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RELATING FISH ASSEMBLAGE VARIABILITY TO ENVIRONMENTAL GRADIENTS IN SMALL AND MID-SIZED STREAMS OF THE ELBE BASIN (CZECH REPUBLIC)

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Abstract: Fish assemblages and environmental variables were studied in 567 sites in small and mid-sized streams of the Elbe basin. A presence-absence data of 28 fish species were analyzed to characterize ichthyocenoses in diverse environments. Several multivariate techniques were used: 1. Detrended correspondence analysis (DCA) for examination of species occurrence changes in the longitudinal profiles in relation to "fish zones"; 2. Partial Canonical correspondence analyses (CCA), and Cluster analysis for the assessment of the fish assemblages' regional and temporal variability; 3. Direct gradient CCA for investigation of the influence of environmental variables on fish assemblages, and partial CCA's for interpretation of the most important fish species-enviroment relations.

The biggest proportion of variability in species composition (13%) was explained by the regional variability (CCA). Major environmental factors determining species distributions (the number of ponds in the catchment, effect of higher order stream, the distance from the source, stream slope, elevation, and stream order) were used for characterization of the environmental influence. All these six variables together explained another 9% of the total variability. The strongest gradients of change in fish assemblages revealed to inversely related distance from the source and stream slope. The second gradient was based on the number of ponds and/or on the effect of higher order stream. The patterns of fish assemblage composition and the associated fish species-environment relations provided a framework for developing an ecologically meaningful classification of small and mid-sized stream sites in the Elbe basin.

Key words: fish assemblages variability; environmental factors; small and mid-sized streams; detrended correspondence analysis; canonical correspondence analysis

Introduction

Multivariate statistical methods are often used for the evaluation of species frequencies and composition of fish assemblages in longitudinal profiles of streams, and for the evaluation of environmental factors and human impact on ecosystems. Fish are a suitable group for this purpose (Angermeier and Winston 1999, Cao et al. 2002)

Considerable variation in fish assemblage composition is related to variability in landscape features (Angermeier and Winston 1999), distinct communities may occur along gradients of stream size or elevation (Lyons 1996). Temporal variability plays an important role as well (Danehy et al. 1998).

Fish species composition and frequencies of occurrence in the Czech Republic is impacted by fish stocking and catching fish like brown trout, grayling, carp, and pike - to mention the most important. In the last thirty years information on a thousand of fish assemblages were gathered in all types of streams in the Czech Republic. A part of these data including the Elbe basin was used in this study (the whole basin covers 51 394 km2, which represents 65.2% of Czech Republic surface).

The aim of this study was: (1) To evaluate species occurrence changes in the longitudinal profiles of small and mid-sized streams in relation to the already known "fish zones". (2) To asses fish assemblages variability in 14 diverse geographical regions (represented by one to several catchments) and to asses fish assemblages variability in the period of

1989-2003. (3) To investigate the influence of important environmental variables on changes in fish assemblages using gradient analysis, and to stress the most important species-environment relations.

Methods

Variability of fish assemblages in streams up to 50 km from the source was analyzed in 567 sites in the Elbe Basin. Some of them were fished repeatedly in the period 1989-2003.

Fish Sampling – Fish were collected by electrofishing, lengths of the reaches where the fish were caught was 100 meters minimum. Only experienced ichthyologists collected the data. All streams were sampled in order to catch all the species of the relevant reaches and to cover all types of habitats. Presence-absence of 28 fish species with the frequency of occurrence > 0.5% (see Appendix for species names and abbreviations used) collected at 567 sites in the Elbe basin was evaluated. Analyses based on the relative abundance data were performed then on a smaller data set of 420 sites and it revealed some new information compared with the presence-absence analysis results. Only the presence-absence analysis results are presented here.

Studied sites belong to various 14 regions represented by one to several catchments with similar stream characteristics (Fig. 1).

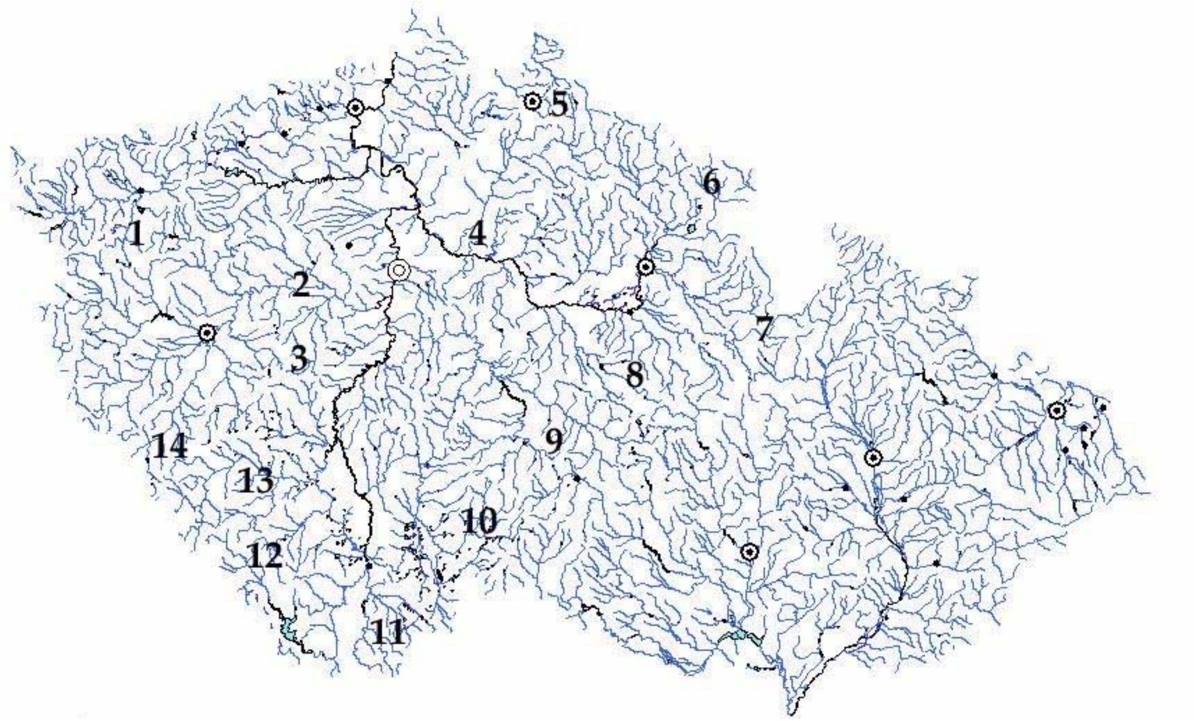

Figure 1: Map showing positions of 14 regions of 567 sample sites studied. Region names and abbreviations used (in parenthesis): 1. Slavkovský les (SLAV), 2. Křivoklátsko (KRIV), 3. Brdy (BRDY), 4. Polabí (POLA), 5. Jizerské hory (JIZH), 6. Broumovsko (BROU), 7. Orlické hory (ORLH), 8. Železné hory (ZELH), 9. Vysočina (VYSO), 10. Třeboňsko (TREB), 11. Novohradské hory (NOVH), 12. Central Šumava (C_SUM), 13. Podšumaví (PODS), 14. West Šumava (W_SUM)

Environmental variables – Nine relevant environmental variables were measured from the Basic hydrological map of Czech Republic 1:50 000 namely: 1. Distance from the source (km), 2. Catchment area (km2), 3. EHOS - effect of higher order stream or water reservoir that: a) represents a source escalating total number of species in observed stream, b) is not situated farther than 10 km from the site studied (categorical variable – present / absent), 4. Elevation (meters above sea level), 5. Stream slope (m/km), 6. Stream order (1-6), 7. Number of ponds up to 5 km upstream from the site studied in the given catchment, 8. Number of settlements in the catchment area, 9. Channel type (categorical variable – natural / regulated).

Statistical analyses – Multivariate statistical analyses used to describe fish assemblage patterns were performed by program CANOCO ver. 4.5 (ter Braak and Šmilauer 2002), correlation and cluster analyses were computed using STATISTICA ver. 5.5 (StatSoft 2000). Summary of all statistical techniques in the order of their application is in Table 1.

All nine environmental variables were first investigated by Principal components analysis (PCA) simultaneously with Spearman's rank correlations matrix. The purpose was to decrease the number of redundant variables.

Detrended correspondence analysis (DCA) was implemented in order to study variability in species composition and their organization in longitudinal profiles of streams. DCA is an unconstrained, unimodal ordination method of indirect gradient analysis. Ordination axes are based on the species composition only. First axis then represents the direction of the highest variability in the species composition (Lepš and Šmilauer, 2003).

Species composition and frequencies of occurrences were related to environmental variables using Canonical correspondence analysis (CCA). The first and the second step was the testing of the influence of regional and temporal variability by partial analyses. The regional variability was also evaluated by Cluster analysis. In the third step final CCA ordination model covered species composition non-influenced by regional and temporal variability. Significance of environmental variables was determined by a stepwise method of variable selection. The pure effect of the significant environmental variables was analyzed using another partial CCA analyses (one separate analysis for each variable); only one environmental variable entered in each of these analyses, other variables together with regions and years joined the analyses as covariables.

Table 1: Summary of statistical techniques used.

Goal	Technique	SPE	ENV	COV	Presentation
Correlations among environmental variables	PCA Spearman's rank correlation	9	0	0	Text
Species distribution in longitudinal profile	DCA	28	0	0	Fig. 2
Partialling out regional variability	partial CCA	28	14	0	Fig. 3
Partialling out temporal variability	partial CCA	28	14	14	Text
Stepwise variable selection	CCA	28	7	14+14	Text
Final relation of fish assemblages and environmental variables	CCA	28	6	14+14	Fig. 4
Pure effect of the best six environmental variables	partial CCA's	28	1	5+14+14	Tab. 2 Fig. 5

Note: SPE – Entities entering multivariate analyses as species, ENV – entities entering multivariate analyses as environmental variables, COV – entities entering multivariate analyses as covariables.

CCA is a constrained ordination method of direct gradient analysis. Ordination axes are here linear combinations of descriptor environmental variables. Environmental variables are represented in the ordination diagram by arrows. Arrow direction and length indicate the relative magnitude and influence of a particular variable on fish assemblages. Symbols of species in diagrams of unimodal ordination techniques represent ecological optima for each species in his environment. A Monte Carlo permutation procedure with 999 permutations was employed for computation of significance of ordination axes and discrete environmental variables. A stepwise method of variable selection was employed using the Monte Carlo forward selection process available in the program. Canonical coefficients, which are analogous to regression coefficients, were examined against the first two axes with nonparametric *t*-test. Rare species were downweighted, environmental variables were standardized to zero mean and unit variance in all multivariate analyses (ter Braak and Šmilauer, 2002).

Results

Results obtained by the Principal components analysis were compared with Spearman's rank correlation matrix prior the ordination analyses. A strong statistically significant dependence was found between the distance from the source and catchment area (Spearman's R = 0.97) and between the distance from the source and number of settlements (Spearman's R = 0.91). Catchment area and number of settlements were then eliminated from the following analyses.

Fish species occurrence in longitudinal profile

The result of DCA supported the treatment of species composition data. Analysis revealed high heterogeneity and corresponded with the decision to choose unimodal ordination methods. Species composition consistently exhibited >2 SD of turnover along the first DCA axis (ter Braak and Šmilauer, 2002).

DCA ordination diagram demonstrated species occurrence changes in the longitudinal profiles of small and mid-size Czech Republic streams reflecting known "fish zones" (Fig. 2)

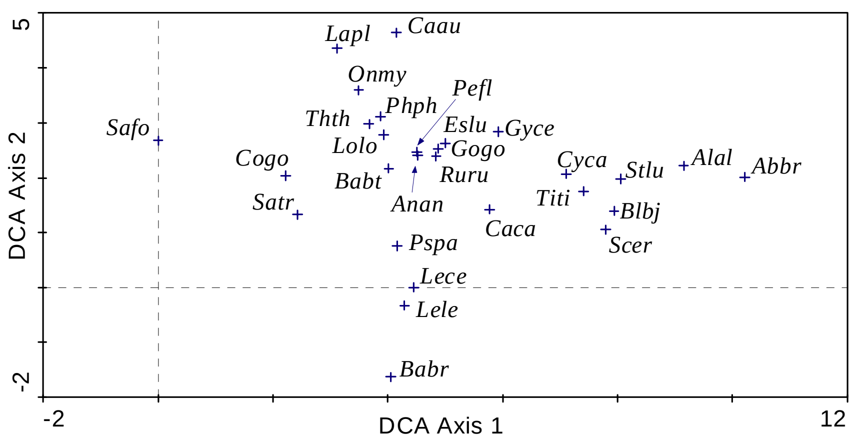

Figure 2: Detrended correspondence analysis ordination based on presence-absence composition of 28 fish species. Axis 1 = 17.4%, Axis 2 = 8.5%.

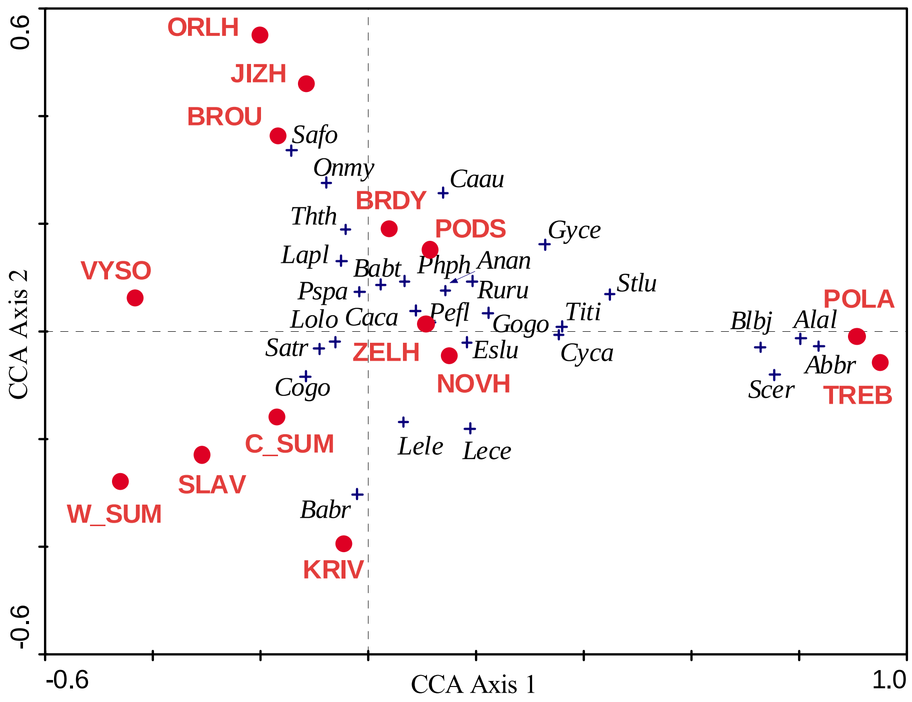

Figure 3: Canonical correspondence analysis ordination based on presence-absence of 28 species showing arrangement of 14 regions. Axis 1 = 6.2%, Axis 2 = 4.3%.

Regional and temporal variability

Partial CCA in the first step confirmed a highly significant influence (P<0.001) of 14 distinct regions on the species composition of fish assemblages (Fig.3). Regional variability from next CCA analyses was partialled out in order to join it as a covariable.

Regions explained 13.02% of the total variability of species composition. The first ordination axis represented the most important headwater-to-valley gradient heading from foothill and highland regions to lowland regions. Second axis distinguished among various regions in the north-south direction approximately (Fig.3). Similar arrangement of the studied regions based on fish species frequencies of occurrence in each region was detected also by Cluster analysis of species frequencies of occurrence in regions (UPGMA linkage method, Euclidean distance), where "POLA" and "TREB" regions joined together forming the most dissimilar cluster.

In the second step partial CCA confirmed also highly significant influence (P<0.001) of temporal variability (1989-2003, altogether 14 years). Individual years explained 3.95% of total variability of species composition. Temporal and regional variability of species composition were partialled out as covariables in the following CCA analyses together explaining 21.25% of the total variability (regional 13.02%, temporal 3.95%, overlay of both 4.28%).

Fish assemblages and environmental variables (CCA)

Finally in the third step direct gradient CCA evaluated environmental variables' influence on residual 78.75% variability of the species composition (regional and temporal variability excluded).

All canonical axes together were significant (Monte Carlo permutation test P<0.001). Six out of seven environmental variables retained by PCA analysis (Table 1) significantly (P<0.01) participated on the explained variability of species composition. The channel type was eliminated by a Monte Carlo forward selection process (P = 0.367). Values showing proportions of variability in species composition explained by six significant environmental variables are in the Table 2. Each value was obtained from a separate analysis in order to extract a pure effect of an individual environmental variable unaffected neither by other environmental variables nor by regional and temporal variability.

The number of ponds explained the most of the species composition variability (2.0%). The effect of higher order stream (EHOS), distance from the source and stream slope were other important environmental variables. All the six environmental variables together explained another 9.0% (20.1% respectively – see discussion) of total variability of fish assemblages after the removal of regional and temporal variability (Table 2).

Distance from the source and stream slope were the most correlated environmental variables with Axis 1. Number of ponds and mouth effect were strongly correlated with Axis 2. (Table 3)

Table 2: Results of canonical correspondence analysis (CCA) showing percentages of variability in species composition explained by 6 significant (P<0.01) environmental variables. Values represent percentages of variability explained when a variable is the only one in the model (pure effect).

	Ponds	**EHOS**	**Dist**	**Slope**	**Elev**	**Order**	**TOTAL**	**Region**	**Year**
Absolute	2.0	1.0	0.9	0.8	0.6	0.5	9.0	13.0	3.9
Relative	11.6	6.0	5.0	4.3	3.3	2.9	20.1	-	-

Note: Ponds-number of ponds in the catchment, EHOS-effect of higher order stream, Dist-distance from the source, Slope-stream slope, Elev-elevation, Order-stream order. TOTAL - total variance explained by all canonical axes when all six variables are in the model. Absolute - absolute proportions of total variability, Relative - proportions of total variability related to a maximum explainable variation of species composition extracted by DCA (17.4% for the Axis 1, and 44.7% for the Axes 1-6 together).

Table 3: Canonical correspondence analysis: standardized canonical coefficients and inter-set correlation of environmental variables with first two CCA axes. Significant t-test's values are marked with asterisks.

	Coefficients		**Correlations**	
Variable	**Axis1**	**Axis2**	**Axis1**	**Axis2**
Ponds	-0.62**	1.00**	-0.43	0.35
EHOS	-0.28**	-0.39**	-0.03	-0.23
Dist	-0.61**	0.07	-0.57	-0.15
Slope	0.40**	0.11	0.54	0.06
Elev	0.23*	0.80**	0.37	0.25
Order	0.08	-0.39**	-0.47	-0.18

Note: * P<0.05 ** P<0.01

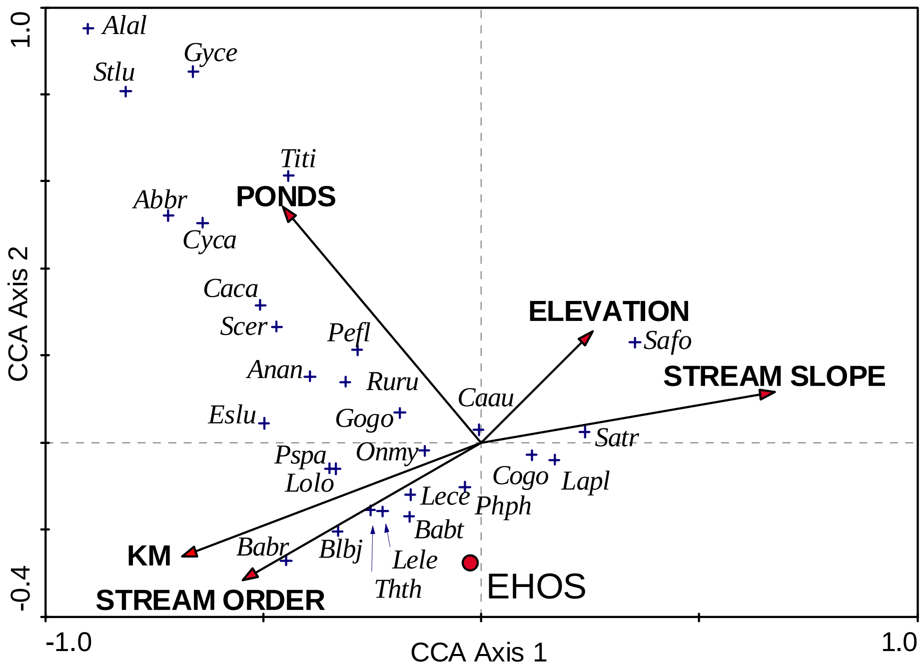

Figure 4: Final Canonical correspondence analysis based on presence-absence of 28 species and six environmental variables. Ordination biplot shows variability in species composition delineated by first two ordination axes. Axis 1 = 5.46%, Axis 2 = 1.44%

Environmental optima for species in relation to six environmental variables are illustrated in the final CCA ordination biplot (Fig. 4). Species that plot near the center of Fig. 4 are more likely to occur in a wide range of environments. The most of the species are correlated with the number of ponds.

The most important species-environment relations

CCA species scores were obtained from the partial analyses of pure effect of six significant environmental variables (see previous Chapter). Ordering the CCA species score values on the first axis we can evaluate which species are associated along environmental gradients and how strong the association is. The three most important environmental gradients represented by number of ponds, effect of higher order stream, and distance from the source are in the Fig. 5.

Discussion

Detrended correspondence analysis along the first ordination axis well described changes in species occurrence within the longitudinal profiles of small and mid-sized Czech Republic streams (Fig 2). Brown trout and bullhead are common in headwaters nearest to the stream source within “the trout zone” (in coldwater and warmwater streams). Farther brook lamprey, grayling, stone loach, minnow, and burbot appear, forming “the grayling zone”. Species of the next zone (“barbel zone”) finally appear in the lower parts of streams studied. Their frequency in individual sites is strongly influenced by environmental factors (Table 2). Barbel occurred in the whole data set six times only - always accompanied by dace and chub, and always in sites influenced by a higher order stream. Its position is thus distorted. Introduced rainbow trout, Gibel carp (*Carassius auratus gibelio*) and stone moroko (*Pseudorasbora parva*) occurrence depends on stocking and/or their expansive dispersion. Brook trout, thanks to its ability to survive in headwater sites with low pH, lies in the extreme position in the DCA diagram.

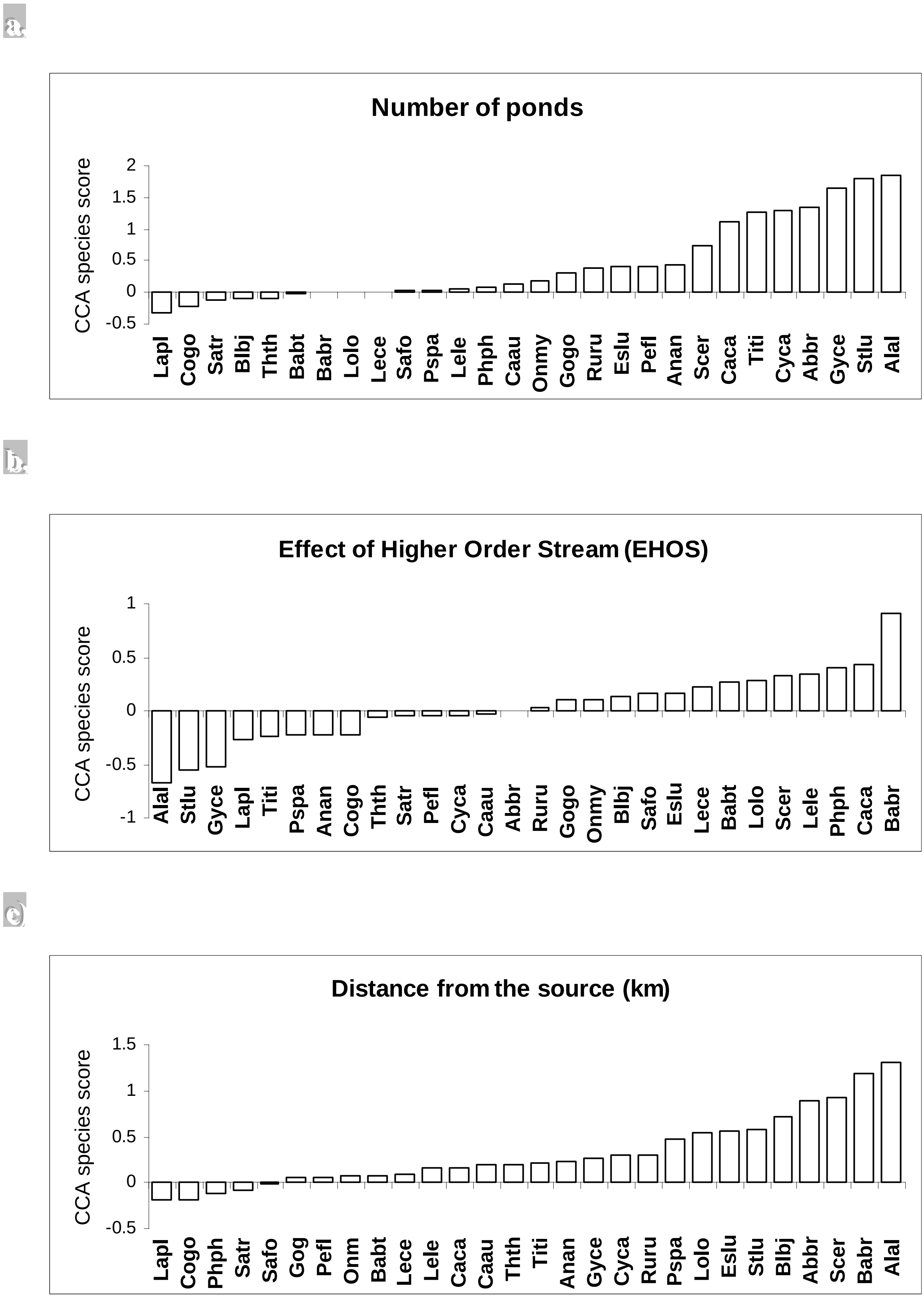

Figure 5: CCA species scores showing species-environment relations with number of ponds (a), EHOS (b), and distance from the source(c).

The highest part of variability of fish assemblages evaluated by direct gradient CCA can be explained by their species composition in different geographical regions, its smaller part by all the six significant environmental variables, and the smallest part by discrete years (Fig. 3, Table 2). Considerable geographical variation in species composition in Virginia streams was documented also by Angermeier and Winston (1999). Cluster analysis of the regional variability showed results very similar to the CCA ordination results. The influence of regions on the number of species was also documented by analysis of variance ($F = 4.4330$, $p<0.0001$).

In the final CCA ordination biplot (Fig. 4) inversely related distance from the source and stream slope were shown to be the most strongly correlated with axis 1. They represented the most important gradient of change in fish assemblages. Sites situated nearer to the source are characterized by higher stream slope – which reflects the fish assemblages living in these environments. Brook trout was strongly associated with vectors of stream slope and elevation (Fig. 4). Species associated with the most correlated variables on axis 2 (number of ponds and EHOS) get to the streams either by escaping from ponds or they ascend the stream from the higher order streams or reservoirs.

Using CCA ordination technique, similar results were achieved by Maret et al. (1997). Catchment area (which is strongly correlated with distance from the source) represented the most important gradient in Upper Snake River Basin. Channel slope was the environmental variable, which was strongly correlated with the second CCA ordination axis here. In small catchments in central New York, stream slope and channel width represented the most important gradient affecting variability of fish densities (Danehy et al., 1998).

Evaluation of fish assemblages' relation to the three most important environmental variables (number of ponds, EHOS, distance from the source) gave the opportunity to see how individual fish species reflect different environmental conditions. Species that revealed to be associated with number of ponds were either the aquaculture species as carp, tench, or crucian carp, or species that occur in lower parts of the streams (ruffe, pikeperch, bleak, bream). Their occurrence in mid-sized streams could have been caused by their passing from the lower parts of river (if possible) or from badly managed ponds (Fig. 5a). One has to take into consideration that the number of ponds is strongly positively correlated with the distance from the source in this case. Barbel was the species the most influenced by the EHOS, its relatively rare occurrence in smaller streams was always supported by the presence of higher order stream (Fig. 5b). In comparison with the DCA results (Fig. 2) demonstrating the direction of the highest variability in species composition, the CCA in Fig. 5c was constrained to analyze the direct relation between the species composition and the distance from the source. CCA species scores then reflected real positions of species within the longitudinal profile up to 50 km from the source. Thus, for example, the position of brown trout was shifted downstream probably thanks to the human activities in streams (Fig. 5c).

In conclusion, the most important gradients affecting the species composition of small and mid-sized Elbe basin streams are distance from the source and stream slope. Number of ponds explained most of the variability, even if it did not represent the most important gradient in species composition.

Together with the regional and temporal variability it was possible to describe 30 % of species composition variability using CCA. Environmental variables delineated 9 % of variability in species composition. This value can be seemingly increased to

20.1 % if we relate the explained variance of constrained technique (CCA) to the maximal possible explainable variance extracted by an unconstrained technique (DCA). But the fact remains the same.

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Appendix

Abbreviations of 28 fish species found in small and mid-sized Elbe Basin streams.

Scientific name	Abbrev.	English name	Scientific name	Abbrev.	English name
Abramis brama	**Abbr**	common bream	*Leuciscus cephalus*	**Lece**	chub
Alburnus alburnus	**Alal**	bleak	*Leuciscus leuciscus*	**Lele**	dace
Anguilla anguilla	**Anan**	european eel	*Lota lota*	**Lolo**	burbot
Barbatula barbatula	**Babt**	stone loach	*Oncorhynchus mykiss*	**Onmy**	rainbow trout
Barbus barbus	**Babr**	barbel	*Perca fluviatilis*	**Pefl**	perch
Blicca bjoerkna	**Blbj**	silver bream	*Phoxinus phoxinus*	**Phph**	minnow
Carassius auratus gibelio	**Caau**	Gibel carp	*Pseudorasbora parva*	**Pspa**	stone moroko
Carassius carassius	**Caca**	crucian carp	*Rutilus rutilus*	**Ruru**	roach
Cottus gobio	**Cogo**	bullhead	*Salmo trutta m. fario*	**Satr**	brown trout
Cyprinus carpio	**Cyca**	carp	*Salvelinus fontinalis*	**Safo**	brook trout
Esox lucius	**Eslu**	pike	*Scardinius erythropthelmus*	**Scer**	rudd
Gobio gobio	**Gogo**	gudgeon	*Stizostedion lucioperca*	**Stlu**	pikeperch
Gymocephalus cernuus	**Gyce**	ruffe	*Thymallus thymallus*	**Thth**	grayling
Lampetra planeri	**Lapl**	brook lamprey	*Tinca tinca*	**Titi**	tench