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Effects of tributaries on mainstem periphyton assemblages in relation to catchment landuse

Master thesis

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Abbreviations

ANOVA: Analysis of variance
AFDM: Ash free dry mass
AI: Autotrophic index
DN: Dissolved nitrogen
DOC: Dissolved organic carbon
DP: Dissolved phosphorus
GIS: Geographic information system
NTU: Nephelometric turbidity unit
PN: Particulate nitrogen
POC: Particulate organic carbon
PP: Particulate phosphorus
RCC: River continuum concept
SDC: Serial discontinuity concept
TIC: Total inorganic carbon

Abstract

The spatial importance of tributaries along a river has been shown in several studies. Tributaries reflect the anthropogenic activities within the catchment and, due to their interruption of the river continuum, they form heterogeneous in which biodiversity and productivity may be enhanced. If productivity rises, we also should find changes in primary production and periphyton community structure. The ecological importance of periphyton has been a topic of numerous studies. Based on these two aspects, I hypothesized that periphyton community structure differs between tributaries draining different kinds of land use types regarding biomass, chlorophyll-a and taxa composition. I also expected tributaries to affect mainstem periphyton community structure as reflected in the basic land use in the respective catchment.

To test these predictions, I analysed in winter 2009-2010 nine confluence zones comprising tributaries draining three different land use types: urban, agricultural and natural. Six confluence zones were within the Mönchaltdorfer-Aa catchment and three within the Kempt catchment. Both catchments are located near Zurich and can be defined as pre-alpine river systems. After defining three sub-sites per confluence zone (upstream, downstream and tributary), various samples were collected and a rough physical characterisation of each site was performed. I took water samples for chemical analysis and replicate stones (n = 10) with periphyton for analysing ash free dry mass (AFDM), chlorophyll-a and taxa composition of the algae. The results did not support the two hypotheses. I therefore suggest that the outcome of the study would have differed if the survey was carried out during spring/summer when the effects of land use on streams are likely most pronounced.

1 Introduction

The longitudinal characteristics of a river system including discharge, substrate size and other physical parameters, and the ecological development along its continuum are generally based on the river continuum concept (RCC) (Vannote et al. 1980). Nevertheless, the RCC, being a clinal concept, does not look at habitat discontinuities as being physically and biologically important. The confluence zones of tributaries with the mainstem are physical disturbances in the river continuum. Rice et al. (2001) showed that species richness of invertebrates are highest in confluence zones and can thus be regarded as biological hotspots. It was speculated that the reason for this peak in biodiversity was a higher habitat complexity and productivity. These hotspots are distributed discontinuously along a river and could rather be described in line with the serial discontinuity concept (SDC) instead of the RCC (Ward 1983; Stannford 1995). The SDC focuses on the interruption of resource continua. These interruptions are, for example, an abrupt change in water volume, nutrient concentration or general water quality, exactly the factors in which a tributary may be able to influence the main stream (Rice et al. 2001). Here we must take into account that these effects vary between different kinds of catchments regarding their basic land use (Hynes 1975; Likens et al. 1977). A tributary draining an agricultural area can have higher nutrient, salt or even herbicide or pesticide concentrations than a tributary flowing through a natural catchment. Even though the importance tributaries are often discussed and their high abundance in river networks, the empirical analysis of tributary effects on mainstems are quite rare.

Regarding the ecological effects of tributaries on mainstems, we must also include the influence on periphyton communities. Attached to submerged surfaces, periphyton communities are composed of photoautotrophic algae, bacteria, protozoa, fungi and detritus, all having various key roles in aquatic ecosystems. They can affect water chemistry, habitat availability and food web dynamics (Larned 2010). In many cases, periphyton is, next to fallen leaves from riparian vegetation, the primary source of energy for a river system and provides habitat and food resources for invertebrates and fish. Therefore, periphyton increases the overall productivity of river ecosystems (Azim 2005). Besides being an energy source, Vymazal (1987) showed that periphyton has an enormous purification potential by taking up and retaining nitrogen and phosphorus. An additional function of periphyton is as an indicator of water quality. Due to the naturally high number of species and the sensitivity / tolerance of some taxa to changes in nutrient availability and chemical conditions, the periphyton composition reflects the water quality and general health of the river ecosystem (Vis 1997).

These attributes of periphyton assemblages lead to two major hypotheses that were tested in the present study.. First, periphyton community structure varies between different kinds of land us types in terms of biomass, chlorophyll-a and taxa composition. Second, tributaries differently affect periphyton assemblages in mainstem rivers depending on the dominant land use in the tributary catchment.

2 Materials and Methods

2.1 Study area

For the study, two river systems were chosen. One was the Mönchaltdorfer-Aa, a main inflow into Lake Greifensee. The Aa was selected as a study system for the NRP61 project iWaQa (Link 1, see references), thus the data collected in my study could be used directly within the iWaQa project (Link 2, see references). The second river was the Kempt, a stream near Dübendorf. Due to its similar size and land use in its catchment, the Kempt served well as a second study catchment. Both systems can be characterized as pre-alpine rivers.

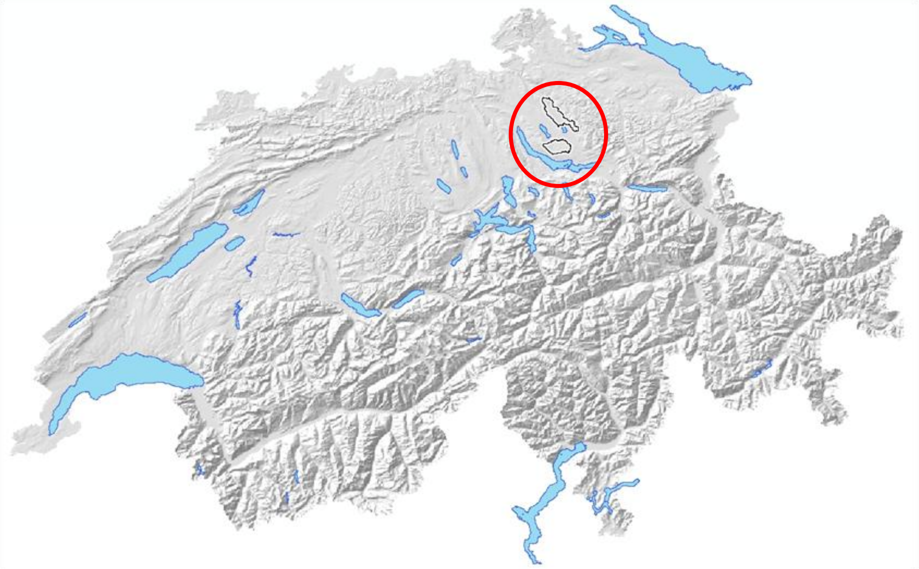


Fig. 1 Map of Switzerland, red circle marking the study systems delineated with a black line.

2.2 Study sites

The sampling sites were chosen based on GIS (Geographic Information System) maps (Fig. 2). The layers for basic land use and stream geomorphology provided the necessary information to define the sampling sites. The tributaries were categorized depending on the dominant land use type within the watershed, such as urban (settlement area), agricultural (intensive, extensive) and natural (forest). Six sites in the Mönchaltdorfer-Aa system and three sites at the Kempt were selected based on these categories. In total, three urban, three agricultural and three natural tributaries were chosen (two of each category within the Mönchaltdorfer-Aa and one within the Kempt system).

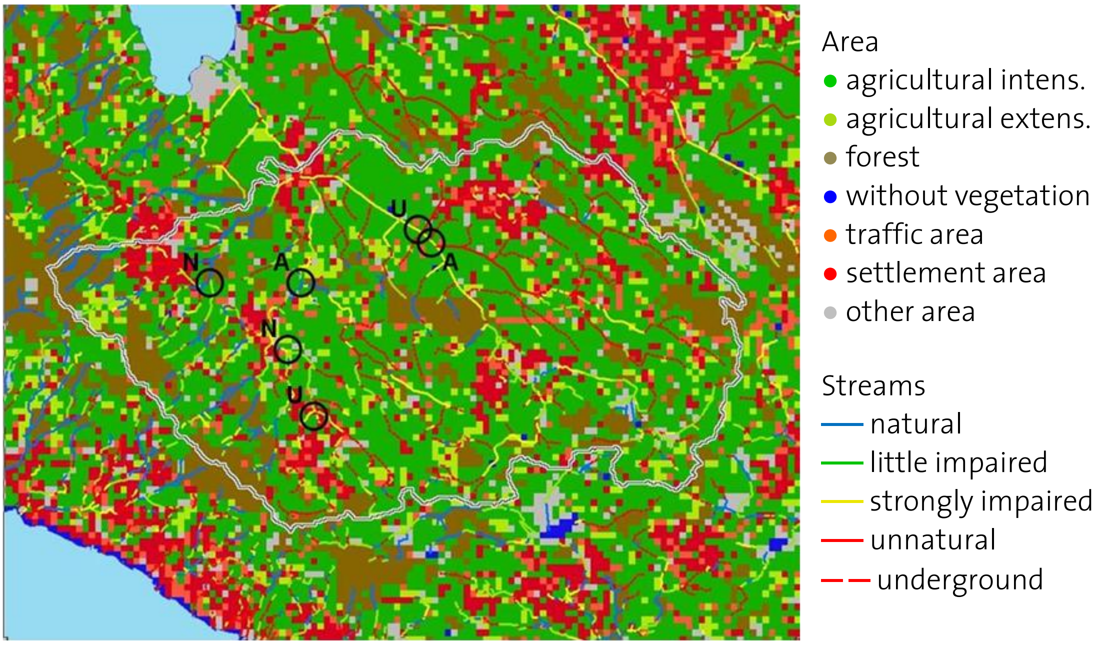


Fig. 2: Example of GIS map (Mönchaltdorfer-Aa), N,A,U marking natural, agricultural and urban sites chosen

Table 1 lists all sites and the categories to which they are assigned. The values are the relative amounts of different kinds of land use in the corresponding catchment. The double listing of each site is due to the discrimination of mainstem and its tributary. These two positions always form a confluence zone. The relative values of the mainstem positions includes the area above the confluence zone within the whole catchment.

Tab. 1: The relative amount of different kinds of land use area, yellow marked cells indicate significance compared to other category types.

Site	Type	Position	Agricultural intensive	Agricultural extensive	Forest	Without vegetation	Traffic area	Settlement area	Other area
Brandbach	Agricultural	Tributary	57.9%	4.5%	28.9%	0.0%	2.4%	4.3%	2.0%
Brandbach	Agricultural	Main Stem	46.9%	6.4%	28.0%	0.4%	4.8%	8.9%	4.7%
Rohrbach	Agricultural	Tributary	70.4%	10.9%	6.6%	0.0%	4.5%	4.5%	3.1%
Rohrbach	Agricultural	Main Stem	51.9%	7.1%	17.5%	0.0%	6.7%	13.0%	3.8%
Gossau A	Agricultural	Tributary	65.3%	8.0%	8.1%	0.0%	9.5%	7.1%	1.9%
Gossau A	Agricultural	Main Stem	59.6%	7.1%	16.5%	0.3%	3.7%	8.1%	4.6%
Hühnerbach	Natural	Tributary	46.3%	3.4%	43.5%	0.0%	3.9%	2.0%	0.8%
Hühnerbach	Natural	Main Stem	49.0%	6.0%	26.5%	0.3%	4.8%	9.0%	4.3%
Egg	Natural	Tributary	61.5%	0.0%	36.6%	0.0%	1.4%	0.0%	0.5%
Egg	Natural	Main Stem	30.1%	10.6%	33.2%	0.3%	3.1%	19.2%	3.5%
Esslingen	Natural	Tributary	43.6%	3.2%	42.3%	0.0%	3.5%	6.0%	1.5%
Esslingen	Natural	Main Stem	55.4%	8.1%	8.9%	0.0%	6.4%	16.9%	4.2%
Effretikon	Urban	Tributary	38.1%	1.1%	22.5%	0.3%	9.6%	20.6%	7.8%
Effretikon	Urban	Main Stem	49.0%	5.7%	28.3%	0.3%	4.9%	8.1%	3.7%
Oetwil	Urban	Tributary	46.4%	8.1%	16.7%	0.0%	9.5%	16.3%	3.0%
Oetwil	Urban	Main Stem	50.5%	9.7%	8.8%	0.0%	5.6%	20.4%	4.9%
Gossau U	Urban	Tributary	50.9%	5.1%	14.0%	0.2%	6.3%	18.5%	4.9%
Gossau U	Urban	Main Stem	61.4%	7.3%	13.9%	0.2%	5.5%	7.7%	3.8%

There are significant variations between the different kinds of land use when analyzing the categorization of the tributaries. The tributaries defined as agricultural have significantly more "agricultural intensive" area (ANOVA, p=0.049) than natural or urban tributaries. There is no significant difference (ANOVA, p=0.142) when comparing the extensive agricultural area between tributary categories, but the extensive area has very low values compared to the intensive and can therefore be neglected. Looking at the amount of forest in the tributary catchments, we see a significantly higher value for the natural category (ANOVA, p=0.013). The area without vegetation can also be neglected due to its very low abundance. The amount of traffic area shows no significances between the different kinds of tributaries (ANOVA, p=0.092), but a trend of higher values in urban areas is visible. Looking at the settlement area, there is a highly significant difference of urban tributaries from the other categories (ANOVA, p=0.0003). The last column "other area" can be neglected as well, although there is significantly more "other area" within the urban tributary catchments (ANOVA, p=0.032). These GIS-based data perfectly supports the categorisation of the chosen tributaries.

As can be seen in the site table, there is a double listing for Gossau. This is due to the very close situation of two different sites, one agricultural and one urban. To prevent misunderstandings regarding site names, Gossau will always be followed by a U for urban and A for agricultural.

2.3 Sampling

Sampling started on 28 January 2010 with the site called Egg. By 18 February 2010, all six sites in the Mönchaltdorfer-Aa system were sampled. The three other sites in the Kempt system were sampled between 25 February and 3 March 2010. Sampling could only be done once, otherwise the generated amount of data could not have been processed within the six month time limit of the master thesis. It must be noted that each site was sampled during one day, so there is no difference in date for any one site.

At each sampling site, 3 sub-sites were defined. One upstream in the mainstem, one within the tributary and one below the confluence zone defined as downstream. This downstream sub-site was located beyond the mixing zone. Measuring and sampling was conducted at each of these sub-sites. For a rough characterisation of each sub-site, five water depths along a transect within each sub-site as well as three stream widths were measured. To characterize substrate size, I measured the B-axis of 10 randomly selected stones. Further a 500ml water sample was taken for analysis in the laboratory at the EAWAG, Dübendorf, for common bioactive parameters (DOC, POC, conductivity, pH, alkalinity, TIC,

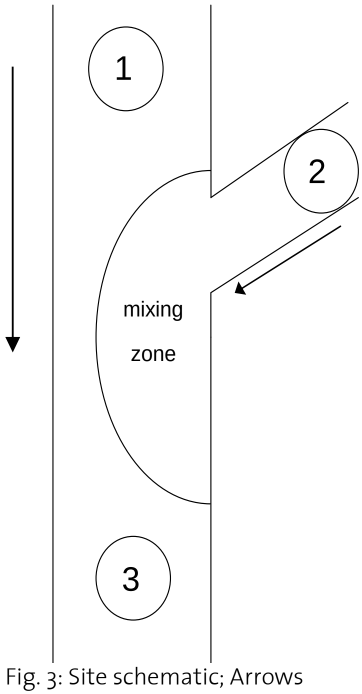


Fig. 3: Site schematic; Arrows indicate flow direction; Sub-sites: 1 Upstream, 2 Tributary, 3 Downstream

NH_4-N, NO_2-N, NO_3-N, DN, PN, PO_4-P, DP, PP). Temperature, conductivity and pH were also measured on the field with a combo pH & EC device (Hanna, Combo pH & EC). Turbidity measurements were taken twice at each sub-site with an optical turbidity meter (Cosmos, Züllig AG). To make any conclusions regarding tributary effects, I quantified the discharge ratio of tributary / main stem. At each sub-site, discharge measurements were conducted using a Doppler velocity meter (Flow tracker, SonTek). For an accurate discharge measurement, it was crucial to pick a transect with a consistent depth and doing as many measurements within a transect as possible. All velocity readings were taken at 60% depth and the discharge was automatically calculated by the device.

Finally, 10 stones with periphyton cover were collected per sub-site. This collection of stones was not completely random, but represented the different kinds of periphyton patches within each sub-site. These stones were put into a zip-lock bag, returned to the lab in a cooler, and stored in a freezer at -20°C for further analysis.

2.4 Laboratory analysis

For each of the 10 stones per sub-site, three parameters were analysed, including ash free dry mass, chlorophyll-a and taxa composition. First, the stones were left to thaw within the zip-lock storage bag. From each stone, an area of $9cm^2$ was scraped of periphyton and placed in an Erlenmeyer flask with a total amount of 100ml water. The scraping was conducted with a dremel (Model 395) and a steel brush (dremel ID:442) at the lowest speed level ($\approx$ 10'000 rpm).

Fig. 4: Stone with scraped area, right top corner of dish: Plexiglas template used for scraping

Two filtrations of this 100ml solution were carried out. For chlorophyll-a analysis, 10ml of this periphyton solution were filtered (Whatman, GF/F, Ø 47mm), and the filter was put into a glass tube filled with 8ml of 90% ethanol. To assure a proper extraction of the chlorophyll, all tubes were put into a hot water bath at 60°C for 10 minutes. After extraction, the samples were covered with aluminium foil and stored at 4°C until analyzed with the HPLC. In a second step, the ash free dry mass was analyzed. Here, 25ml of the basic solution was filtered and the filters placed in a ceramic dish for drying. After drying (Binder, FD 115) for at least two days at 60°C, the samples were weighed, burned at 500°C for four hours (Oven: Nabertherm, Model N150) and then weighed again. The weight difference before and after burning corresponds to the ash free dry mass.

From these two parameters, AFDM and chlorophyll-a concentration, the autotrophic index (AI) was generated. By simply dividing AFDM/chlorophyll-a concentrations, the value tells us how strong a system is affected by organic pollutants. According to Collins & Weber (1978), AI values between 50 and 100 indicate non-polluted systems and autotrophs are dominating the system. Values between 100 and 400 define a system affected by organic substances. Systems with values higher than 400 are dominated by heterotrophs and have high concentrations of organic pollutants.

For a semi-quantitative (categories: 1 sporadic, 2 seldom, 3 regularly, 4 frequent, 5 dominant) taxonomic analysis of the collected periphyton assemblages, a 3ml algae solution from each stone per sub-site was placed in a storage vial and later analysed by an Eawag technician.

2.5 Statistics

The statistical analysis was carried out with two statistic programs. Analysis of variance (ANOVA) and plotting of regressions was done with JMP (SAS) and principal component analysis (PCA) was made using Statistica (StatSoft).

Analysing the variation of data within stream types and position and between sites was conducted by a one factorial ANOVA. This test was used to indentify significant differences among the data.

To compare the results of AFDM, chlorophyll-a and autotrophic index between stream types and positions a Tukey-test was performed.

The high amount of variables from the chemical analysis, was reduced to a manageable amount of principal components by carrying out a PCA.

To be able to see any relations between species richness, chlorophyll-a, AFDM and the AI a correlation matrix was generated.

3 Results

3.1 Physical characterization

The physical parameters give a rough impression of the study streams. As seen in figure 5, the mean width range ranges from about 1 meter at the tributary site at Egg to nearly 8 meters at the Brandbach downstream site. Comparing all sites (downstream sub-sites excluded), the tributaries are, as expected, significantly smaller (p=0.024) than the main stem. Mean depths (Fig. 6) ranged from 6 cms at the tributary site at Egg to nearly 40 cm at the Effretikon main stem site, and there is no significant difference between the tributaries and the main stem (p=0.138).

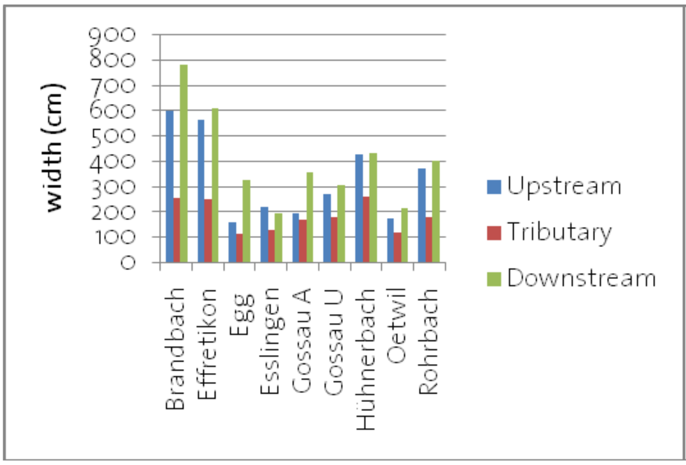


Fig. 5: Mean width of each sub-site

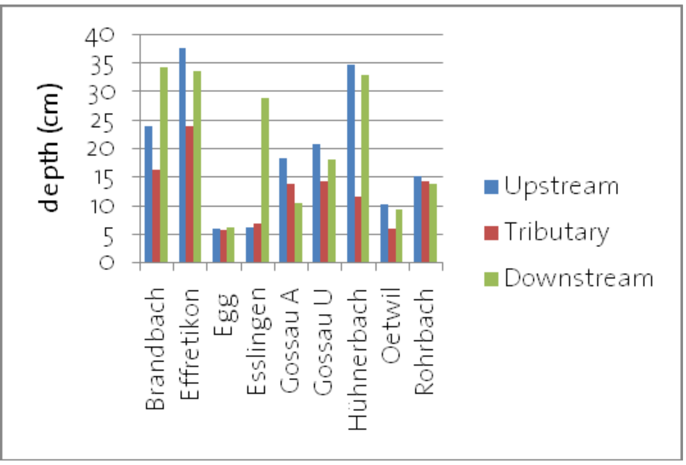


Fig. 6: Mean depth of each sub-site

The 10 randomly measured stones at each sub-site resulted in mean values ranging from 3.5 cm at the Esslingen tributary site to 11.6 cm at the Gossau A upstream sub-site. No significance difference between tributaries and respective mainstems (p=0.594) or between land use types (p= 0.834) could be detected.

The turbidity measured at all sites was in general quite similar (Fig. 7). At the Brandbach (agricultural), the mainstem sub-sites at Egg (natural), the tributary sub-site at Gossau (agricultural) and the Oetwil (urban) site had the highest NTU values. Here it must be noted that the maximum depth was so low at some sites that it could have affected the accuracy of the turbidity meter, although this

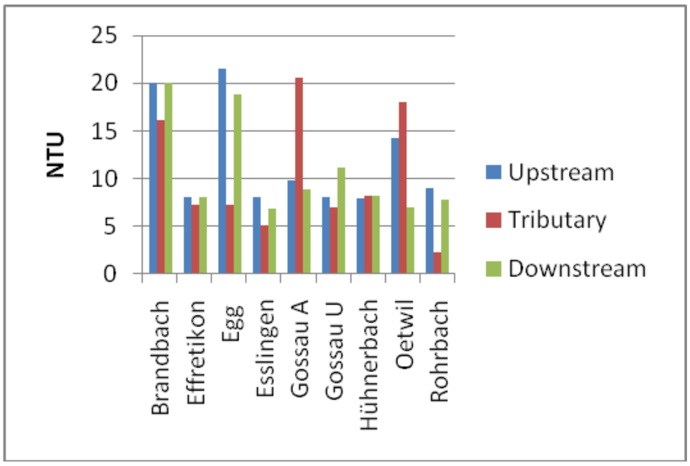


Fig. 7: Mean NTU values of each sub-site

is not the case at each site with high NTU values.

Conductivity values showed some variation (Fig. 8). The lowest value of 417 µS/cm was found at the Hühnerbach (natural) tributary sub-site and the highest at the Gossau U tributary sub-site at 1031 µS/cm. Despite this quite high variation, there was no significant difference between natural and agricultural (p=0.073) or natural and urban (p=0.111) sites.

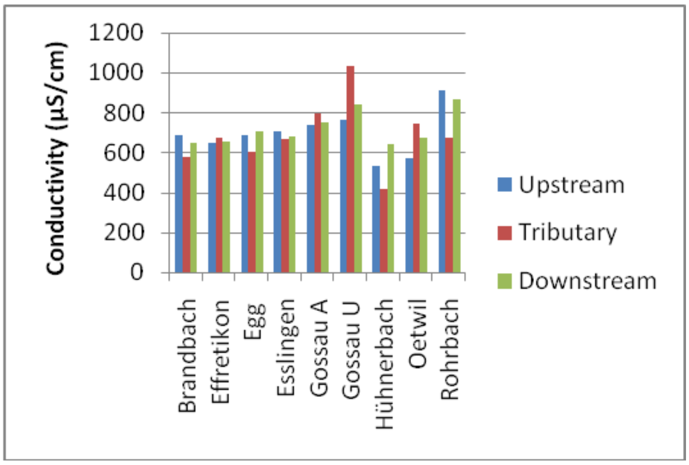


Fig. 8: Conductivity values of each sub-site

Figure 9 shows the measured discharge at each site. Here we must take into account that these values just represent one point in time and therefore cannot be compared to the annual mean. There is nearly a significant difference in the discharge of all tributary and upstream sub-sites (p=0.055), but if we take the size ratios (upstream-tributary) of each site it looks as shown in figure 10. The highest ratio is at the Egg site with a 12.4 times higher discharge at the upstream sub-site than in the tributary. The most equal site regarding discharge was at Gossau U with a ratio of 1.27. These data shows that the site selection was appropriate because there should not be too high maintem-tributary discharge ratio. A too high ratio would have reduced a possible tributary effect.

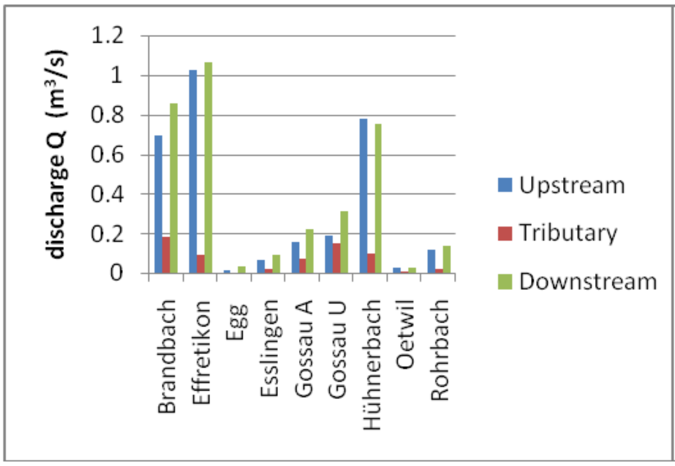


Fig.9: Discharge values per sub-site

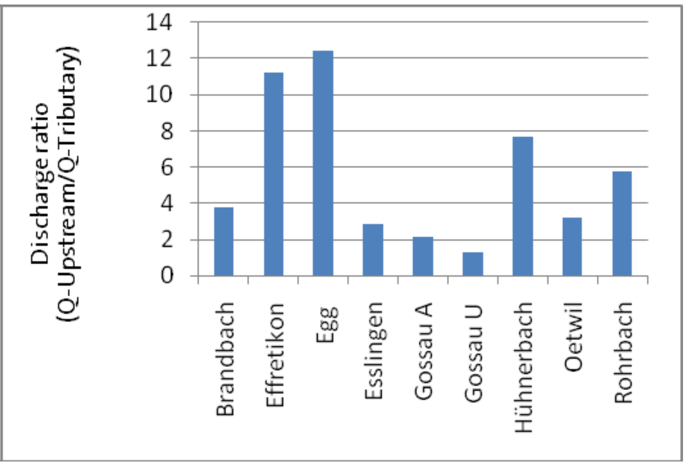


Fig. 10: Discharge ratio; Q-Upstream/Q-Downstream

3.2 Chemical characterization

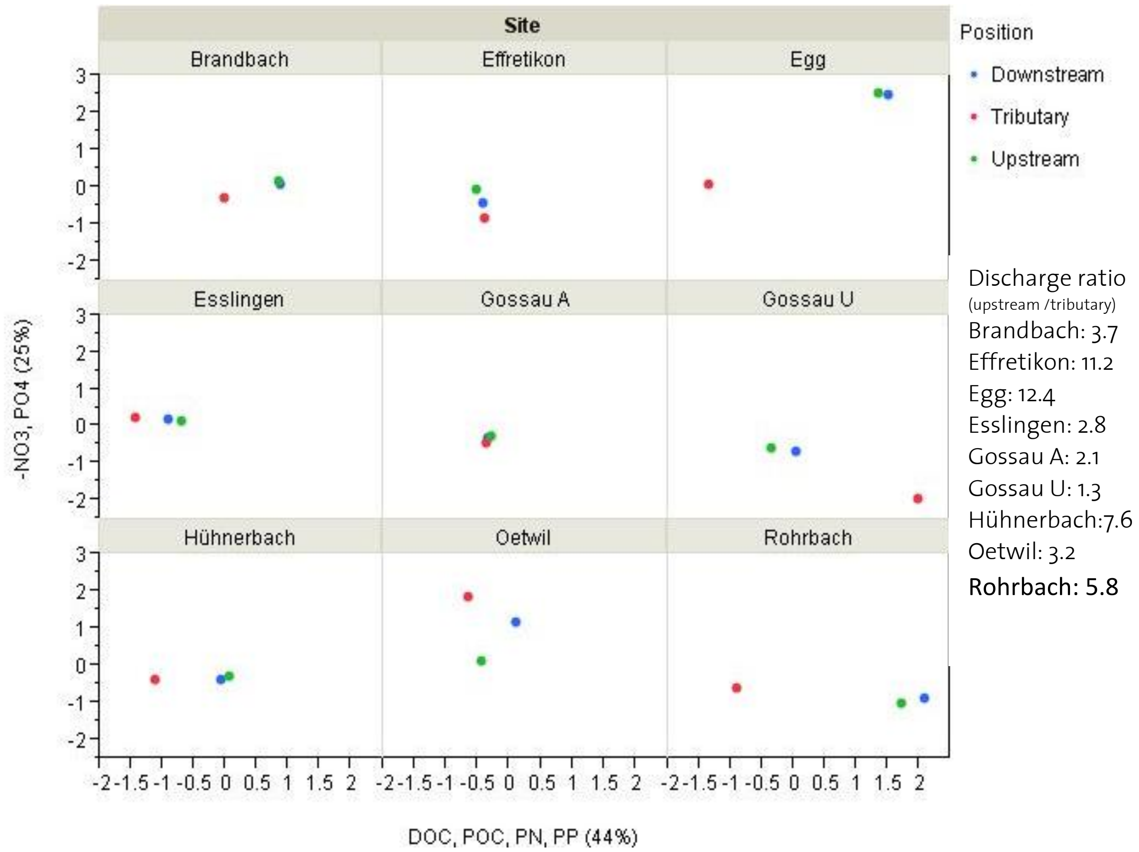
Chemical analysis of the water samples taken at each sub-site was conducted by the AuA-Laboratory at Eawag, Dübendorf. Table 2 shows all the results of the analysis.

Tab. 2: Summary table of chemical analysis for each sub site.

Date	Site	Type	Position	DOC mg C/L	POC mg C/L	Conductivity µS/cm	pH	Alkalinity mmol/L	TIC mg C/L	NH_4-N µg N/L	NO_2-N µg N/L	NO_3-N mg N/L	DN mg N/L	PN mg N/L	PO4-P µg P/L	DP µg P/L	PP µg P/L
28.01.2010	Egg	Natural	Downstream	3.1	1.94	638	8.15	5.64	67.7	1232.0	17.6	2.0	3.9	0.21	192.4	201.4	10.9
28.01.2010	Egg	Natural	Tributary	1.6	0.30	550	8.12	6.03	72.4	26.9	1.2	1.9	2.0	0.03	10.8	13.9	2.2
28.01.2010	Egg	Natural	Upstream	2.9	1.96	619	8.20	5.50	66.0	1015.0	11.8	1.9	3.0	0.20	138.6	156.6	11.2
28.01.2010	Rohrbach	Agricultural	Downstream	3.7	1.33	859	7.93	5.23	62.8	984.0	147.2	9.1	10.4	0.19	13.4	27.5	15.6
28.01.2010	Rohrbach	Agricultural	Tributary	2.3	0.45	610	8.19	6.22	74.6	15.6	4.6	3.1	3.3	0.03	10.5	14.6	2.7
28.01.2010	Rohrbach	Agricultural	Upstream	3.2	1.19	824	7.89	5.24	62.9	76.4	117.8	8.9	9.1	0.16	11.4	23.4	11.2
04.02.2010	Gossau U	Urban	Downstream	2.8	0.71	758	8.01	6.01	72.1	183	22.5	3.6	3.6	0.07	6.1	9.9	<1.0
04.02.2010	Gossau U	Urban	Tributary	3.8	1.14	959	7.68	4.64	55.7	1774	179.0	9.3	11.2	0.15	7.4	19.4	6.2
04.02.2010	Gossau U	Urban	Upstream	2.6	0.58	717	8.09	6.09	73.0	25.1	6.1	2.8	2.9	0.06	5.0	8.4	1.1
04.02.2010	Gossau A	Agricultural	Downstream	2.7	0.70	686	8.11	5.90	70.8	9.9	4.6	2.7	2.8	0.06	6.9	10.8	<1.0
04.02.2010	Gossau A	Agricultural	Tributary	2.1	0.50	744	8.05	5.75	69.0	7.1	5.6	3.7	3.8	0.05	6.0	9.0	<1.0
04.02.2010	Gossau A	Agricultural	Upstream	2.7	0.77	689	8.08	5.88	70.5	7.4	4.1	2.3	2.4	0.06	5.9	8.8	<1.0
11.02.2010	Esslingen	Natural	Downstream	2.3	0.40	654	8.27	6.18	74.2	8.9	3.0	2.9	3.0	0.04	28.1	28.7	<1.0
11.02.2010	Esslingen	Natural	Tributary	1.8	0.30	616	8.22	6.24	74.9	<5.0	1.3	2.1	2.2	0.02	29.7	30.4	<1.0
11.02.2010	Esslingen	Natural	Upstream	2.7	0.42	656	8.23	6.24	74.9	7.5	3.6	2.9	3.1	0.04	27.4	28.3	<1.0
18.02.2010	Oetwil	Urban	Downstream	2.4	1.49	538	8.25	5.35	64.2	23.3	6.2	2.3	2.3	0.13	23.2	26.5	3.8
18.02.2010	Oetwil	Urban	Tributary	2.2	0.48	631	8.41	6.02	72.2	7.2	4.7	1.9	1.8	0.06	109.5	116.6	2.6
18.02.2010	Oetwil	Urban	Upstream	2.1	0.73	466	7.94	4.49	53.8	121.7	12.2	2.5	2.4	0.07	5.2	7.3	2.5
25.02.2010	Brandbach	Agricultural	Downstream	2.5	0.94	595	7.82	5.49	65.9	21.1	9.9	3.9	3.9	0.10	14.4	18.2	16.8
25.02.2010	Brandbach	Agricultural	Tributary	2.1	0.85	528	8.06	5.66	67.9	10.4	1.5	5.0	5.0	0.06	3.0	22.4	7.7
25.02.2010	Brandbach	Agricultural	Upstream	2.2	0.97	625	7.84	5.50	66.0	80.3	39.5	4.2	4.2	0.11	17.9	25.4	17.8
03.03.2010	Effretikon	Urban	Downstream	1.9	0.53	585	7.98	6.09	73.0	< 1	7.8	4.4	4.4	0.04	16.4	23.2	4.1
03.03.2010	Effretikon	Urban	Tributary	2.1	0.63	598	8.01	6.22	74.6	< 1	5.2	4.6	4.7	0.04	5.8	18.9	3.1
03.03.2010	Effretikon	Urban	Upstream	2.1	0.56	582	8.15	6.03	72.4	1.2	5.9	4.2	4.3	0.04	17.9	20.4	3.2
03.03.2010	Hühnerbach	Natural	Downstream	2.5	0.50	587	7.99	5.99	71.9	34.8	27.4	4.7	4.7	0.05	18.9	27.5	5.7
03.03.2010	Hühnerbach	Natural	Tributary	1.5	0.45	477	8.05	5.45	65.4	< 1	1.9	3.9	3.9	0.03	6.2	8.0	2.6
03.03.2010	Hühnerbach	Natural	Upstream	2.1	0.91	605	7.95	6.11	73.3	38.0	31.8	4.7	4.8	0.06	18.8	22.5	5.0

Regarding all sub-sites (up-, downstream, tributary) as one, chemical analysis of the two river systems showed no significant differences between the different kinds of land use categories. Even by solely analyzing tributaries or main stem (up-, donwstream) in land use categories, no significant difference in chemical components was visible. However, some sites showed elevated values for some specific parameters. For example Gossau U had a very high mean conductivity value of 811.3 µS/cm and the variation among all sites showed a significant difference ($p=0.003$). Another outlier site was Rohrbach with a mean NO_3-N concentration of 7.02 mg/L. The overall variation between sites for NO_3-N was also significant ($p=0.032$). It must be noted that this high mean value was derived from the mainstem sub-sites (up-, downstream) having a mean concentration of 9.0 mg/L. The tributary at 3.6 mg/L was close to the overall mean of 3.9 mg/L. For the PO_4-P and DP components, the Egg site had extremely high mean values of PO_4-P (113.9 µg/L) and DP (123 µg/L). Here we have the same situation as for NO_3-N in which the very high mean values were derived from the mainstem sub-sites.

A multivariate statistical analysis was done using principal component analysis. This reduces the high amount of variables to a manageable number of principal components. Before performing a PCA with Statistica all the data was log(x+1) transformed. The PCA analysis was carried out with the most biological relevant parameters such as DOC, POC, conductivity, pH, NO_3-N, PN, PO_4-P, PP, and turbidity. The first principal component (PC1) shows that DOC, POC, PN and PP have a higher (or lower) loading value than +(-)0.7 and explain 44% of the total variation among sites. NO_3-N and PO_4-P had a higher loading value than +(-)0.7 for PC2, and explain 25% of the total variation among sites. The first two principal components together explained 69% of the total variation among sites.



Discharge ratio
(upstream /tributary)
Brandbach: 3.7
Effretikon: 11.2
Egg: 12.4
Esslingen: 2.8
Gossau A: 2.1
Gossau U: 1.3
Hühnerbach:7.6
Oetwil: 3.2
Rohrbach: 5.8

Fig. 9: Score plot of all positions separated by sites; Discharge ratio shown in the legend gives an indication of possible tributary effects.

Figure 11 shows the PCA scores of all sites separately. Here you can see how the tributary ences the respective mainstem. At sites where the up- and downstream sub-site (green and blue dots) are on the same spot, there is essentially no influence of the tributary on physico-chemistry of the mainstem downstream. Here we must take the discharge ratio into account. The lower this value the higher a possible effect of the tributary could be on mainstem down-stream sites. For instance, the strongest tributary effect can be seen at the Oetwil site where the downstream sub-site clearly shifted away from the upstream data point. With a discharge ratio of 3.2, it is one of the more even confluence zones in respect to flows. Also, the Gossau U site with a size ratio of 1.3 and the Rohrbach site with a discharge ratio of 5.8 show some shift-ing between mainstem sites. All the other sites show no influence or only a small difference of the up- and downstream sub-site regardless of the tributary size.

By looking only at the scores of all tributaries (Fig. 12), there is some grouping visible. All natural and agricultural tributaries are clustered in two groups, whereas urban tributaries are scattered over the whole score plot.

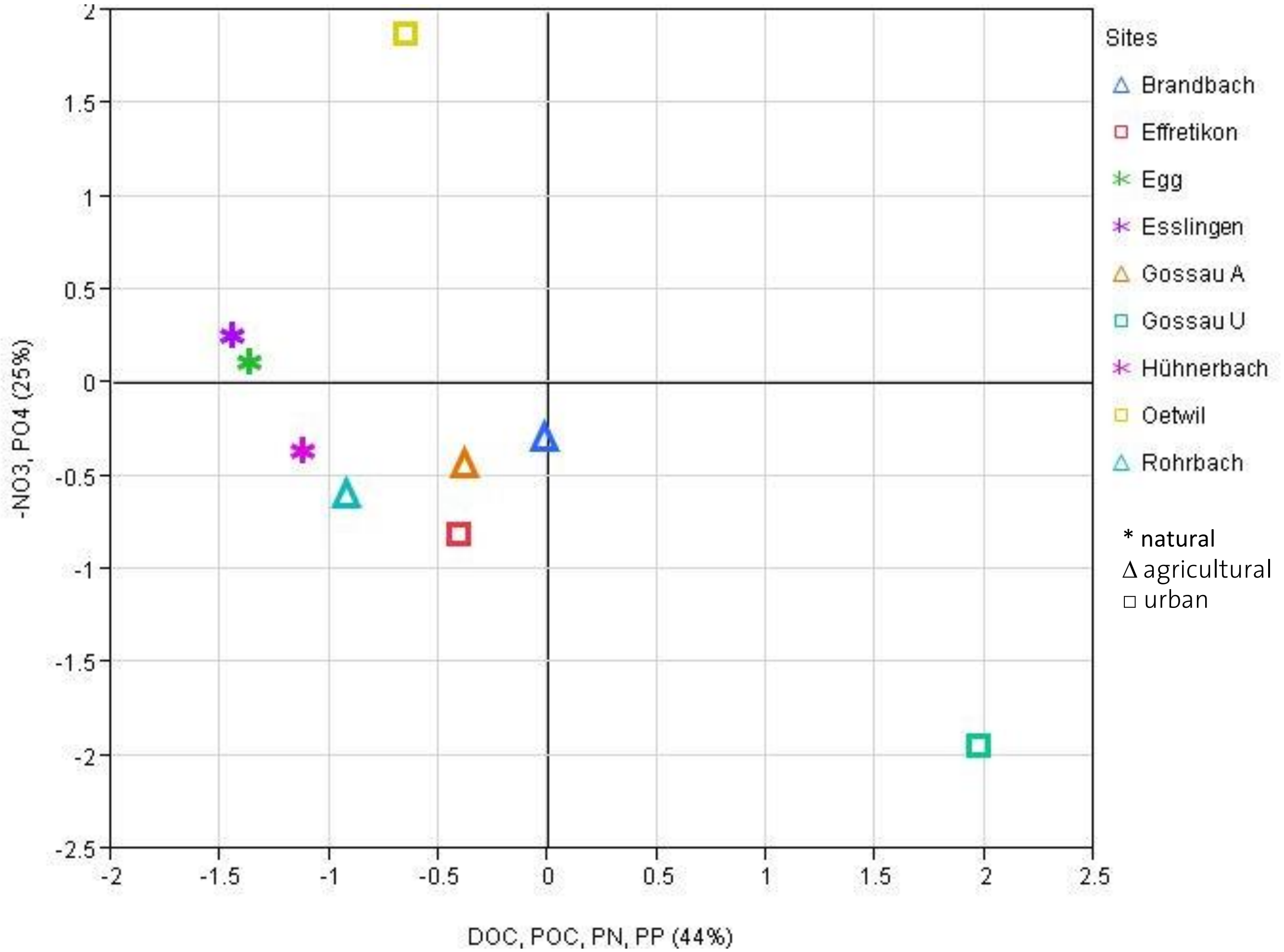


Fig. 10: Score plot of all tributaries marked by types

3.3 Periphyton assemblages

The 10 analyzed stones per sub-site provided the following results. For chlorophyll-a, the mean mass per sub-site ranged from 103.7 mg/m² at the Effretikon tributary site up to 467 mg/m² at the Oetwil tributary site. Figure 13 displays the average chlorophyll-a amounts for all sub-sites. The multivariate analysis showed that the variation in chlorophyll-a mass between all positions (up-, downstream, tributary) was significant (p=0.033) and the variation between stream types and position was significant as well (p=0.005). There was no significant difference when comparing stream types with each other (p=0.901).

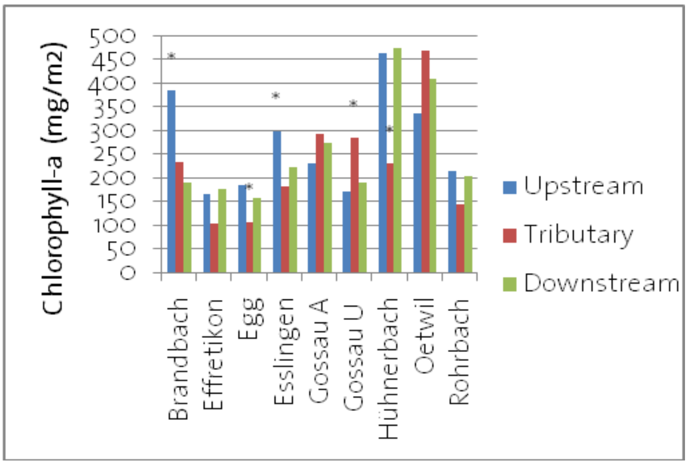


Fig. 11: Mean chlorophyll-a values per sub-site; * indicates significant differences within site.

The analysis of AFDM (Fig. 14) showed a similar variation as chlorophyll-a. At the Rohrbach downstream site, the lowest AFDM values were detected, on average 31.1 g/m^2. In contrast, at the Hühnerbach upstream site, there was a nearly three times higher mean amount of ash free dry mass at 91.9 g/m^2. A significant difference was found in the AFDM between stream types and positions (p=0.001). No significant difference was found between types (p=0.079) or positions (p=0.469).

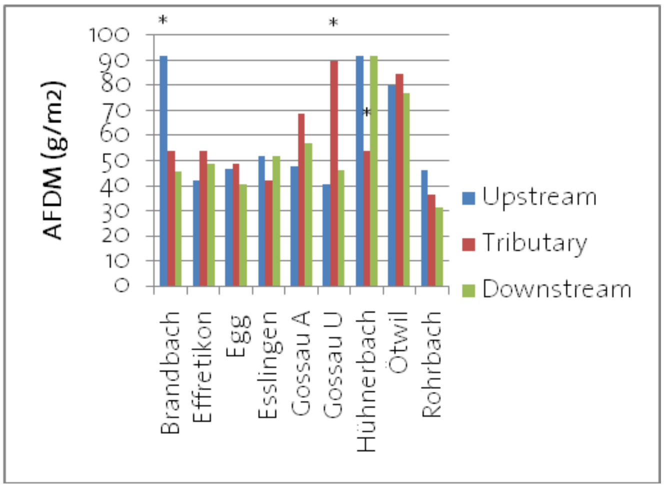


Fig. 12: Mean ash free dry mass values per sub-site; * indicates significant difference within site

Figure 15 shows autotrophic index (AI) values higher than 100 for each sub-site analyzed. This means that every site is effected by organic pollutants and every site with value higher than 400 is dominated by heterotrophs (Collins & Weber 1978). By analyzing the variation in the AI, the multivariate analysis showed, in contrast to the variation of chlorophyll-a and AFDM, no difference between stream types and positions (p=0.315) but differences within types (p=0.0005) and positions (p<0.0001).

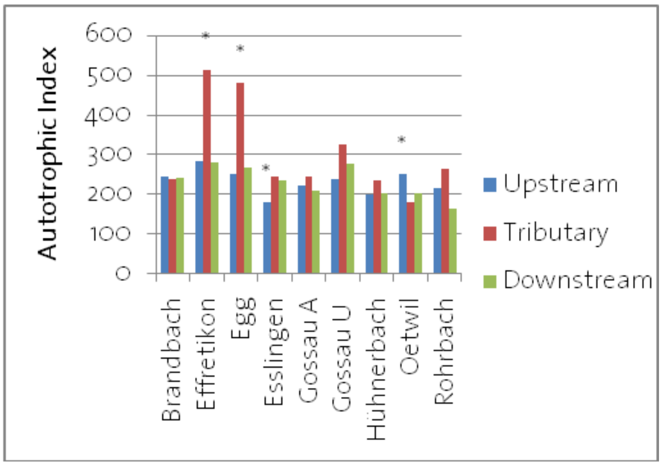


Fig. 13: Mean autotrophic index; * indicates significant differences within site

The algal taxonomic composition analysis conducted is shown in table 3.

Tab. 3: Table showing all sepcies found in the samples; Values stand for: 1 sporadic, 2 seldom, 3 regularly, 4 frequent, 5 dominant; Site codes: Eg = Egg, Ro = Rohrbach, GA = Gossau A, GU = Gossau U, Es = Esslingen, Oe = Oetwil, Br = Brandbach, Hü = Hühnerbach, Ef = Effretikon; Number coded: 1 = Downstream, 2 = Tributary, 3 = Upstream.

Diatomeen	Eg1	Eg2	Eg3	Ro1	Ro2	Ro3	GA1	GA2	GA3	GU1	GU2	GU3	Es1	Es2	Es3	Oe1	Oe2	Oe3	Br1	Br2	Br3	Hü1	Hü2	Hü3	Ef1	Ef2	Ef3
Achnanthes minutissima	3	3	3	2	2	2	2	3	2	3	3	3	2	2	2	2	2	2	2	3	3	4	3	3	4	3	4
Amphora ovalis		1			1						1	1	1					1	2	1	2	1	1	2	1		1
Amphora pediculus				2	2	2	2	2	2	2	1	2	3	2	3	3	2	2	3	4	4	2	3	3	3	3	3
Cocconeis placentula	1	1	1			1	2	4	2	2	2	2	2	1	2	3	3	2	2		3	3	1	3	2		3
Cymbella affinis							2	1										1			1		1			1	
Cymbella minuta			1							1	1	2					1		2	3	2	2	2	2	3		2
Diatoma mesodon							2	3		2	1	1											1				
Diatoma vulgare	3		3	3		2	3	4	4	3	4	3	3	4	4	4	4	4	3	3	4	3	2	3	3		3
Fragilaria ulna	3	1	2	3	2	3	4	3	4	3	3	4	4	3	2	4	4	4	3	3	3	2	2	2	2	1	1
Frustulia vulgaris											2			1		1		1								2	
Gomphonema olivaceum	3	3	4	2	1	1	4	3	4	4	3	4	3	4	4	3	3	2	2	3	2	2	2	2	2		3
Gyrosigma accuminatum	1	3	1		1			1	1				1	1	1								1			2	
Melosira varians					1	1	2	2	2	1		2	2	2	2	3	3	2	2		2	2		2	1	3	1
Meridion circulare			2				1			1		1	2	1	2	3	2	3		1		1	1	1	1	1	1
Navicula exigua	4	4	4	4	4	3	3	2	2	2	2	3	3	3	3	4	3	3	3	1	3	3		1	2	3	2
Navicula sp.			3	2	2	2	2	2	1		2	2	2	1	2	2	3	3	3	4	4	4	3	3	3	3	4
Navicula pupula							3	3	4	2	3	3	3	3	3	3	1	3	3	3	2	2	2	2		2	2
Navicula radiosa													3	3	3	1	3		2		2			2	2		2
Navicula tripunctata	4	4	4	4	4	3	4	3	3	3	3	4	3	3	3	3	2	3	3	3	3	4	3	3	3	3	4
Nitzschia dissipata	3	3	3	3	3	3	3	3	3	2	2	3	2	3	3	2	2	2	2	3	3	3	3	3	3	3	4
Nitzschia linearis	1	1	1	1	1	1	1		1		1	1		1	1	2		1	2		1	1	2	1		2	2
Nitzschia palea	4	4	4	3	3	2	3	3	3	2	2	2	2	2	2	2			2	1		1	2		1	3	1
Rhoicosphenia abbreviata	2		1	2		3	2	3	2	2	2	2	2	1	1	3	4	2	3	1	3	3	2	3	2		2
Surirella linearis							1																			1	
Surirella brebissonii	1		1		1	1	2	2	2	1		1	2	1	2	2	3	2			1		1	1	1	2	
Gomphonema accumainatum																	1	1			1						
Diploneis ovalis																				1			1		1	1	
other algae																											
Lyngbya		2	1		1		1	1	1			1				2				2	2	2	2	2			2
Trentepholia							1																				
Ulothrix	2		1			1	1	1	1										1	1	1			2			
Cladophora											1					1	3				1		1				

The most common species detected in the samples were *Achnanthes minutissima*, *Fragilaria ulna*, *Gomphonema olivaceum*, *Navicula exigua*, *Navicula tripunctata* and *Nitzschia dissipata*. All these species appear in every sample and mostly with high abundance. As this data is semi-quantitative, there is no information available regarding total numbers of cells. Nevertheless, species richness can be calculated and this is shown in figure 16. Species richness shows similar values for nearly all sites. Most of the sites have a species richness between 15 and 20 or even higher. Lower values were detected only at the Egg tributary (12) and downstream (14) sub-site and also at the Rohrbach downstream (12) sub-site.

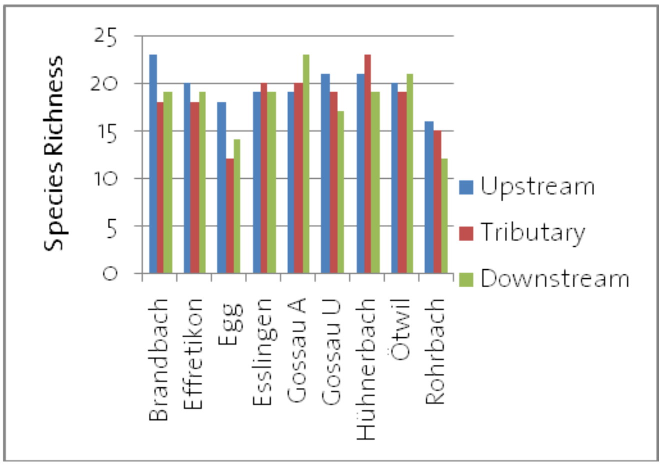


Fig. 14: species richness of diatoms per sub-site.

Comparing all the biological data, there are some correlations visible (Fig. 17). Ash free dry mass and chlorophyll-a show a positive correlation (r=0.79). Thus the more AFDM detected, the more chlorophyll-a is present. Another interesting interaction can be seen between chlorophyll-a and

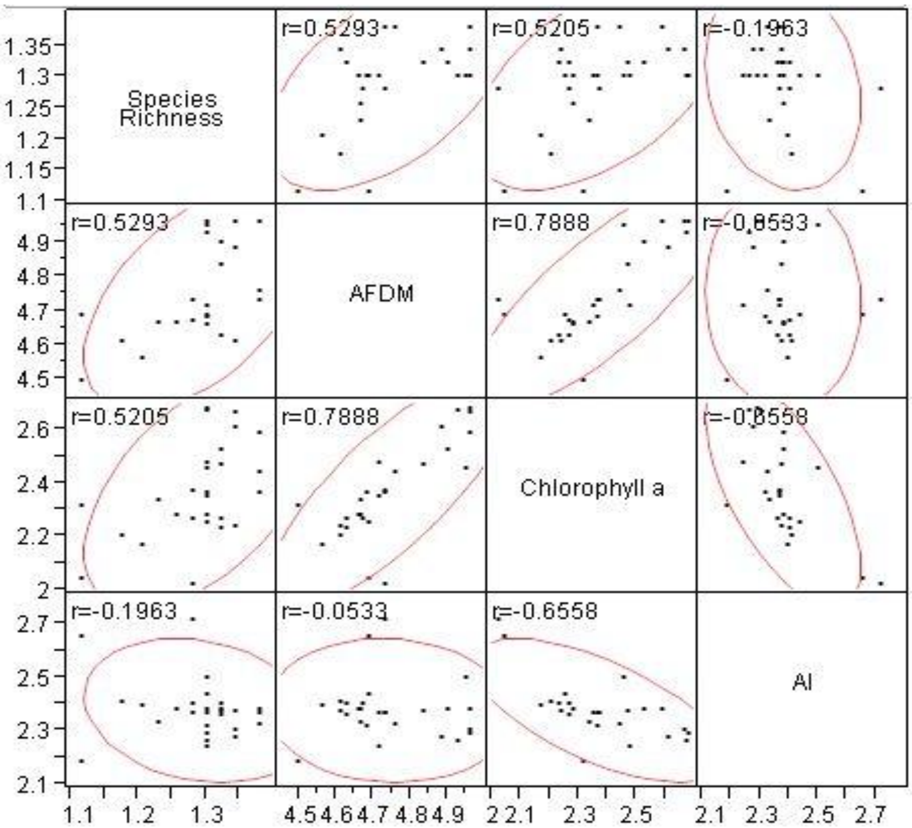


Fig. 15: Correlation matrix comparing species richness, ash free dry mass, chlorophyll-a and autotrophic index; all values are log(x+1) transformed.

the autotrophic index. This negative correlation (r=0.66) shows that the AI (AFDM/chlorophyll-a) is driven by the amount of chlorophyll-a in the system and not by the amount of AFDM present.

4 Discussion

As shown in the chemical analysis, there was little difference between the different kinds of sites and land use types. Even by comparing tributaries and mainstem (up-, downstream) sub-sites separately, no significant differences in physico-chemistry were found. Only some sites, regardless of their land use characterization, had significantly higher concentrations of some chemical components. The fact that these high concentrations were always from the up- and downstream sub-site makes it impossible to determine the source because of the high variation in the inputs to the mainstem sites.

Despite the lack of significant differences between site categories, the tributary PCA score plot showed quite nicely that the natural and agricultural tributaries are driven similarly by the same principal components. The variation in urban scores are on the one hand due to a high concentration of DOC and NO3-N at the Gossau U tributary sub-site and on the other hand due to a high concentration of PO4-P at the Oetwil tributary sub-site. At Gossau U, we know that a wastewater treatment plant is situated some hundred meters upstream of our sampling site, and this probably explains the high levels of DOC and NO3-N.

Importantly, we must take into account that all sampling and measurements were conducted in winter. At this time of year, the agricultural areas were not in use and probably reduced the probability of a significant influence from these tributaries. Conducting the study in spring or summer would likely have shown more tributary effects than results from winter. For example, after applying fertilizer such as liquid manure on the fields, chemical conditions in agricultural tributaries would have more pronounced than those in natural tributaries. Also, the winter in 2009/2010 had some strong ice periods in which a lot of salt was applied to roads. This may explain the high conductivity values at Gossau U tributary sub-site. Gossau is one of the largest settlements in the Mönchaltdorfer-Aa area and has many roads that were treated with salt.

As for the biological aspects, we cannot expect major differences between tributaries of different land use types. As mentioned, periphyton communities reflect the water quality and general health of aquatic ecosystems (Vis 1997), but since the chemical conditions of tributaries were similar between the different land use types we can expect little variation in periphyton assemblages (especially in winter). For instance, there was indeed no significant differences in the amount of chlorophyll-a and AFDM between the land use types. Only the autotrophic index

(AI) showed significant variation between streams of the different land use types. The Effretikon and Egg tributaries showed, for example, AI values around 500. Therefore, we expect that they are highly impacted by organic pollutants. But when looking at the chlorophyll-a and AFDM values of these two sites, we see low values of AFDM, which is unexpected if they were dominated by heterotrophs. The AI scores reflect the low chlorophyll values at these sites. One explanation could be that, for example, at the Egg tributary sub site the riparian vegetation mainly consisted of coniferous forest that absorbs a certain amount of light also in winter in addition to the already low radiation input due to the time of year. The tributary also flows through a basin with a high amount of natural shading that reduces radiation inputs to the stream. At the Effretikon sub-site, a similar situation of riparian vegetation and landscape form could be the reason for the low chlorophyll-a values.

The taxonomic composition can be described as being homogenous among all sites, types and positions. There were no species present or absent in specific tributaries with a certain land use type. This low variation in assemblage structure can also be explained by the similar chemical conditions at all sites. The occurrence of certain species at only two or three sub-sites was always accompanied with a very low counts of individuals. For example, *Surirella linearis*, *Gomphonema accumainatum*, *Diploneis ovalis* and, as an example for a filamentous alga, the genus *Trentopholia* only occured at a maximum of three sites with a occurrence value of one, which means sporadic abundances. They may occur at other sites as well but were not detected in samples due to very low counts.

In general, we can say that for hypothesis one:
- Periphyton community structure differs between different kinds of land use types in terms of biomass, chlorophyll-a and taxonomic composition- was not supported as no differences were found for any of the tested parameters.

For the second hypothesis:
- Tributary affects on periphyton community structure in mainstem river systems depends on the dominant land use in the catchment- is partially supported.

The amount of chlorophyll-a and AFDM often shows a certain pattern in which the tributary had higher values then the respective up- and downstream sub-site. However, the downstream sub-site also had a higher value than the respective upstream sub-site. This suggests an increase in chlorophyll-a and AFDM due to a tributary influence. This can be explained by the input of nutrients into the mainstem that increases the overall productivity of the system downstream of the confluence. For example, the Gossau U tributary sub-site was significantly different from the mainstem sub-sites in both chlorophyll-a and AFDM, and increased the mean chlorophyll-a value to about 18.6 mg/m^2 and the mean AFDM to about 195.6 mg/m^2 from up- to downstream.

In contrast to this pattern, there are some sites that show the opposite relationship. The most extreme example is the Brandbach site. Here, the amount of chlorophyll-a detected between the up- and downstream sub-site varied by a factor of two. This drastic reduction of chlorophyll-a from a mean value of 385.3 mg/m^2 to 190.2 mg/m^2 and AFDM from 91.8 g/m^2 to 45.5 g/m^2 could be due to harmful substances brought in by the tributary that reduced the overall abundance of periphyton in the mainstem. However, this idea needs further study to make any concrete conclusions.

5 Conclusion

This study did not show any differences in chemical conditions and periphyton community structure between tributaries draining different kinds of land use areas. Only the autotrophic index showed a significant difference between different types of sites. But even this evidence can be explained by factors other than land use, namely riparian vegetation and suboptimal geological conditions leading to very low chlorophyll-a values and therefore a high AI. So, the first hypothesis must be rejected. As for the second hypothesis, there were patterns visible that could be seen as indicators suggesting tributaries influence the mainstem by increasing the overall productivity of the system. But having sites that show exactly the opposite behaviour, by reducing the productivity of the mainstem further downstream, leads to the conclusion that further analysis focusing on these effects needs completed. Also, the time of the year (seasonality) should be taken into account. For example, the study should also be completed in spring/summer when the effects of land use may be more clear.

Acknowledgements

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6.1 Internet links

Link 1: http://www.nrp61.ch/E/Pages/home.aspx (25. 7. 2010)

Link 2: http://www.eawag.ch/organisation/abteilungen/uchem/schwerpunkte/iwaqa/index (25.7. 2010)

6.2 Figure references

Fig. 1, 2: Maps from GIS, Data given by Rosi Siber

Fig. 4: Picture taken by Michael Scheurer

Fig. 11, 12, 16: Graphs generated with JMP (SAS).