence analyses were computed and a forward selection was done.

Graphics were created with RStudio, Sigmaplot (v11.0) and further adaptations done by using the Adobe Illustrator CS6 (v 16.0.0).

Tables were edited in Microsoft Excel for Mac 2011 (v14.4.9)

3. RESULTS

3.1. Environmental and structural parameters

The 14 travertine-depositing headwaters investigated were distributed all over Austria covering the federal states of Lower and Upper Austria, Carinthia, Tyrol and Vorarlberg. The physico-chemical parameters of these sites, geology of the aquifer and the most important catchment characteristics (after Wimmer *et al.*, 2000) are given in **Table 4**. Except slope, altitude, disturbance, geological and flow regime information and calcium carbonate precipitation all parameters were measured twice (spring and autumn).

Generally, a nival discharge regime, primarily affected by snowmelt events, dominated at all investigated headwaters. Discharge at Woellersdorf, however, was mainly driven by rain (pluvial regime), and Lingenau was classified as a complex regime.

Most of the headwater sites investigated were categorized as “less disturbed with possible but no visible anthropogenic impacts”. Disturbance classes 3 (disturbed) and 4 (highly disturbed) were assigned to six sites due to distinct anthropogenic influence. No sampling site has been identified as class 5 (completely disturbed), and disturbance class 1 (rarely disturbed) was attributed to Hochtalalm (Hoc), Alpenzoo (Zoo) and Lappenbach (Lap). Slope values ranged from 3.8 (Poellerbach) to 63.7 % (Preinmuehle), discharges from 1 (Almassysschloessl) to 726 l s^{-1} (Dandlgraben).

Percentage area of the most important microhabitat types (sinter, cPOM, fPOM) is given for each sampling date (spring and autumn). With few exceptions (Edlbach and Maiszinken top) the proportions of sinter is increasing during the summer while cPOM and fPOM habitats were strongly variable in their proportion.

The highest sinter coverage was estimated for Dandlgraben station (Dan) in spring (93 %).

Table 4. Summary of physico-chemical parameters of the sampling sites. Data are given as minima, means and maxima and 95 % confidence intervals (lower level; upper level). Calcium carbonate precipitation is given as mean with standard deviation.

Site	ID	Sampling-Date	Coordinates	Slope [%]	Altitude [m asl]	Water temperature [°C] min - mean - max CI (LL; UL)
Woellersdorf, Lower Austria	Woe	Spring 20 May 2014 Autumn 19 September 2014	N 47.8567, E 16.1364	12.2	417	12.1 - 12.3 - 12.5 0.2 (12.2; 12.5)
Maiszinken at Lake Lunz (top), Lower Austria	Lut	Spring 22 May 2014 Autumn 15 September 2014	N 47.861343, E 15.067526	18.5	732	12.1 - 12.7 - 13.1 0.5 (12.2; 13.2)
Maiszinken at Lake Lunz (down), Lower Austria	Lud	Spring 22 May 2014 Autumn 15 September 2014	N 47.8599, E 15.0666	21.3	698	12.6 - 13.7 - 14.8 1.3 (12.4; 15.0)
Side arm of the Poellerbach in Alland, Lower Austria	Poe	Spring 26 May 2014 Autumn 19 September 2014	N 48.055684, E 16.025906	3.8	431	12.9 - 14.1 - 15.1 1.2 (12.8; 15.3)
Almassysschloessl next to Schloeglmuehl Gloggnitz, Lower Austria	Alm	Spring 31 May 2014 Autumn 18 September 2014	N 47.699812, E 15.904347	20.8	635	9.8 - 10.6 - 11.4 0.9 (9.7; 11.4)
Alpenzoo Innsbruck, Tyrol	Zoo	Spring 22 June 2014 Autumn 09 September 2014	N 47.283133, E 11.398982	26.3	696	10.4 - 10.6 - 10.8 0.2 (10.4; 10.8)
Hochtalalm, Tyrol	Hoc	Spring 23 June 2014 Autumn 09 September 2014	N 47.549090, E 11.888078	14.6	892	11.2 - 13.2 - 15.8 2.3 (10.9; 15.5)
Lingenau, Vorarlberg	Lin	Spring 24 June 2014 Autumn 09 September 2014	N 47.444036, E 9.907163	52.4	587	11.3 - 11.5 - 11.8 0.2 (11.2; 11.7)
Preinmuehle next to Schwarzau/ Preintal Lower Austria	Pre	Spring 01 July 2014 Autumn 18 September 2014	N 47.794759, E 15.660054	63.7	747	7.2 - 7.4 - 7.5 0.2 (7.2; 7.5)
Maria Neustift, Upper Austria	Mar	Spring 04 July 2014 Autumn 22 September 2014	N 47.930808, E 14.610769	25.8	473	11.2 - 13.1 - 15.0 2.1 (11.0; 15.2)
Dandlgraben next to Maria Neustift Losenstein, Upper Austria	Dan	Spring 04 July 2014 Autumn 22 September 2014	N 47.930454, E 14.451295	47.2	440	11.3 - 13.4 - 15.4 2.3 (11.1; 15.7)
Lappenbach next to Stein Drauntal, Carinthia	Lap	Spring 15 July 2014 Autumn 11 September 2014	N 46.727105, E 13.040664	37.1	723	9.8 - 10.4 - 11.0 0.7 (9.8; 11.0)
Teschengraben Lower Austria	Tes	Spring 25 July 2014 Autumn 15 September 2014	N 47.926322, E 14.800572	24.6	546	10.1 - 10.6 - 11.1 0.5 (10.1; 11.1)
Edlbach next to Spital am Phyrn, Upper Austria	Edl	Spring 25 July 2014 Autumn 22 September 2014	N 47.673229, E 14.35100	11.6	675	9.2 - 11.1 - 13.0 2.2 (8,9; 13.3)

Table 4. (Continued)

ID	Conductivity [μS cm^{-1}] min - mean - max CI (LL; UL)	pH min - mean - max CI (LL; UL)	O_2 [mg l^{-1}] min - mean - max CI (LL; UL)	O_2 [%] min - mean - max CI (LL; UL)	Calcium carbonate precipitation (ccp) [mm a^{-1}] mean ± SD
Woe	710 - 713 - 715 1.93 (711.20; 715)	8.21 - 8.24 - 8.27 0.03 (8.20; 8.27)	10.52 - 10.73 - 10.86 0.17 (10.55; 10.90)	105.90 - 108 - 111.70 3.02 (104.90; 111)	0.6 ± 0.06
Lut	506 - 534 - 561 29.23 (504.70; 563.20)	7.63 - 7.79 - 7.90 0.09 (7.70; 7.88)	8.90 - 9.07 - 9.26 0.17 (8.90; 9.24)	92.20 - 93.06 - 93.90 0.80 (92.26; 93.86)	0.03 ± 0.02
Lud	410 - 442 - 474 36.02 (405.60; 477.60)	8.20 - 8.27 - 8.55 0.15 (8.12; 8.41)	9.33 - 9.42 - 9.51 0.09 (9.33; 9.50)	95.10 - 96.56 - 98 1.36 (95.20; 97.92)	2.43 ± 0.33
Poe	603 - 611 - 620 9.22 (601.70; 620.20)	8.08 - 8.12 - 8.16 0.05 (8.07; 8.17)	9.82 - 10.18 - 10.38 0.29 (9.89; 10.47)	104.30 - 107.50 - 109.70 2.70 (104.80; 110.20)	0.48 ± 0.08
Alm	450 - 454 - 457 3.85 (449.80; 457.50)	8.21 - 8.24 - 8.26 0.02 (8.22; 8.25)	8.00 - 8.56 - 9.14 0.49 (8.07; 9.05)	81.50 - 93.95 - 109 13.76 (80.18; 107.70)	1.24 ± 0.09
Zoo	964 - 984.8 - 1,009 19.11 (965.70; 1,003)	8.21 - 8.23 - 8.26 0.02 (8.21; 8.25)	7.50 - 9.21 - 10.48 1.39 (7.82; 10.60)	91 - 98.08 - 102.30 4.28 (93.80; 102.30)	0.41 ± 0.07
Hoc	437 - 476 - 508 36.30 (439.10; 511.80)	8.23 - 8.30 - 8.32 0.04 (8.26; 8.33)	7.24 - 8.51 - 9.95 1.31 (7.20; 9.81)	95.70 - 99.93 - 103.90 2.80 (97.13; 102.70)	2.87 ± 0.15
Lin	594 - 611 - 630 16.94 (593.70; 627.60)	8.00 - 8.05 - 8.08 0.04 (8.02; 8.09)	7.50 - 8.81 - 10.14 1.16 (7.65; 9.96)	90.70 - 96.65 - 103.60 4.64 (92.00; 101.20)	4.15
Pre	264 - 300 - 386 45.48 (254; 344.90)	8.20 - 8.23 - 8.31 0.04 (8.19; 8.27)	7.20 - 9.40 - 10.65 1.32 (8.08; 10.71)	82.10 - 85.90 - 92.90 5.34 (80.6; 91.24)	0.12 ± 0.05
Mar	433 - 545 - 610 75.57 (469; 620.20)	8.21 - 8.30 - 8.40 0.07 (8.22; 8.36)	7.73 - 9.88 - 11.38 1.75 (8.13; 11.62)	89.10 - 100.40 - 109.90 10.55 (89.87; 110.90)	1.07 ± 0.02
Dan	480 - 489 - 509 11.87 (477.10; 500.80)	8.29 - 8.32 - 8.35 0.03 (8.29; 8.35)	8.56 - 9.93 - 11.27 1.50 (8.42; 11.43)	82.40 - 96.08 - 109 14.59 (81.48; 110.6)	1.58 ± 0.19
Lap	511 - 580 - 604 39.59 (540.20; 619.40)	8.23 - 8.28 - 8.31 0.03 (8.24; 8.31)	4.25 - 9.17 - 11.3 2.70 (6.47; 11.87)	67.50 - 95.35 - 114.80 16.53 (78.81; 111.80)	1.48 ± 0.06
Tes	548 - 562 - 577 15.02 (547.30; 577.30)	8.12 - 8.20 - 8.27 0.07 (8.13; 8.27)	8.29 - 8.61 - 9.2 0.48 (8.12; 9.09)	75.60 - 80.63 - 84.10 4.18 (76.44; 84.82)	1.81 ± 0.06
Edl	626 - 671 - 715 50.77 (619.70; 721.20)	8.26 - 8.31 - 8.35 0.04 (8.28; 8.35)	11.8 - 11.83 - 11.9 0.05 (11.77; 11.88)	105.20 - 110.10 - 112.70 4.04 (106.10; 114.20)	0.46 ± 0.10

Table 4. (Continued)

ID	Sky openess [%] min - mean - max CI (LL; UL)	Discharge [l s^{-1}] min - mean - max CI (LL; UL)	Sinter [%]	cPOM [%]	fPOM [%]	Disturbance class	TIC [mg l^{-1}] min - mean - max CI (LL; UL)	DOC [mg l^{-1}] min - mean - max CI (LL; UL)
Woe	3.5 - 5.5 - 8.7	11 - 25 - 52	20	30	50	2	300.1 - 414.7 - 469.3	2.44 - 3.89 - 7.28
	1.9 (3.6; 7.4)	18 (8; 43)	40	25	35		61.9 (352.8; 476.6)	1.97 (1.92; 5.86)
Lut	6.8 - 11.2 - 17.9	9 - 65 -161	65	25	10	3	334.1 - 358.5 - 384.4	1.19 - 1.63 - 2.17
	4.0 (7.1; 15.2)	61 (4; 126)	50	10	40		24.9 (333.6; 383.5)	0.46 (1.17; 2.09)
Lud	14.9 - 19.9 - 24.1	11 - 69 - 148	70	25	5	2	264.2 - 290.6 - 323.3	1.80 - 2.18 - 2.89
	3.4 (16.5; 23.4)	49 (2; 118)	85	5	10		28.0 (262.6; 318.6)	0.44 (1.74; 2.61)
Poe	27.0 - 36.2 - 41.8	22 - 32 - 46	35	35	30	3	339.2 - 373.1 - 415.6	1.86 - 2.49 - 5.09
	6.3 (29.9; 42.5)	1 (22; 42)	30	30	40		25.7 (347.4; 398.8)	1.34 (1.15; 3.83)
Alm	6.7 - 10.1 - 14.4	01.09.19	65	25	10	2	259.5 - 270.4 - 284.2	1.18 - 1.39 - 1.79
	3.0 (7.1; 13.1)	7 (2; 17)	60	30	10		8.8 (261.7; 279.2)	0.22 (1.17; 1.62)
Zoo	6.7 - 8 - 9.4	27 - 59 - 119	85	14	1	1	196.4 - 201.8 - 206.3	0.65 - 2.09 - 6.09
	1.2 (6.7; 9.2)	35 (24; 93)	90	5	5		3.4 (198.3; 205.2)	2.13 (-0.03; 4.21)
Hoc	8.8 - 11.8 - 14.2	9 - 32 - 49	45	40	15	1	277.3 - 306.2 - 334.7	1.74 - 2.45 - 3.68
	2.4 (9.4; 14.15)	19 (14; 51)	80	10	10		23.9 (282.4; 330.1)	0.75 (1.70; 3.20)
Lin	11 - 14.4 - 17.5	18 - 28 - 41	70	5	25	2	355.3 - 377.3 - 399.8	0.75 - 0.98 - 1.63
	2.5 (11.9; 16.9)	11 (17; 39)	90	9	1		18.4 (358.9; 395.8)	0.34 (0.64; 1.32)
Pre	4.2 - 4.8 - 5.2	56 - 99 - 14	40	40	20	2	162.2 - 167.7 - 174.6	0.72 - 1.91 - 3.43
	0.4 (4.4; 5.2)	32 (67; 131)	50	40	10		4.434 (163.3; 172.1)	0.97 (0.95; 2.88)
Mar	5.1 - 9.8 - 17.4	12 - 35 - 48	80	10	10	4	247.8 - 274.8 - 302.7	0.88 - 1.36 - 1.67
	5.8 (4.1; 15.7)	14 (21; 49)	85	10	5		28.1 (246.7; 302.9)	0.37 (0.99; 1.72)
Dan	4.14 - 6.367 - 7.95	2 - 217 - 726	93	5	2	3	278.5 - 303.7 - 328.6	1.22 - 2.57 - 3.74
	1.5 (4.9; 7.9)	314 (-9; 531)	90	8	2		21.3 (282.4; 325.1)	1.06 (1.50; 3.63)
Lap	8.4 - 9.2 - 10.2	28 - 188 - 535	40	40	20	1	148.4 - 178.1 - 199.1	1.05 - 1.60 - 3.02
	0.8 (8.5; 10)	194 (0.00; 382)	40	40	20		21.5 (156.6; 199.6)	0.81 (0.79; 2.41)
Tes	4.9 - 7.2 - 9.7	04.03.61	60	5	35	4	359.9 - 380.2 - 413.7	1.06 - 1.39 - 1.97
	1.9 (5.2; 9.1)	26 (4; 56)	75	20	5		21.8 (358.4; 402.0)	0.37 (1.02; 1.77)
Edl	25 - 28.2 - 33	39 - 71 - 187	90	5	5	4	181.3 - 203.4 - 224.9	0.89 - 1.35 - 2.04
	3.1 (25.1; 31.2)	6 (11; 131)	75	20	5		18.6 (184.8; 222.0)	0.44 (0.90; 1.79)

Table 4. (Continued)

ID	PO_4^{3-} [µg l^{-1}] min - mean - max CI (LL; UL)	TP [µg l^{-1}] min - mean - max CI (LL; UL)	NH_4^+ [µg l^{-1}] min - mean - max CI (LL; UL)	NO_2^- [µg l^{-1}] min - mean - max CI (LL; UL)	NO_3^- [mg l^{-1}] min - mean - max CI (LL; UL)	Cl^- [mg l^{-1}] min - mean - max CI (LL; UL)
Woe	2.76 - 3.19 - 3.61 0.37 (2.81; 3.56)	10 - 20.87 - 48.16 15.84 (5.03; 36.71)	2.6 - 12.5 - 46.7 18.3 (-5.7; 30.8)	2.92 - 3.94 - 5.91 1.15 (2.28; 5.08)	5.67 - 6.789- 7.84 1.19 (5.6; 7.98)	9.77 - 9.91 - 9.99 0.10 (9.82; 10.01)
Lut	1.80 - 2.59 - 3.07 0.65 (1.93; 3.24)	4 - 5.76 - 9 1.92 (3.84; 7.68)	2.6 - 12.9 - 35.5 13.7 (-0.8; 26.6)	2.01 - 2.65 - 3.61 0.66 (1.98; 3.32)	3.23 - 3.84 - 4.51 0.69 (3.16; 4.53)	0.57 - 0.74 - 1.30 0.29 (0.45; 1.03)
Lud	0.90 - 2.28 - 3.07 0.96 (1.32; 3.25)	8 - 17.05 - 29.19 9.28 (7.78; 26.33)	2.6 - 9.9 - 21.0 7.5 (2.4; 17.3)	1.28 - 1.79 - 2.30 0.48 (1.32; 2.27)	3.42 - 4.11 - 4.91 0.79 (3.32; 4.89)	0.47 - 0.51 - 0.53 0.03 (0.48; 0.53)
Poe	2.71 - 2.89 - 3.07 0.21 (2.68; 3.09)	2 - 8.20 - 25.05 9.19 (-0.98; 17.39)	1.3 - 20.6 - 96.6 39.4 (-18.8; 60.0)	3.28 - 3.57 - 3.94 0.29 (3.28; 3.86)	5.40 - 7.12 - 8.86 1.94 (5.18; 9.05)	2.65 - 2.71 - 2.76 0.05 (2.65; 2.71)
Alm	0 - 1.41 - 3.07 1.26 (0.15; 2.67)	1 - 4.62 - 10.23 3.57 (1.05; 8.19)	0 - 8.1 - 23.0 9.9 (-1.9; 18.0)	0.99 - 1.86 - 2.63 0.70 (1.16; 2.55)	3.52 - 3.82 - 4.13 0.33 (3.49; 4.15)	1.66 - 1.81 - 1.96 0.15 (1.66; 1.96)
Zoo	1.80 - 2.59 - 3.07 0.65 (1.93; 3.24)	2 - 3.62 - 5.40 1.48 (2.13; 5.10)	2.6 - 31.1 - 113.4 46.2 (-15.1 ; 77.3)	1.09 - 1.93 - 3.28 0.84 (1.09; 2.77)	4.68 - 4.75 - 4.84 0.08 (4.68; 4.83)	5.75 - 6.25 - 6.50 0.30 (5.95; 6.55)
Hoc	1.80 - 2.43 - 3.07 0.73 (1.71; 3.16)	1.95 - 5.17 - 10.23 3.93 (1.24; 9.11)	58.0 - 68.7 - 79.1 9.6 (59.2; 78.3)	0.91 - 1.44 - 2.01 0.48 (0.96; 1.91)	0.82 - 0.86 - 0.88 0.03 (0.83; 0.89)	0.77 - 0.87 - 1.05 0.12 (0.76; 0.99)
Lin	1.80 - 2.43 - 3.07 0.73 (1.71; 3.16)	1 - 1.67 - 2 0.41 (1.26; 2.08)	1.3 - 3.6 - 7.1 3.0 (0.7; 6.6)	0.91 - 2.02 - 3.28 0.82 (1.20; 2.84)	11.04 - 11.85 - 12.69 0.578 (11.28; 12.43)	14.40 - 15.58 - 16.81 1.31 (14.27; 16.89)
Pre	1.80 - 3.25 - 6.13 1.67 (1.57; 4.92)	2.64 - 13.11 - 25 8.96 (4.16; 22.07)	1.2 - 10.2 - 33.5 12.9 (-2.8; 23.1)	1.28 - 2.84 - 9.53 3.45 (-0.60; 6.29)	6.89 - 7.33 - 7.54 0.28 (7.05; 7.60)	0.62 - 0.70 - 0.85 0.09 (0.61; 0.79)
Mar	2.71 - 3.40 - 7.21 1.81 (2.13; 5.75)	8 - 18.24 - 60.23 21.64 (-3.40; 39.88)	3.9 - 18.5 - 45.1 15.1 (3.4; 35.6)	1.97 - 3.68 - 9.86 3.19 (0.49; 6.87)	3.21 - 3.434 - 3.64 0.22 (3.22; 3.66)	1.20 - 1.29 - 1.42 0.10 (1.18; 1.37)
Dan	39.86 - 65.62 - 90.18 24.44 (41.18; 90.07)	23 - 103.6 - 179.1 64.45 (39.20; 168.1)	2.6 - 4.2 - 6.4 1.6 (2.6; 5.8)	5.91 - 8.87 - 12.59 3.21 (5.66; 12.08)	2.05 - 4.37 - 5.90 1.74 (2.64; 6.11)	2.52 - 2.68 - 2.89 0.16 (2.52; 2.83)
Lap	0.90 - 1.50 - 2.71 0.77 (0.73; 2.28)	1.49 - 4.48 - 10.23 3.49 (0.99; 7.969)	0 - 18.0 - 63.2 24.0 (-6.1; 41.9)	0.55 - 1.43 - 3.65 1.41 (0.02; 2.84)	1.19 - 1.30 - 1.47 0.12 (1.18; 1.42)	0.74 - 0.79 - 0.89 0.06 (0.73; 0.85)
Tes	0.90 - 1.50 - 2.71 0.77 (0.73; 2.28)	0.46 - 8.81 - 18.73 7.58 (1.23; 16.39)	1.1 - 6.52 - 13.7 5.4 (1.1; 11.9)	1.82 - 3.59 - 7.85 2.54 (1.05; 6.13)	4.05 - 4.63 - 5.25 0.53 (4.10; 5.16)	1.76 - 1.85 - 1.92 0.07 (1.78; 1.92)
Edl	0.90 - 1.95 - 3.61 1.26 (0.70; 3.21)	0.80 - 2.64 - 4.25 1.25 (1.40; 3.89)	0.4 - 13.7 - 50.7 19.6 (-6.0; 33.3)	1.09 - 2.40 - 5.84 1.94 (0.46; 4.35)	2.07 - 2.41 - 2.59 0.19 (2.22; 2.60)	1.83 - 2.09 - 2.34 0.28 (1.81; 2.38)

Table 4. (Continued)

ID	SO_4^{2-} [mg l^{-1}] min - mean - max CI (LL; UL)	Na^{+} [mg l^{-1}] min - mean - max CI (LL; UL)	K^{+} [mg l^{-1}] min - mean - max CI (LL; UL)	Ca^{2+} [mg l^{-1}] min - mean - max CI (LL; UL)	Mg^{2+} [mg l^{-1}] min - mean - max CI (LL; UL)
Woe	40.9 - 42.8 - 44.8 2.2 (40.6; 45.0)	5.22 - 5.33 - 5.45 0.09 (5.24; 5.42)	0.91 - 1.06 - 1.30 0.15 (0.91; 1.21)	97.1 - 102.9 - 108.3 5.7 (97.2; 108.6)	39.6 - 40.9 - 42.3 1.3 (39.6; 42.1)
Lut	2.3 - 2.6 - 2.9 0.3 (2.3; 2.9)	0.67 - 0.91 - 1.04 0.18 (0.74; 1.09)	1.67 - 1.90 - 2.05 0.17 (1.72; 2.07)	113.8 - 119.0 - 124.2 5.2 (113.8; 124.2)	8.5 - 8.8 - 9.0 0.2 (8.6; 9.1)
Lud	2.3 - 2.8 - 3.1 0.4 (2.4; 3.1)	0.30 - 0.50 - 0.67 0.20 (0.30; 0.70)	0.71 - 1.00 - 1.34 0.31 (0.68; 1.30)	92.2 - 98.4 - 104.3 6.5 (92.0; 104.8)	6.1 - 6.4 - 6.7 0.3 (6.2; 6.7)
Poe	41.5 - 43.2 - 44.9 1.7 (41.5; 44.9)	2.53 - 2.60 - 2.71 0.08 (2.52; 2.68)	1.79 - 1.99 - 2.19 0.18 (1.82; 2.17)	91.3 - 101.9 - 112.7 11.5 (90.5; 113.4)	27.5 - 28.2 - 28.9 0.7 (27.5; 28.9)
Alm	29.1 - 30.3 - 31.6 1.4 (28.9; 31.6)	1.13 - 1.20 - 1.27 0.07 (1.13; 1.28)	1.15 - 1.47 - 1.77 0.30 (1.18; 1.77)	72.4 - 75.7 - 79.2 3.3 (72.4; 78.9)	16.2 - 17.3 - 18.4 1.2 (16.1; 18.4)
Zoo	366.7 - 400.3 - 435.2 38.5 (361.9; 438.8)	2.83 - 3.17 - 3.44 0.26 (2.91; 3.43)	1.02 - 1.35 - 1.70 0.33 (1.02; 1.68)	149.4 - 157.1 - 164.7 8.5 (148.7; 165.6)	54.6 - 57.9 - 61.1 3.7 (54.2; 61.5)
Hoc	0.8 - 1.1 - 1.4 0.2 (0.9; 1.3)	0.12 - 0.30 - 0.43 0.15 (0.16; 0.45)	0.83 - 0.96 - 1.12 0.12 (0.85; 1.08)	73.2 - 80.1 - 87.3 7.1 (73; 87.2)	24.4 - 24.6 - 24.8 0.1 (24.4; 24.7)
Lin	7.9 - 8.6 - 9.2 0.8 (7.8; 9.3)	6.59 - 6.87 - 7.16 0.29 (6.59; 7.16)	4.73 - 5.14 - 5.52 0.39 (4.75; 5.53)	119.1 - 124.1 - 127.7 3.5 (120.6; 127.6)	4.5 - 4.6 - 4.6 0.1 (4.5; 4.6)
Pre	5.9 - 6.3 - 6.8 0.5 (5.9; 6.8)	0.04 - 0.21 - 0.37 0.18 (0.04; 0.39)	0.32 - 0.60 - 0.88 0.30 (0.30; 0.90)	59.3 - 63.3 - 67.2 4.4 (58.9; 67.6)	1.3 - 1.5 - 1.7 0.2 (1.3; 1.7)
Mar	106.4 - 115.3 - 124.6 10.1 (105.2; 125.4)	1.66 - 1.69 - 1.72 0.02 (1.67; 1.71)	1.20 - 1.42 - 1.67 0.22 (1.20; 1.63)	91.6 - 93.8 - 95.5 1.9 (91.9; 95.6)	29.9 - 32.0 - 34.0 2.2 (29.9; 34.2)
Dan	11.0 - 11.2 - 11.5 0.2 (11.0; 11.4)	1.91 - 2.21 - 2.44 0.25 (1.96; 2.46)	1.23 - 1.45 - 1.78 0.27 (1.18; 1.72)	77.7 - 79.8 - 82.2 1.97 (77.8; 81.7)	20.9 - 23.8 - 26.4 2.9 (20.9; 26.7)
Lap	170.7 - 174.8 - 178.7 4.4 (170.5; 179.2)	1.33 - 1.48 - 1.57 0.10 (1.38; 1.58)	0.75 - 0.81 - 0.84 0.04 (0.76; 0.85)	84.6 - 88.9 - 93.9 4.6 (84.2; 93.5)	29.0 - 30.0 - 31.4 1.2 (28.8; 31.2)
Tes	3.8 - 4.5 - 5.2 0.8 (3.7; 5.3)	1.03 - 1.07 - 1.11 0.04 (1.03; 1.11)	1.19 - 1.31 - 1.40 0.08 (1.22; 1.39)	72.0 - 86.7 - 99.5 14.6 (72.1; 101.2)	26.2 - 27.0 - 27.8 0.8 (26.2; 27.8)
Edl	157.8 - 194.5 - 232.3 42.1 (152.5; 236.6)	1.63 - 1.80 - 1.95 0.16 (1.63; 1.96)	1.02 - 1.11 - 1.16 0.06 (1.05; 1.17)	100.5 - 105.3 - 111.0 5.1 (100.2; 110.4)	24.1 - 26.4 - 28.7 2.6 (23.9; 29.0)

Table 4. (Continued)

ID	$c(CO_2)$ [mg l^{-1}] min - mean - max CI (LL; UL)	$c(HCO_3^-)$ [mg l^{-1}] min - mean - max CI (LL; UL)	LSI min - mean - max CI (LL; UL)	Geology	Flow Regime	Aquativ Landscape Units
Woe	3.01 - 3.73 - 4.44 0.60 (3.13; 4.33)	297.1 - 411.0 - 465.5 61.5 (349.5; 472.5)	0.58 - 0.77 - 0.87 0.11 (0.66; 0.87)	Sandstone	Pluvial Regime	Southern Vienna Basin
Lut	4.05 - 7.11 - 9.59 2.38 (4.74; 9.49)	330.1 - 351.4 - 375.2 22.9 (328.5; 374.3)	0.26 - 0.37 - 0.45 0.08 (0.29; 0.45)	Sandstone	Nival Regime	Limestone Foothills
Lud	0 - 2.26 - 3.06 1.20 (1.07; 3.46)	261.7 - 288.4 - 320.3 27.9 (260.4; 316.3)	0.63 - 0.73 - 1.00 0.15 (0.58; 0.88)	Reifling formation	Nival Regime	Limestone Foothills
Poe	3.09 - 3.83 - 4.28 0.53 (3.30; 4.36)	336.2 - 369.3 - 411.8 25.5 (343.8; 394.8)	0.63 - 0.67 - 0.74 0.04 (0.62; 0.71)	Hauptdolomit, Norium (Dolomitstein, Bankig)	Nival Regime	Limestone Foothills
Alm	2.70 - 2.81 - 2.96 0.09 (2.72; 2.90)	256.8 - 267.6 - 281.2 8.7 (258.9; 276.3)	0.45 - 0.48 - 0.52 0.03 (0.45; 0.51)	Werfen formation	Nival Regime	Greywacke Zone
Zoo	1.85 - 1.91 - 1.96 0.04 (1.87; 1.95)	194.6 - 199.9 - 204.4 3.4 (196.5; 203.3)	0.49 - 0.53 - 0.57 0.04 (0.49; 0.56)	Hauptdolomit	Nival Regime	Limestone High Alps
Hoc	2.13 - 2.60 - 3.47 0.55 (2.05; 3.15)	275.1 - 303.6 - 331.3 23.4 (280.3; 327.0)	0.61 - 0.67 - 0.72 0.04 (0.63; 0.71)	Sandstone, marl, limes, breccias	Nival Regime	Limestone Foothills
Lin	5.71 - 6.00 - 6.31 0.27 (5.74; 6.27)	349.6 - 371.3 - 393.5 18.2 (353.2; 389.5)	0.58 - 0.63 - 0.66 0.03 (0.60; 0.66)	Abraded melasse	Complex Regime	Western Foothills
Pre	1.44 - 1.78 - 1.93 0.19 (1.60; 1.97)	160.4 - 165.9 - 172.6 4.4 (161.6; 170.3)	0.12 - 0.17 - 0.23 0.04 (0.12; 0.21)	Wettersteinkalk	Nival Regime	Limestone Foothills
Mar	1.57 - 2.48 - 3.19 0.78 (1.70; 3.26)	245.8 - 272.3 - 299.5 27.4 (244.9; 299.6)	0.58 - 0.66 - 0.76 0.07 (0.59; 0.73)	Siliciclastic rich sediments of the autochthonous mesozoic, the flysch zone and the limestone Alps	Nival Regime	Limestone Foothills
Dan	2.13 - 2.57 - 3.43 0.50 (2.07; 3.06)	276.4 - 301.2 - 325.2 20.9 (280.3; 322.1)	0.61 - 0.69 - 0.78 0.06 (0.62; 0.75)	Schrambach formation	Nival Regime	Limestone Foothills
Lap	1.33 - 1.61 - 2.04 0.32 (1.29; 1.93)	147.0 - 176.5 - 197.0 21.3 (155.3; 197.7)	0.32 - 0.36 - 0.42 0.04 (0.32; 0.40)	Sinter	Nival Regime	Southern Alps
Tes	2.98 - 4.17 - 5.54 1.33 (2.84; 5.50)	356.9 - 376.0 - 408.2 20.6 (355.4; 396.6)	0.59 - 0.61 - 0.63 0.02 (0.59; 0.63)	Predominantly carbonate rocks	Nival Regime	Limestone Foothills
Edl	1.36 - 1.68 - 2.23 0.36 (1.32; 2.03)	180 - 201.7 - 222.7 18.3 (183.4; 220.0)	0.46 - 0.55 - 0.63 0.07 (0.48; 0.61)	Predominantly carbonate rocks	Nival Regime	Limestone High Alps

Water temperature varied from 7.2 (Preinmuehle) to 15.8 °C (Hochtalalm). Eleven of 28 samplings took place in temperature ranges of 11 – 13 °C. The elevations of the investigated headwaters were mostly in the 500 m (Woellersdorf, Poellerbach, Maria Neustift and Dandlgraben) to 600 – 700 m range (Maiszinken down, Almassysschloessl, Alpenzoo and Edlbach). Conductivity values ranged from 264 (Preinmuehle) to 1,009 µS cm^{-1} (Alpenzoo) and the majority of the pH measurements from 8.2 to 8.3, highest (8.5). The lowest (7.6) pH values were measured in Lunz area (Maiszinken top and down). Calcium and bicarbonate concentration, water temperature, conductivity and pH values were combined in the Langelier Saturation Index (LSI), which was always well above 0 indicating that water was supersaturated and that $CaCO_3$ precipitation may occur. The calcium carbonate precipitation rates mostly varied between 0.8 and 2.0 mm per year (**Fig. 5**).

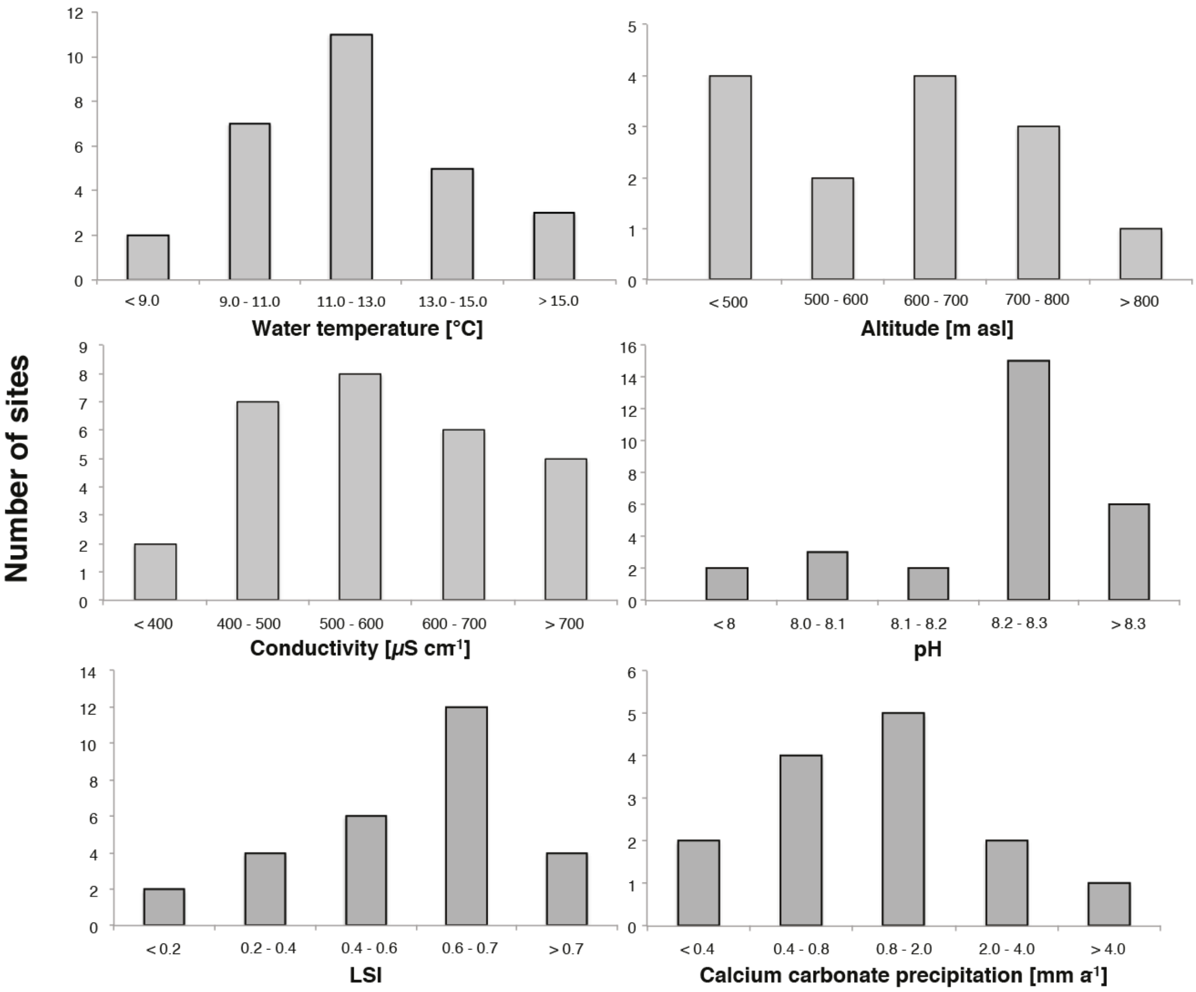


Fig. 5. Frequency histograms of selected environmental parameters observed at the 14 sampling sites.

Major anion and cation distribution patters are shown by the ternary plots in **Fig. 6**. We observed higher values for Ca^{2+} than Mg^{2+} or Na^{+}/K^{+} combinations. The highest calcium values were measured at Alpenzoo (164.7 mg l^{-1}) in combination with peak SO_4^{2-} and Mg^{2+} concentrations as well as very high conductivity. The lowest Ca^{2+}, Na^{+}, K^{+} and Mg^{2+} were measured at Preinmuehle, combined with the lowest conductivity and water temperature measurements. For major anions we observed always lower Chloride concentrations next to higher hydrogen carbonate and sulphate concentrations. Lingenau showed the highest Cl^{-}, Na^{+} and K^{+} values next to lowest total phosphorus concentrations, combined with the highest calcium carbonate precipitation rates (4.15 mm a^{-1}). In accordance with major ions the nutrients showed no seasonal fluctuations. Highest phosphate concentrations were measured twice (in spring and autumn) at Dandlgraben (mean = 65.62 µg l^{-1}), with the remaining headwater sites ranging from 0 to 6.1 µg l^{-1}. At Dandlgraben station we also noticed the highest total phosphorus (179.10 µg l^{-1}) and NO^{2-} (12.59 µg l^{-1}) concentrations next to the highest discharge (726 l s^{-1}) and pH (8.3). Highest NO^{3-} values were measured in Lingenau, lowest in Hochtalalm (**Table 4, Fig. 6**).

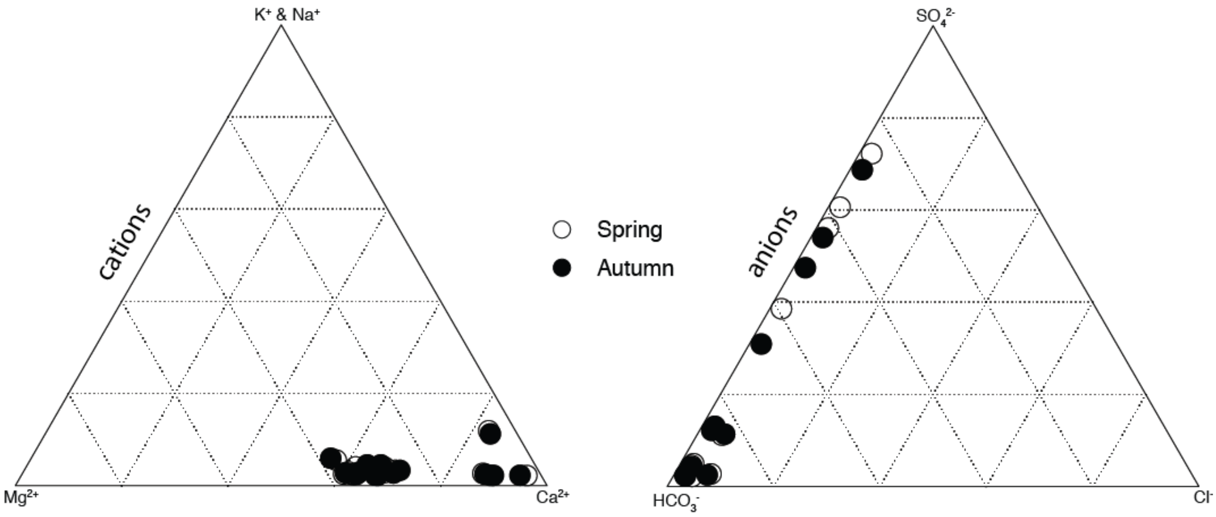


Fig. 6. Ternary plots of major anions/ cations for each sampling station. The filled circles indicate the autumn samplings, the empty circles the spring samples. The values are standardized to 1. Dashed lines indicate intervals of 0.2 units.

3.2. Fauna

3.2.1. Taxa composition and functional feeding groups

In the 14 travertine-depositing headwaters investigated, 52 taxa and 1493 specimens of aquatic macroinvertebrates were collected **(Table 5).** The majority of specimens belonged to the orders Ephemeroptera (8 taxa), Plecoptera (5 taxa), Trichoptera (7 taxa), Coleoptera (4 taxa), Diptera (12 taxa) and Odonata (1 taxon).

Within Diptera the most abundant family was Chironomidae, with the most abundant subfamily of Orthocladiinae. *Ibisia marginata* (Athericidae) was only found in springtime at Lappenbach in low abundance. In Ephemeroptera, Baetidae were abundant whereas Heptageniidae and Ephemeridae were rare. In Plecoptera *Protonemura* was by far the most abundant genus whereas *Brachyptera risi* was the rarest stonefly taxon. In Trichoptera, *Rhyacophila pubescens* was collected most frequently. *Potamophylax cingulatus*, *Crunoecia kempnyi*, and *Plectrocnemia geniculata* were rare in this study. The only representative of the order Odonata was *Cordulegaster bidentata*, collected in Woellersdorf and Maiszinken (d) during springtime. Coleoptera were generally rare and represented by two families: Elmidae (*Elmis* sp., *Limnius volckmari*) and Staphylinidae.

The crustacean *Gammarus fossarum* was one of the most abundant species and was present at nearly all sampling sites whereas the groundwater-associated genus *Niphargus* sp. occurred only at the Edlbach station in springtime.

In molluscs, four different *Bythinella* species were identified in this study (*B. cylindrica*, *B. opaca opaca*, *B. bavarica* and *B. austriaca austriaca*).

Two larvae of *Salamandra salamandra* were collected at Woellersdorf station in springtime among cPOM core samples and released after identification.

Table 5. Macrozoobenthos inventory of 14 meteogene travertine-depositing headwaters. Details on abundance classes are given in chapter 2.5. In total, 1493 specimens of macrozoobenthos were collected.

	Spring														Autumn													
	Woe	Lut	Lud	Poe	Alm	Zoo	Hoc	Lin	Pre	Mar	Dan	Lap	Tes	Edl	Woe	Lut	Lud	Poe	Alm	Zoo	Hoc	Lin	Pre	Mar	Dan	Lap	Tes	Edl
Turbellaria																												
Crenobia alpina	-	-	-	-	2	2	-	-	2	-	-	-	-	-	-	-	-	1	2	3	-	-	3	-	-	3	-	-
Dugesia sp.	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-
Ephemeroptera																												
Ecdyonurus sp.	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemeroptera	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	2	-	-	-	-	-	-	1	-	-	-
Baetis sp.	-	1	-	1	-	-	-	1	-	-	-	-	1	1	-	-	1	-	-	-	-	-	-	-	-	-	1	-
Baetidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	1	1	-	2	-
Baetis vernus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	1	-	1	-	1	-	-	-	-	-	1
Heptageniidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemera danica	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heptageniidae cf *Ecdyonurus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Plecoptera																												
Protonemura sp.	1	3	3	2	-	1	3	4	-	2	-	2	2	2	1	1	1	1	2	3	2	4	-	-	-	-	-	1
Nemoura sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachyptera risi	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leuctra braueri	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	-	1	-	-	-	-	1	-	1	-	-	2	1	2	2	1	1	1	-	-	1	-	1	1	2
Trichoptera																												
Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Rhyacophila pubescens	1	-	1	1	1	-	1	2	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Potamophylax cingulatus	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crunoecia kempnyi	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila s.str.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnephilidae juv.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Plectrocnemia geniculata	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diptera																												
Dixa sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1	1	-	-	-	-	-	-
Limoniidae juv.	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Simulium sp.	1	-	-	1	2	1	1	-	-	2	3	-	2	1	2	4	1	2	2	1	3	-	-	1	-	1	2	-
Ceratopogonidae indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Muscidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Ibisia marginata	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae indet.	2	1	-	-	2	-	2	2	-	1	-	1	-	-	1	1	-	2	-	-	2	2	-	-	-	-	-	-
Tanytarsus sp.	-	-	-	3	-	-	-	-	1	-	-	-	-	2	-	2	-	-	-	1	-	2	-	-	-	1	-	-
Tanytarsini	-	-	-	3	-	-	-	-	3	-	-	-	-	2	-	2	-	-	-	-	-	1	-	-	-	-	-	-
Orthocladiinae	-	-	-	1	1	2	-	1	1	2	-	1	2	4	3	1	3	3	2	3	-	2	1	1	1	2	4	2
Paratrichocladius nivalis ident.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-
Krenosmittia sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coleoptera																												
Elmidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Elmis sp.	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Limnius volckmari	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-
Staphylinidae	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Odonata																												
Cordulegaster bidentata	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea																												
Gammarus fossarum	2	1	4	3	4	3	2	3	3	1	4	-	1	2	4	1	1	3	1	2	-	2	2	-	4	-	3	2
Niphargus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda ident.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Macrocyclops ident.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Isopoda	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda																												
Bathyomphalus contortus	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planorbidae	-	-	-	1	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bythinella cylindrica	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bythinella bavarica	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bythinella opaca opaca	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
Bythinella austriaca austriaca	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Bivalvia																												
Pisidium sp.	-	-	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	3	-	-	-	-	-	-	-	-	-	-
Amphibia																												
Salamandra salamandra	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Generally, taxa richness at the 14 sites varied with season (**Fig. 7**). At six sites, the spring taxa numbers in April/ May were higher than in autumn, whereas at six sites the reverse was true. In Poellerbach and Lingenau the taxa numbers were equal in both seasons. *Ecdyonurus* sp., *Ephemera danica*, *Nemoura* sp., *Brachyptera risi*, *Leuctra braueri*, *Crunoecia kempnyi*, *Plectrocnemia geniculata*, *Ibisia marginata*, *Krenosmittia* sp., *Niphargus* sp., *Bathyomphalus contortus*, *Bythinella cylindrica*, *B. bavarica* and *B. opaca opaca* were only present in spring samples. The lowest taxa numbers were found at Dandlgraben (Dan) in spring. *Gammarus fossarum* was very abundant (class 4) next to *Simulium* sp. (class 3). The highest discharge, PO_4^{3-}, NO^{2-} and total phosphorus concentrations were measured at this station. Furthermore, sinter coverage peaked at the latter site (area percentage = 93 %). Taxa richness throughout the study period was highest at Poellerbach-station where sky openness and water temperature was highest (42 % and 14.1 °C, respectively) and slope was lowest (3.8 %).

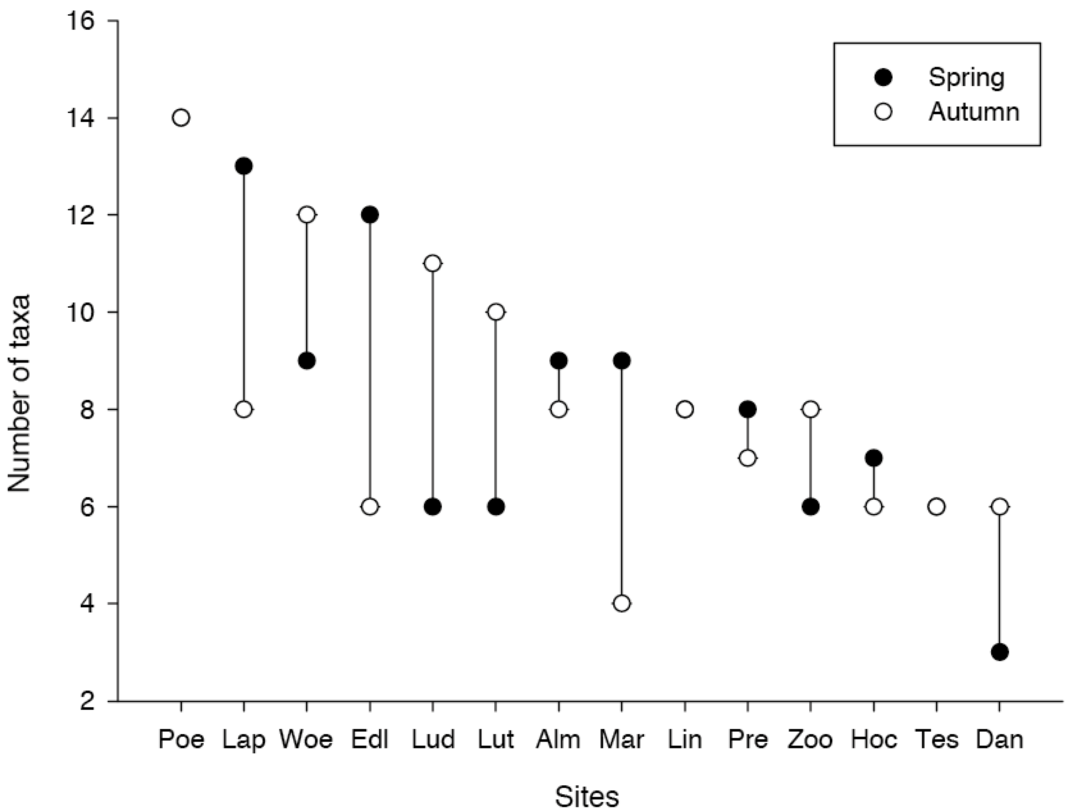


Fig. 7. Number of taxa obtained from the spring and autumn samples at the 14 study sites. Acronyms are explained in **Table 4**.

The percentage distribution of functional feeding groups (Moog, 2002; Vannote *et al.* 1980; Merritt & Cummins, 1996) are shown in **Figure 8**. Collectors, shredders and grazers were the major groups next to predators. No significant patterns were found between study sites. Generally, filtering collectors and grazers were most abundant.

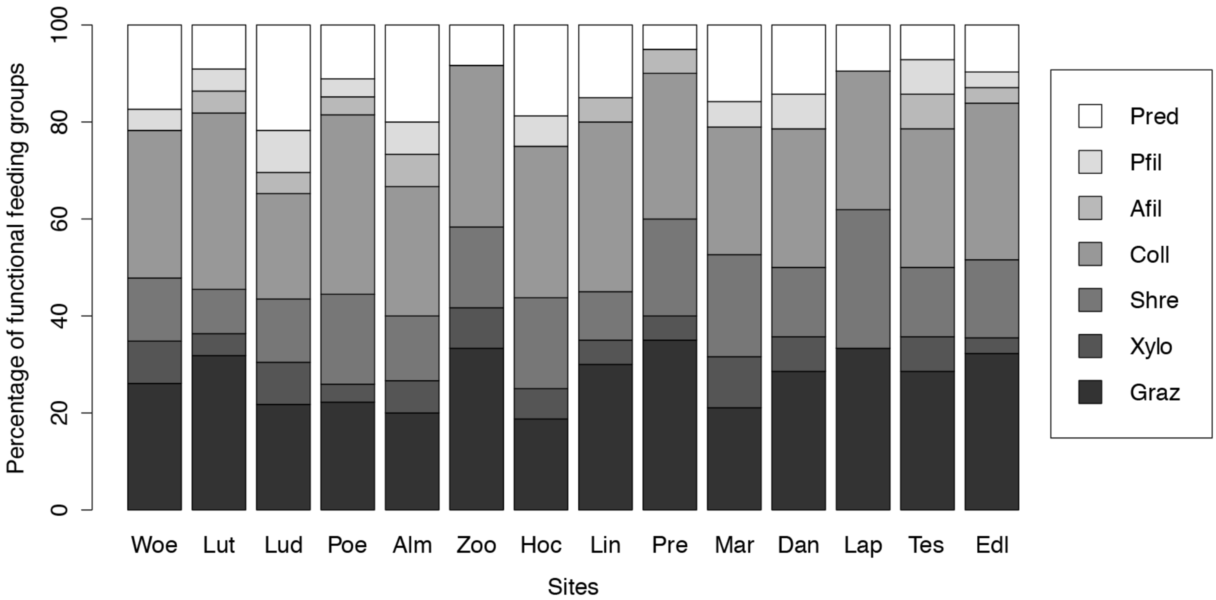


Fig. 8. Percentage of functional feeding groups for each site. Pred = predators; Pfil = passive filter feeders; Afil = active filter feeders; Coll = collectors; Shre = shredders; Xylo = xylophagous; Graz = grazers.

3.2.2. Cluster analysis and nonmetric multidimensional scaling (nMDS)

The cluster analysis, calculated on the basis of taxa inventories transformed in a Bray-Curtis dissimilarity matrix, yielded seven site groups (**Fig 9**). Optimum group number was established using Mantel tests, and the cluster method "average" was recommended by a cophenetic correlation function. The same clusters were processed by a nMDS ordination procedure based on a 3D stress of 0.215 (**Fig. 10**). In addition ANOSIM analyses were performed which confirmed high significant differences between these seven groups ($R = 0.7718$; $P < 0.001$). The clusters are geographically and seasonally well mixed except group III which includes the spring and autumn samplings of the Preinmuehle (Pre) station and group IV with both samplings of Dandlgraben station (Dan). Both are closely related to each other within the nMDS ordination frame.

Group V (LapS) and group VI (HocA) both consist of a single sampling station only. The fourth smallest group VII includes stations Maria NeustiftA and LappenbachA and has a higher proximity to group V and VI than to the rest. Group II includes 14 well-mixed samples, group I includes six samples.

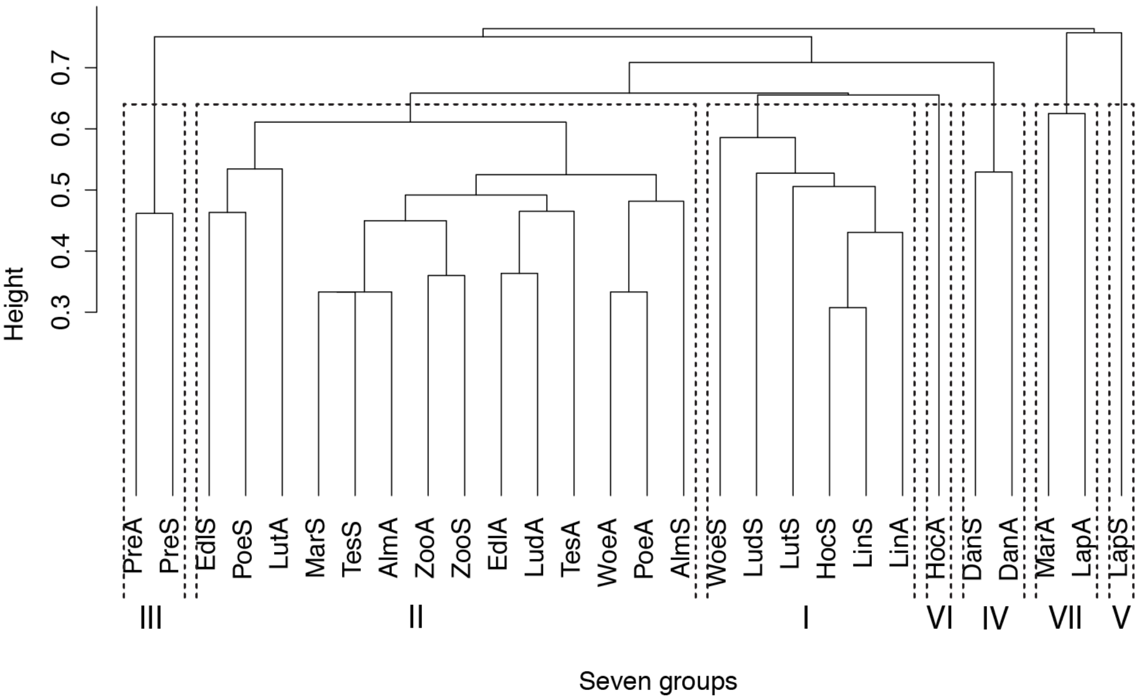


Fig. 9. Dendrogram based on cluster analysis (Bray-Curtis distances, average method). Dashed lines represent the cut level of seven groups.

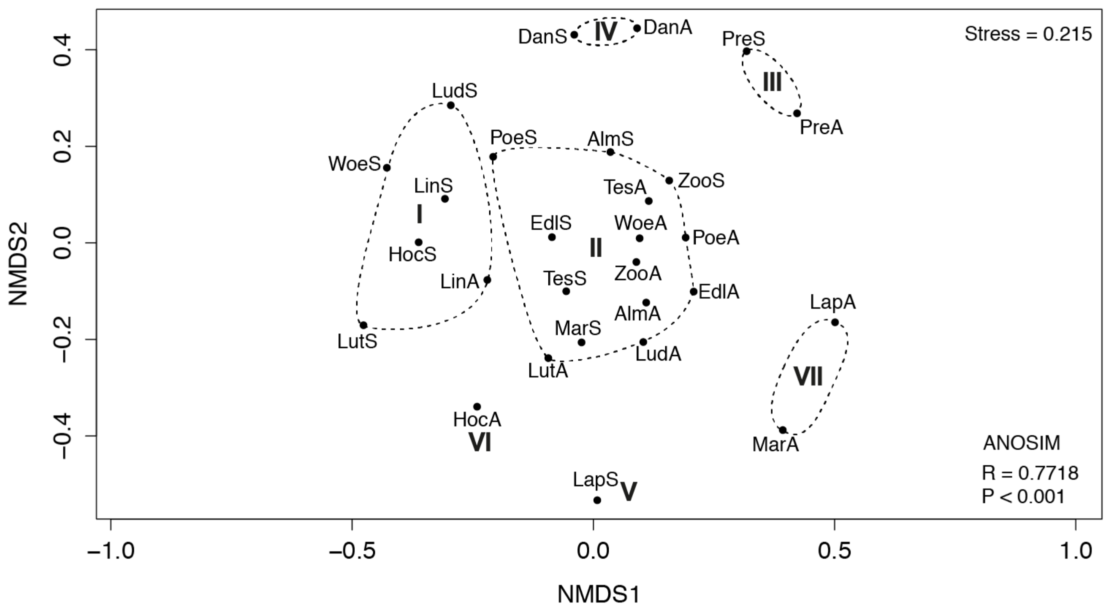


Fig. 10. Non-metric multidimensional scaling (nMDS): ordination of site scores. Suffices: S = spring sampling, A = autumn sampling. Dashed lines = seven groups based on cluster analysis. Stress value and ANOSIM results are shown at right.

The synoptic **Table 6** summarizes the most important environmental parameters (temperature, discharge, conductivity, pH, oxygen and sinter coverage, LSI and total phosphorus concentration) as well as eudominant (> 36 %) and dominant (16-35.9 %) MZB and Bryophyta taxa (Schiemenz in Müller, 1984).

Group I, a cluster of six samples (WoeS, LutS, LudS, HocS, LinS, LinA), is characterized by low pH values. The stonefly genus *Protonemura* sp. and *Gammarus fossarum* are eudominant, chironomid subfamilies Tanypodiniae and Orthocladiinae dominant at these locations.

Group II, consists of 14 data sets (= 50 % of the samples) obtained from five sites (Poe, Alm, Zoo, Tes and Edl*)*. Low discharge and high conductivity defines the abiotic framework of this group, combined with high water temperatures and sky openness (Poe), SO_4^{2-} and Mg^{2+} (Zoo) as well as high O_2 (Edl). Slope was very low (Poe), as was discharge and PO_4^{3-} in Almassysschloessl. No MZB taxa were found to be eudominant. However, *Crenobia alpina*, *G. fossarum, Protonemura* sp., *Simulium* sp. and *subfamily* Orthocladiinae were dominant (16 - 35.9 %).

Group III includes sites PreinmuehleS and PreinmuehleA, characterized by the lowest water temperature, conductivity, sky openness, Na^+, K^+, Mg^{2+}, TIC, HCO_3^- and LSI values of all study sites. However, slope was highest (63.7 %). *Bythinella austriaca austriaca* is dominant and only present in this group. *Limnius volckmari* is also dominant but was also collected in less abundance at station Edlbach. No eudominant taxa were present in group III.

Group IV includes both Dandlgraben samplings (DanS and DanA) and is characterized by high pH, water temperature and sinter coverage (90 – 93 %) as well as the highest PO_4^{3-} and total phosphorus concentrations of this study. *Gammarus fossarum* and *Simulium* sp. are eudominant in this group.

Group V only contains the LapS data set. At this spring sample, we noticed the lowest oxygen and total phosphorus contents of all sites. MZB taxa were collected only in low abundance. Furthermore, Lappenbach station shows low NO^{2-} and high CO_2 concentrations.

Group VI consists of the autumn sample at Hochtalalm station; here, the highest Langelier saturation index (combining calcium, bicarbonate concentration, water temperature, conductivity and pH) was observed. The LSI offers key information on precipitation and erosion of calcium carbonate. This group includes dominant taxa such as *Protonemura* sp., *Simulium* sp. and the chironomid subfamily Tanypodinae.

Group VII includes the autumn samples at Maria Neustift and Lappenbach stations where high discharge and oxygen concentrations were measured. The gastropod *Bythinella opaca opaca*, only collected at Lappenbach station, was dominant in autumn. Other dominant specimens include *Crenobia alpina* and *Simulium* sp. At Maria Neustift station more than twice the taxa numbers (9) were collected in spring when compared to the autumn sample (4).

Table 6. Synopsis of hydrological and physico-chemical parameters for the seven groups identified by cluster analysis. In addition, the eudominant (> 36 %) and dominant (16-35.9 %) MZB and Bryophyta taxa (Schiemenz in Müller, 1984) are shown.

	Group I min - mean - max	**Group II** min - mean - max	**Group III** min - max	**Group IV** min - max	**Group V**	**Group VI**	**Group VII** min - max
Temperature [°C]	11.3 - 12.9 - 15.2	9.2 - 11.9 - 15.1	7.2 - 7.5	11.4 - 15.4	10.9	11.2	9.9 - 11.2
Discharge [l s⁻¹]	26 - 55 - 109	9 - 38 - 96	93 - 104	182 - 253	77	29	27 - 299
Conductivity [µS cm⁻¹]	410 - 549 - 713	450 - 635 - 993	279 - 320	483 - 490	603	507	508 - 556
pH	7.8 - 8.1 - 8.3	7.7 - 8.2 - 8.3	8.2 - 8.2	8.3 - 8.3	8.3	8.3	8.2 - 8.2
Oxygen [mg l⁻¹]	7.4 - 9.0 - 10.7	8.0 - 9.6 - 11.8	8.4 - 10.3	8.6 - 11.2	8.0	9.6	10.3 - 11.3
Sinter	20 - 60 - 90	30 - 65.7 - 90	40 - 50	90 - 93	40	80	40 - 85
LSI	0.37 - 0.63 - 0.84	0.37 - 0.59 - 0.82	0.14 - 0.19	0.64 - 0.73	0.36	0.67	0.36 - 0.60
Total Phosphorus [µg l⁻¹]	1.50 - 5.97 - 12.50	1.84 - 8.76 - 29.24	11.23 - 15.00	63.50 - 143.82	4.02	7.01	4.94 - 27.82
Sites	WoeS, LutS, LudS, HocS, LinS, LinA	PoeS, AlmS, ZooS, MarS, TesS, EdlS, WoeA, LutA, LudA, PoeA, AlmA, ZooA, TesA, EdlA	PreS, PreA	DanS, DanA	LapS	HocA	MarA, LapA
Dominant taxa	*Gammarus fossarum* (ED) Orthocladiinae (D) *Protonemura* sp. (ED) Tanypodinae indet. (D)	*Crenobia alpina* (D) *Gammarus fossarum* (D) Orthocladiinae (D) Plecoptera (D) *Protonemura* sp. (D) *Simulium* sp.(D)	*Bythinella austriaca austriaca* (D) *Crenobia alpina* (D) *Gammarus fossarum* (D) *Limnius volckmari* (D) Tanytarsini (D)	*Gammarus fossarum* (ED) *Simulium* sp. (ED)		*Protonemura* sp. (D) *Simulium* sp. (D) Tanypodinae indet. (D)	Baetidae (D) *Bythinella opaca opaca* (D) *Crenobia alpina* (D) Orthocladiinae (D) Plecoptera (D) *Simulium* sp.(D)
Bryophytes	*Neckera complanata* *Hypnum cupressiforme* *Eurhynchium hians* *Cratoneuron filicinum* *Calliergonella cuspidata* *Palustriella commutata* *Fissidens dubius* *Plagiomnium rostratum* *Ctenidium molluscum*	*Neckera complanata* *Hypnum cupressiforme* *Eurhynchium hians* *Cratoneuron filicinum* *Calliergonella cuspidata* *Palustriella commutata* *Fissidens dubius* *Brachythecium rivulare*	*Palustriella commutata*	*Palustriella commutata* *Leucodon sciuroides*	*Palustriella commutata* *Hymenostylium recurvirostre*	*Plagiomnium rostratum* *Ctenidium molluscum*	*Palustriella commutata* *Hymenostylium recurvirostre* *Calliergonella cuspidata* *Brachythecium rivulare*

3.2.3 Indicator species analysis (ISA)

After cluster analysis, we performed a subsequent indicator species analysis verified by permutation tests (999 permutations). Indicator values are high when taxa are more abundant within a single group when compared to the other groups identified by cluster analysis. In addition, those taxa should be present at most sites of that group.

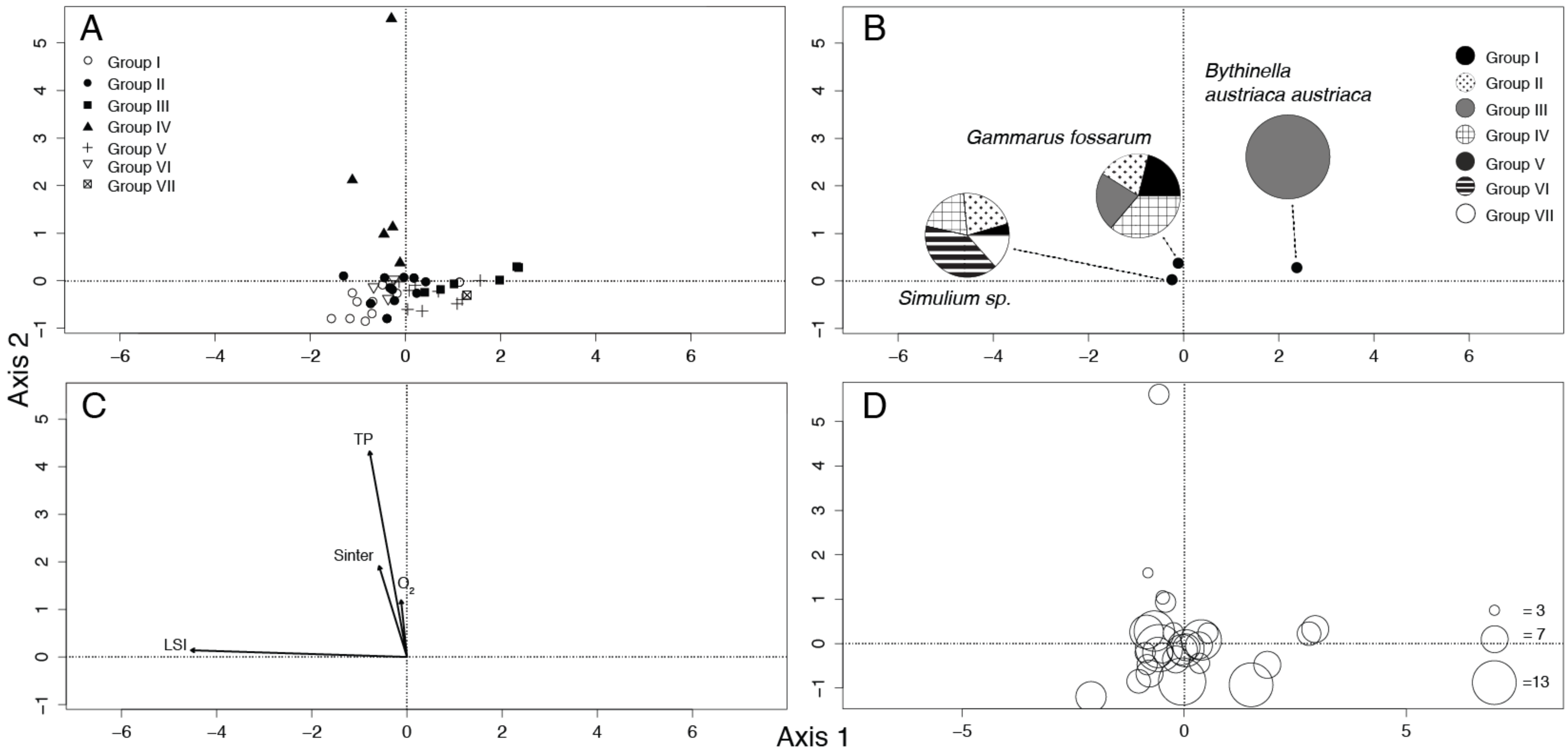
The results of ISA are shown in **Table 7**; three significant species were retained ($p < 0.05$: *Bythinella austriaca austriaca*, *Gammarus fossarum* and *Simulium* sp.

Table 7. Indicator values based on indicator species analysis.

Species	Group	Indicator Value [%]
Bythinella austriaca austriaca	III	100.0
Gammarus fossarum	IV	36,2
Simulium sp.	VI	40.1

Bythinella austriaca austriaca was collected only at station Preinmuehle (Pre) in Lower Austria and was identified as indicator species for group III. Indicator species for group IV (DanS, DanA) is *Gammarus fossarum*, which was also eudominant at this station. *G. foss*arum was also collected as dominant taxon in groups I, II and III, however with lower indicator values. *Simulium* sp. is indicative for group VI (HocA) and also dominant in groups II, IV and VII. In very small quantities *Simulium* sp. is also present in group I.

Fig. 11. Canonical correspondence analysis (CCA; ordination by species). **A)** Group-specific cluster split; **B)** Position of group-specific indicator species percentage in the ordination room; **C)** Biplot of the most important abiotic parameters; **D)** Site scores and taxa numbers for each site. The first two axes explained 14.8 % of total variance.



3.2.4. Canonical correspondence analysis (CCA)

The results of CCA are shown in **Fig. 11**. The ordination procedure in **Figs. 11A**, **B** and **C** is based on species data. **Fig. 11C** summarizes the most important environmental parameters ($p < 0.05$). As can be seen in **Table 8**, the first axis as well as all canonical axes were highly significant ($p < 0.001$). **Fig. 11D** based on site scores and was computed using environmental data. A total of 19.8 % of total variance could be explained by CCA analysis.

As shown in **Fig. 11A**, Group IV data including *Gammarus fossarum* as indicator species represent the spring and autumn samples at the Dandlgraben site and are in line with high total phosphorus, sinter coverage and oxygen concentrations (**Fig. 11C**). CCA results are fully in accordance with nMDS and cluster analysis data.

On the other hand, group V (spring sample at Lappenbach site) is driven by the lowest sinter coverage, oxygen and total phosphorus concentrations of all sites.

Table 8. Summary of CCA parameters.

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.353	0.291	0.205
Species - environment correlations	0.913	0.964	0.887
Cumulative percentage variance of species – environmental relations	8.1	14.8	19.8
Sum of all eigenvalues	4.362		
Test of significance of the first canonical axis: p-value	< 0.001		
Test of significance of all canonical axes: p-value	< 0.001		

Group VI (HocA), including *Simulium* sp. as indicator species, is characterized by higher Langelier saturation indices and lower total phosphorus concentrations. Similar tendencies to lower LSI values are also obvious in group III (PreS, PreA) where also lower water temperatures and conductivity values were measured.

Group I is defined by lower TP concentrations and higher LSI values, group II arranged in the centre of the ordination room, by low discharge and high conductivity. Similar results are shown for group VII with a tendency to high discharge and oxygen concentration.

The position of indicator species in the ordination room of the CCA is shown in **Fig. 11B** where group-specific proportions were indicated by pie charts. The indicator value of *Bythinella austriaca austriaca* was up to 100 % for group III only, whereas group proportions for *G. fossarum* and *Simulium* sp. were more evenly distributed over four to five sites.

No obvious patterns could be detected in the ordination plot based on site scores (**Fig. 11D**) where total taxa numbers correspond with circle size.

4. DISCUSSION

4.1. Environmental and structural parameters

When compared to other international studies, the environmental data of the 14 travertine-depositing springs and headwaters investigated show mostly similar ranges. Hahn (2000) measured nearly the same water temperature ranges (7.4 – 17.9 °C) combined with lower pH (4.1 – 7.3) and conductivity (60 – 392 µS cm^{-1}) values at 33 travertine springs in the Pfälzerwald mountains (Germany), whereas in this study the water temperature ranged from 7.2 to 15.8 °C, pH from 7.6 to 8.5 and conductivity from 264 to 1,009 µS cm^{-1}. He also measured the concentrations of the primary hardness constituents calcium and magnesium, whose ranges were lower (Ca^{2+} 2.8 – 32.0 mg l^{-1}; Mg^{2+} 1.2 – 22.0 mg l^{-1}) when compared to our data (Ca^{2+} 59.32 – 164.7 mg l^{-1}; Mg^{2+} 4.45 – 61.1 mg l^{-1}). Furthermore, the nitrate values are more than two times higher in Pfälzerwald mountain samples (0.2 – 24.7 mg l^{-1}) than in our study (1.2 – 12.7 mg l^{-1}), and discharge ranges (0.03 to 5.01 l s^{-1}) are also lower when compared to our data (1 – 726 l s^{-1}). The Pfälzerwald mountain area is dominated by the Buntsandstein formation, and the more acidic conditions were explained by sulphuric and nitrogenous impacts in higher altitudes.

Comparable data for pH (7.21 – 8.44) and water temperature (7.3 – 10.4 °C) as reported here for Austria were also found in Germany by Arp *et al.* (2001), as were similar Ca^{2+} and Mg^{2+} concentrations. While the conductivity in our study did not exceed 1,009 µS cm^{-1} (Alpenzoo), Staudacher & Füreder (2007) documented values as high as 2,630 µS cm^{-1} in the landslide area “Schütt” in Carinthia (Austria), yet with similar pH ranges (7 – 8.3).

More comparable results were reported by Sanders & Rott (2009) at Lingenau (Lin) and Alpenzoo station (Zoo). They measured similar values years ago at the same stations for water temperature, conductivity, pH, sulphate and chloride. Our data for calcium and magnesium at the Lingenau station are nearly the same, but the values at Alpenzoo station are somewhat higher. Three years later, Rott *et al.* (2012) investigated these two stations again, in addition to Hochtalalm station in Tyrol. They found similar results when compared to our study for nitrate, phosphate, hydrogen carbonate and conductivity, especially the unusual high conductivity values at Alpenzoo site (almost twice as high as at the other two stations). All measured pH data in 2012 are lower than in 2015, and major cations ($Ca^{2+}$and Mg^{2+}) are mostly much higher. The high sulphate values of Alpenzoo station were already present in 2012.

Much lower water temperatures (3.7 – 7.0 °C) along with similar pH, conductivity and calcium data were measured at travertine springs in the Western Carpathian Flysch belt (borderland between the Czech Republic and Slovakia) by Křoupalová *et al.* (2011). Compared with our study, data from the United Kingdom (Pentecost, 1991) show the same pH values with broader water temperature ranges (5.0 – 20.0 °C), as well as much lower values for alkaline earth metals (Ca^{2+}; Mg^{2+}), sulphate and chloride. Lower sulphate and chloride concentrations were also found by Boch *et al.* (2006) in Eastern Tyrol (Austria), whereas pH, water temperature and conductivity are in same ranges as in our study.

Comparisons of oxygen saturation and total phosphorus are difficult because less is known about these parameters in travertine-depositing springs and headwaters: this study yielded oxygen values from 4.3 to 11.9 mg l^{-1}. Omelková *et al.* (2013) documented values from 3.5 to 10.4 mg l^{-1} in calcareous spring fens in the Western Carpathian Flysch belt. The Czech ecologists measured PO_4^{3-} instead of total phosphorus, with ranges from 0 to 0.5 mg l^{-1}, which are more than five times higher than our values (0 - 0.090 mg l^{-1}).

Martin & Brunke (2012) investigated 170 lowland springs in northern Germany and measured O_2 saturation levels from 47 to 61 % and total phosphorus values from 21 to 41 µg l^{-1}. For 30 springs in the Italian Alps (Cantonati *et al.*, 2006) the values ranged from 1 to 12 µg l^{-1} (TP) and from 29 to 106 % (O_2-saturation). The 14 investigated travertine-depositing springs in this study were always highly saturated with oxygen (67.5 – 111.7 %), and total phosphorus ranges were higher (1 – 179 µg l^{-1}). The Dandlgraben station (Dan) shows the highest total phosphorus (mean = 103.6 µg l^{-1}) in both seasons, which can explained by anthropogenic inputs by private estates several meters upstream.

The investigated travertine-depositing springs and headwaters show high structural heterogeneity and similar microhabitat distribution when compared to each other. Most sites were sinter (travertine) encrusted microhabitats, which formed terraces, cascades, dams and walls by travertine formation processes. Leaf litter, dead wood and other terrestrial inputs were rapidly encrusted and integrated into surfaces. New coarse particular organic matter was caught at dams and contributes to pool size growth. In lentic, usually deeper parts with slow flow regime, fine particular organic matter was deposited and accumulated, providing detritus as a food source.

4.2. Fauna

4.2.1. Taxa composition and functional feeding groups

Little is known about the faunal distribution in travertine-depositing springs. Headwaters and springs are sometimes considered as island-like habitats with relatively stable conditions within the terrestrial landscape (Thienemann, 1924). Despite the high structural heterogeneity of such sites, some studies show evidence for taxonomic impoverishment (especially Coleoptera), without any characteristic species (Zollhöfer, 1997;1999; Martin & Wischniowsky, 2014). High rates of encrustation at active travertine surfaces may be a hostile setting for organisms without any adaptation, but is also a source of food in the form of encrusting algae and detritus (Pentecost, 2005).

During this study, 52 taxa on different taxonomic levels were identified. Some of the fauna was in younger development stages and could not be identified to species level. The most abundant taxon was the amphipod *Gammarus fossarum*, which was present in nearly all sites except for Teschenbach station. The rheophilous *G. fossarum* is ubiquitous in freshwaters and also a dominant taxon in other studies on travertine-depositing habitats (Hahn, 2000; Pentecost, 2005; Křoupalová *et al.*, 2011). In terms of functional feeding group, *Gammarus* is a typical detritus feeder and shredder. This genus plays a major role in the organic matter cycle and often serves as prey for other organisms (Karaman & Pinkster, 1977; Kelly *et al.*, 2002a). Moreover, a range of studies shows that this genus is also a good predator on a range of macro-invertebrate species, especially mayfly nymphs of the family Baetidae (Kelly *et al.*, 2002b), which was the most abundant family of Ephemeroptera in our investigations. Another gammarid amphipod, *Niphargus* sp., was identified but was rare compared to *G. fossarum*. *Niphargus* is a typically stygobiontic genus that often migrates into spring habitats. Due to its groundwater adaptation, this genus tolerates the acidic conditions in CO_2-enriched water. Studies show a shift in the presence of these two taxa with different environmental conditions. *G. fossarum* is dominant over *Niphargus* sp. at good water-buffering capacity and nutrient-rich conditions. This is reversed at pH lower than 6 (Hahn, 2000). Freshwater crustaceans were positively affected by lowered osmotic stress at high alkalinity conditions and plenty of calcium for shell formation, which could explain the dominance of this subphylum in our study (Glazier, 1991).

Chironomids, members of the taxa-rich order Diptera, were also found at nearly all sites during this study. Chironomids are typically high in terms of abundance and taxa richness in spring habitats, making them good bioindicators for water quality (Gerecke *et al.*, 1998). This family includes a range of organic matter-dwelling subfamilies such as Tanypodinae, as well as Tanytarsini which inhabit muddy sediments with fine particular organic matter microhabitats. The subfamily Orthocladiinae, as expected, accounted for a large part of this family and preferred bryophytes adjoining mud and gravel habitats (Lencioni *et al.*, 2012).

This distribution of abundances is in line with other studies (Thienemann, 1934; Hahn, 2000; Staudacher & Füreder, 2007; Lencioni *et al.*, 2011; Omelková *et al.*, 2013).

A further abundant family was the blackflies (Simulidae), whose larvae and pupae are restricted to running waters. This family is typical in travertine cascades during summer (Pentecost, 2005). All species of this taxon are filter feeders and attach to planar surfaces (e.g., stones, vegetation) to tolerate high water velocities. Some evidence suggests that the travertine encrustation is helpful in their attachment (Minckley, 1963). The larvae normally filter particles from the water column using their cephalic fans (Nilsson, 1996b) . The genus *Simulium* was present in 19 out of 28 samplings and also inhabits travertine-depositing springs in Germany (Hahn, 2000). In our study, higher abundance was always combined with higher discharge values.

Stoneflies are typical for oxygen-saturated lotic systems. The order Plecoptera is represented by four different taxa. The most abundant by far is the genus *Protonemura*, a typical detritus and algae feeder. Stoneflies are poor flyers, which limits dispersal distances and promotes local populations (Nilsson, 1996a; Bo *et al.*, 2009). The genera *Leuctra* and *Nemoura* are also present in this study and, next to *Protonemura*, are known to feed on travertine algae (Pentecost, 2005). Further study sites in Germany (Hahn, 2000) and Austria (Staudacher & Füreder, 2007) recorded similar patterns.

Rhyacophila pubescens is a highly specialized cold-stenotherm caddisfly that shows a postglacial distribution restricted to travertine spring brooks in limestone areas of the Alps in Central Europe (Pitsch, 1993; Engelhardt *et al.*, 2011). It was the only characteristic travertine species in our investigation. *R. pubescens* occurs at altitudes from 160 m to more than 2000 m (Coppa *et al.*, 2012), and all our sites were located in this range. It was the most abundant caddisfly and present at 6 of 14 sites. This travertine-favouring species (Pentecost, 2005) was also present in different travertine spring habitats in the Western Carpathian Flysch belt (Křoupalová *et al.*, 2011), but was absent in similar habitats in Austria and Germany (Hahn, 2000; Staudacher & Füreder, 2007), whereas the non-specialized species *Plectrocnemia geniculata* is present.

Only few vertebrates inhabit travertine formations. Pools made by travertine dams provide deeper lentic parts with higher sedimentation rates. The fire salamander (*Salamandra salamandra*) was found twice in Woellersdorf-station in larval stages. It is also a well-known and colourful amphibian of the Schwäbische Alp travertine, yet without any special travertine association (Pentecost, 2005).

4.2.2. Cluster analysis, nonmetric multidimensional scaling (nMDS)

The cluster analysis based on the taxa inventories yielded seven site groups, which were plotted into an nMDS ordination frame. The site scores within these groups are seasonally and geographically well-mixed, and ANOSIM analyses confirm significant differences between the seven groups. As evident in the synoptic **Table 6**, the composition of eudominant and dominant taxa differs, with less overlaps of generally abundant taxa. With few exceptions, the ranges of environmental data are mostly narrow and reflect the inter-habitat homogeneity. All investigated travertine-depositing springs and headwaters could be characterized as rheocrenes with similar structural elements and microhabitat distribution. The only explanation for this clear separation of groups within nearly the same abiotic framework would be shifts in taxa composition and abundance.

4.2.2. Indicator species analysis – ISA

To further analyse these shifts, an indicator species analysis was performed and verified by permutation tests. Three significant species were retained:

Bythinella austriaca austriaca: a freshwater snail with preferences for oligotrophic, stable, cold water springs, making it a good indicator for water quality (Glöer, 2002). The four *Bythinella* species found in Austria are endemic and strictly restricted to small areas. *B. austriaca austriaca* is restricted to eastern Austria and marked as “near threatened” in the red lists of the European habitat directive (Travnitzky & Patzner, 2009). With an indicator value of 100 %, the dominant *B. austriaca austriaca* defines group III, which consists of spring and autumn samples at Preinmuehle station and is characterized by the lowest water temperature and lower total phosphorus values.

Gammarus fossarum: this amphipod is typical for the epirhithral and an eudominant indicator for group IV, which includes both Dandlgraben samplings (spring and autumn). Characterized by high pH, water temperature and sinter coverage, this station contains the highest measured PO_4^{3-} and total phosphorus concentrations. As previously described, *Gammarus fossarum* is generally ubiquitous in freshwater habitats and known as a typical detritus feeder and shredder. This genus prefers nutrient-rich conditions along with high water buffering capacity, ideally provided by Dandlgraben station.

Simulium sp.: a blackfly and the only aquatic insect representative within the indicator species, is an indicator for group VI. This group consists of the autumn sample at Hochtalalm station and has the highest mean LSI values of all sampling sites. This is reflected by the second highest calcium carbonate precipitation rate of 2.87 mm a^{-1}. Development stages of this taxon inhabit only running waters, and the presence of individuals of this family is typical in travertine cascades. *Simulium* sp. is dominant in group VI but eudominant in group IV (Dandlgraben station), where the highest discharge of 726 l s^{-1} was measured. The reason why *Simulium* sp. is an indicator for group VI despite its high abundance at Dandlgraben station is that it occurs at this station only in spring and is no longer present in autumn. This could be due to the more than twice as high discharge in autumn versus spring.

4.2.4. Canonical correspondence analysis (CCA)

The results of CCA are fully in accordance with the previously described patterns in nMDS and cluster analysis. The analysis identified the following environmental parameters as significantly influencing macrozoobenthic community composition: sinter coverage, O_2 and total phosphorus concentration as well as the Langelier saturation index. The calcium carbonate precipitation rate was not significant, but the LSI (which combines water temperature, pH, calcium and bicarbonate concentration and conductivity) can be used as a proxy for $CaCO_3$ precipitation.

Group IV with the detritus feeder *Gammarus fossarum* as indicator tended to higher total phosphorus values, whereas group III with *Bythinella austriaca austriaca*, which prefers oligotrophic and calcareous conditions, shows tendencies to lower LSI and phosphorus concentrations. This partly agrees with studies that identified acidity and eutrophication (Verdonschot & Schot, 1987), substratum characteristics (Bonettini & Cantonati, 1996; Fischer *et al.*, 1998) and hydrochemistry (Mezquita *et al.*, 1999) as key determinants for community assemblages.

The first two axes of the CCA explained 14.8 % of total variance. This indicates that our set of measured environmental parameters shows trends but is not able to significantly explain the whole range of investigated community composition. The complexity of regulating factors for macroinvertebrates is commonly very high (Fischer *et al.*, 1998) and could not be more fully encompassed in this study.

The findings of Hahn (2000) suggest that springs are ecotones between groundwater habitats, with typically cold water and acidic conditions, and headwaters, highly linked to terrestrial inputs and diverse in structural heterogeneity. The convergence of these different habitats, combined with the special hydrochemical characteristics of travertine-depositing springs and headwaters, leads to a community composition mixture of groundwater-dwelling and upstream-migrating organisms.

Most of the taxa collected during this study also occur in other study sites (Hahn, 2000; Staudacher & Füreder, 2007; Křoupalová *et al.*, 2011; Omelková *et al.*, 2013). We also found similar evidence for lower species richness of travertine-depositing springs and headwaters versus other spring habitats. Especially the order of Coleoptera was poorly represented (only two families). This, however, is in line with the investigations by Zollhöfer (1999). This paucity of Coleoptera, which usually prefer slow-flowing waters, could reflect the rapid flow conditions in which most of the calcium carbonate is deposited (Pentecost, 2005).

In contrast, the highly specialized cold-stenotherm caddisfly *Rhyacophila pubescens* was found in 6 of 14 sites (although in low abundance), whereas this species was not recorded in similar German and Austrian investigations. Studies demonstrate the endemic status of this species within stable, travertine-depositing springs in Central Europe and the Italian peninsula. The genus *Bythinella*, in turn, is strongly restricted to small areas and can be identified to species level based on geographic factors (Glöer, 2002). This genus reflects the endemic character of spring habitats as island-like habitats, with low connectivity to each other, in the terrestrial landscape. The grade of isolation is higher for specialized species versus generalist species due to the lower habitat availability (Engelhardt *et al.*, 2011). Immigration and emigration can occur only along stream corridors from up- to downstream or vice-versa by dispersal of winged adult stages (Sode & Wiberg-Larsen, 1993). This lateral dispersion is impossible for species strongly bound to stable environmental conditions such as *Bythinella* or *Rhyacophila*. This leads to limited dispersal rates after postglacial recolonisation and to sets of endemic organisms in these island-like habitats.

4.2. Conclusion and challenges

This investigation was designed to characterize macrozoobenthic invertebrates at travertine-depositing springs and headwaters in Austria and to investigate the interactions between these communities and environmental conditions, such as different calcium carbonate precipitation. The results show that travertine-depositing springs and headwaters in Austria are nearly homogeneous in terms of hydrochemistry and that differences, such as higher nutrient concentrations, probably mainly reflect anthropogenic impacts. Differences to similar sites in other countries are minimal and based on geological and catchment factors. The analysis determined the following environmental parameters as being most important for macrozoobenthic community composition: sinter coverage, O_2, total phosphorus concentration and the Langelier saturation index. The calcium carbonate precipitation rate merely highlighted trends but yielded no significant correlations with macrozoobenthos species sets. Nonetheless, the carbonate precipitation seems to lead to higher structural heterogeneity and provides a range of new niches, which contribute to broader ranges of taxonomic diversity.

The macrozoobenthic composition consists of stygobiontic taxa from groundwater refugia and of immigrated generalists that prefer the stable conditions there (e.g., water temperature and buffering capacity). Only a few endemic species (e.g., *Bythinella austriaca austriaca, B. opaca opaca, B. bavarica* and *Rhyacophila pubescens*) and specialists separated the study sites geographically, but the majority were well-known spring- and headwater-dwelling species (e.g., from the genera *Gammarus* and *Simulium*) without any known adaptation to carbonate precipitation or association with travertine. The macrozoobenthic community composition is clearly based on a poorly-understood complex of environmental conditions and regulatory factors that can rarely be covered in full by sampling procedures.

Underestimated factors such as interspecific competition or grain size (Bonettini & Cantonati, 1996) could be major determinants for spring communities (Fischer, 1996). Future investigations should strive to incorporate such parameters to gain a better understanding of these special habitats. Furthermore, absolute numbers instead of abundance classes could be incorporated and additional samplings be conducted at non-travertine-depositing sites in similar catchments. This would improve direct comparisons and enable more detailed statistical analyses.

5. APPENDIX

5.1 Appendix A

Table 9. Abiotic raw data of spring samplings.

Study site ID	Lap ID	Date	pH	Conductivity [µS cm^{-1}]	Water temperature [°C]	O_2 [mg l^{-1}]	O_2 [%]	Sky Openess [%]	Slope [%]	Depth [m]	Width [m]	Flow velocity [m s^{-1}]	Discharge [m^3 s^{-1}]	Altiude [m asl]	Sinter [%]	cPOM [%]	fPOM [%]
Woe	a_1_1	20.05.14	8.27	714	12.1	10.52	105.9	8.69	12.2	0.38	0.85	0.043	0.014	417	20	30	50
Woe	a_1_2	20.05.14	8.27	714	12.2	10.86	111.7	5.64	12.2	0.54	1.3	0.031	0.022	417	20	30	50
Woe	a_1_3	20.05.14	8.27	710	12.3	10.82	106.4	3.48	12.2	0.16	0.5	0.521	0.042	417	20	30	50
Lut	b_1_1	22.05.14	7.8	506	12.6	8.9	93.9	12.51	18.5	0.54	0.46	0.246	0.061	732	65	25	10
Lut	b_1_2	22.05.14	7.9	509	12.2	9.26	93.1	11	18.5	0.87	1.1	0.168	0.161	732	65	25	10
Lut	b_1_3	22.05.14	7.8	511	12.1	9.04	92.2	6.77	18.5	0.29	0.82	0.437	0.104	732	65	25	10
Lud	c_1_1	22.05.14	8.2	411	14.8	9.41	96.6	24.1	21.3	0.14	0.91	1.163	0.148	698	70	25	5
Lud	c_1_2	22.05.14	8.2	410	14.8	9.51	98	22.44	21.3	0.4	0.63	0.326	0.082	698	70	25	5
Lud	c_1_3	22.05.14	8.2	410	14.8	9.33	95.1	18.62	21.3	0.57	0.5	0.272	0.077	698	70	25	5
Poe	d_1_1	26.05.14	8.08	618	12.9	9.82	104.3	34.42	3.8	0.083	1.6	0.345	0.046	431	35	35	30
Poe	d_1_2	26.05.14	8.08	620	13	10.34	108.7	32.33	3.8	0.066	2.1	0.201	0.028	431	35	35	30
Poe	d_1_3	26.05.14	8.08	619	13.1	10.38	109.7	27.02	3.8	0.095	1.45	0.247	0.034	431	35	35	30
Alm	e_1_1	31.05.14	8.26	457	9.8	8.7	109	14.41	20.8	0.041	0.22	0.735	0.007	635	65	25	10
Alm	e_1_2	31.05.14	8.23	457	9.8	9.14	105	12.03	20.8	0.034	0.24	0.278	0.002	635	65	25	10
Alm	e_1_3	31.05.14	8.23	457	9.8	9.03	103.4	10.7	20.8	0.048	0.38	1.02	0.019	635	65	25	10
Zoo	f_1_1	22.06.14	8.24	1005	10.8	7.5	97	6.69	26.3	0.04	1.54	0.518	0.032	696	85	14	1
Zoo	f_1_2	22.06.14	8.23	964	10.7	8.3	91	6.86	26.3	0.06	1.47	0.735	0.065	696	85	14	1
Zoo	f_1_3	22.06.14	8.26	1009	10.6	8.3	97	7.3	26.3	0.096	1	1.235	0.119	696	85	14	1
Hoc	g_1_1	23.06.14	8.32	454	14.5	7.47	99.7	13.64	14.6	0.15	1.69	0.194	0.049	892	45	40	15
Hoc	g_1_2	23.06.14	8.29	442	15.8	7.45	99.7	8.8	14.6	0.045	0.97	0.286	0.012	892	45	40	15
Hoc	g_1_3	23.06.14	8.29	437	15.3	7.24	95.7	9.56	14.6	0.103	1.26	0.35	0.045	892	45	40	15
Lin	h_1_1	24.06.14	8.06	625	11.3	8.1	95.7	14.26	52.4	0.02	2.2	0.505	0.022	587	70	5	25
Lin	h_1_2	24.06.14	8.07	594	11.3	7.5	94.5	15.62	52.4	0.033	2.7	0.223	0.02	587	70	5	25
Lin	h_1_3	24.06.14	8	595	11.3	7.9	90.7	12.54	52.4	0.064	0.9	0.699	0.04	587	70	5	25
Pre	i_1_1	01.07.14	8.31	386	7.2	10.18	92	4.44	63.7	0.042	6.3	0.446	0.118	747	40	40	20
Pre	i_1_2	01.07.14	8.21	287	7.2	10.2	92.9	4.84	63.7	0.036	6.9	0.562	0.14	747	40	40	20
Pre	i_1_3	01.07.14	8.23	286	7.3	10.65	83	4.24	63.7	0.06	4.2	0.221	0.056	747	40	40	20
Mar	j_1_1	04.07.14	8.37	529	14.9	8.6	94	5.12	25.8	0.098	0.75	0.621	0.046	473	80	10	10
Mar	j_1_2	04.07.14	8.32	605	14.9	8.86	91	5.62	25.8	0.086	1	0.417	0.036	473	80	10	10
Mar	j_1_3	04.07.14	8.35	610	15	7.73	89.1	16.38	25.8	0.05	1.2	0.806	0.048	473	80	10	10
Dan	k_1_1	04.07.14	8.35	484	15.4	8.56	84.4	4.14	47.2	0.075	7.9	0.13	0.077	440	93	5	2
Dan	k_1_2	04.07.14	8.3	483	15.3	8.69	83.4	5.32	47.2	0.31	3.9	0.366	0.443	440	93	5	2
Dan	k_1_3	04.07.14	8.35	482	15.4	8.61	82.4	6.51	47.2	0.017	2.5	0.588	0.025	440	93	5	2
Lap	l_1_1	15.07.14	8.31	604	10.9	11.3	114.8	8.79	37.1	0.035	2.71	0.3	0.028	723	40	40	20
Lap	l_1_2	15.07.14	8.29	603	10.9	8.5	90.2	8.58	37.1	0.068	6.26	0.214	0.091	723	40	40	20
Lap	l_1_3	15.07.14	8.28	603	11	4.25	67.5	8.44	37.1	0.053	4.55	0.463	0.112	723	40	40	20
Tes	m_1_1	25.07.14	8.27	550	11	9.2	82.2	9.7	24.6	0.032	0.84	0.263	0.007	546	60	5	35
Tes	m_1_2	25.07.14	8.26	548	11.1	8.33	84.1	8.76	24.6	0.061	1.17	0.763	0.054	546	60	5	35
Tes	m_1_3	25.07.14	8.25	550	11	8.29	75.6	4.89	24.6	0.023	0.73	0.241	0.004	546	60	5	35
Edl	n_1_1	25.07.14	8.34	714	13	11.9	105.2	30	11.6	0.086	0.63	0.714	0.039	675	90	5	5
Edl	n_1_2	25.07.14	8.35	715	13	11.8	112.6	27.44	11.6	0.152	0.79	0.441	0.053	675	90	5	5
Edl	n_1_3	25.07.14	8.32	715	13	11.8	112.7	25.79	11.6	0.118	0.8	0.493	0.047	675	90	5	5

Table 9. Abiotic raw data of spring samplings (Continued).

PO_4^{3-} [µg l^{-1}]	NO_2^- [µg l^{-1}]	NH_4^+ [µg l^{-1}]	TP [µg l^{-1}]	DOC [mg l^{-1}]	Cl^- [mg l^{-1}]	NO_3^- [mg l^{-1}]	SO_4^{2-} [mg l^{-1}]	Na^+ [mg l^{-1}]	K^+ [mg l^{-1}]	Ca^{2+} [mg l^{-1}]	Mg^{2+} [mg l^{-1}]	TIC [mg l^{-1}]	c(CO_2) [mg l^{-1}]	c(HCO_3^-) [mg l^{-1}]	LSI
3.066	3.941	2.576	33	2.79	9.987	7.799	44.662	5.276	1.299	107.531	41.525	469.332	3.774	465.558	0.87
3.066	4.27	2.576	10	2.44	9.772	7.827	44.789	5.219	1.114	107.592	42.056	415.204	3.34	411.864	0.81
3.066	5.912	3.863	15	7.28	9.83	7.84	44.831	5.288	1.092	108.348	42.273	427.511	3.444	424.067	0.83
3.066	2.956	2.576	9	1.26	1.295	4.508	2.919	1.035	2.023	115.441	8.734	339.823	4.841	334.982	0.35
3.066	2.956	2.576	4	1.19	0.693	4.359	2.784	0.668	2.049	113.819	8.542	337.185	7.084	330.101	0.43
3.066	3.613	3.863	5	1.28	0.725	4.427	2.806	0.724	2.028	114.478	8.556	334.15	4.049	330.101	0.33
3.066	2.299	7.727	8	1.97	0.532	4.901	3.115	0.356	1.231	92.234	6.082	274.09	2.565	271.525	0.65
3.066	1.971	2.576	12	1.81	0.478	4.783	3.079	0.316	1.197	93.624	6.266	264.233	2.471	261.762	0.64
3.066	2.299	2.576	12	1.8	0.474	4.682	3.046	0.304	1.34	92.604	6.232	264.233	2.471	261.762	0.63
3.066	3.941	96.586	2	2.04	2.742	8.858	41.847	2.533	2.109	111.57	28.83	374.651	4.278	370.372	0.64
3.066	3.613	1.288	3	5.09	2.764	8.814	41.535	2.534	2.186	111.562	28.715	368.502	4.232	364.271	0.63
3.066	3.285	6.439	20	1.97	2.745	8.723	41.89	2.543	2.125	112.734	28.864	368.488	4.218	364.271	0.64
3.066	1.314	16.742	2	1.41	1.956	4.11	31.441	1.167	1.732	78.782	18.438	284.251	2.964	281.288	0.52
0	0.985	5.151	5	1.18	1.938	4.125	31.604	1.137	1.678	79.146	18.231	269.438	2.794	266.644	0.47
0	2.628	0	1	1.27	1.907	4.088	31.297	1.125	1.774	77.46	18.197	269.451	2.807	266.644	0.46
3.066	1.971	2.576	2	1.68	6.104	4.838	435.202	2.969	1.694	164.787	61.104	202.662	1.917	200.745	0.56
3.066	1.642	2.576	5	0.945	5.751	4.808	434.202	2.833	1.494	164.486	60.946	196.49	1.846	194.644	0.54
3.066	2.299	2.576	4	0.649	6.265	4.812	432.14	3.078	1.701	164.397	61.069	202.662	1.917	200.745	0.57
3.066	1.971	78.556	2	1.74	1.051	0.867	1.369	0.237	1.039	75.355	24.586	277.383	2.197	275.186	0.66
3.066	1.314	72.117	6	23.1	0.929	0.815	1.149	0.184	1.115	73.391	24.466	299.387	2.235	297.152	0.69
3.066	1.314	57.951	2	1.94	0.891	0.823	1.155	0.121	1	73.238	24.402	285.856	2.127	283.728	0.66
3.066	2.299	1.288	1	1.63	16.723	12.696	9.246	7.162	5.418	126.357	4.602	399.868	6.31	393.559	0.66
3.066	1.971	1.288	64	0.907	16.818	11.048	9.171	7.056	5.516	127.756	4.594	375.075	5.923	369.152	0.65
3.066	1.642	1.288	2	0.873	16.639	12.171	9.244	7.142	5.493	121.997	4.631	387.477	6.122	381.355	0.58
3.066	1.314	14.166	5	3.43	0.733	7.543	6.765	0.044	0.832	67.243	1.282	165.571	1.435	164.135	0.23
3.066	1.314	33.483	56	2.06	0.73	7.524	6.748	0.043	0.879	66.886	1.36	162.266	1.792	160.474	0.16
6.132	9.525	3.863	25	0.715	0.845	7.52	6.751	0.095	0.875	67.131	1.319	165.941	1.806	164.135	0.19
3.066	9.854	3.863	8	1.56	1.415	3.635	124.681	1.722	1.671	95.513	33.93	253.567	1.567	252	0.76
3.066	1.971	45.073	9	0.879	1.337	3.626	123.916	1.66	1.583	95.139	33.888	250.293	1.955	248.339	0.68
3.066	2.956	15.454	9	0.984	1.311	3.612	123.65	1.703	1.547	95.265	33.989	247.825	1.927	245.898	0.71
52.125	6.241	2.576	23	1.22	2.886	5.776	11.376	2.158	1.776	77.838	26.197	278.585	2.179	276.406	0.72
39.86	6.241	3.863	438	1.47	2.838	5.765	11.451	1.963	1.762	81.456	26.399	288.301	2.132	286.169	0.7
42.926	5.912	2.576	104	2.59	2.516	5.9	11.276	1.909	1.42	77.669	26.221	319.145	2.468	316.677	0.78
0.902	2.555	0	4.253	1.44	0.824	1.39	178.778	1.33	0.761	84.867	28.975	156.919	1.326	155.593	0.33
0.902	0.547	5.726	6.322	1.05	0.887	1.426	178.569	1.439	0.829	85.162	29.061	185.095	1.434	183.661	0.38
0.902	0.547	12.33	1.494	1.05	0.802	1.387	178.565	1.417	0.749	84.643	28.998	191.276	1.513	189.762	0.38
0.902	1.825	13.651	0.46	1.06	1.916	4.614	5.232	1.035	1.309	76.029	26.405	372.242	3.09	369.152	0.63
0.902	4.927	12.33	0.804	1.14	1.905	5.251	5.151	1.027	1.186	72.044	26.191	359.935	2.986	356.949	0.59
0.902	1.825	1.103	10.115	1.1	1.882	5.223	5.142	1.038	1.273	74.056	26.358	359.924	2.976	356.949	0.59
0.902	2.007	12.99	0.804	2.04	2.341	2.59	232.367	1.935	1.022	108.882	28.648	193.639	1.436	192.203	0.58
0.902	5.839	1.763	2.873	0.891	2.324	2.552	230.905	1.931	1.149	109.323	28.706	181.355	1.356	180	0.56
0.902	3.102	0.442	1.839	0.984	2.348	2.069	230.23	1.945	1.159	111.008	28.604	189.951	1.409	188.542	0.56

Table 10. Abiotic raw data of autumn samplings.

Study site ID	Lap ID	Date	pH	Conductivity [µS cm^{-1}]	Water temperature [°C]	O_2 [mg l^{-1}]	O_2 [%]	Calcium carbonate precipitation [mm a^{-1}]	Sky Openess [%]	Slope [%]	Depth [m]	Width [m]	Flow velocity [m s^{-1}]	Discharge [m^3 s^{-1}]	Altiude [m asl]	Sinter [%]	cPOM [%]	fPOM [%]
Woe	a_2_1	19.09.14	8.219	715	12.5	10.52	105.9		3.95	12.2	0.048	1.21	0.2247	0.0131	417	40	25	35
Woe	a_2_2	19.09.14	8.21	714	12.4	10.86	111.7	0.6049	5.48	12.2	0.071	1.38	0.5263	0.0516	417	40	25	35
Woe	a_2_3	19.09.14	8.212	712	12.4	10.82	106.4		5.73	12.2	0.0196	0.69	0.8064	0.0109	417	40	25	35
Lut	b_2_1	15.09.14	7.634	556	13.1	8.9	93.9		17.89	18.5	0.0316	0.66	0.4444	0.0093	732	50	10	40
Lut	b_2_2	15.09.14	7.795	561	13	9.26	93.1	0.0348	10.22	18.5	0.0478	1.03	0.7692	0.0379	732	50	10	40
Lut	b_2_3	15.09.14	7.828	561	13	9.04	92.2		8.63	18.5	0.0314	0.96	0.5181	0.0156	732	50	10	40
Lud	c_2_1	15.09.14	8.214	474	12.6	9.41	96.6		18.55	21.3	0.0628	1.16	0.7353	0.0536	698	85	5	10
Lud	c_2_2	15.09.14	8.24	473	12.6	9.51	98	2.4271	20.93	21.3	0.058	0.52	0.3521	0.0106	698	85	5	10
Lud	c_2_3	15.09.14	8.55	472	12.6	9.33	95.1		14.89	21.3	0.0658	0.83	0.7575	0.0414	698	85	5	10
Poe	d_2_1	19.09.14	8.16	603	15.1	9.82	104.3		41.79	3.8	0.0514	1.73	0.2518	0.0224	431	30	30	40
Poe	d_2_2	19.09.14	8.161	603	15.1	10.34	108.7	0.4846	41.84	3.8	0.0544	2.5	0.2923	0.0398	431	30	30	40
Poe	d_2_3	19.09.14	8.163	603	15.1	10.38	109.7		39.89	3.8	0.051	1.81	0.2331	0.0215	431	30	30	40
Alm	e_2_1	18.09.14	8.246	451	11.4	8	83		9.42	20.8	0.0258	0.49	1.1364	0.0144	635	60	30	10
Alm	e_2_2	18.09.14	8.25	450	11.3	8.29	81.5	1.2406	6.7	20.8	0.084	0.55	0.2659	0.0123	635	60	30	10
Alm	e_2_3	18.09.14	8.214	450	11.3	8.2	81.8		7.59	20.8	0.0045	0.29	0.7462	0.001	635	60	30	10
Zoo	f_2_1	09.09.14	8.215	982	10.4	10.39	100.5		9.42	26.3	0.039	1.31	0.5319	0.0272	696	90	5	5
Zoo	f_2_2	09.09.14	8.22	972	10.4	10.3	100.7	0.4143	8.95	26.3	0.0446	1.29	0.8474	0.0488	696	90	5	5
Zoo	f_2_3	09.09.14	8.21	977	10.6	10.48	102.3		8.49	26.3	0.1226	0.83	0.6024	0.0613	696	90	5	5
Hoc	g_2_1	10.09.14	8.323	506	11.2	9.53	99.4		14.21	14.6	0.0246	1.7	0.2116	0.0088	892	80	10	10
Hoc	g_2_2	10.09.14	8.316	508	11.3	9.95	101.2	2.8701	13.2	14.6	0.085	1.24	0.3063	0.0323	892	80	10	10
Hoc	g_2_3	10.09.14	8.228	506	11.2	9.42	103.9		11.32	14.6	0.1356	2.1	0.1608	0.0458	892	80	10	10
Lin	h_2_1	09.09.14	8.02	630	11.5	9.5	99.5		17.51	52.4	0.028	3.5	0.2817	0.0276	587	90	9	1
Lin	h_2_2	09.09.14	8.08	620	11.7	10.14	103.6	4.1506	15.56	52.4	0.028	2.8	0.2299	0.018	587	90	9	1
Lin	h_2_3	09.09.14	8.08	600	11.8	9.7	95.9		10.98	52.4	0.084	1.1	0.4425	0.0409	587	90	9	1
Pre	i_2_1	18.09.14	8.22	264	7.5	9.03	82.1		4.99	63.7	0.0474	3.5	0.4405	0.0731	747	50	40	10
Pre	i_2_2	18.09.14	8.207	287	7.5	9.12	82.9	0.116	5.19	63.7	0.031	3.6	0.8928	0.0996	747	50	40	10
Pre	i_2_3	18.09.14	8.202	287	7.5	7.2	82.5		4.95	63.7	0.0456	3.57	0.6536	0.1064	747	50	40	10
Mar	j_2_1	22.09.14	8.244	597	11.2	11.36	109.9		7.31	25.8	0.0406	0.79	0.3802	0.0122	473	85	10	5
Mar	j_2_2	22.09.14	8.212	433	11.2	11.33	109.7	1.0676	7.45	25.8	0.0466	0.77	0.8	0.0287	473	85	10	5
Mar	j_2_3	22.09.14	8.244	494	11.3	11.38	108.9		17.4	25.8	0.093	0.58	0.7246	0.0391	473	85	10	5
Dan	k_2_1	22.09.14	8.31	480	11.3	11.27	108.8		6.74	47.2	0.0222	4.2	0.3413	0.0318	440	90	8	2
Dan	k_2_2	22.09.14	8.303	496	11.5	11.18	108.5	1.5759	7.54	47.2	0.2196	8.2	0.4032	0.7261	440	90	8	2
Dan	k_2_3	22.09.14	8.293	509	11.4	11.25	109		7.95	47.2	0.0032	2.6	0.25	0.0021	440	90	8	2
Lap	l_2_1	11.09.14	8.31	598	9.8	10.37	99.7		9.86	37.1	0.062	8	0.5	0.248	723	40	40	20
Lap	l_2_2	11.09.14	8.25	511	9.9	10.24	100.2	1.4795	9.54	37.1	0.068	2.83	0.5847	0.1125	723	40	40	20
Lap	l_2_3	11.09.14	8.229	560	9.9	10.35	99.7		10.17	37.1	0.144	4.05	0.9174	0.535	723	40	40	20
Tes	m_2_1	15.09.14	8.123	577	10.1	9.2	82.2		5.58	24.6	0.0606	1.61	0.3952	0.0386	546	75	20	5
Tes	m_2_2	15.09.14	8.154	573	10.2	8.33	84.1	1.8096	6.91	24.6	0.049	2.6	0.4807	0.0612	546	75	20	5
Tes	m_2_3	15.09.14	8.136	576	10.2	8.29	75.6		7.11	24.6	0.0322	1.54	0.2865	0.0142	546	75	20	5
Edl	n_2_1	22.09.14	8.322	252	9.3	11.9	105.2		33.01	11.6	0.1014	1.12	0.4545	0.0516	675	75	20	5
Edl	n_2_2	22.09.14	8.258	626	9.2	11.8	112.6	0.4553	28.04	11.6	0.1626	0.99	1.1628	0.1872	675	75	20	5
Edl	n_2_3	22.09.14	8.293	627	9.2	11.8	112.7		24.98	11.6	0.084	1.4	0.4184	0.0492	675	75	20	5

Table 10. Abiotic raw data of autumn samplings. (Continued).

PO_4^{3-} [µg l^{-1}]	NO_2^- [µg l^{-1}]	NH_4^+ [µg l^{-1}]	TP [µg l^{-1}]	DOC [mg l^{-1}]	Cl^- [mg l^{-1}]	NO_3^- [mg l^{-1}]	SO_4^{2-} [mg l^{-1}]	Na^+ [mg l^{-1}]	K^+ [mg l^{-1}]	Ca^{2+} [mg l^{-1}]	Mg^{2+} [mg l^{-1}]	TIC [mg l^{-1}]	c(CO_2) [mg l^{-1}]	c(HCO_3^-) [mg l^{-1}]	LSI
3.6073	3.467	46.7244	10.5748	3.07	9.985	5.81	40.988	5.38	0.906	99.859	39.829	434.5187	4.3499	430.1687	0.76
2.7054	3.1021	4.4578	48.161	2.86	9.939	5.79	40.885	5.369	0.942	97.062	39.611	441.9276	4.4368	437.4907	0.74
3.6073	2.9196	15.0245	95.4024	4.91	9.971	5.666	40.922	5.445	0.991	97.137	40.068	300.1616	3.0096	297.152	0.58
1.8036	2.0072	13.0432	6.7817	2.17	0.566	3.24	2.411	1.012	1.671	124.223	9.023	378.746	9.5941	369.1519	0.26
1.8036	2.0072	19.6474	4.7128	2	0.567	3.228	2.309	0.999	1.867	123.555	9.016	377.0736	7.9217	369.1519	0.41
2.7054	2.3722	35.4973	5.0576	1.89	0.592	3.257	2.305	1.039	1.73	122.858	8.973	384.4309	9.1773	375.2536	0.45
1.8036	1.4598	13.7036	14.0231	2.37	0.512	3.431	2.472	0.673	0.737	104.357	6.584	317.2502	3.0135	314.2367	0.71
0.9018	1.2773	11.7224	27.1266	2.89	0.524	3.42	2.495	0.672	0.724	104.113	6.594	323.3991	3.0607	320.3384	0.74
1.8036	1.4598	20.9682	29.1955	2.22	0.524	3.415	2.479	0.662	0.706	103.587	6.691	300.813	0	300.813	1
2.7054	3.467	1.8161	7.4714	2.08	2.669	5.469	44.876	2.708	1.887	92.698	27.643	372.5389	3.3871	369.1519	0.69
2.7054	3.2846	3.137	9.1955	1.89	2.645	5.432	44.659	2.611	1.856	92.083	27.56	415.6431	3.7794	411.8637	0.74
2.7054	3.832	14.364	25.0576	1.86	2.667	5.4	44.607	2.677	1.788	91.267	27.506	339.2936	3.0908	336.2028	0.65
1.8036	2.5547	22.9494	2.9886	1.79	1.707	3.539	29.068	1.26	1.263	73.281	16.278	274.3583	2.8333	271.5249	0.5
1.8036	1.6423	1.8161	51.2645	1.41	1.66	3.524	29.119	1.262	1.249	72.391	16.238	259.584	2.7031	256.8809	0.47
1.8036	2.0072	1.8161	10.23	1.3	1.665	3.522	29.112	1.27	1.147	73.02	16.302	265.7378	2.7552	262.9826	0.45
2.7054	3.2846	17.6661	2.299	2.05	6.469	4.699	367.138	3.375	1.018	149.95	54.635	202.6502	1.9048	200.7454	0.49
1.8036	1.0949	48.0452	2.9886	6.09	6.421	4.682	366.851	3.439	1.053	150.069	54.762	200.1978	1.893	198.3047	0.49
1.8036	1.2773	113.4263	5.4024	1.11	6.501	4.682	366.795	3.339	1.162	149.427	54.597	206.3702	1.9638	204.4064	0.5
1.8036	2.0072	62.5744	1.9541	2.1	0.777	0.882	1.128	0.424	0.847	87.342	24.611	313.3125	2.7368	310.5757	0.69
1.8036	1.0949	79.0847	8.8507	2.41	0.799	0.877	0.848	0.434	0.939	86.597	24.79	326.8297	2.8303	323.9994	0.72
1.8036	0.9124	61.9139	10.23	2.85	0.772	0.878	0.81	0.418	0.834	84.747	24.582	334.7931	3.4716	331.3214	0.61
1.8036	0.9124	7.0995	1.6093	0.753	14.466	11.807	7.908	6.592	4.734	126.6	4.452	387.5788	6.2236	381.3553	0.61
1.8036	2.0072	7.0995	1.9541	0.817	14.458	11.794	7.923	6.623	4.9	123.087	4.564	355.3401	5.7136	349.6265	0.63
1.8036	3.2846	3.7974	1.9541	0.912	14.405	11.634	7.852	6.67	4.792	119.111	4.467	359.0147	5.7272	353.2875	0.63
1.8036	2.0072	5.1182	2.6438	2.2	0.626	7.293	5.925	0.363	0.319	59.594	1.651	169.6706	1.8743	167.7963	0.15
3.6073	1.2773	3.137	19.5403	1.29	0.622	7.161	5.921	0.35	0.341	59.427	1.7	174.6069	1.9292	172.6777	0.14
1.8036	1.6423	1.1557	56.4369	1.78	0.634	6.889	5.885	0.374	0.351	59.32	1.612	168.4365	1.8605	166.576	0.12
7.2145	2.5547	22.289	11.9541	1.67	1.203	3.246	106.706	1.672	1.259	91.81	29.943	294.1442	3.0939	291.0503	0.58
2.7054	2.3722	10.4015	11.2645	1.38	1.205	3.304	106.445	1.677	1.254	91.576	29.959	302.7777	3.1851	299.5927	0.61
4.5091	2.3722	13.7036	60.23	1.67	1.196	3.206	106.511	1.698	1.197	93.242	30.578	300.311	3.159	297.152	0.62
89.2797	12.5909	6.4391	81.2645	3.74	2.597	2.049	11.028	2.4	1.241	79.018	20.932	291.0972	2.4875	288.6097	0.61
79.3597	10.7661	5.1182	332.6438	3.18	2.629	3.494	11.021	2.439	1.229	82.164	21.508	316.932	2.6952	314.2367	0.66
90.1815	11.496	4.4578	179.1955	3.17	2.605	3.248	11.003	2.411	1.258	80.368	21.444	328.6523	3.4326	325.2198	0.65
2.7054	3.6495	63.2348	1.9541	1.11	0.776	1.202	171.052	1.567	0.838	92.821	31.024	148.4475	1.3969	147.0506	0.32
1.8036	0.7299	9.7411	2.6438	27.5	0.738	1.189	170.768	1.569	0.844	93.903	31.37	199.1231	2.0387	197.0844	0.42
1.8036	0.5474	16.3453	10.23	1.91	0.738	1.195	171.449	1.547	0.808	91.769	30.782	188.0489	1.9475	186.1014	0.35
2.7054	3.2846	3.7974	148.7355	1.57	1.874	4.054	3.823	1.111	1.376	99.083	27.45	413.7428	5.5401	408.2027	0.61
1.8036	1.8248	4.4578	18.7355	1.49	1.764	4.294	3.818	1.095	1.286	99.391	27.821	391.5344	5.2978	386.2366	0.63
1.8036	7.8465	3.7974	8.7355	1.97	1.777	4.341	3.81	1.103	1.401	99.544	27.798	384.0405	5.1259	378.9146	0.6
3.6073	1.2773	7.7599	3.2183	1.57	1.869	2.428	158.075	1.703	1.129	101.536	24.381	209.9502	1.8827	208.0674	0.63
2.7054	1.0949	8.4203	2.8734	1.21	1.832	2.405	157.82	1.628	1.049	100.581	24.186	224.9392	2.2277	222.7115	0.46
2.7054	1.0949	50.6869	4.2528	1.38	1.836	2.411	158.103	1.637	1.139	100.779	24.06	220.7904	1.74	219.0505	0.49

Fig. 12. Field data sheet.

Study Site Name:______________________________ ID:_____ Datum:__________________

	1	**2**	**3**
pH [-log H+]			
Leitfähigkeit [µS cm^{-1}]			
Wassertemperatur [°C]			
O_2 [%]			
O_2 [mg l^{-1}]			
HCL [ml]			
NaOH [ml]			
Tiefe [m]			
Breite [m]			
Geschwindigkeit [s m^{-1}]			
Störfaktoren			
Umgebung			

Wasserproben	
Choriotopenskizze zeichnen	
pH, Leitfähigkeit, Temperatur, O_2 messen	
Titration	
Proben nehmen (MZB, Algen, Moose, Bakterien)	
Tiefen und Breiten messen	
Fisheye-Fotos	
Schlauchwaage	
Methylenblau	
Niederschlagsrate	

5.2. Appendix B

Fig. 13. *Overview* of the sampling sites.

Woe - Woellersdorf

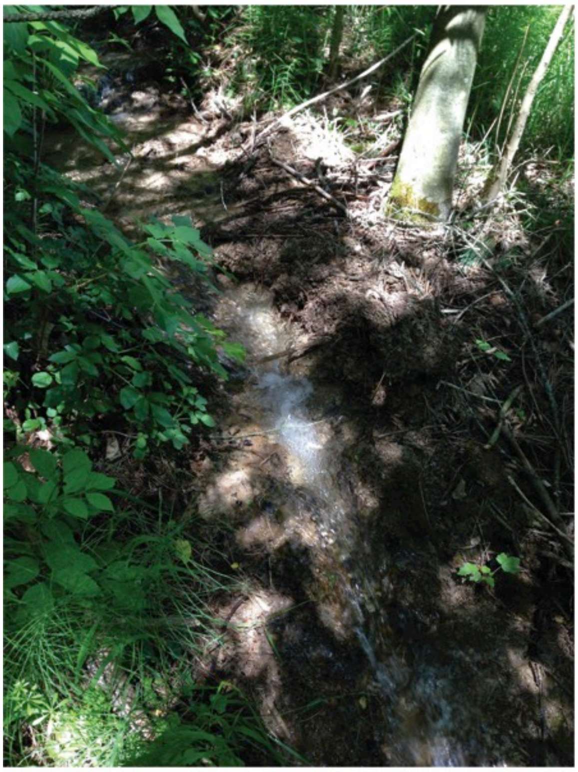
Lut - Lunz (top)

Lud - Lunz (down)

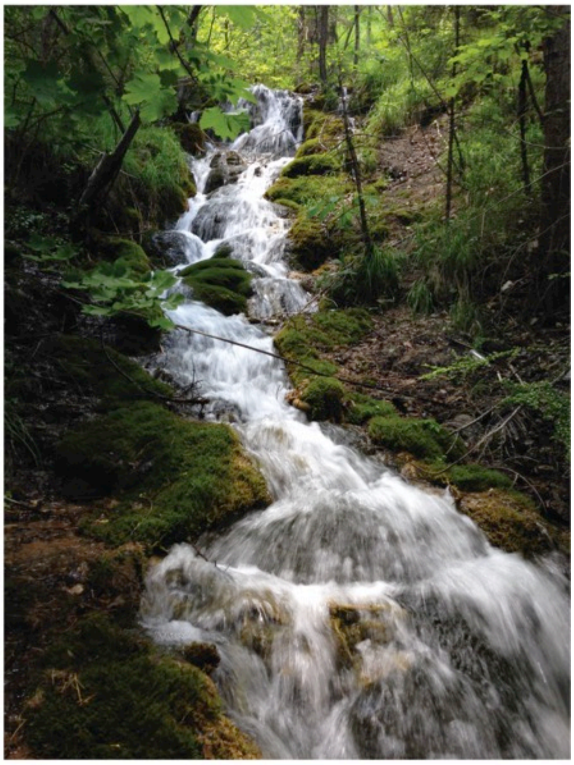
Poe - Poellerbach

Fig. 13. *Overview* of the sampling sites (Continued).

Alm - Almassysschloessl



Zoo- Zoo of Alps



Hoc - Hochtalalm

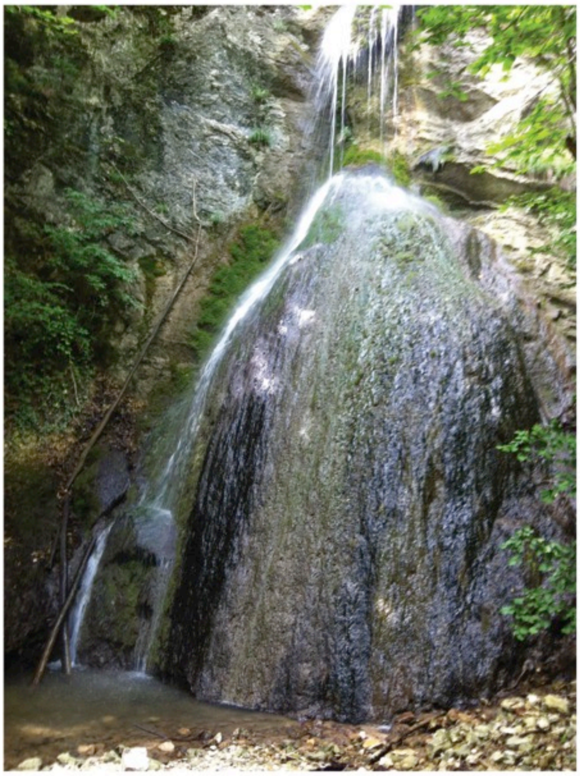
Lin - Lingenau

Fig. 13. Overview of the sampling sites (Continued).

Pre - Preinmuehle

Mar - Maria Neustift

Dan - Dandlgraben



Lap - Lappenbach

Fig. 13. *Overview* of the sampling sites (Continued).

Tes - Teschengraben

Edl - Edlbach

Fig. 14. *Overview* of key taxa

Fig. 14. *Overview* of key taxa (Continued)

Dixa sp. (Diptera)

Simulium sp. (Diptera)

Gammarus fossarum (Amphipoda)

Niphargus sp. (Amphipoda)

Fig. 14. *Overview* of key taxa (Continued)

Cordulegaster bidentata (Odonata), ventral

Cordulegaster bidentata (Odonata), dorsal

Fig. 14. *Overview* of different taxa (Continued)

Bythinella austriaca austriaca (Gastropoda)

6. REFERENCES

6.1 Literature

Arp G., Wedemeyer N., & Reitner J. 2001. Fluvial tufa formation in a hard-water creek (Deinschwanger Bach, Franconian Alb, Germany). *Facies* 44, 1-22.

Barnes I. 1965. Geochemistry of Birch Creek, Inyo County, California a travertine depositing creek in an arid climate. *Geochimica et Cosmochimica Acta* 29, 85-112.

Barquin J. & Scarsbrook M. 2008. Management and conservation strategies for coldwater springs. *Aquatic Conservation: Marine and freshwater ecosystems* 18, 580-591.

Bauernfeind E. & Humpesch U. H. 2001. Die Eintagsfliegen Zentraleuropas (Insecta: Ephemeroptera): Bestimmung und Ökologie. Naturhistorisches Museums Wien, Wien, 239 pp.

Bellmann H. 2010. Der Kosmos-Libellenführer: alle Arten Mitteleuropas. Kosmos, Stuttgart, 279 pp.

Bo T., Fenoglio S., López-Rodríguez M. J., & de Figueroa J. M. T. 2009. Phenology of adult Stoneflies (Plecoptera) of the Curone stream (northern Apennines, Italy). *Journal of Freshwater Ecology* 24, 279-283.

Boch R., Spoetl C., Reitner J. M., & Kramers J. 2006. A lateglacial travertine deposit in eastern Tyrol (Austria). *Mitteilungen der Oesterreichischen Geologischen Gesellschaft [Austrian Journal of Earth Sciences]* 98, 78-91.

Bonettini A. M. & Cantonati M. 1996. Macroinvertebrate assemblages of springs of the River Sarca catchment (Adamello-Brenta Regional Park, Trentino, Italy). *Crunoecia* 5, 71-78.

Botosaneanu L. 1998. Studies in crenobiology - the biology of springs and springbrooks. Backhuys Publishers, Leiden, 261 pp.

Cantonati M., Gerecke R., & Bertuzzi E. 2006. Springs of the Alps – Sensitive Ecosystems to Environmental Change: From Biodiversity Assessments to Long-term Studies. *Hydrobiologia* 562, 59-96.

Carter J. L., Resh V. H., Hannaford M. J., & Myers M. J. 2007. Chapter 35 - Macroinvertebrates as Biotic Indicators of Environmental Quality. *In:* Hauer F. R. & Lamberti G. A., (Eds.), Methods in Stream Ecology (Second Edition). 805-831. Academic Press, San Diego.

Coppa G., Graf W., & Tachet H. 2012. A revised description of the larvae of three species of the Rhyacophila tristis group: *Rhyacophila aquitanica*, *Rhyacophila pubescens* and *Rhyacophila tristis* (Trichoptera: Rhyacophilidae). *Annales de Limnologie-International Journal of Limnology* 48, 215-223.

Dodds W. K. 2002. Freshwater ecology - Concepts and environmental applications. Academic Press, San Diego, California., 569 pp.

Durack P. J. 2015. Ocean salinity and the global water cycle. *Oceanography* 28, 20-31.

Eggers T. O. & Martens A. 2001. Bestimmungsschlüssel der Süßwasser-Amphipoda (Crustacea) Deutschlands. *Lauterbornia* 42, 1-68.

Engelhardt C. H. M., Haase P., & Pauls S. U. 2011. From the Western Alps across Central Europe: Postglacial recolonisation of the tufa stream specialist Rhyacophila pubescens (Insecta, Trichoptera). *Frontiers in Zoology* 8, 10-10.

Ferrington L. C. J. 1995. Biodiversity of Aquatic Insects and Other Invertebrates in Springs: Introduction. *Journal of the Kansas Entomological Society* 68, 1-3.

Fischer J. 1996. Kaltstenothermie - Einziger Schlüssel zum Verständnis der Krenobionten. *Crunoecia* 5, 91-96.

Fischer J., Fischer F., Schnabel S., Wagner R., & Bohle H. W. 1998. Die Quellenfauna der Hessischen Mittelgebirgsregion. Besiedlungsstruktur, Anpassungsmechanismen und Habitatbindung der Makroinvertebraten am Beispiel von Quellen aus dem Rheinischen Schiefergebirge und der osthessischen Buntsandsteinlandschaft. *In:* Studies in Crenobiology. The biology of springs and springbrooks. 181-199. Backhuys Publishers, Leiden.

Ford T. D. & Pedley H. M. 1996. A review of tufa and travertine deposits of the world. *Earth Science Reviews* 41, 117-175.

Frazer G. W., Canham C., & Lertzman K. 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York, 36 pp.

Gerecke R., Cantonati M., Spitale D., Stur E., & Wiedenbrug S. 2011. The challenges of long-term ecological research in springs in the northern and southern Alps: indicator groups, habitat diversity, and medium-term change. *Journal of Limnology* 70, 168-187.

Gerecke R., Meisch C., Stoch F., Acri F., & Franz H. 1998. Eucrenon-Hypocrenon ecotone and spring typology in the Alps of Berchtesgaden. *In:* Studies in crenobiology. 167-182. Blackhuys Publishers, Leiden.

Glazier D. S. 1991. The fauna of North American temperate cold springs: patterns and hypotheses. *Freshwater Biology* 26, 527-542.

Glazier D. S. 2009. Springs. *In:* Likens G. E., (Ed.), Encyclopedia of inland waters. 734-755. Academic Press Elsevier, Oxford, UK.

Glöer P. 2002. Die Süßwassergastropoden Nord- und Mitteleuropas. ConchBooks, Hackenheim, Jena, 327pp.

Glöer P. & Meier-Brook C. 2003. Süßwassermollusken - ein Bestimmungsschlüssel für die Bundesrepublik Deutschland. DJN, Hamburg, 137 pp.

Graf W. & Schmidt-Kloiber A. 2002. Kursunterlagen (LV 801116) zum 'Spezialpraktikum Plecoptera - Steinfliegen, WS 2002/ 2003' [Identification keys to Plecoptera larvae]. University of Vienna, Vienna, 160 pp.

Hahn H. J. 2000. Studies on classifying of undisturbed spring in Southwestern Germany by macrobenthic communities. *Limnologica - Ecology and Management of Inland Waters* 30, 247-259.

Hauer F. R. & Resh V. H. 2007. Chapter 20 - Macroinvertebrates. *In:* Hauer F. R. & Lamberti G. A., (Eds.), Methods in Stream Ecology (Second Edition). 435-454. Academic Press, San Diego.

Hoffsten P. O. & Malmqvist B. 2000. The macroinvertebrate fauna and hydrogeology of springs in central Sweden. *Hydrobiologia* 436, 91-104.

Hütter L. A. 1994. Wasser und Wasseruntersuchung: Methodik, Theorie u. Praxis chemischer, chemisch-physikalischer, biologischer u. bakteriologischer Untersuchungsverfahren. Salle, Frankfurt/Main, 515 pp.

Hynes H. B. 1970. The ecology of running waters. Liverpool University Press, Liverpool, 555 pp.

Illies J. & Botosaneanu L. 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considérées surtout du point de vue faunistique. *SIL Mitteilung* 12, 1-57.

Janeček B. 2003. Kursunterlagen (LV 300428) zu 'Fauna Aquatica Austriaca'—Taxonomie und Ökologie aquatischer wirbelloser Organismen: Teil V Chironomidae (Zuckmücken) Larven.[Identification keys to chironomid larvae.]. University of Vienna, Vienna, 128 pp.

Karaman G. S. & Pinkster S. 1977. Freshwater *Gammarus* species from Europe, North Africa and adjacent regions of Asia (Crustacea-Amphipoda). *Bijdragen tot de Dierkunde* 47, 1–97.

Kelly D. W., Dick J. T. A., & Montgomery W. I. 2002a. The functional role of Gammarus (Crustacea, Amphipoda): Shredders, predators, or both? *Hydrobiologia* 485, 199-203.

Kelly D. W., Dick J. T. A., & Montgomery W. I. 2002b. Predation on mayfly nymph, Baetis rhodani, by native and introduced Gammarus: Direct effects and the facilitation of predation by salmonids. *Freshwater Biology* 47, 1257-1268.

Kløve B., Ala-aho P., Bertrand G., Boukalova Z., Ertürk A., Goldscheider N., Ilmonen J., Karakaya N., Kupfersberger H., Kvœrner J., Lundberg A., Mileusnić M., Moszczynska A., Muotka T., Preda E., Rossi P., Siergieiev D., Šimek J., Wachniew P., Angheluta V., & Widerlund A. 2011. Groundwater dependent ecosystems. Part I: Hydroecological status and trends. *Environmental Science & Policy* 14, 770-781.

Křoupalová V., Bojková J., Schenková J., Pařil P., & Horsák M. 2011. Small-Scale Distribution of Aquatic Macroinvertebrates in Two Spring Fens with Different Groundwater Chemistry. *International Review of Hydrobiology* 96, 235-256.

Lamberti G. A. & Gregory S. V. 2007. Chapter 13 - CPOM Transport, Retention, and Measurement. *In:* Hauer F. R. & Lamberti G. A., (Eds.), Methods in Stream Ecology (Second Edition). 273-289. Academic Press, San Diego.

Lencioni V., Marziali L., & Rossaro B. 2011. Diversity and distribution of chironomids (Diptera, Chironomidae) in pristine Alpine and pre-Alpine springs (Northern Italy). *Journal of Limnology* 70, 106-121.

Lencioni V., Marziali L., & Rossaro B. 2012. Chironomids as bioindicators of environmental quality in mountain springs. *Freshwater Science* 31, 525-541.

Lenntech 2015. Langelier Saturation Index Calculator. *Online* under http://www.lenntech.com/calculators/langelier/index/langelier.htm (access on 2nd February 2015)

Likens G. E. 2009. Encyclopedia of inland waters. Academic Press, 6492 pp.

Lutz B. D., Bernhardt E. S., Roberts B. J., Cory R. M., & Mulholland P. J. 2012. Distinguishing dynamics of dissolved organic matter components in a forested stream using kinetic enrichments. *Limnology and Oceanography* 57, 76-89.

Martin P. & Brunke M. 2012. Faunal typology of lowland springs in northern Germany. *Freshwater Science* 31, 542-562.

Martin P. & Wischniowsky L. 2014. Kalktuffquellen: Ein FFH-Lebensraum ohne Charakterarten in der Limnofauna? *Deutsche Gesellschaft für Limnologie (DGL)* Jahrestagung 2013, 72-76.

Merritt R. W. & Cummins K. W. 1996. An introduction to the aquatic insects of North America. Kendall, Hunt Pub. Co, Dubuque, Iowa, 722 pp.

Merz M. & Zankle H. 1991. The influence of the sheath on carbonate precipitation by cyanobacteria. *Bollettino della Società Paleontologica Italiana - Special Volume* 1, 325-331.

Mezquita F., Tapia G., & Roca J. 1999. Ostracoda from springs on the eastern Iberian Peninsula: ecology, biogeography and palaeolimnological implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 148, 65-85.

Minckley W. L. 1963. The ecology of a spring stream: Doe Run, Meade County, Kentucky. *Wildlife Monographs* 11, 3-124.

Moog O. (Ed.) 2002. Fauna Aquatica Austriaca - Katalog zur autökologischen Einstufung aquatischer Organismen Österreichs - Lieferung 2002. Wasser-Wirtschafts-Kataster, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirschaft, Wien.

Mulholland P. J., Houser J. N., & Maloney K. O. 2005. Stream diurnal dissolved oxygen profiles as indicators of in-stream metabolism and disturbance effects: Fort Benning as a case study. *Ecological Indicators* 5, 243-252.

Mulholland P. J., Newbold J. D., Elwood J. W., Ferren L. A., & Jackson R. W. 1985. Phosphorus Spiralling in a Woodland Stream: Seasonal Variations. *Ecology* 66, 1012-1023.

Müller J. H. 1984. Ökologie. Gustav Fischer (UTB), Jena, 395 pp.

Newbury R. W. & Bates D. J. 2007. Chapter 4 - Dynamics of Flow. *In:* Hauer F. R. & Lamberti G. A., (Eds.), Methods in Stream Ecology (Second Edition). 79-101. Academic Press, San Diego.

Nilsson A. N. 1996a. Aquatic insects of North Europe: a taxonomic handbook. Volume 1: Ephemeroptera, Plecoptera, Heteroptera, Neuroptera, Megaloptera, Coleoptera, Trichoptera, Lepidoptera. Apollo Books, 247 pp.

Nilsson A. N. 1996b. Aquatic insects of North Europe: a taxonomic handbook. Volume 2: Odonata & Diptera. Apollo Books, 440 pp.

Odum E. P. 1971. Fundamentals of ecology. Saunders, Philadelphia, 574 pp.

Odum H. T. 1956. Primary Production in Flowing Waters. *Limnology and Oceanography* 1, 102-117.

Omelková M., Syrovátka V., Křoupalová V., Rádková V., Bojková J., Horsák M., Zhai M., & Helešic J. 2013. Dipteran assemblages of spring fens closely follow the gradient of groundwater mineral richness. *Canadian Journal of Fisheries and Aquatic Sciences* 70, 689-700.

Payn R. 2005. Estimation of stream nutrient uptake from nutrient addition experiments. *Limnology and Oceanography: Methods* 3, 174-182.

Pentecost A. 1991. A new and interesting site for the calcite-encrusted desmid *Oocardium stratum* Naeg. in the British Isles. *British Phycological Journal* 26, 297-301.

Pentecost A. 2005. Travertine. Springer, Berlin, 445 pp.

Pentecost A. & Viles H. 1994. A Review and Reassessment of Travertine Classification. *Géographie physique et Quaternaire* 48, 305-314.

Pitsch T. 1993. Zur Larvaltaxonomie, Faunistik und Ökologie mitteleuropäischer Fließwasser-Köcherfliegen (Insecta, Trichoptera). Technical University, Berlin. 316 pp.

Pomeisl E. 1953. Beiträge zur Limnologie der Wienerwaldbäche. *Wetter und Leben* II, 103-121.

Reynoldson T. B. & Young J. O. 2000. A key to the British species of freshwater triclads (Turbellaria, Paludicola). Freshwater Biological Association Scientific Publications No. 58, 72 pp.

Roca J. R. & Baltanás A. 1993. Ecology and distribution of Ostracoda in Pyrenean springs. *Journal of Crustacean Biology* 13, 165-174.

Rott E., Hotzy R., Cantonati M., & Sanders D. 2012. Calcification types of *Oocardium stratum* Nägeli and microhabitat conditions in springs of the Alps. *Freshwater Science* 31, 610-624.

Sanders D. & Rott E. 2009. Contrasting styles of calcification by the micro-alga *Oocardium stratum* Naegeli 1849 (Zygnematophyceae) in two limestone-precipitating spring creeks of the Alps. *Austrian Journal of Earth Sciences* 102, 34-49.

Sanders D., Wertl W., & Rott E. 2011. Spring-associated limestones of the Eastern Alps: overview of facies, deposystems, minerals, and biota. *Facies* 57, 395-416.

Scarsbrook M. R., Barquín J., & Gray D. P. 2007. New Zealand coldwater springs and their biodiversity. Science & Technical Publishing, Department of Conservation, Wellington, New Zealand, 73 pp.

Sherwood A. R. & Sheath R. G. 1998. Seasonality of macroalgae and epilithic diatoms in spring-fed streams in Texas, USA. *Hydrobiologia* 390, 73-82.

Shiklomanov I. A. 1998. Appraisal and assessment of world water resources. *Water international* 25, 11-32.

Sode A. & Wiberg-Larsen P. 1993. Dispersal of adult Trichoptera at a Danish forest brook. *Freshwater Biology* 30, 439-446.

Stanford J. A., Ward J. V., & Ellis B. K. 1994. Ecology of the alluvial aquifers of the Flathead River, Montana. *In:* Danielopol D. L., Gibert J., & Stanford J. A., (Eds.), Groundwater ecology. 367-390. Academic Press, San Diego.

Staudacher K. & Füreder L. 2007. Habitat Complexity and Invertebrates in Selected Alpine Springs (Schütt, Carinthia, Austria). *International Review of Hydrobiology* 92, 465-479.

Stumm W. 1995. Aquatic chemistry - chemical equilibria and rates in natural waters. Wiley, New York, NY, 1022 pp.

Tchobanoglous G. & Burton F. L. 1991. Wastewater engineering. *Management* 7, 1-4.

Thienemann A. 1924. Hydrobiologische Untersuchungen an Quellen. *Archiv für Hydrobiologie* 14, 151–190.

Thienemann A. 1934. Eine gesteinsbildende chironomide [*Lithotanytarsus emarginatus* Goethgebuer]. *Zoomorphology* 28, 480-496.

Townsend C. R. 1989. The patch dynamics concept of stream community ecology. *Journal of the North American Benthological Society* 8, 36-50.

Travnitzky R. & Patzner R. A. 2009. Beitrag zur Molluskenfauna (Gastropoda und Bivalvia) des Bundeslandes Salzburg, Österreich mit besonderer Berücksichtigung der Vertigo-Arten. *Linzer biologische Beiträge* 41, 2039-2050.

Trobej M. 2015. Characterization of algae communities in spring-associated limestone habitats of Austria. University of Vienna, Vienna. 80 pp.

van der Kamp G. 1995. The Hydrogeology of Springs in Relation to the Biodiversity of Spring Fauna: A Review. *Journal of the Kansas Entomological Society* 68, 4-17.

Vannote R. L., Minshall G. W., Cummins K. W., Sedell J. R., & Cushing C. E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37, 130-137.

Verdonschot R. E. M. & Schot J. A. 1987. Macrofaunal community types in helocrenal springs. *In:* Annual Report 1986. 85-103. Research Institute for Nature Management, Arnhem, Leersum and Texel.

Waringer J. & Graf W. 2011. Atlas der mitteleuropäischen Köcherfliegenlarven [Atlas of Central European Trichoptera larvae]. Mauch, Dinkelscherben, 468 pp.

Wetzel R. G. 2001. Limnology - lake and river ecosystems. Academic Press., San Diego, 1006 pp.

Wimmer R., Chovanec A., Gruber O., Moog M. H., & Fink D. 2000. Abiotic Stream Classification as a Basis for a Surveillance Monitoring Network in Austria in Accordance with the EU Water Framework Directive. *Acta Hydrochimica et Hydrobiologica* 28, 177-184.

Wright J. S. 2000. Tufa Accumulations in Ephemeral Streams: Observations from The Kimberley, north-west Australia. *Australian Geographer* 31, 333-347.

Zollhöfer J. M. 1997. Quellen - Die unbekannten Biotope im Schweizer Jura und Mittelland: Erfassen - Bewerten - Schützen. Bristol-Stiftung, 153 pp.

Zollhöfer J. M. 1999. Spring biotopes in northern Switzerland: habitat heterogeneity, zoobenthic communities and colonization dynamics. Simon Fraser University, Burnaby, British Columbia. 142 pp.

6.2. Figures and Tables

ZUSAMMENFASSUNG

Im Rahmen der Charakterisierung der Makroinvertebraten-Gemeinschaften von Tuffquellen wurden 14 Standorte in ganz Österreich als aktiv klassifiziert und weitere detaillierte Untersuchungen durchgeführt. Ziel dieser Studie war die Erforschung der standortsspezifischen Assoziationen des Makrozoobenthos sowie die Interaktionen dieser Gemeinschaften mit den herrschenden Umweltbedingungen, besonders im Bezug auf die Calciumcarbonat-Ausfällungen. Um etwaige saisonale Effekte erkennen und berücksichtigen zu können, wurden die Proben im Frühling sowie im Herbst 2014 gesammelt. Die Auswertungen der Proben ergab, dass diese durch Tuffausfällungen gekennzeichneten Habitate annähernd homogene hydrochemische Eigenschaften aufweisen und Abweichungen zu Untersuchungen ähnlicher Standorte im internationalen Vergleich minimal sind und durch geologische sowie weitere standortspezifische Faktoren des Einzugsgebiets bedingt sind. Die vorgefundenen Gesellschaften setzten sich primär aus stygobionten Taxa des Grundwasserefugiums sowie stromaufwärts gewandterer Generalisten zusammen, welche das stabile abiotische Faktorengefüge (z.B. konstante Wassertemperatur, Pufferkapazität) bevorzugen. Auf dem Taxa-Inventar basierende Analysen eruierten sieben saisonal und geografisch gut durchmischte Gruppen. Weitere statistische Analysen identifizierten die Tuff-Bedeckung, den Sauerstoffgehalt, die Konzentration des totalen Phosphors sowie den Langelier Sättigungs-Index als maßgeblich signifikante Umweltparameter für die Zusammensetzung der gefundenen Makrozoobenthos-Gesellschaften. Die Calciumcarbonat-Ausfällungsrate deutete zwar Trends an, zeigte aber keinen eindeutigen signifikanten Einfluss auf die Artenzusammensetzungen. Endemische Arten (z.B. *Bythinella austriaca austriaca*, *B. opaca opaca*, *B. bavarica* und *Rhyacophila pubescens*) und Spezialisten separierten die Untersuchungsgebiete geografisch, der Großteil jedoch waren typische Quell- und Bacharten (z.B. aus den Gattungen *Gammarus* und *Simulium*) ohne jede bekannte Adaptierung auf

Calciumcarbonat-Ausfällungen. Nichtsdestotrotz scheint diese Ausfällung zu einer Erhöhung der Habitatstruktur beizutragen, welche zu einer Vielzahl neuer Besiedelungsnischen führt und somit die taxonomische Vielfalt erhöht.

Jean-Pierre BEDNAR, BSc

CURRICULUM VITAE

Ausbildung und Arbeitserfahrung

2013 - 2015	Masterstudium der Ökologie, Department für Limnologie und biologischer Ozeanographie, Universität Wien. Spezialisierung auf Limnologie und Meeresbiologie. Masterthesis-Titel: "*Characterization of macrozoobenthic communities at travertine-depositing springs and headwaters in Austria*".
2015	Tutor in leitender Funktion für diverse Lehrveranstaltungen im Labor und Feldforschungen.
November 2014	Forschungsreise zur Untersuchung des Jagdverhaltens von Schwertwalen (*Orcinus orca*) und Buckelwalen (*Megaptera novaeangliae*) in der subpolaren Zone nahe der norwegischen Küste.
Mai 2014	Teilnehmer und Mitglied des Organisationsteams der internationalen „*Biofilm 6*"-Konferenz in Wien.
2009 - 2013	Bachelorstudium der Biologie, Universität Wien.
Sommer 2011	Praktikum in der Seehundstation des Nationalparks Wattenmeer, Norddeich; Zum Aufgabenbereich zählten die Aufzucht, Pflege und Auswilderung der Robben und Seehunde sowie der Wild- und Greifvögel in der dazugehörigen Bildungseinrichtung „Waloseum".
2009 - 2015	Während des Studiums diverse Anstellungen als:

- Laborleiter, Biotop GmbH (Weidling bei Klosterneuburg); Hauptaufgabenbereich war die Analytik von internationalen Wasserproben sowie die Identifizierung und Klassifizierung von aquatischen Organismen.
- Angestellter, Agenda Austria Wien. Der Aufgabenbereich umfasste die wissenschaftliche Recherche sowie die Wartung der technischen Infrastruktur.

2007 - 2009	Wiener Tourismusverband, Wien; Die Anstellung umfasste die Umsetzung diverser internationaler Projekte und Publikationen. Weiters war ich als Assistent des Direktors maßgeblich für die Organisation der Direktion verantwortlich.
2004 - 2007	departure – Wirtschaft, Kunst und Kultur GmbH, Wien; Hauptaufgabenbereich war nebst des Projektmanagements die Leitung des Back-Offices sowie die Assistenz des Geschäftsführers. Der Zuständigkeitsbereich umfasste u.a. die Organisation von Pressekonferenzen, Publikationen und Veranstaltungen.

Engagement

2014	Erhalt eines Förderstipendiums der Universität Wien für die Masterarbeit aufgrund des zu erwartenden ausgezeichneten Erfolgs.
2013	Erhalt eines Leistungsstipendiums der Universität Wien aufgrund des Notendurschnitts von 1,01.
2009 -	Ehrenamtliche Schülernachhilfe in naturwissenschaftlichen Fächern.

Zusätzliche Qualifikationen

Sprach-Kenntnisse	Deutsch: Muttersprache Englisch: Gut in Wort und Schrift
EDV-Kenntnisse	MS Office, Apple Works, Graphik-Design (Adobe Photoshop & Illustrator), Statistiksoftware wie R Studio, SPSS, SigmaPlot
Mikroskopie- & Photographie	Zusätzliche Ausbildungen im Umgang der Licht- und konfokalen Mikroskopie (CLSM) sowie Erfahrungen mit Elektronenmikroskopen und DSLR
Sonstiges	Führerschein B, Tauchbrevet
Persönliche Interessen	Tauchen und Fechten

Wien, August 2015