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# Relationship between environmental variables and the distribution of macrozoobenthos in an urban brook system

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A b s t r a c t : In the study presented here Canonical Correspondence Analysis (CCA) and weighted average (WA) procedure were applied to investigate the influence of different environmental factors on the macrozoobenthos community in an urban brook system in the city of Salzburg, Austria. The studied water system included the Alte Glan in the North of the city, which has preserved its natural appearance over wide distances, and the Glan canal, an additional drain into the Salzach River during periods of high water. Results extracted from CCA clearly exhibited that in the exemplary case distribution of the macrozoobenthos is mainly affected by the anthropogenic influence on the water system, reflected by the $BOD_5$ and the nitrogen content in the water, as well as the ecomorphology of the brook, e.g. mirrored by the current velocity, and the grain size of the river-bed. Except for two species (*Haemopis sanguisuga* and *Simulium* sp.) most macrozoobenthic organisms covered by the investigation either preferred intermediate values of most factors or showed a somewhat indifferent behaviour. According to the results obtained from CCA and WA, the examined brook system was subdivided into two categories: category 1 with low influence by man but enhanced current velocity and grain size of the river-bed, as well as category 2 exhibiting contrary characteristics. Integration of macrozoobenthos within one of these categories was discussed.

K e y w o r d s : Canonical correspondence analysis, weighted average analysis, macrozoobenthos, Salzburg, physico-chemical factors.

## Introduction

Since the middle of the 19th century, increased constructional influence on the course of urban brooks and rivers as well as their enhanced pollution due to sewage have continuously reduced the macrozoobenthic species diversity living in such running waters (e.g. SCHUHMACHER & THIESMEIER 1991, MOOG 1995). Concerning the city of Salzburg, a case study exhibiting possible relationships between anthropogenic modifications of urban running waters and their content of macrozoobenthos was conducted by HASLAUER et al. (1988). By investigating the Gersbach, a small river in the Southeast of the city, the authors could find a dramatic decrease of the aquatic fauna within a short period of time due to a highly restricted ecomorphology in the urban area and especially near the mouth of the brook into the Salzach River. Special attention to the aquatic mollusc fauna in the Gersbach was paid by RATHMAYR & PATZNER (1999), who came to the result that both abundance and species diversity are subject to a considerable reduction with increased anthropogenic influence of the river's course. However, the results from studies in the city of Salzburg corresponded well with those obtained from similar investigations in other cities of Central Europe (e.g. BAADE 1993, DORNINGER et al. 1994, WITTMANN et al. 1994). The main objective of all these studies was the collection of data documenting the present environmental and faunistic conditions, which should form the basis for respective protection or restoration projects (OSBORNE et al. 1993, STATZNER & SPERLING 1993, RATHMAYR & PATZNER 1999).

In the past, investigation of aquatic community structures and their influence by any kinds of environmental factors was frequently conducted by using ordination techniques like Canonical Correspondence Analysis (CCA) proposed by TER BRAAK (1986, 1988, 1994) or the so-called Dualism Method developed by ROMANISZYN (1970). Especially the first mathematical method has found a wide application in numerous fields of ecological science (e.g. COPP 1992, PALMER 1993, PIRES et al. 1999, PENCZAK et al. 2000, ONDINA et al. 2004) due to the exhibition of complex results by simple two-dimensional graphs and the availability of several computer codes including the CCA algorithm. In some cases, normalized frequency profiles (DAGET & GODRON 1982) have been additionally used to verify and specify the results obtained from CCA (e.g. ONDINA et al. 2004). Regarding respective investigations of macrozoobenthic species communities, application of mathematical procedures has so far been limited to various regression techniques including Generalized Linear Models (e.g. UDEVITZ et al. 1987, EYRE et al. 1993, PEETERS & GARDENIERS 1998) and Generalized Additive Models (e.g. STURM 2005).

## Materials and Methods

### Study site

The Glan River with a length of about 12 km has its source in Fürstenbrunn, a small village South-west of the city of Salzburg, and crosses the city approximately in North-South direction (Fig. 1). Over wide distances the river is marked by significant antropogenic influence, i.e. the course has been straightened and the banks as well as the riverbed have been consolidated with large rocks. In the centre of the city, the Glan River branches out into a brook (Alte Glan), which has more or less preserved its natural appearance and flows into the Salzach River at the outermost North of the town, and a fully artificial canal ('Entlastungsgerinne'), serving as an additional drain into the Salzach River during a period of high water. In the study presented here, these two branches (i.e. natural vs. artificial) were subject to a detailed limnological investigation, including both the sampling of macrozoobenthos and the analysis of various water parameters. Respective sampling localities are represented in the detail map of Fig. 1. While in the Alte Glan two main positions for sampling and water analysis (i.e., one in the middle of the course and one at the mouth) were selected, in the Glan canal sampling was conducted at one area situated on half distance of the running water (Fig. 2).

### Sampling of macrozoobenthos and water analysis

In each sampling area collection of macrozoobenthos was carried at ten different, randomly distributed points, giving a total of 30 samples. Field work was conducted in June 2005. Sampling procedure was done by using a Surber sampler with a basal surface of 1125 cm². Collected animals were first separated from fine mineral particles by sieving (sieve mesh size: 0.4 mm) and afterwards sorted by species and fixed in formalin. Species abundances (individuals $m^{-2}$) necessary for further theoretical investigations were finally determined in the laboratory. Main organisms representing the macrozoobenthic corpus of the water system and therefore being used for mathematical analysis, their CCA codes as well as results of the counting procedure are summarized in Fig. 3 and Tab. 2.

Analysis of physical and chemical water parameters took place at the same points, where macrozoobenthos was collected. Respective quantities measured in the field or, after evacuation of a water sample, in the laboratory included water temperature, pH, electric conductivity, total hardness, oxygen content, oxygen saturation, biological oxygen demand after five days ($BOD_5$), nitrogen content, current velocity, depth, and width of the running water at the specific site. In addition to these parameters, at each of the three sampling areas, the sediment of the river bed was analyzed by a well-defined sieving procedure (e.g. SCHÖNBORN 1993, SCHWOERBEL 2005), finally determining the mean grain diameters by plotting substrate masses against grain size in a double-logarithmic diagram. Results of environmental parameter analysis including maximum, minimum, and mean values as well as standard deviations are listed in Tab. 1.

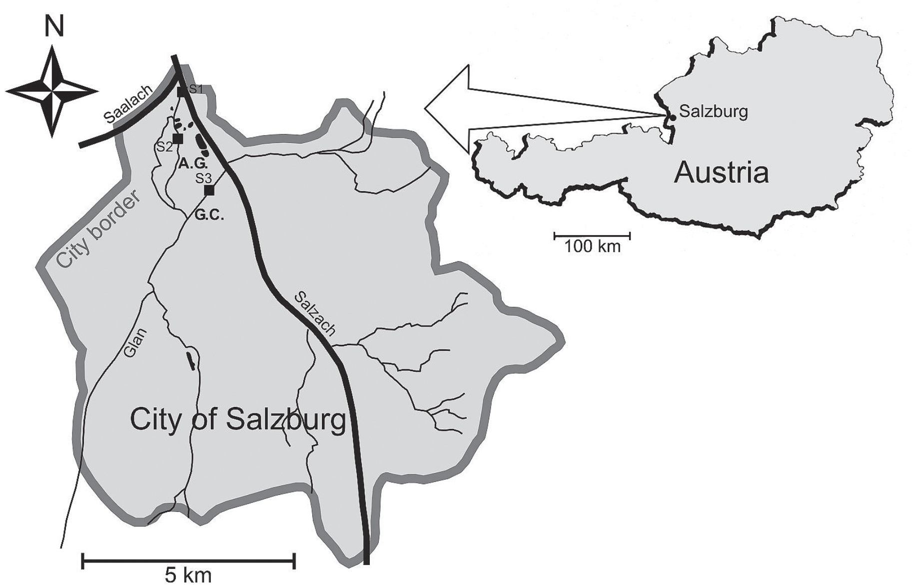


**Fig. 1**: Map illustrating the course of the Glan river through the city of Salzburg and its branching out into the Alte Glan (A. G.) and the Glan canal (G. C.). Sampling sites are indicated by S1-S3.

## Mathematical treatment of the data

Biological and environmental data were processed mathematically by using Canonical Correspondence Analysis (CCA). In general, this method represents an eigen-value technique analyzing the two data sets by writing them in separate matrices and carrying out a reciprocal averaging procedure based on linear least-squares regression (TER BRAAK 1986, 1988, 1994). By applying the respective algorithm, one assumes that a given


**Fig. 2**: Photographs of the three sampling sites. (**A**) Sampling site 1, (**B**) Sampling site 2, (**C**) Sampling site 3.

given species occurs in a specific range of habitats, thereby being most abundant around an optimum, so that community composition changes along a gradient. Results of CCA are, by convention, plotted into graphs, where species are represented as points and environmental factors are drawn as arrows starting from the origin. The length of each arrow expresses the degree of correlation between the factor exhibited by the line and the axes of the plot, i.e. longer arrows indicate highly important determinants of animal distribution and vice versa. To determine the distribution of a species with respect to a given factor, a line perpendicular to the factor arrow is drawn through the species point and the distance between point and arrow is estimated. The shorter this distance is, the higher is the influence of the factor in question. Since the coordinate origin represents the mean value of all factors, species far from this point exhibit a preference for more marginal values of given environmental variables. Goodness of fit for the CCA model used in this study was obtained by application of a Monte Carlo permutation test outlined by VERDONSHOT & TER BRAAK (1994). Values for species abundance were log-transformed

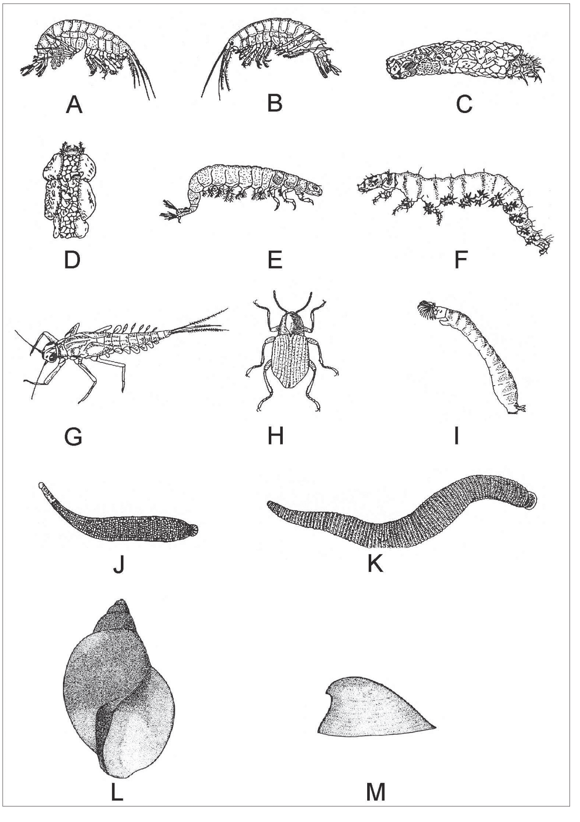


**Fig. 3**: Representative macrozoobenthic organisms, whose abundance was investigated in detail in this study (see also table 2): (**A**) *Gammarus fossarum*, (**B**) *Gammarus roeseli*, (**C**) *Allogamus auricolis*, (**D**) *Silo pallipes*, (**E**) *Hydropsyche pellucidula*, (**F**) *Rhyacophila* sp., (**G**) *Baetis rhodani*, (**H**) *Elmis maugei*, (**I**) *Simulium* sp., (**J**) *Erpobdella octoculata*, (**K**) *Haemopis sanguisuga*, (**L**) *Radix balthica*, (**M**) *Ancylus fluviatilis*.

formed, resulting in a better approximation to the normal distribution, which is an unavoidable requirement for the use of CCA.

For an additional description of the relationship between species distribution and environmental factors, the weighted average (WA) procedure introduced by TER BRAAK & LOOMAN (1986) was performed. With this mathematical technique environmental variables measured at specific sites were weighted against the abundances of single species recorded at the same positions. Hence, increased statistical weight was attributed to sampling sites with higher animal numbers and vice versa. Mean values and standard deviations obtained from WA gave an impression of a species' with respect to a selected environmental variable, i.e. small standard deviations indicated low tolerance, while high standard deviations indicated enhanced tolerance.

## Results

### Characteristics of the environmental variables

Concerning the current velocity, sample site 2 exhibiting a mean velocity of 1.54 m $s^{-1}$ differed significantly from the other two sites which were characterized by very similar velocity values (Tab. 1). Also measurement of water temperature provided some significant discrepancies among the sample sites, with site 1 showing the lowest value (7.35 °C) and site 3 the highest (10.61 °C). Water pH recorded at the sample sites ranged from 6.37 (site 3), indicating slightly acidic conditions, to 7.53 (site 2), representing a slightly alkaline medium. Regarding electric conductivity, oxygen content, and oxygen saturation, a uniform increase of measured values from sample site 1 to sample site 3 could be observed. At sites 2 and 3, water oxygen was marked by a significant supersaturating (108 and 111 %), indicating a predominance of oxygen production over oxygen consumption. Maximum values of water depth were recorded at sample site 1 (75.99 cm), whereas at the other sites respective mean values ranged from 42 to 46 cm. Brook width was subject to a variation from ca. 470 cm (site 2) to ca. 600 cm (site 3), while for nitrogen, $BOD_5$ and total hardness respective maxima could be, again, registered at sample site 3. When comparing site 3 with site 2, nitrogen differed by a factor of 4 (7.61 vs. 1.76 mg $l^{-1}$) and $BOD_5$ by a factor of 6.5 (8.22 vs. 1.22 mg $l^{-1}$).

### Abundances of the macrozoobenthos

Due to the partly significant differences of physical and chemical conditions among the sample sites, also abundances (individuals $m^{-2}$) of macrozoobenthic species recorded for this study exhibited some noticeable variations (Tab. 3). Within the Trichoptera, all species uniformly decreased in number from sample site 1 to sample site 3, whereby respective reductions of abundance ranged from 60 to 95 %. For instance, *Allogamus auricolis* occurred with a mean abundance of 26.80 individuals m-2 at site 1 and 3.60 individuals m-2 at site 3 (Tab. 3). A similar result was obtained for *Gammarus fossarum*, decreasing its population density at site 3 to about 1.5 % with respect site 1 (4.80 vs. 302.40 individuals $m^{-2}$). *Gammarus roeseli* showed a somewhat different behaviour, because here highest population density was again recorded at sample site 1, but lowest density a site 2 being characterized by highest values of current velocity. Within the

Hirudinea, *Erpobdella octoculata* exhibited a decreasing abundance from sample site 1 to sample site 3, whereas *Haemopis sanguisuga* had its highest abundance at sample site 3, differing from the other sites by a factor between 15 and 20. For *Baetis rhodani*, a similar tendency of abundance as for the Trichoptera could be registered (Tab. 3), while *Elmis maugei* occurred with highest abundance at sample site 1 and with nearly identical abundances at sample sites 2 and 3. The abundance of *Simulium* sp. can be compared with

**Tab. 1**: Mean values (M) and standard deviations (SD) of the environmental factors determined in the sampling areas (total number of samples: 30; grain size, total sample number: 3).

| | **Sample site 1** | | **Sample site 2** | | **Sample site 3** | | | |
|---|---|---|---|---|---|---|---|---|
| **Abiotic Factor, CCA code** | M | SD | M | SD | M | SD | TOT. M | TOT. SD |
| Current velocity (m $s^{-1}$), CV | 1.05 | 0.06 | 1.54 | 0.10 | 0.90 | 0.15 | 1.14 | 0.26 |
| Temperature (°C), T | 7.35 | 0.30 | 9.23 | 0.42 | 10.61 | 0.43 | 8.64 | 1.44 |
| Water pH, PH | 7.05 | 0.23 | 7.53 | 0.20 | 6.37 | 0.19 | 7.00 | 0.47 |
| El. Conduct. (µS $cm^{-1}$), EC | 279.50 | 18.79 | 313.60 | 8.80 | 337.40 | 15.48 | 302.50 | 29.33 |
| Oxygen content (mg $l^{-1}$), O2 | 11.06 | 0.31 | 12.09 | 0.46 | 12.61 | 0.45 | 11.70 | 0.78 |
| $O_2$-saturation (%), O2S | 94.80 | 3.37 | 108.30 | 3.95 | 111.00 | 5.75 | 102.23 | 8.62 |
| Water depth (cm), D | 75.99 | 8.73 | 46.35 | 4.90 | 42.13 | 2.57 | 60.11 | 17.46 |
| Bottom substr. MGS (mm),BS | 1.33 | 0.25 | 73.60 | 7.43 | 5.50 | 0.53 | 20.44 | 31.33 |
| Width of brook (cm), W | 583.30 | 34.55 | 477.00 | 26.95 | 599.10 | 18.60 | 560.68 | 57.14 |
| Nitrogen content (mg $l^{-1}$), N | 2.95 | 0.55 | 1.76 | 0.38 | 7.61 | 1.20 | 3.82 | 2.38 |
| $BOD_5$ (mg $l^{-1}$), BOD | 1.92 | 0.44 | 1.22 | 0.33 | 8.22 | 1.01 | 3.32 | 2.94 |
| Total hardness (mg $l^{-1}$), TH | 8.70 | 0.55 | 11.80 | 1.11 | 13.45 | 0.50 | 10.66 | 2.19 |

that of *Haemopis sanguisuga*, thereby showing a very significant maximum at sample site 3. Regarding the molluscs recorded for this study, *Ancylus fluviatilis* occurred with highest abundance at sample site 2 and lowest abundance at site 3. *Radix balthica*, on the other hand, continuously decreased its abundance from site 1 to site 3.

## Multivariate analysis

CCA was performed on both the malacological and physico-chemical data set to elucidate possible relationships between the spatial distribution of macrozoobenthos species and environmental conditions and to try a classification of the sample sites according to the 12 environmental factors recorded for this study (Fig. 4). The first two axes counted for 36.4 % of the variance, with axis 1 (24.2 % of the variance) setting nitrate content, $BOD_5$, total hardness, and water temperature against pH. Axis 2 (12.4 % of the variance) was mainly determined by the bottom substrate and the width of the brooks at the sample sites, whereby these two factors were negatively correlated. Possible multi-collinearity between the variables could be evaluated as insignificant, because respective variance inflation factors ranged from 1.65 (current velocity) to 4.13 ($BOD_5$).

The projection of macrozoobenthos species together with the environmental variables (Fig. 4 A) indicated a main accumulation of species in the second and third quadrant of the graph. *Hydropsyche pellucidula*, *Allogamus auricollis*, *Gammarus fossarum*, *Baetis rhodani*, and *Erpobdella octoculata* plotted adjacent to the negative part of axis 1, thereby exhibiting an enhanced affinity for intermediate to slightly increased pH values as well as lower values of total hardness, $BOD_5$, temperature, and nitrate content in the water. On the other side, *Radix balthica*, *Elmis maugei*, *Gammarus roeseli*, and *Silo pallipes* partly plotted adjacent to the negative section of axis 2 and thus showed a preference for intermediate to higher water depth, but smaller grain size of the bottom substrate. Also lower values of $BOD_5$, nitrate content in water, total hardness, and temperature are preferred by these species.

**Tab. 2**: Main macrozoobenthic species collected in the sampling areas, which are illustrated in figure 1. The listed species have been used for CCA. For completeness of information, also the CCA codes of the species as well as their total number obtained from 30 samples are provided.

| **Order** | **Species** | **CCA code** | **Total number** |
|---|---|---|---|
| Amphipoda | *Gammarus fossarum* (Koch, 1835) | *Gf* | 960 |
| | *Gammarus roeseli* (Gervais, 1835) | *Gr* | 43 |
| Trichoptera | *Allogamus auricolis* (Pictet, 1834) | *Aa* | 77 |
| | *Silo pallipes* (Fabricius, 1781) | *Si* | 68 |
| | *Hydropsyche pellucidula* (Curtis, 1834) | *Hp* | 26 |
| | *Rhyacophila* sp. (Pictet, 1834) | *Rh* | 44 |
| Ephemeroptera | *Baetis rhodani* (Pictet, 1843) | *Br* | 48 |
| Coleoptera | *Elmis* maugei (Latreille, 1798) | *El* | 89 |
| Diptera | *Simulium* sp. (Latreille, 1798) | *Sim* | 29 |
| Hirudinea | *Erpobdella octoculata* (Linnaeus, 1758) | *Eo* | 20 |
| | *Haemopis sanguisuga* (Linnaeus, 1758) | *Ha* | 28 |
| Basommatophora | *Radix balthica* (Linnaeus, 1758) | *Rb* | 24 |
| | *Ancylus fluviatilis* (Linnaeus, 1758) | *Af* | 65 |
| | | **Total** | 1521 |

*Ancylus fluviatilis* was positioned near the vector for current velocity, expressing its affinity for higher values of this variable. Due to the position of the vectors in the diagram, the freshwater snail also prefers enhanced values of the substrate grain size (Fig. 4 A). *Haemopis sanguisuga* and *Simulium* sp. remarkably differed from the other species due to their plot at high positive values of axis 1. Based on this deviating position in the graph both species indicate among other an affinity for high values of nitrate in the water and $BOD_5$.

Regarding a possible relationship between sampling sites and environmental variables, respective sampling points belonging to site 1 uniformly plotted in the third quadrant of the graph (Fig. 4 B), expressing an enhanced correlation with water depth. Sampling points of site 2 exclusively plotted in the second quadrant, thereby chiefly correlating with the grain size of the bottom substrate and the current velocity of the running water. Sampling points of site 3 were accumulated at higher positive values of axis 1, exhibiting a correlation with $BOD_5$, nitrate content of the water, total hardness, and water temperature. Summing up the results of figure 3 B, at least two classes of running waters can be distinguished in the present study: 1) waters with higher current velocities, partly enhanced grain size of the bottom substrate and low anthropogenic influence and 2) waters with decreased current velocities, lower substrate grain sizes, and higher influences by man expressed by respective values for $BOD_5$ and nitrate content in the water.

**Tab. 3**: Mean values (M) and standard deviations (SD) of the abundances (individuals m-2) of macrozoobenthos species at the sampling sites.

| | **Sample site 1** | | **Sample site 2** | | **Sample site 3** | | | |
|---|---|---|---|---|---|---|---|---|
| **Species** | M | SD | M | SD | M | SD | TOT. M | TOT. SD |
| *Allogamus auricolis* | 26.80 | 15.74 | 10.40 | 5.72 | 3.60 | 4.40 | 16.90 | 15.47 |
| *Silo palipes* | 23.80 | 10.18 | 2.80 | 4.24 | 3.40 | 3.50 | 13.50 | 12.90 |
| *Hydropsyche pellucidula* | 9.20 | 5.52 | 4.80 | 4.13 | 0.60 | 1.68 | 6.00 | 5.66 |
| *Rhyacophila* sp. | 15.20 | 6.69 | 4.60 | 6.20 | 2.80 | 4.24 | 9.50 | 8.29 |
| *Gammarus fossarum* | 302.40 | 230.54 | 48.40 | 20.17 | 4.80 | 4.54 | 164.50 | 213.90 |
| *Gammarus roeseli* | 29.40 | 18.41 | 1.60 | 2.80 | 2.00 | 2.83 | 15.60 | 19.08 |
| *Erpobdella octoculata* | 8.60 | 5.39 | 2.40 | 2.80 | 0.80 | 1.82 | 5.10 | 5.43 |
| *Haemopis sanguisuga* | 3.00 | 4.28 | 1.20 | 1.93 | 41.20 | 22.87 | 12.10 | 20.51 |
| *Baetis rhodani* | 22.40 | 15.92 | 5.60 | 5.40 | 2.00 | 2.86 | 13.10 | 14.91 |
| *Elmis maugei* | 33.20 | 14.40 | 4.00 | 4.22 | 5.60 | 4.70 | 19.00 | 17.81 |
| *Simulium* sp. | 2.80 | 4.24 | 1.20 | 2.70 | 60.80 | 38.54 | 17.00 | 31.78 |
| *Ancylus fluavitilis* | 17.20 | 10.79 | 39.20 | 20.29 | 2.40 | 2.58 | 18.90 | 18.27 |
| *Radix balthica* | 11.00 | 7.33 | 2.00 | 2.83 | 0.72 | 1.46 | 6.20 | 7.24 |

## Weighted averaging analysis

As summarized in table 4, results of the WA procedure correspond very well with the data obtained from CCA and plotted in figure 4A. Concerning current velocity, weighted averages range from 0.89 m $s^{-1}$ (*Haemopis sanguisuga*) to 1.31 m $s^{-1}$ (*Ancylus fluviatilis*), whereas for water temperature highest values were obtained for *Haemopis sanguisuga* and *Simulium* sp. and lowest values for the two amphipode species. Regarding water pH, electric conductivity, oxygen content of the water, oxygen saturation, and water depth *Haemopis sanguisuga* and *Simulium* sp. partly significantly differed from the remaining species, preferring lower values of pH and depth, but higher values of the other environmental variables (Tab. 4). Higher preferences for enhanced values of the substrate grain size could be obtained for *Ancylus fluviatilis* with a respective weighted average of 38.45 mm, while weighted averages for the other species varied from 3.49 to 16.06 mm. Weighted averages for the brook width did not remarkably differ among the investigated species and ranged from 534 to 601 cm. Concerning nitrate content of the water, $BOD_5$, and total hardness, highest averages were again available for *Haemopis sanguisuga* and *Simulium* sp., being between 30 and 250 % higher than the respective averages of the other species (Tab. 4).

## Discussion

Studies on the macrozoobenthos in urban brook and river systems, especially those, which have been subject to remarkable anthropogenic modifications, are highly important for documenting possible adaptations of organisms to the modified environmental conditions and, more interesting for eventual projects of re-naturalization, the development of species diversities and specific abundances (e.g. HASLAUER et al. 1988, SCHUH-

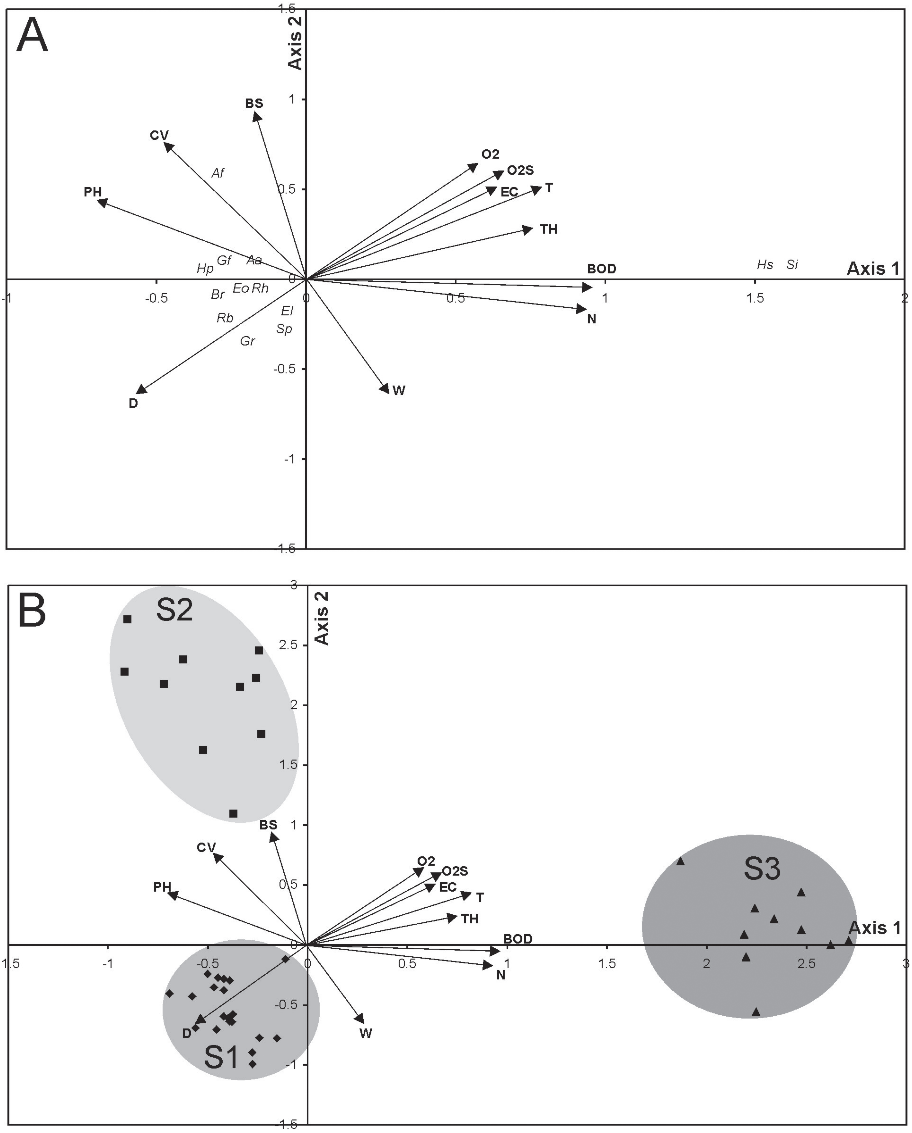


**Fig. 3**: (**A**) Diagram with the first two axes extracted from CCA and the positions of species and environmental factors with respect to these axes. Macrozoobenthos is depicted by the abbreviations of the scientific names (see Tab. 2). Environmental factors on the other hand are represented by arrows starting from the origin of the diagram and pointing towards the direction of maximum variation. The effect of single parameters on the community structure is indicated by the lengths of the respective arrows. (**B**) Site-specific CCA plot exhibiting the position of single sample points with respect to the first two axes. Sample sites are marked by specific grey tones.

MACHER & THIESMEIER 1991, DORNINGER et al. 1994, RATHMAYR & PATZNER 1999). The work presented here should be understood as a further exemplary case decoding the relationship between anthropogenic influence on natural habitats and compositions of species communities living therein. However, to fulfil this ambitious aim, the well documented Glan River system (SINNHUBER 1949) in the North of the city of Salzburg was investigated ecologically by recording the macrozoobenthic communities at different sampling areas, analyzing the water for various physical and chemical parameters, and determining ecomorphological factors such as depth and width of the river as well as properties of the bottom substrate. The question stated above was followed by choosing the sample points in parts of the river system being characterized by different degrees of anthropogenic influence: a) the Alte Glan with its more or less natural appearance and b) the Glan canal representing an additional drain during periods of high water.

**Tab. 4**: Results of the weighted averaging (WA) procedure. Weighted averages and related standard deviations provide specific information on the preferential range of a species concerning an environmental variable. High standard deviations indicate an enhanced tolerance regarding the variable and vice versa.

| | CV | | T | | PH | | EC | | O2 | | O2S | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | WA | SD | WA | SD | WA | SD | WA | SD | WA | SD | WA | SD |
| *Allogamus auricolis* | 1.12 | 0.26 | 7.8 | 1.29 | 7.1 | 0.42 | 292 | 28.42 | 11.34 | 0.74 | 97.65 | 8.35 |
| *Silo palipes* | 1.07 | 0.22 | 7.65 | 1.39 | 6.99 | 0.39 | 285.2 | 31.32 | 11.2 | 0.74 | 96.23 | 8 |
| *H. pellucidula* | 1.14 | 0.24 | 7.83 | 1.17 | 7.09 | 0.38 | 289.0 | 25.9 | 11.28 | 0.63 | 98.03 | 7.57 |
| *Rhyacophila* sp. | 1.12 | 0.24 | 7.88 | 1.28 | 7.04 | 0.41 | 286.0 | 27.2 | 11.3 | 0.68 | 97.72 | 7.67 |
| *Gammarus fossarum* | 1.08 | 0.26 | 7.51 | 1.36 | 7.13 | 0.44 | 288.8 | 27.46 | 11.16 | 0.78 | 95.39 | 8.68 |
| *Gammarus roeseli* | 1.06 | 0.19 | 7.51 | 1.29 | 7.03 | 0.38 | 284.7 | 26.58 | 11.12 | 0.68 | 95.32 | 7.52 |
| *Erpobdella octoculata* | 1.11 | 0.25 | 7.68 | 1.23 | 7.1 | 0.35 | 285.1 | 25.21 | 11.26 | 0.69 | 97.14 | 7.94 |
| *Haemopis sanguisuga* | 0.89 | 0.25 | 10.3 | 1.59 | 6.49 | 0.53 | 331.7 | 32.66 | 12.42 | 0.76 | 108.6 | 8.28 |
| *Baetis rhodani* | 1.12 | 0.23 | 7.72 | 1.28 | 7.07 | 0.43 | 284.2 | 26.28 | 11.32 | 0.74 | 97.67 | 8.46 |
| *Elmis maugei* | 1.08 | 0.22 | 7.65 | 1.34 | 7.03 | 0.42 | 286.5 | 27.72 | 11.2 | 0.71 | 96.43 | 7.88 |
| *Simulium* sp. | 0.89 | 0.26 | 10.37 | 1.56 | 6.46 | 0.49 | 332.2 | 32.05 | 12.38 | 0.78 | 107.4 | 8.62 |
| *Ancylus fluavitilis* | 1.31 | 0.26 | 8.43 | 1.29 | 7.29 | 0.42 | 299.7 | 26.21 | 11.61 | 0.74 | 101.8 | 8.37 |
| *Radix balthica* | 1.09 | 0.22 | 7.61 | 1.14 | 7.07 | 0.35 | 280.5 | 26.29 | 11.19 | 0.65 | 96.73 | 7.09 |

| | D | | BS | | W | | N | | BOD | | TH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | WA | SD | WA | SD | WA | SD | WA | SD | WA | SD | WA | SD |
| *Allogamus auricolis* | 70.8 | 17.09 | 12.43 | 32.99 | 572 | 58.98 | 3.11 | 2.01 | 2.22 | 2.41 | 9.47 | 2.06 |
| *Silo palipes* | 72.76 | 16.68 | 5.4 | 25.03 | 580.3 | 50.97 | 3.26 | 2.28 | 2.27 | 2.52 | 9.12 | 2.10 |
| *H. pellucidula* | 69.73 | 16.91 | 16.06 | 33.23 | 560.7 | 60.5 | 2.86 | 1.73 | 1.91 | 1.75 | 9.50 | 1.97 |
| *Rhyacophila* sp. | 70.18 | 16.65 | 10.59 | 28.14 | 569.5 | 53.76 | 3.13 | 1.79 | 2.27 | 2.49 | 9.39 | 1.87 |
| *Gammarus fossarum* | 77.06 | 17.19 | 6.87 | 32.31 | 581.3 | 57.67 | 2.94 | 2.07 | 1.99 | 2.69 | 9.01 | 2.09 |
| *Gammarus roeseli* | 75.38 | 16.37 | 3.49 | 25.66 | 582.7 | 53.86 | 3.01 | 1.87 | 2.08 | 2.31 | 9.07 | 2.11 |
| *Erpobdella octoculata* | 72.07 | 16.26 | 10.18 | 30.39 | 577.7 | 60.09 | 2.94 | 1.78 | 2.06 | 1.68 | 9.24 | 1.77 |
| *Haemopis sanguisuga* | 46.83 | 18.42 | 6.75 | 24.98 | 595.5 | 49.96 | 7.13 | 2.69 | 7.03 | 3.37 | 12.89 | 2.15 |
| *Baetis rhodani* | 71.6 | 17.18 | 8.96 | 30.22 | 568.1 | 52.9 | 2.9 | 1.79 | 2.05 | 2.42 | 9.35 | 1.99 |
| *Elmis maugei* | 70.92 | 17.81 | 5.49 | 28.13 | 582 | 54.95 | 3.15 | 2.06 | 2.36 | 2.83 | 9.23 | 2.16 |
| *Simulium* sp. | 44.85 | 18.41 | 6.27 | 18.08 | 601 | 42.06 | 7.22 | 2.64 | 7.4 | 3.36 | 13.01 | 2.23 |
| *Ancylus fluavitilis* | 60.26 | 16.99 | 38.45 | 33.35 | 534.3 | 58.28 | 2.45 | 1.85 | 1.73 | 2.25 | 10.44 | 1.98 |
| *Radix balthica* | 71.33 | 15.58 | 7.78 | 30.26 | 570.3 | 59.19 | 3.05 | 1.81 | 2.03 | 2.03 | 9.18 | 1.99 |

Data of species abundances and environmental factors were processed by the application of Canonical Correspondence Analysis (CCA; TER BRAAK 1986, 1988, 1994), representing a user-friendly ordination technique, with the help of which the effect of numerous extern factors on a pre-defined community of species can be modelled simultanuously. Previous ecological studies have exhibited that CCA is an appropriate mathematical method for the definition and creation of ecological models (e.g. PENCZAK et al. 2000, ONDINA et al 2004). As another major advantage with respect to multivariate regression models (Generalized Linear Models or Generalized Additive Models) results obtained from CCA may be immediately presented in graphical form, where species and environmental factors are plotted with respect to two axis extracted by the ordination technique. This, contrary to the numerical output of multivariate regression, allows an efficient interpretation of the calculation results. The WA procedure used in the present study has to be understood as a mathematical technique giving numerical results for a more precise classification of the relationship between animal abundance and environmental variables.

As exhibited by the results obtained from both CCA and WA, all of the 13 macrozoobenthic species recorded for this study had a preference for at least one environmental variable and, as a further consequence, a preference for one of the three sampling sites. Concerning sampling site 1, representing a natural habitat with low current velocity, fine- to medium-grained bottom sediment, and less anthropogenic influence, 10 species occurred with highest abundances, whereby most significant specialization with respect to this site was given for *Allogamus auricolis*, *Silo palipes*, *Hydropsyche pellucidula*, *Rhyacophila* sp., *Gammarus fossarum*, *Gammarus roeseli*, *Baetis rhodani*, *Elmis maugei*, and *Radix balthica* (Tab. 3). Except for *Radix balthica*, all of these species have to be understood as indicator organisms for clear and unpolluted water, with the amphipods not exhibiting an appropriate adaptation to higher current velocities (e.g. SCHÖNBORN 1993). A clear preference for sampling site 2, differing from site 1 by a higher current velocity and a coarser bottom substrate, is only given by *Ancylus fluviatilis*, which due to its hydrodynamic shell form is a typical exponent of fast running waters (GLÖER & MEIER-BROOK 2003). Two species, namely *Haemopis sanguisuga* and *Simulium* sp. exhibited a strong preference for sampling site 3. These two organisms represent well-known indicators for running waters standing under an enhanced anthropogenic influence. Above all the latter species has the ability to obtain the predominance in waters with slight to intermediate pollution and then partly may occur in masses (SCHÖNBORN 1993).

With the exemplary study presented here it could be demonstrated that the colonization of urban brooks by macrozoobenthic organisms strongly depends upon physical and chemical factors reflecting the anthropogenic influence on the water system. Low influence by man, which is chiefly mirrored by low values for nitrogen content in water and $BOD_5$, results in a highly increased species diversity and abundance of single organisms. High influence by man, on the other side, successively decreases the macrozoobenthic fauna and thereby favours the partly excessive propagation of organisms being adapted to the modified environmental conditions. As could be additionally shown by this case study, macrozoobenthic colonization of a brook not only exhibits dependence upon water quality, but also upon the morphology of the river-bed and its content of submerged vegetation. Running waters with highly artificial ecomorphology do not offer those micro-habitats necessary for the occurrence of most benthic animals. Hence, in future a further careful restoration of running waters highly affected by man should be a main topic of environmental politics.

## Zusammenfassung

Zusammenhang zwischen Umweltvariablen und der Verbreitung des Makrozoobenthos in einem städtischen Fließgewässersystem − In der vorliegenden Studie wurde mit Hilfe der kanonischen Korrespondenzanalyse und des gewichteten Mittelwerts der Einfluss verschiedener Umweltfaktoren auf die Makrozoobenthosgemeinschaft in einem Fließgewässersystem der Stadt Salzburg (Österreich) untersucht. Das studierte Bachsystem umfasste neben der Alten Glan im Norden der Stadt, welche über weite Strecken ihr natürliches Erscheinungsbild bewahrt hat, den Glankanal, ein Entlastungsgerinne zur Eindämmung von Hochwässern. Ergebnisse aus der Korrespondenzanalyse zeigen deutlich, dass die Verbreitung makrozoobenthischer Organismen im vorliegenden Fall hauptsächlich durch den anthropogenen Einfluss auf das Gewässersystem, welcher sich durch den $BOD_5$ und die aquatische Stickstoffkonzentration widerspiegelt, kontrolliert wird. Weitere wichtige Faktoren sind die Ökomorphologie des Bachsystems, ausgedrückt etwa durch die Fließgeschwindigkeit, und die Korngröße des Bachsediments. Mit Ausnahme zweier Spezies (*Haemopis sanguisuga* und *Simulium* sp.) bevorzugten die meisten hier vorgestellten makrozoobenthischen Organismen entweder intermediäre Werte der Faktoren oder sie zeigten ein quasi indifferentes Verhalten. Gemäß den durch die beiden mathematischen Methoden erhaltenen Resultaten konnte das Bachsystem in zwei Gewässerkategorien unterteilt werden: Kategorie 1 umfasst Gewässerabschnitte mit geringem anthropogenen Einfluss, erhöhter Fließgeschwindigkeit und signifikanter Korngröße des Sediments. Kategorie 2 hingegen zeigt die genau entgegengesetzten Verhältnisse. Die Integration des Makrozoobenthos innerhalb einer der beiden Kategorien stand zur Diskussion.

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