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The diatom communities in Swiss springs: A first approach

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INTRODUCTION

Due to human population's density in Central Europe, intact natural habitats have become rare. This applies to both terrestrial and limnological habitats. Natural springs are very special habitats of physicochemical stability, which are not yet largely affected by human pollution and therefore provide a basis to describe naturally preserved, limnological habitats (Werum 2001). Despite this stability, springs are highly sensitive to external disturbances.

In Switzerland only little research has been done on these habitats. According to (Zollhöfer 1997) there used to be between 500 and 1000 springs per 210 km^2 more than 100 years ago. Nowadays, over 90 % of the springs have been artificially enclosed (so called walled springs) and are now used as sources for drinking water.

Research on the biodiversity found in natural springs has been done only mostly incompletely. Many investigations concerned invertebrates, whereas algae were studied only very rarely. Also outside Switzerland, springs have been investigated only sporadically and mostly not as part of a larger concept. Germany (e.g. Werum 2001) and Italy (e.g. Cantonati et al. 2006) are notable exceptions, where in the recent years research on springs has become more organised and productive.

The pivotal questions of this work deal with the biodiversity of diatoms in Swiss springs and their community structures in the springs and some distance down the off-flowing water. Further aspects that were examined concern the current state of springs referring to impacts of nutrients and other anthropogenically caused disturbances: A particular focus was given to the endangered species and what their occurrence implies for the conservation of natural springs.

MATERIAL & METHODS

Parallel to the biological examination each spring was tested once for some physicochemical parameters which could indicate possible nutrient input. Nitrogen compounds (NO_3-N, NO_2-N and NH_4-N), phosphate (PO_4-P) and chloride (Cl^-) were measured with a Hach-Lange cuvette test [$mg \cdot l^{-1}$]. With a digital analyser (WMW Multi 340i) each spring was tested on site for oxygen saturation [%], electric conductivity [$\mu S \cdot cm^{-1}$], temperature [°C], pH and German degree of hardness [°d] (Table 1).

Out of 17 springs examined, two groups of springs (consisting of 3 and 2 springs, respectively) were located in the Jura Mountains near Basel (Röserental and St. Chrischona), whereas two other groups of springs at Sihlwald and Höhronen (consisting of 4 springs each) and four isolated springs (Tüfelschilen, Rötler b. Buchs, Ranzachtobel and Sädelrain) were situated on the Swiss plateau in the area of Zürich. Field work was done in May and September 2006. Epilithic diatoms were taken from the springs themselves and two sites 2 and 10 metres downstream from the runoff. The sampling and preparation of diatoms followed the standard methods published by Hürlimann and Niederhauser (2006). For preparation of diatoms for permanent slides the material was ashed in a muffle furnace, followed by a treatment with hydrochloric acid (HCl 32 %) and hydrogen peroxide (H_2O_2 30 %) and finally embedded in Naphrax (synthetic resin with refractive index of 1.7).

The main literature for the identification of the diatoms was the 'Süßwasserflora von Mitteleuropa' (Krammer & Lange-Bertalot 1986, 1988, 1991a, b), but for identifying several species of *Cymbella, Navicula* and *Pinnularia* some volumes of 'Diatoms of Europe' (Krammer 2000, 2002; Lange-Bertalot 2000) were also consulted. Taxon names were mostly used in accordance to Werum (2001).

To evaluate the Swiss Diatom Index DI-CH (Fig. 2; Hürlimann & Niederhauser 2006) between 400 and 600 diatom valves per slide were identified and counted along parallel and non-overlapping paths. Girdle views have only been counted if species identification was possible.

Endangered species were recorded following the German 'Red List' of Lange-Bertalot (1996). Three categories of taxa were distinguished in this list: (1) the endangered Red List ("RL") taxa (symbols 0, 1, 2, 3, G and R in Lange-Bertalot 1996), (2) the near-threatened ("NT") taxa (symbol V in Lange-Bertalot 1996) and (3) the taxa at present not considered to be endangered (symbols * and ** in Lange-Bertalot 1996)

To examine the collected data linear regression analysis and analysis of variance (ANOVA) were applied (Stahel 2002). All data sets were analysed with the computer programme SPSS (Version 14).

RESULTS

The physicochemical data indicate values of oligotrophic waters and do not give clear evidence for a possible external input of nutrients in any of the investigated springs (Table 1). The values from the Swiss Diatom Index (DI-CH, last column in Table 1) mostly confirm this rating. With 5.2 only one value is above the critical threshold of 4.5 (Table 6 in Hürlimann & Niederhauser 2006) indicating a poorer water quality in a single spring in Sihlwald. In natural springs we calculated a very low median DI-CH value of 1.99 and in walled springs a value of 3.56.

In total, 31 genera and 118 species (plus 18 additional infraspecific taxa) of diatoms were identified (Table 2). The range of numbers of taxa found at the different sites was wide, varying from 9 taxa (at Röserental 15) up to 43 taxa (at Sihlwald 18). The mean number of taxa was 30 at natural spring sites and 20 at walled spring sites.

Table 1. The individual values of physicochemical measurements at the springs. Most values are within the range of typical oligotrophic waters. The Swiss Diatom Index DI-CH represents the mean value of three evaluations at the corresponding sites.

Spring	NO_3-N [mg·l^{-1}]	NO_2-N [mg·l^{-1}]	NH_4-N [mg·l^{-1}]	PO_4-P [mg·l^{-1}]	Cl^- [mg·l^{-1}]	Temp. [°C]	Cond. [µS·cm^{-1}]	pH	O_2 [%]	°d	DI-CH
Lowest value	**1.00**	**0.011**	**0.014**	**0.002**	**0.8**	**7.2**	**162**	**7.0**	**23.9**	**5**	**1.51**
Highest value	**9.17**	**0.024**	**0.315**	**0.028**	**53.4**	**14.8**	**890**	**8.2**	**76.0**	**25**	**5.20**
Median	**2.21**	**0.019**	**0.093**	**0.005**	**2.6**	**10.1**	**472**	**7.6**	**38.5**	**15**	**2.35**
Tüfelschile 02	5.09	0.020	0.015	x[2]	6.72	9.6	717	7.0	23.9	20	-[3]
Röserental 13	2.21	0.014	0.015	x[2]	2.63	9.2	474	7.5	75.0	10	2.77
Röserental 14	1.65	0.011	0.014	x[2]	3.22	9.2	442	7.5	75.6	10	1.86
Röserental 15	1.48	0.013	0.014	x[2]	1.33	9.3	380	7.7	76.0	10	1.99
Sihlwald 16	1.64	0.020	0.016	0.002	0.80	13.0	456	8.1	32.1	5	3.83
Sihlwald 17	2.44	0.019	0.016	x[2]	0.93	10.4	490	7.4	29.8	15	5.20
Sihlwald 18	1.96	0.019	0.016	x[2]	0.99	10.8	470	7.8	38.1	5	-[3]
Sihlwald 19	1.29	0.021	0.301	0.028	2.01	11.3	461	7.8	37.4	10	1.72
Rötler b. Buchs 20[1]	9.17	0.021	0.111	0.002	6.26	14.8	621	7.7	37.6	20	3.87
Höhronen 32	2.03	0.021	0.104	0.010	0.92	7.2	162	8.1	40.8	5	1.86
Höhronen 35	2.25	0.024	0.164	x[2]	1.18	8.6	190	8.2	39.0	5	1.51
Höhronen 36[1]	1.00	0.019	0.175	0.009	1.49	11.8	164	7.9	42.1	15	3.25
Höhronen 37[1]	2.59	0.018	0.057	0.003	5.95	9.5	605	7.5	35.9	20	2.71
Ranzachtobel	3.33	0.012	0.093	0.003	8.53	10.7	582	7.2	67.0	15	2.35
St. Chrischona 40	4.61	0.017	0.132	0.005	53.40	10.1	890	7.3	38.5	25	2.15
St. Chrischona 42	1.69	0.021	0.315	x[2]	7.45	9.5	-[4]	7.2	31.5	25	1.51
Sädelrain 50[1]	4.04	0.019	0.167	0.005	7.09	13.0	670	7.6	47.0	20	4.03

[1] walled spring [2] value below measurable threshold [3] DI-CH not calculated [4] missing value.

Table 2. List of diatom taxa occurring in Swiss springs. In total, 31 genera and 136 taxa were identified. In the springs proper there were 28 genera and 102 taxa; 3 additional genera and 34 taxa were recorded at sites located 2 and 10 metres downstream. The frequency of each taxon is given separately for both the spring proper and the downstream sites.

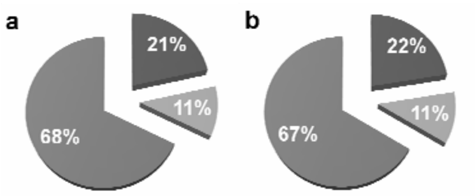
Taxa		Frequency spring	Frequency site
Achnanthes	- *biasolettiana* Grunow var. *biasolettiana*	64.71 %	88.24 %
	- *caledonica* Lange-Bert.	11.76 %	23.53 %
	- *curtissima* J.R.Carter	11.76 %	23.53 %
	- *daonensis* Lange-Bert.	5.88 %	5.88 %
	- *grischuna* Wuthrich	23.53 %	23.53 %
	- *helvetica* (Hust.) Lange-Bert.	5.88 %	5.88 %
	- *laevis* Østrup var. *laevis*		5.88 %
	- *lanceolata (*Bréb.) Grunow ssp. *lanceolata* var. *lanceolata*	70.59 %	82.35 %
	- *lanceolata* ssp. *lanceolata* var. *boyei* (Østrup) Lange-Bert.	23.53 %	23.53 %
	- *lanceolata* ssp. *dubia* Grunow	5.88 %	11.76 %
	- *lanceolata* ssp. *frequentissima* Lange-Bert.	29.41 %	41.18 %
	- *levanderi* Hust.	5.88 %	5.88 %
	- *minutissima* Kütz. var. *minutissima*	94.12 %	100.00 %
	- *minutissima* var. *affinis* (Grunow) Lange-Bert.		5.88 %
	- *minutissima* var. *inconspicua* Østrup	58.82 %	82.35 %
	- *minutissima* var. *jackii* (Rabenh.) Lange-Bert. & Ruppel	76.47 %	100.00 %
	- *minutissima* var. *saprophila* H.Kobayasi & Mayama	11.76 %	11.76 %
	- *minutissima* "*Sippe mit rhombisch-lanzettlichen Schalen*" sensu Krammer 1991b, Fig. 32/57-61		5.88 %
	- *oblongella* Østrup	5.88 %	11.76 %
	- *rechtensis* Leclercq	23.53 %	23.53 %
	- *scotica* Flower	23.53 %	11.76 %
Amphora	- *aequalis* Krammer		11.76 %
	- *inariensis* Krammer	64.71 %	76.47 %
	- *normanii* Rabenh.	5.88 %	5.88 %
	- *pediculus* (Kütz.) Grunow	70.59 %	88.24 %
	- *veneta* Kütz.	11.76 %	29.41 %
Brachysira	- *vitrea* (Grunow) R.Ross		5.88 %
Caloneis	- *alpestris* (Grunow) Cleve		5.88 %
	- *bacillum* (Grunow) Cleve	64.71 %	88.24 %
	- *silicula* (Ehrenb.) Cleve	5.88 %	5.88 %
Cavinula	- *variostriata* (Krasske) D.G.Mann & Stickle	5.88 %	5.88 %
Cocconeis	- *placentula* Ehrenb. var. *placentula*	41.18 %	52.94 %
	- *placentula* var. *euglypta* (Ehrenb.) Cleve	17.65 %	23.53 %
	- *placentula* var. *pseudolineata* Geitler	17.65 %	23.53 %
Cyclotella	- cf. *praetermissa* J.W.G.Lund		5.88 %
Cymbella	- *affinis* Kütz. var. *affinis*	11.76 %	11.76 %
	- *amphicephala* var. *hercynica* (A.W.F.Schmidt) Cleve	5.88 %	11.76 %
	- *aspera* (Ehrenb.) H.Perag.		5.88 %
	- *austriaca* Grunow var. *austriaca*		11.76 %
	- *compacta* Østrup		5.88 %
	- *delicatula* Kütz.		5.88 %
	- *helvetica* Kütz.	5.88 %	5.88 %
	- *hustedtii* Krasske	5.88 %	11.76 %
	- *incerta* Grunow var. *incerta*	5.88 %	5.88 %
	- *laevis* Nägeli	5.88 %	5.88 %
	- *lange-bertalotii* Krammer	5.88 %	5.88 %
	- *pusilla* (Grunow) Krammer	17.65 %	29.41 %
	- *subaequalis* Grunow	5.88 %	17.65 %
Denticula	- *tenuis* Kütz.	35.29 %	70.59 %
Diadesmis	- *contenta* (Grunow) D.G.Mann	11.76 %	17.65 %
	- *perpusilla* (Grunow) D.G.Mann	11.76 %	11.76 %
Diatoma	- *hyemalis* var. *mesodon* (Ehrenb.) Grunow	5.88 %	29.41 %
Diploneis	- *elliptica* (Kütz.) Cleve var. *elliptica*	5.88 %	5.88 %
	- *oblongella* (Nägeli) A.Cleve	29.41 %	47.06 %
	- *ovalis* (Hilse) Cleve	17.65 %	41.18 %
Ellerbeckia	- *arenaria* (D.Moore) R.M.Crawford		11.76 %
Encyonema	- *alpinum* (Grunow) D.G.Mann	23.53 %	29.41 %
	- *lunatum* (W.Sm.) Van Heurck	5.88 %	11.76 %
	- *microcephala* (Grunow) Krammer	29.41 %	58.82 %
	- *minutum* (Hilse) D.G.Mann	35.29 %	47.06 %
	- *silesiacum* (Bleisch) D.G.Mann	29.41 %	41.18 %
Encyonopsis	- *cesatii* (Rabenh.) Krammer		5.88 %
	- *falaisensis* (Grunow) Krammer	5.88 %	17.65 %
	- *hebridicum* Grunow ex Cleve		5.88 %
Eunotia	- *arcus* Ehrenb. var. *arcus*	5.88 %	11.76 %
	- *arcus* var. *bidens* Grunow		5.88 %
	- *bilunaris* (Ehrenb.) Schaarschm. var. *bilunaris*	17.65 %	17.65 %
	- *subarcuatoides* Alles, Nörpel-Schempp & Lange-Bert.		5.88 %
Fragilaria	- *arcus* (Ehrenb.) Cleve var. *arcus*	5.88 %	5.88 %
	- *capucina* Desm. var. *capucina*		5.88 %
	- *capucina* var. *gracilis* (Østrup) Hust.	5.88 %	11.76 %
	- *construens* f. *venter* (Ehrenb.) Hust.		5.88 %
	- *pinnata* Ehrenb. (sensu lato)	11.76 %	11.76 %
	- *ulna* (Nitzsch) Lange-Bert. var. *ulna*	5.88 %	11.76 %
	- *virescens* Ralfs	11.76 %	11.76 %

Continuation of Table 2

Taxa		Frequency spring	Frequency site
Frustulia	- *vulgaris* (Thwaites) De Toni	5.88 %	11.76 %
	- *weinholdii* Hust.	5.88 %	11.76 %
Gomphonema	- *acuminatum* Ehrenb. var. *acuminatum*	5.88 %	5.88 %
	- *clavatum* Ehrenb. [sensu lato]		5.88 %
	- *lagerheimii* Cleve	5.88 %	5.88 %
	- *lateripunctatum* E.Reichardt & Lange-Bert.	5.88 %	5.88 %
	- *olivaceum* var. *calcareum* (Cleve) Van Heurck	5.88 %	11.76 %
	- *parvulum* (Kütz.) Van Heurck var. *parvulum*	29.41 %	35.29 %
	- *parvulum* var. *micropus* (Kütz.) Cleve		11.76 %
	- *vibrio* var. *intricatum* (Kütz.) Playfair	52.94 %	70.59 %
Gyrosigma	- *acuminatum* (Kütz.) Rabenh.		5.88 %
	- *nodiferum* (Grunow) Reimer		5.88 %
	- *scalproides* (Rabenh.) Cleve	5.88 %	5.88 %
Hantzschia	- *amphioxys* (Ehrenb.) Grunow var. *amphioxys*	11.76 %	11.76 %
Luticola	- *mutica* (Kütz.) D.G.Mann	17.65 %	17.65 %
Meridion	- *circulare* (Grev.) C.Agardh var. *circulare*	35.29 %	47.06 %
Navicula	- *absoluta* Hust.	17.65 %	17.65 %
	- *angusta* Grunow		11.76 %
	- *cari* Ehrenb.	11.76 %	23.53 %
	- *cincta* (Ehrenb.) Ralfs	5.88 %	11.76 %
	- *cryptocephala* Kütz.	47.06 %	52.94 %
	- *cryptotenella* Lange-Bert.	5.88 %	17.65 %
	- *lanceolata* (C.Agardh) Kütz. var. *lanceolata*	5.88 %	5.88 %
	- *lanceolata* var. *phyllepta* (Kütz.) Cleve		11.76 %
	- *minima* Grunow	23.53 %	23.53 %
	- *minuscula* Grunow		5.88 %
	- *phylleptosoma* Lange-Bert.	5.88 %	5.88 %
	- *radiosa* Kütz.	11.76 %	11.76 %
	- *recens* (Lange-Bert.) Lange-Bert.	5.88 %	23.53 %
	- *stroemii* Hust.	11.76 %	35.29 %
	- *subminuscula* Manguin		5.88 %
	- *tenelloides* Hust.	11.76 %	11.76 %
	- *tripunctata* (O.F.Müll.) Bory	11.76 %	17.65 %
	- *veneta* Kütz.	35.29 %	35.29 %
Nitzschia	- *amphibia* Grunow var. *amphibia*	11.76 %	23.53 %
	- *angustata* (W.Sm.) Grunow		11.76 %
	- *aurariae* Cholnoky		5.88 %
	- cf. *debilis* (Arn.) Grunow	11.76 %	11.76 %
	- *dissipata* (Kütz.) Grunow var. *dissipata*	29.41 %	47.06 %
	- *dissipata* var. *media* (Hantzsch) Grunow		5.88 %
	- *linearis* (C.Agardh) W.Sm. var. *linearis*	17.65 %	29.41 %
	- *palea* (Kütz.) W.Sm. var. *palea*	35.29 %	47.06 %
	- *palea* var. *debilis* (Kütz.) Grunow	5.88 %	5.88 %
	- *perminuta* (Grunow) Perag.	11.76 %	11.76 %
	- *sigmoidea* (Nitzsch) W.Sm.		11.76 %
	- *sinuata* var. *delognei* (Grunow) Lange-Bert.	11.76 %	11.76 %
	- *supralitorea* Lange-Bert.		5.88 %
Pinnularia	- *appendicula* (C.Agardh) Cleve	11.76 %	11.76 %
	- *isselana* Krammer	5.88 %	5.88 %
	- *microstauron* (Ehrenb.) Cleve var. *microstauron*	5.88 %	5.88 %
	- *rupestris* Hantzsch var. *rupestris*		5.88 %
	- *subcapitata* W.Greg. var. *subcapitata*	11.76 %	11.76 %
Rhoicosphenia	- *abbreviata* (C.Agardh) Lange-Bert.	11.76 %	11.76 %
Sellaphora	- *pupula* (Kütz.) Mereschk. var. *pupula*	23.53 %	47.06 %
	- *pupula* var. *aquaeductae* (Krasske) E.Y.Haw. & M.G.Kelly	5.88 %	5.88 %
Simonsenia	- *delognei* (Grunow) Lange-Bert.	5.88 %	11.76 %
Stauroneis	- *anceps* Ehrenb. var. *anceps*		5.88 %
	- *smithii* Grunow var. *smithii*	5.88 %	17.65 %
Surirella	- *angusta* Kütz.	11.76 %	17.65 %
	- *brebissonii* Krammer & Lange-Bert. var. *brebissonii*	5.88 %	5.88 %
	- *minuta* Bréb.	17.65 %	23.53 %

Of the total 136 recorded taxa, 125 were listed by Lange-Bertalot (1996), 28 (or 22 %) of which were classified as "Red List" (RL) taxa and 14 (or 11 %) as "near-threatened" (NT) taxa (Fig. 1b). Of the springs proper values of a similar range were calculated (21 % “RL” and 11 % “NT” taxa, respectively; Fig. 1a). Distinguishing between the sites of natural and walled springs the following mean percentages occurred: 23.1 % “RL” and 12 % “NT” taxa in natural and 12.5 % “RL” and 4.2 % “NT” taxa in walled springs.

Comparing the number of recorded taxa and the “RL” and “NT” taxa against their distance to the spring, neither ANOVA nor linear regression analyses showed significant variation.



$$DI-CH = \frac{\sum_{i=1}^{n} D_i G_i H_i}{\sum_{i=1}^{n} G_i H_i}$$

Fig. 2. Diatom Index Switzerland DI-CH; D = indication value; G = weighting value; H = frequency of single taxon.

Fig. 1. Pie diagram showing the percentages of the endangered (RL), near-threatened (NT) and non-threatened taxa.
a) In springs proper: 20 “RL” taxa (21 %), 10 “NT” taxa (11 %), 63 non-threatened taxa (68 %);
b) In springs including runoff: 28 “RL” taxa (22 %), 14 “NT” taxa (11 %), 83 non-threatened taxa (67 %).

DISCUSSION

In the present study on diatoms in 17 springs of Switzerland we recorded 31 genera and 136 taxa, while Werum (2001) and Werum and Lange-Bertalot (2004), in considerably more extensive studies on 96 springs in SW-Germany, found 416 taxa. 96 (= 71 %) of the taxa which occurred in the Swiss springs were also present in the German springs examined by Werum and Lange-Bertalot.

Our number amounts to nearly 10 % of the altogether 1437 taxa of diatoms recorded in all fresh-/brackish water and terrestrial habitats in Germany (Lange-Bertalot 1998). This proportion increases to about 13%, if it is taken into account that species from brackish water and usually also from plankton do not occur in springs.

Of the 136 taxa found in our study, 28 (= 22 %) were listed in Germany (Lange-Bertalot 1996) as threatened (RL taxa) and 14 (= 11 %) as "near-threatened" (NT taxa). Comparing the nature-near springs with those which have been structured by man, the natural springs showed a higher diatom diversity and a higher percentage of threatened and near-threatened taxa. The communities in the springs were found to be very similar to those some metres down the runoff. This suggests that the springs and the off-flowing water should be considered to be a more or less uniform habitat.

The calculated Swiss Diatom Index DI-CH of the different springs varied from 1.51 (in a spring at Höhronen) to 5.20 (in a spring at Sihlwald), but the median of 2.35 clearly indicates that the water quality in our springs was generally very good. For comparison, a median of 3.6 was calculated in more than 2800 samples analysed from rivers, streams and brooks across the Swiss plateau and the Prealps (400–800 metres altitude) by AquaPlus (Hürlimann, unpublished data).

Further studies will certainly be necessary to learn more about the role of springs as very special habitats.

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