How does Salinisation of Running Waters Affect Aquatic Communities? Answers from A Case Study

Claus-Jürgen Schulz

Thüringer Landesanstalt für Umwelt und Geologie, Regionalstelle Sondershausen, Am Petersenschacht 3, D-99706 Sondershausen, Germany
Claus-Juergen.Schulz@tlug.thueringen.de

Abstract

The introduction of brines from salt mining into nearby running waters is still a prevalent method of disposal. These salt waste waters often originate from processing of salt-containing rocks and drainage of the residue heaps. Hereby salt waste waters may still accumulate for a long time after shutdown of the mines.

Indeed it has early been reported that elevated salt concentrations as caused by this disposal method may damage the aquatic communities of the running waters afflicted. The question in which way salinisation of running waters affects aquatic communities was answered by means of a case study. It was performed along the Wipper river (Central Germany) where salt inputs from 4 residue heaps along the river cause an increase in salinity thus forming a salt gradient (95 km stretch). Monitoring data of 7 sampling sites (31 – 1,286 mg Cl^-/l) of the period 2008 to 2014 were analysed for salts, nutrients and changes in the benthic macroinvertebrate and diatom communities. Benthic macroinvertebrates responded to elevated salt concentrations with decrease in species numbers and diversity. Development of r-species and spreading of neozooa was favoured, whereas salt-sensitive groups declined. Freshwater species were replaced by more salt-tolerant forms. Similar effects were observed in view of benthic diatom assemblages. Numbers of reference species decreased, and shifts in the diatom assemblages took place whilst the proportion of salt-tolerating (meso- and polyhalobic) taxa increased.

Key words: diatoms, macroinvertebrates, salinisation, Wipper river,

Introduction

Salinisation may affect running waters seriously. A number of reasons are in line for anthropogenic salinisation, among them salt mining (Canedo-Argüelles et al. 2016). In this case, salt brines from mining and/or production are often discharged into nearby rivers, causing elevated salt concentrations here which may influence structure and function of the afflicted aquatic ecosystems distinctly (Canedo-Argüelles et al. 2013).

The catchment area of the Wipper river (Northern Thuringia, Germany) forms an example for this. Here salt brines are especially rich in single ions such as potassium which is reported to have toxic effects on aquatic organisms (Ziemann & Schulz 2011) and magnesium. Besides this anthropogenic salinisation saline tributaries of geogenic origin join in. This paper presents a case study of the Wipper river catchment area. It focuses on the question in which way aquatic communities are influenced by salinisation by special reference to benthic macroinvertebrates and benthic diatoms.

Methods

Sampling area and locations

The catchment area of the Wipper river is situated in Northern Thuringia (Central Germany, fig. 1). It

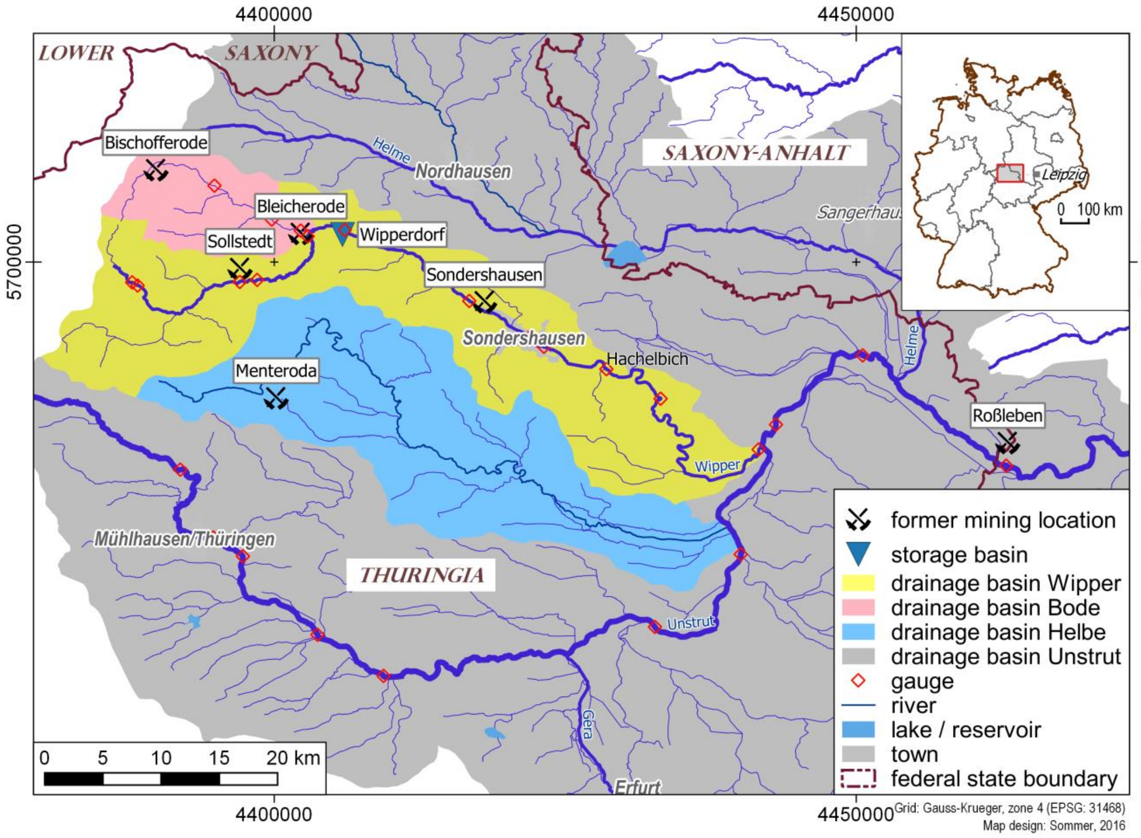

Fig. 1: *Catchment area of the Wipper river. Map design: Thomas Sommer, Dresden (Germany)*

is a tributary river of the Unstrut river (rivers Saale, Elbe). Its total length is 95.3 km, the catchment area is 649.1 km^2, mean discharge 3.5 m s^{-1} and average low discharge 1.1 m s^{-1}. The headwater is a small coarse substrate dominated calcarous highland river (German WFD classification: type 7), the lower course is a mid-sized fine to coarse substrate dominated calcarous highland river (type 9,1, all data; Thuringian State Institute for Environment and Geology, Jena, Germany).

Four potash mines and their affiliated factories (Sollstedt, Bischofferode, Bleicherode and Sondershausen) discharged their salt brines into the Wipper river and its tributary creek Bode during the potash mining period from 1893 to the early 1990s. Since shutdown in the 1990s, still drainage waters from the stockpiles left behind accumulate, are stocked up in two storage basins (near Wipperdorf and Sondershausen) and are and discharged into the river Wipper during periods of sufficient runoff. Salt springs below the river bed and a few tributaries rich in electrolytes cause an additional increase in salinity (Thuringian State Institute for Environment and Geology, Jena, Germany).

Sampling and sample processing

Data presented in this case study were collected as part of the governmental sampling to fulfil the monitoring requirements of the EU-Water Framework Directive. The sampling period considered in this study involved the years from 2008 to 2014. Chemical sampling was performed once a month. Water samples were taken, preserved if necessary, cooled and transported to the laboratory where analyses were conducted. Involved were salts (ions: K^+, Mg^{++}, Cl^-, SO_4^{--}), nutrients (NO_3, total phosphorous TP) and carbon (TOC).

Biological samples were taken once a year. Samples of benthic invertebrates were taken by means of substrate-specific multi-habitat kick-sampling, preserved in EtOH (96%) and stored at 4°C in the dark in the laboratory until processing according to Meier et al. (2006). For evaluation the ASTERICS/PEROLODES software was used. The following metrics were used for interpretation: No.

of taxa, diversity (Shannon-Weaner-index), r/K ratio, proportion of neozoa, proportion of EPT and EPTCBO taxa, percentage of freshwater, oligo- and mesohaline species, resp.

Sampling and evaluation of the diatoms followed the PHYLIB procedure by BayLfU (2006ff). For the calculation of the final result the metrics proportion of reference species, trophy index according to Rott and Halobion index are necessary which at once give valuable insights into structure and loads of diatom assemblages.

Statistical calculations followed Sachs (1982).

Results and Discussion

Chemical parameters

Concentrations of carbon, nutrients and salts are compiled in table 1 and illustrated in fig. 2 and 3.

Table 1: *Carbon, nutrient and salt concentrations of 7 sampling locations along the Wipper river. Values given are average concentrations and corresponding standard deviations of the sampling period 2008 – 2014 (12 samples/a).*

serial no.		1	2	3	4	5	6	7
location		Worbis	Wülfingerode	Sollstedt	Bleicherode	Großfurra	Hachelbich	Sachsenburg
river km	km	85.6	73.2	68.7	62	43.8	29.2	0.4
TOC	mg/l	2.45±0.93	4.63±0.50	4.58±0.55	4.64±0.32	4.83±0.47	4.83+0.50	4.49±0.51
TP	µg/l	60±10	400±60	400±50	300±30	230±30	220±30	180±20
NO_3-N	mg/l	6.11±0.34	5.76±0.39	5.59±0.51	5.29±0.31	5.17±0.67	4.95±0.58	4.59±0.70
K^+	mg/l	2.1±0.30	7.3±0.43	20±2.31	30±3.23	67±7.32	75±4.47	61±5.77
Mg^{++}	mg/l	20±0.53	23±0.52	28±2.45	56±6.37	94±4.42	110±5	101±3
Cl^-	mg/l	31±9.68	84±3.99	196±20	471±60	1004±365	1286±107	1024±113
$SO4^{--}$	mg/l	90±5.64	213±8	222±12	305±21	351±18	370±16	455±33

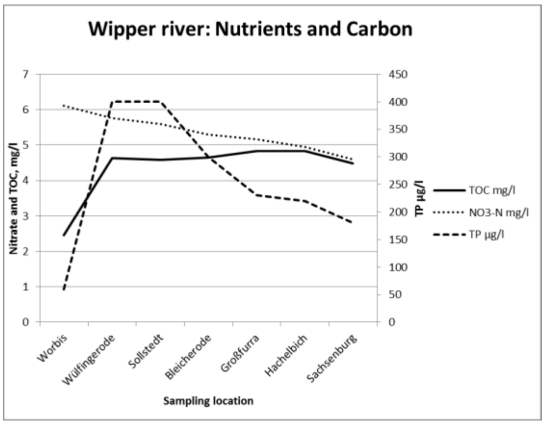

Fig. 2 *Nutrient and carbon concentrations Average means of the years 2008 – 2014.*

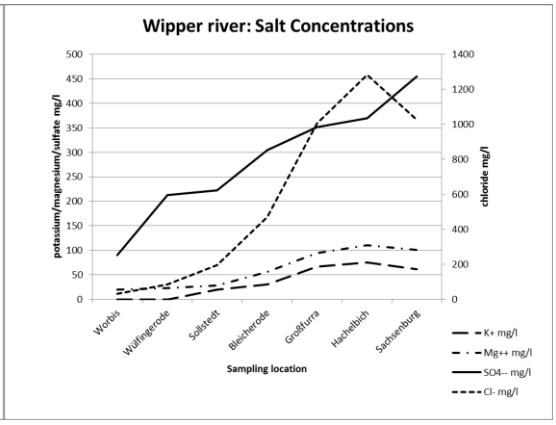

Fig. 3 *Salt concentrations. Average means of the years 2008 – 2014.*

The data show that TOC concentrations are lowest below the source near the village of Worbis. Further down they increase and remain comparatively stable afterwards. In contrast to this, NO_3-N concentrations are highest near the source and decrease slightly furthermore. Regarding the phosphorous concentrations they are lowest below the spring, leap distinctly between Wülfingerode and Sollstedt and drop beneath.

Salt concentrations show different patterns. Regarding the concentrations of potassium, magnesium and chloride, three sections may be distinguished: A slightly salanised section extends until the village of

Sollstedt where the first heap is situated. Here the moderately salanised part begins where the Wipper river receives salt waste waters from (i) the abandoned mine of Sollstedt, (ii) the dead mine near the city of Bleicherode, (iii) the tributary creek Bode polluted with waters from the disused mine of Bischofferode and (iv) geogenic sources emitting below the river bed (Sommer and Stodolny 2012). Further down between the sampling locations Bleicherode and Großfurra (situated just above the city of Sondershausen, fig. 1) brines of the storage basin near the village of Wipperdorf are discharged causing a strong increase in salinity. This is the third section being strongly salanised that extends up to the oulet near the village of Sachsenburg. Along this section salt concentrations decrease only slightly due to the freshwater dilution by a few creeks flowing in. – Sulfate concentrations increase from spring to outlet over the whole transect. The reason for this are mostly geogenic inputs (76%) whereas mining inputs are less important (24%, Sommer and Stodolny 2012).

Based on the effects of elevated salt concentrations on aquatic communities, sensitivity groups can be distinguished. From field data Coring et al. (2016) identified 5 chloride classes for benthic macroinvertebrates (< 200; 200 – 600; 600-1,100; 1,100 – 2,000; > 2,000 mg Cl^-/l, annual mean). A comparison of these concentration ranges with the values from table 1 suggests that impacts of salinisation on the aquatic communities are to be expected whereas the threshold value above which changes take place is probably considerably < 200 mg/l (Halle and Müller 2013, Pohlon and Schulz 2016).

Biological parameters

Results of the macroinvertebrate metrics are given in table 2 and figure 4. The metrics no. of taxa and diversity indicate the integrity of a biocoenosis, unaffected invertebrate communities being characterised by high species numbers and low abundances. Numbers of macroinvertebrate taxa were highest at the freshwater-marked sampling location near the city of Worbis. In the following section numbers dropped slightly, a distinct decrease was found for the strongly salanised section below the storage basin near Wipperdorf between Großfurra and Sachsenburg. At Hachelbich, macroinvertebrate numbers increased a little (fig. 4, top left). An explanation for this may be that the creek Hachel flows in somewhat above the sampling location and transports animals into the Wipper river. Number of macroinvertebrate species were inversely correlated with chloride (r= -0.7912) and moreover sulfate (r=-0.9370). These findings are in contrast to the observation that slightly salanised river sections often display enhanced species numbers probably due to a faciliated osmoregulation of many aquatic insect

Table 2: *Macroinvertebrate metrics. Values are given as average means of the years 2008 to 2014 and the corresponding standard deviation. Parameters are number of taxa, diversity (SWI, Shannon Weaner Index), percentage of neozoa, percentage of sensitive species (EPT=Ephemeroptera, Plecoptera, Trichoptera, EPTCBO= Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Bivalvia, Odonata), r/K proportion, percentage of freshwater, oligo and mesohaline species.*

serial no.		1	2	3	4	5	6	7
location		Worbis	Wülfingerode	Sollstedt	Bleicherode	Großfurra	Hachelbich	Sachsenburg
river km	km	85.6	73.2	68.7	62.0	43.8	29.2	0.40
no. of taxa		29.7±3.5	26.6±5.0	26.7±3.3	26.5±3.2	22.7±2.8	24.3±3.8	19.3±1.3
SWI		2.17±0.40	2.11±0.42	2.22±0.27	2.57±0.18	2.17±0.24	1.99±0.59	1.41±0.36
neozoa	%	0.68±0.76	1.2±2.25	1.42±1.73	3.35±3.55	8.14±6.64	9.41±7.64	4.18±3.48
EPT	%	39.6±6.34	33.0±14.11	39.2±7.29	43.6±5.01	23.4±5.19	11.8±9.92	15.8±5.14
EPTCBO	%	14.00±3.63	13.29±1.83	13.00±1.93	14.00±1.53	9.86±.2.17	11.00±2.78	7.00±1.31
r/K ratio	%	0.13±0.03	0.15±0.03	0.16±0.03	0.14±0.03	0.17±0.05	0.18±0.06	0.24±0.03
freshwater	%	41.1±13.9	50.2±10.2	51.2±8.8	33.3±3.9.	27.8±8.3	42.1+18.9	23.8±13
oligohaline	%	0.5±0.3	0.5±0.5	0.5±0.4	0.9±0.9	5.2±3.3	4.2	1.3±1.0
mesohaline	%	0.1+0.1	0.5±0.5	0.3±0.3	0.7±0.7	0.3±0.3	1.2+1.49	0.8±0.6
no data	%	56.6±14.2	49.1±10.2	48±8.5	65.1±4.2	66.7±10.5	51.2+23.8	74.1±13.9

species (Kefford et al. 2016 and observations of the author). However, this pattern can be observed with regard to the diversity (Shannon Weaner Index): The index showed increased values in the moderately and dropping ones in the strongly salanised section (fig. 4, top right).

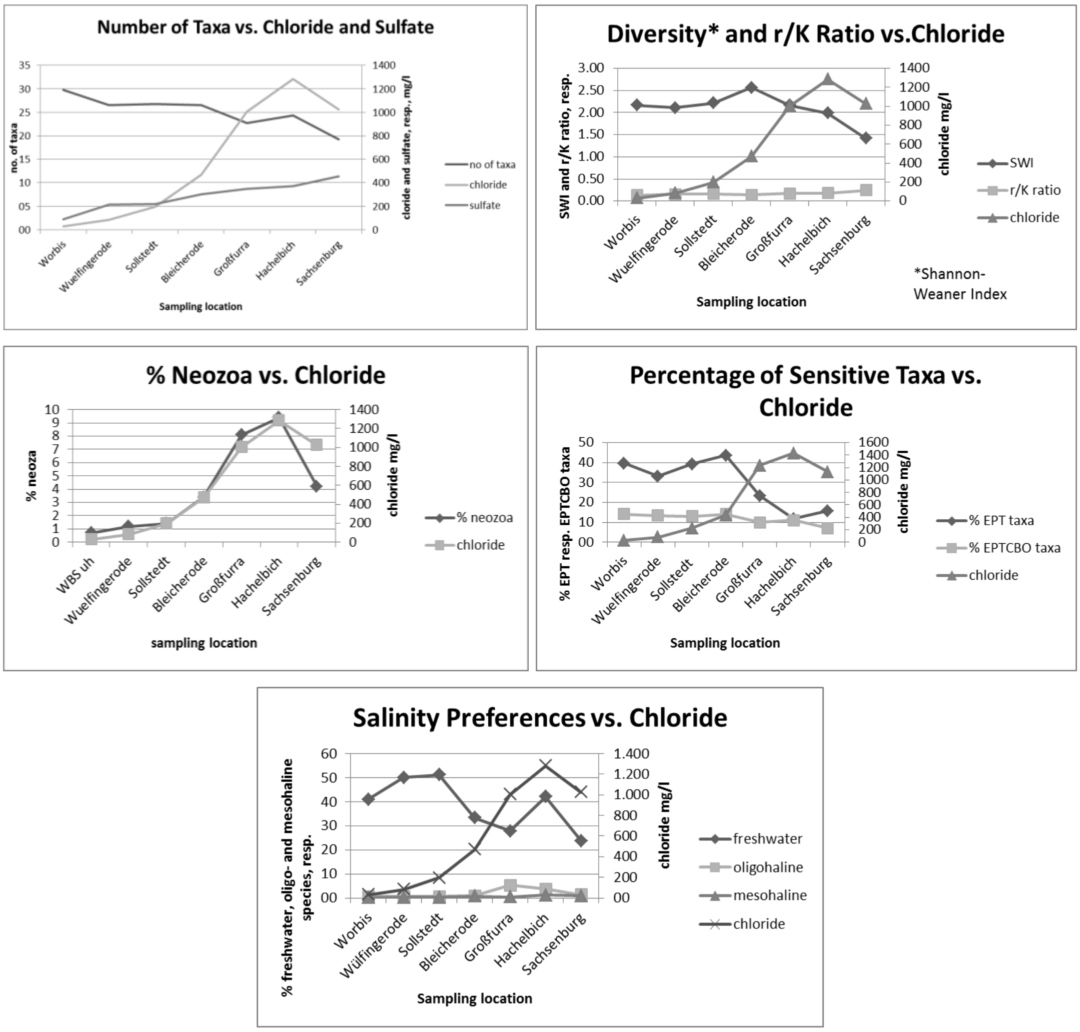

Fig. 4: *Macroinvertebrate metrics: Total number of species (top left), diversity/Shannon Weaner Index and r/K ratio (top right), percentage of neozoa (middle left), percentage of sensitive (=EPT and EPTCBO taxa, middle right) and salinity preferences.*

The r/K proportion describes the ratio between pioneer and climax species. Data show that r-species increased with rising salt concentrations, namely sulfate. They benefit the occurrence of species characterised by short generation times, small body sizes and high indivudual numbers ("r-species").

A suppression of the authochtonous fauna by increasing salt concentrations favours the spreading of neozoa due to their tolerance of salinity and further environmental parameters (Canedo-Arguelles et al. 2015). The proportion of neozoa is usually low in unaffected, stable communities. This is consistent with the observed distribution of neozoa species: Except for the last sampling location their percentage increases continually (fig. 4, middle left), thus following the concentrations of potassium, magnesium and chloride.

Aquatic macroinvertebrates may differ considerably in their salt sensitivity. Especially among the mayflies, stoneflies and caddis flies (Ephemeroptera, Plecoptera, Trichoptera) being typical for near-natural running waters ecosystems, are many sensitive taxa. A high proportion of EPT taxa indicates undisturbed conditions. In reference to the Wipper river low values were found in the strongly salinised section (Großfurra – Sachsenburg). Here salt conctrations obviously exceed the salt thresholds tolerable for many species. Percentage of EPT taxa was inversely correlated with the concentrations of potassium, magnesium, chloride and sulfate (r=- -0.8495, -0.8620, -0.8720, -0.7448, resp.). Interestingly the percentage of EPT taxa of the moderately salanised section exceeds that of the unsalanised reference site Worbis in at least one case (Bleicherode). Here a pattern similar to the above mentioned becomes visible: Slightly elevated salt concentrations may favour the occurrence of EPT species on the whole although it must be taken into account that a number of strongly salt sensitive species may have been eliminated already. Even though beetles, mussels and dragonflies (Coleoptera, Bivalvia, Odonata) are included (→ % EPTCBO) higher vales of the un- and slightly salanised section were opposed to lower values of the strongly salinised part (fig. 4, middle right). In this case also negative correlations between macroinvertebrates and salts are given (potassium r=-0.7727, magnesium r=-0.7995, chloride r=-0.7688, sulfate r=-0.8345).

The PERLODES software designates the macroinvertebrates to one of the following salinity groups: freswater, oligohaline, mesohaline, polyhaline and euhaline species. The proportion of freshwater, oligo- and mesohaline species indicates the salt tolerance focus of a given invertebrate community. In the present evaluation neither poly- nor euhaline species were found. The percentage of freshwater species was highest in the un- and slightly salanised part and lowest in the strongly salanised section. Increasing salinities were followed by a decrease of freshwater species and elevated proportions of oligo- and mesohaline species (fig. 4, bottom). This means that salt sensitive freshwater taxa were replaced by more salt resistant forms.

Table 3: *Diatom metrics. Values are given as average means of the years 2008 to 2014 and the corresponding standard deviation.*

serial no.		1	2	3	4	5	6	7
location		Worbis	Wülfingerode	Sollstedt	Bleicherode	Großfurra	Hachelbich	Sachsenburg
river km	km	85.6	73.2	68.7	62	43.8	29.2	0.4
no.of ref. species	%	53.0±17.1	35.7±4.6	26.7±8.1	29.2±9.1	15.8±3.8	16.8±11.1	25.5±11.8
Trophy Index (Rott)		2.67±0.2	3.01+0.1	3.05±0.1	2.99±0.1	3.04±0.1	3.07±0.1	3.06±0.1
Halobion Index		2.6±2.1	6.5±2.6	14.3±4.4	18.0±6.7	28.1±7.3	34.5±6.8	33.4±6.0

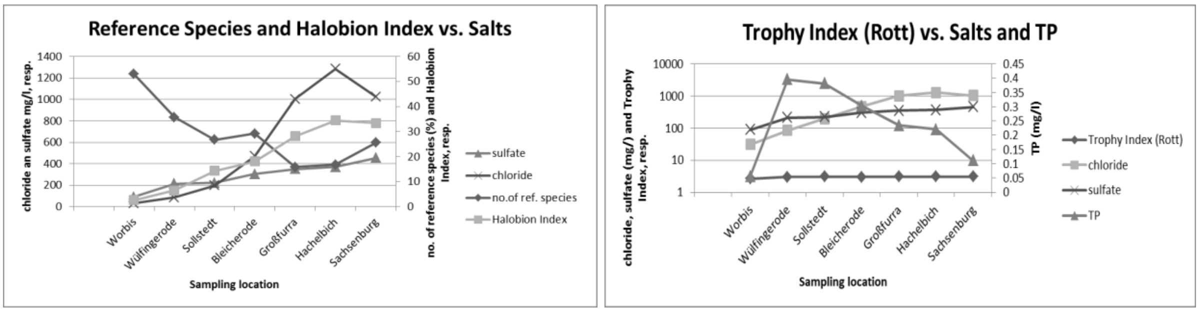

Fig. 5: *No. of reference species and Halobion Index vs. salts (left) and the Trophy Index according to Rott vs. salts and total phosphorus (right)*

Results from the diatom metrics are presented in table 3 and fig. 5.The proportion of reference species gives a measure for the conformance of a given diatom assemblage with type-specific reference assemblages and was highest by far at the salt-free sampling location near the city of Worbis. This indicates that under conditions free of anthropogenic salt inputs the composition of the diatom assemblages were most similar to that of reference conditions. Further down (section Wülfingerode to Bleicherode) the proportion of reference species dropped to values between 35.7 and 26.7%. A further increase of salt concentrations (sampling locations at Großfurra, Hachelbich and Sachsenburg) coincided with another decline of reference species reflecting changes in the composition of the diatom communities. There was a distinct negative correlation between the proportion of reference species and concentrations of chloride (r=-0.7985), sulfate (r=-0.8108), potassium (r=-0.8234) and magnesium (r=-0.7495) visible. The opposite pattern occurred with respect to the Halobion index which indicates the biological impacts of salinisation, especially osmotic pressure and relative ion composition, on benthic diatom communities (Ziemann & Schulz 2011). Values around 0 indicate freshwater, values from +10 to +30 indicate elevated salt concentrations, values > +30 ibdicate moderate and > +50 strong salinization (Ziemann 1999, BAYLfU 2006). The Halobion Index values increased nearly continually over the total transect. They were lowest at the unsalanised locations near Worbis and Wülfingerode (2.6/6.5, resp.), slightly elevated near Sollstedt and Bleicherode (14.3 and 18.0. resp.) and peaked at Großfurra and below (28.1 to 34.5). Values were strongly correlated with the concentrations of potassium (r=0.9796), magnesium (r=0.9824), chloride (r= 0.9749) and sulfate (r=0.9419). Data suggest that increasing salt concentrations led to shifts in the species structure whilst haloxenic taxa were replaced by halophilic, meso- and polyhalobic forms.

The trophy index according to Rott describes the trophic condition of a running water, In contrast to the reference species metric the trophy index remained rather balanced over the transect and did hardly reflect changes in nutrient concentrations. This is a surprising result and the reasons are still not understood. Probably elevated salt concentrations overlay the effects of other stressors.

Conclusions

As demonstrated by the case study salinisation may affect the aquatic communities of running waters in several ways. In general, benthic macroinvertebrates responded to elevated salt concentrations with a decrease in species numbers and diversity. Development of r-species and spreading of neozooa were favoured, and salt-sensitive groups declined. Freshwater species were replaced by more salt-tolerant forms.

Similar effects were observed in view of benthic diatom communities. Numbers of reference species decreased, and shifts in the diatom assemblages took place whilst the proportion of salt-tolerating (meso- and polyhalobic) taxa increased.

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