Results from the participation of Switzerland to the International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes (ICP Waters)

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Sampling and determination of macroinvertebrates: Bomio & Fürst SA

Content

Abstract

Compared to previous years, precipitations during 2012 in southern Switzerland were slightly higher than average (120-135% compared to 1961-1990; MeteoSvizzera, 2013). In general, concentrations of the main chemical parameters in precipitation and wet depositions were comparable to values of the last years. For some parameters temporal trends in concentrations are immediately visible. From 1990 as a consequence of reduced SO_2 emissions, yearly deposition of sulphate decreased below 50 meq m^{-2} at all stations. Because of the reduction of the emissions of NO_x and NH_3, deposition of nitrate and ammonium also slightly decreased during the last decade especially at the more polluted sites (Locarno Monti, Lugano, Stabio). It followed a reduction of deposition of acidity from around 60 meq m^{-2} to below 0 meq m^{-2} at all sites. For rivers both seasonal and yearly mean concentrations were similar to values of the period 2000-2010 and no significant trend could be observed. Differently, in lakes in agreement with wet deposition, concentrations of sulphate and nitrate also decreased, leading to an increase of alkalinity and pH. It followed also a significant decrease of concentrations of aluminium especially after 2005 in the most acid lakes Lago Tomé and Lago del Starlaresc da Sgiof (pH < 6) to values around 20 mg l^{-1} in the first and close to 40 mg l^{-1} in the second. Nevertheless, a recovery of macroinvertebrate in these lakes cannot yet be observed and moderately sensitive species, as they occur in the other less acid monitored lakes with pH >= 6.5 (Lago Bianco, Laghetto Inferiore, Lago Superiore) are still rare or absent.

Introduction

The International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes (ICP Waters) was established under the United Nations Economic Commission for Europe's Convention on Long-Range Transboundary Air Pollution (LRTAP) in 1985, when it was recognised that acidification of freshwater systems provided some of the earliest evidence of the damage caused by sulphur emissions. The monitoring programme is designed to assess, on a regional basis, the degree and geographical extent of the impact of atmospheric pollution, in particular acidification on surface waters. The monitoring data provide a basis for documenting effects of long-range transboundary air pollutants on aquatic chemistry and biota. An additional important programme activity is to contribute to quality control and harmonisation of monitoring methods. The Programme is planned and coordinated by a Task Force under the leadership of Norway. Up to now chemical and site data from more than 200 catchments in 20 countries in Europe and North America are available in the database of the Programme Centre. Switzerland joined the Programme in 2000 on behalf of the Swiss Federal Office for the Environment with the support of Canton Ticino.

1 Study site

The study area is located in the southern part of the Alps in the Canton of Ticino in Switzerland. Precipitation in this region is mainly determined by warm, humid air masses originating from the Mediterranean Sea, passing over the Po Plain and colliding with the Alps. The lithology of the north-western part of Canton Ticino is dominated by base-poor rocks especially gneiss. As a consequence soils and freshwaters in this region are sensitive to acidification. In order to assess the impact of long-range transboundary air pollution, 20 lakes (21 from 2006) and 3 rivers have been monitored. In addition, wet deposition has been monitored at 9 sampling stations distributed over all Canton Ticino. The lake's watersheds are constituted mainly by bare rocks with vegetation often confined to small areas of Alpine meadows. The selected Alpine lakes are situated between an altitude of 1690 m and 2580 m and are characterized by intensive irradiation, a short vegetation period, a long period of ice coverage and by low nutrient concentrations. The sampling points of the selected rivers are located at lower altitudes (610-918 m), implying larger catchment areas and therefore less sensitivity toward acidification than lakes. The geographic distribution of lakes, rivers and wet deposition sampling sites are shown in Fig. 1.1, while their main geographic and morphometric parameters are resumed in Tab. 1.1, 1.2 and 1.3.

Figure 1.1 Sampling sites

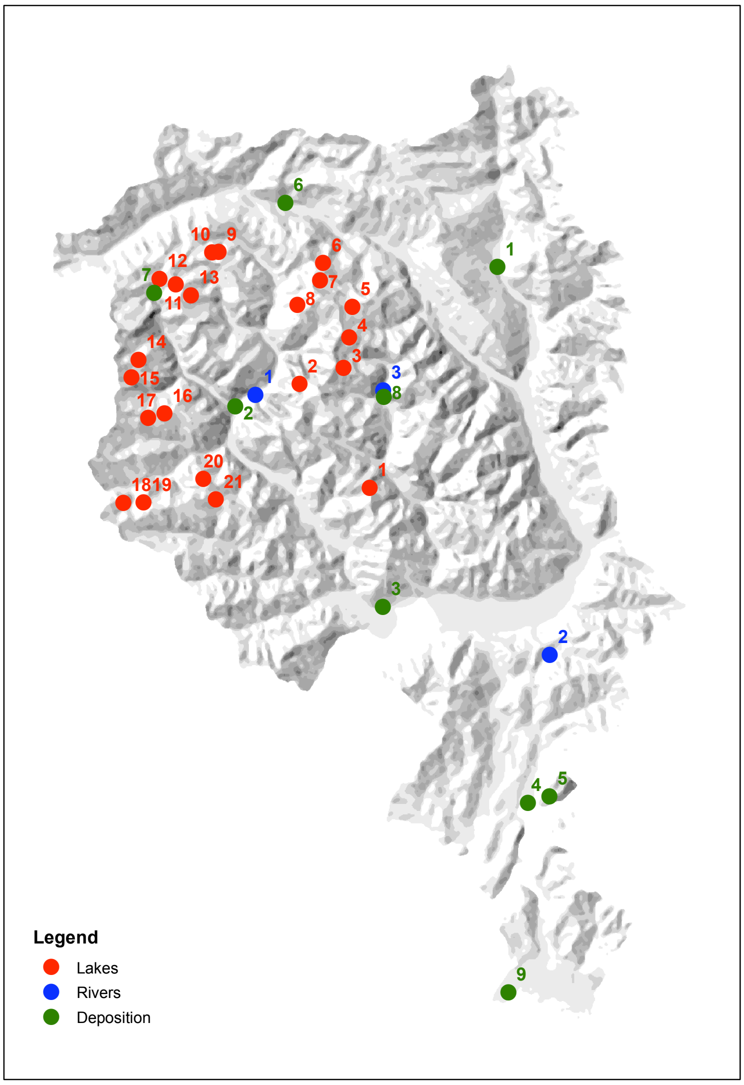


Table 1.1 Lake parameters

Lake number	Lake name	Longitude CH m	Latitude CH m	Longitude	Latitude	Altitude m a.s.l.	Catchment area ha	Lake area ha	Max depth m
1	Lago del Starlaresc da Sgiof	702905	125605	8°46'25''	46°16'26''	1875	23	1.1	6
2	Lago di Tomè	696280	135398	8°41'23''	46°21'47''	1692	294	5.8	38
3	Lago dei Porchieirsc	700450	136888	8°44'39''	46°22'33''	2190	43	1.5	7
4	Lago Barone	700975	139813	8°45'06''	46°24'07''	2391	51	6.6	56
5	Laghetto Gardiscio	701275	142675	8°45'22''	46°45'22''	2580	12	1.1	10
6	Lago della Capannina Leit	698525	146800	8°43'17''	46°27'55''	2260	52	2.7	13
7	Lago di Morghirolo	698200	145175	8°43'00''	46°27'03''	2264	166	11.9	28
8	Lago di Mognòla	696075	142875	8°41'19''	46°25'49''	2003	197	5.4	11
9	Laghetto Inferiore	688627	147855	8°35'34''	46°28'34''	2074	182	5.6	33
10	Laghetto Superiore	688020	147835	8°35'05''	46°28'34''	2128	125	8.3	29
11	Lago Nero	684588	144813	8°32'22''	46°26'58''	2387	72	12.7	68
12	Lago Bianco	683030	145330	8°31'10''	46°27'15''	2077		ca. 4.0	
13	Lago della Froda	686025	143788	8°33'29''	46°26'24''	2363	67	2.0	17
14	Laghetto d'Antabia	681038	137675	8°29'32''	46°23'08''	2189	82	6.8	16
15	Lago della Crosa	680375	136050	8°28'60''	46°22'16''	2153	194	16.9	70
16	Lago d'Orsalìa	683513	132613	8°31'24''	46°20'23''	2143	41	2.6	16
17	Schwarzsee	681963	132188	8°30'11'	46°20'10''	2315	24	0.3	7
18	Laghi dei Pozzöi	679613	124200	8°28'17''	46°15'52''	1955	33	1.1	4
19	Lago di Sfille	681525	124213	8°29'46''	46°15'52''	1909	63	2.8	12
20	Lago di Sascòla	687175	126413	8°34'11''	46°17'01''	1740	90	3.2	5
21	Lago d'Alzasca	688363	124488	8°35'05''	46°15'58''	1855	110	10.4	40

Table 1.2 River parameters

River number	River name	Sampling site	Longitude CH m	Latitude CH m	Longitude	Latitude	Altitude m a.s.l.	Catchment area km^2
1	Maggia	Brontallo	692125	134375	8°38' 8''	46°21'16''	610	ca. 189
2	Vedeggio	Isone	719900	109800	8°59'24''	46°07'45''	740	20
3	Verzasca	Sonogno	704200	134825	8°47'33''	46°21'24'	918	ca. 27

Table 1.3 Parameters of wet deposition monitoring sites

Sampling site number	Sampling site	Longitude CH m	Latitude CH m	Longitude	Latitude	Altitude m a.s.l.
1	Acquarossa	714998	146440	8°56'12''	46°27'41''	575
2	Bignasco	690205	132257	8°59'17''	46°00'32''	443
3	Locarno Monti	704160	114350	8°47'17''	46°10'27''	366
4	Lugano	717880	95870	8°57'18''	46°00'24''	273
5	Monte Brè	719900	96470	8°59'17''	46°00'32''	925
6	Piotta	694930	152500	8°40'35''	46°31'7''	1007
7	Robiei	682540	143984	8°30'51''	46°26'43''	1890
8	Sonogno	704250	134150	8°47'14''	46°21'05''	918
9	Stabio	716040	77970	8°55'52''	45°51'36''	353

2 Water chemistry analysis

2.1 Introduction

Acid deposition in acid sensitive areas can cause acidification of surface waters and soils. Because of its particular lithology (base-poor rocks especially gneiss) and high altitudes (thin soil layer) the buffer capacity of the north-western part of Canton Ticino is low. This area is therefore very sensitive to acidification. Acidification can be defined as a reduction of the acid neutralizing capacity of soils (=alkalinity) or waters. Alkalinity is the result of complex interactions between wet and dry deposition and the soil and rocks of the watershed and biologic processes. Freshwaters are considered acidic when alkalinity < 0 meq m^{-3}, sensitive to acidification when 0 < alkalinity < 50 meq m^{-3} and with low alkalinity but not sensitive to acidification when 50 < alkalinity < 200 meq m^{-3} (Mosello et al., 1993). With decreasing acid neutralizing capacity, pH also decreases. It is reported that at pH<6 the release of metals from soils or sediments becomes more and more important. The release of aluminium at low pH is particularly important because of its toxic effects on organisms.

2.2 Sampling methods

In order to monitor and assess acidification of freshwaters in acid sensitive areas of Canton Ticino water chemistry of 20 Alpine lakes (21 from 2006) and 3 rivers (Maggia, Vedeggio, Verzasca) and wet deposition has been monitored.

From 2000 to 2005 lake surface water was sampled twice a year (once at beginning of summer, once in autumn). After 2006 lakes were monitored three times a year (once at beginning of summer, twice in autumn) and the alkaline Lago Bianco was added to the monitored lakes in order to compare biology of Alpine lakes with acid sensitive and alkaline characteristics. Before 2000 lake surface water was sampled irregularly. Lake surface water was collected directly from the helicopter. River water has been sampled monthly since 2000. Weekly sampling of rainwater with wet-only samplers started in 1988.

2.3 Analytical methods

Measured parameters, conservation methods, analytical methods and quantification limits are resumed in Tab 2.1. The quality of the data was assured by participating regularly at national and international intercalibration tests. In addition, data were accepted only if the calculation of the ionic balance and the comparison of the measured with the calculated conductivity corresponded to the quality requests indicated by the programme manual of ICP Waters (ICP waters Programme Centre, 2010). Furthermore, the data were checked for outliers. If available, as for metals, dissolved concentrations were compared with total concentrations.

2.4 Data handling

Monthly and yearly mean concentrations in precipitation were calculated by weighting weekly concentrations with the sampled precipitation volume, while monthly and yearly wet deposition were calculated by multiplying monthly and yearly mean concentrations with the precipitation volume measured by a meteorological sampling station. In particular, for our sampling sites, data from the pluviometric stations of MeteoSwiss (Acquarossa -> Comprovasco, Bignasco -> Cevio, Locarno Monti -> Locarno Monti, Lugano -> Lugano, Monte Brè -> Lugano, Piotta -> Piotta, Robiei -> Robiei, Sonogno -> Sonogno, Stabio -> Stabio) and of Canton of Ticino (Bignasco -> Cavergno) have been chosen.

Table 2.1 Measured parameters, conservation methods, analytical methods, accuracy and quantification limits

CA, PC, GF, PP stay for cellulose acetate, polycarbonate, glass fibre and polypropylene, respectively. ICP-OES for inductively coupled plasma atomic-emission spectroscopy.

Parameter	Filtration	Conservation	Method	Accuracy
pH	No	No	potentiometry	0.02
conductivity	No	No	Kolrausch bridge (20°C)	0.5 μS cm^{-1}
alkalinity	No	No	potentiometric Gran titration	0.001 meq l^{-1}
				Quantification limit
Ca^{2+}	CA filter	PP bottle, 4°C	ion cromatography	0.010 mg l^{-1}
Mg^{2+}	CA filter	PP bottle, 4°C	ion cromatography	0.005 mg l^{-1}
Na^{+}	CA filter	PP bottle, 4°C	ion cromatography	0.005 mg l^{-1}
K^{+}	CA filter	PP bottle, 4°C	ion cromatography	0.010 mg l^{-1}
NH_4^{+}	CA filter	PP bottle, 4°C	spectrophotometry	3 μg N l^{-1}
SO_4^{2-}	CA filter	PP bottle, 4°C	ion cromatography	0.005 mg l^{-1}
NO_3^{-}	CA filter	PP bottle, 4°C	ion cromatography	0.010 mg N l^{-1}
NO_2^{-}	CA filter	PP bottle, 4°C	spectrophotometry	2.5 μg N l^{-1}
Cl^{-}	CA filter	PP bottle, 4°C	ion cromatography	0.010 mg l^{-1}
soluble reactive P	CA filter	PP bottle, 4°C	spectrophotometry	2 μg P l^{-1}
soluble reactive Si	CA filter	PP bottle, 4°C	ICP-OES with ultrasonic nebulizer	0.003 mg Si l^{-1}
total P	No	glass bottle, immediate mineralisation	persulphate digestion, spectrophotometry	2 μg P l^{-1}
DOC	PC filter	brown glass bottle, + H_3PO_4	UV-persulfate	0.05 mg C l^{-1}
soluble Al	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
total Al	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
soluble Cu	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
total Cu	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
soluble Zn	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
total Zn	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
soluble Pb	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
total Pb	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
soluble Cd	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}
total Cd	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.2 μg l^{-1}

2.5 Results and discussion

2.5.1 Wet deposition

Spatial variation

Annual average rainwater concentrations of the main chemical parameters and their yearly deposition rates during 2012 are shown in Tab. 2.2.

Table 2.2 Yearly mean rain water concentrations and deposition rates during 2012

Sampling site	Precipitation (mm)	Analysed precipitation (mm)	Conductivity 25°C (μS cm^{-1})	pH	Ca^{2+}		Mg^{2+}		Na^{+}		K^{+}		NH_4^{+}		HCO_3^{-}		SO_4^{2-}		NO_3^{-}		Cl^{-}		Acidity = $H^{+}- HCO_3^{-}$	
					Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})
Acquarossa	1507	1460	12	5.5	20	30	6	10	8	12	2	3	35	53	23	34	19	29	27	41	7	10	-20	-30
Bignasco	1702	1629	10	5.4	15	26	4	6	7	11	2	4	31	53	13	22	16	27	27	45	7	11	-9	-16
Locarno Monti	1863	1649	12	5.3	15	29	4	7	7	14	2	3	37	69	11	21	20	38	32	60	7	14	-6	-11
Lugano	1412	1145	12	5.4	14	20	4	5	9	12	2	3	41	58	13	19	20	28	32	44	9	13	-10	-14
Monte Brè	1412	1350	11	5.4	13	18	4	5	8	11	2	2	35	49	12	17	17	23	29	41	8	11	-9	-12
Piotta	1602	1367	9	5.6	15	23	3	1	8	5	2	4	32	51	18	30	15	24	20	32	7	11	-16	-26
Robiei	2721	2103	8	5.5	10	28	2	5	3	8	1	2	30	82	9	24	15	40	23	63	3	9	-6	-15
Sonogno	2280	1984	11	5.6	15	35	3	8	8	19	3	6	35	79	16	36	17	39	28	63	8	18	-13	-30
Stabio	1462	1390	11	5.5	14	20	4	5	9	13	2	3	37	55	15	22	17	24	29	43	8	12	-12	-17

In general, ion concentrations of anthropogenic origin (sulphate, nitrate, ammonia) increase from sites with low to high latitude and from high to low altitude. During 2012 highest concentrations were measured at Locarno, Lugano and lowest at Piotta, Robiei, Bignasco. The correlation with latitude and altitude reflects the influence of long-range transboundary air pollution moving along a south to north gradient from the Po plain toward the Alps and the distance from pollution sources. Concentrations of base cations, bicarbonate and acidity correlate better with the amount of precipitation. In fact, lower yearly precipitation results in smaller dilution of single alkaline rain events on an annual base, leading to higher mean concentrations of base cations and bicarbonate and lower concentrations of acidity. During 2012 highest concentrations of base cations, bicarbonate and lowest concentrations of acidity were found at Acquarossa and lowest concentrations of base cations, bicarbonate and highest concentrations of acidity at Robiei.

Wet deposition of chemical parameters depends on both concentration and the amount of precipitation. Highest precipitation usually occurs in the north-western part of Canton Ticino. The reason for this distribution is air masses rich in humidity that move predominantly from southwest toward the southern Alps and the particular orography of the area that causes a steep raise of the air masses to higher altitudes. During 2012 highest deposition rates of ammonia, nitrate and sulphate occured at Robiei, Sonogno, Locarno Monti while lowest were observed at Monte Brè, Piotta. For base cations and bicarbonate, deposition rates were highest at Sonogno and Acquarossa and lowest at Monte Brè. The opposite occured for acidity. A detailed analysis on spatial distribution of rainwater quality and deposition rates is described in (Steingruber and Colombo, 2010).

Seasonal variation

The amount of monthly precipitation at each sampling site during 2012 and their average values during the period 2000-2010 are reported in Fig. 2.1. Similarly, seasonal variations of monthly mean rainwater concentrations of the main chemical parameters during 2012 and their mean values during the period 2000-2010 are shown in Fig. 2.2.

Average monthly precipitation is normally low from December to April and higher from May to November. Highest precipitation volumes normally occur in May, August and November. Compared to average values, precipitation of 2012 was lower in winter and slightly higher than average during most other months.

Monthly average sulphate concentrations are normally higher during summer months and lower during winter months at sampling stations with low concentrations (Bignasco, Piotta, Robiei, Sonogno). At sites with higher concentrations, the period with high sulphate concentrations starts already in late winter. This seasonality is in contrast with concentrations of SO_2 in the air (high in winter and low in summer). Therefore SO_2 cannot be the main factor influencing seasonality of sulphate concentrations in rainwater. Interestingly, dividing sulphate concentrations with concentrations of SO_2 for all sampling sites maximum summer values and minimum winter values can be observed (data not shown), suggesting that the oxidation rate of SO_2 to SO_4^{2-} is higher in summer than in winter (Hedin et al. 1990). The observed seasonality of sulphate concentration in rainwater is therefore the result of the combination with the seasonality of SO_2 concentration in the air and the oxidation rate from SO_2 to SO_4^{2-}. Compared to the mean values concentrations of sulphate during 2012 were in general lower, especially in April and May and differences between sampling stations were much less pronounced.

Monthly mean concentrations of nitrate are highest in February-March and lowest in December-January. Differently, concentrations of NO_2 in the air are highest in November-February in and lowest in May-August. Dividing concentrations of nitrate with those of NO_2 maximum values occur during summer and minimum values during winter (data not shown), suggesting that, as already observed for sulphate, oxidation rate of NO_x to NO_3^- is higher in summer than in winter (Hedin et al. 1990). The concentration peak of nitrate in February-March is therefore most probably the result of the remaining high concentrations of NO_2 and the already increasing oxidation rates of NO_x to NO_3^- in spring. During 2012 concentrations were similar to average values with generally a slightly lower peak in February and much lower values in April and May.

Monthly mean chloride concentrations are in general very low. Higher values can be measured during winter months when chloride is spread on the roads to inhibit ice formation. This happens regularly at Piotta. Concentrations during 2012 were similar to average values.

The seasonality of monthly mean ammonium concentrations is very similar to that of sulphate. Hedin et al. 1990 explained this similarity with a chemical coupling between ammonia and sulphate, with acidic sulphate aerosol acting as a vehicle for long-range transport of ammonia. Seasonal variations in ammonium concentrations at sites distant from major sources of ammonia emissions thus may be influenced strongly by the supply of sulphate aerosol, and by seasonal variations in emissions and oxidation of SO_2. During 2012 concentrations of ammonia were similar to the average values. Only in April and May, similar to what observed for sulphate and nitrate, concentrations were lower than average.

Interestingly, comparing the monthly mean concentrations of sulphate, nitrate and ammonia of 2012 with the average values during the period 2000-2010 it appears that concentrations at the most polluted sampling sites (Locarno Monti, Lugano, Stabio) decreased to values similar to the other sites.

The seasonality of the monthly mean concentrations of base cations and bicarbonate are very similar indicating that the two are in general connected to each other. During 2000-2010 concentrations of base cations and bicarbonate are on average highest in April-June and October-November overlapping with periods rich in precipitation. It is possible that more numerous rain events increase the possibility of the occurrence of alkaline rain events. Opposite to base cations and bicarbonate behaves acidity, whose monthly mean concentrations are highest during winter and lowest during spring and autumn, indicating that the concentrations of base cations and bicarbonate are the main responsible in determining the seasonality of acidity. As a consequence of decreased acidity during summer, pH values are also highest during summer. During 2012, similar to the amount of precipitations, concentrations of base cations, bicarbonate and pH were generally higher in spring-summer and lower in autumn-winter, but, especially for the first two, concentrations could vary greatly from one month to the next and among sampling sites. The opposite occurred for acidity with lower values in spring-summer and higher in autumn-winter.

Figure 2.1 Monthly precipitation

Precipitation at the sampling stations estimated with data from MeteoSwiss (Acquarossa-Comprovasco, Locarno Monti, Lugano, Piotta, Robiei, Sonogno, Stabio) and from Canton of Ticino (Bignasco).

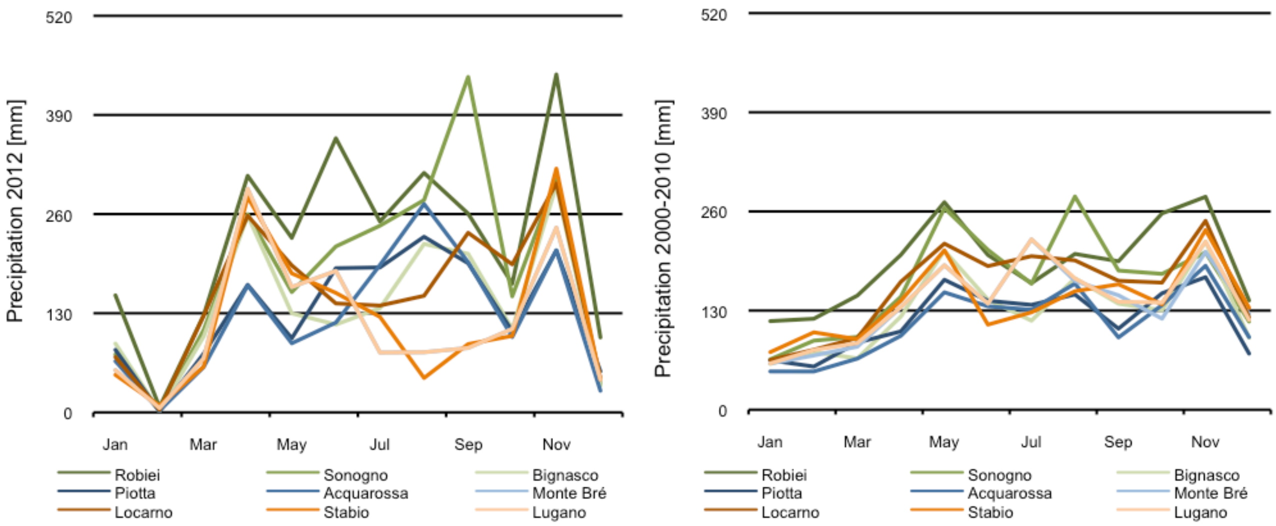
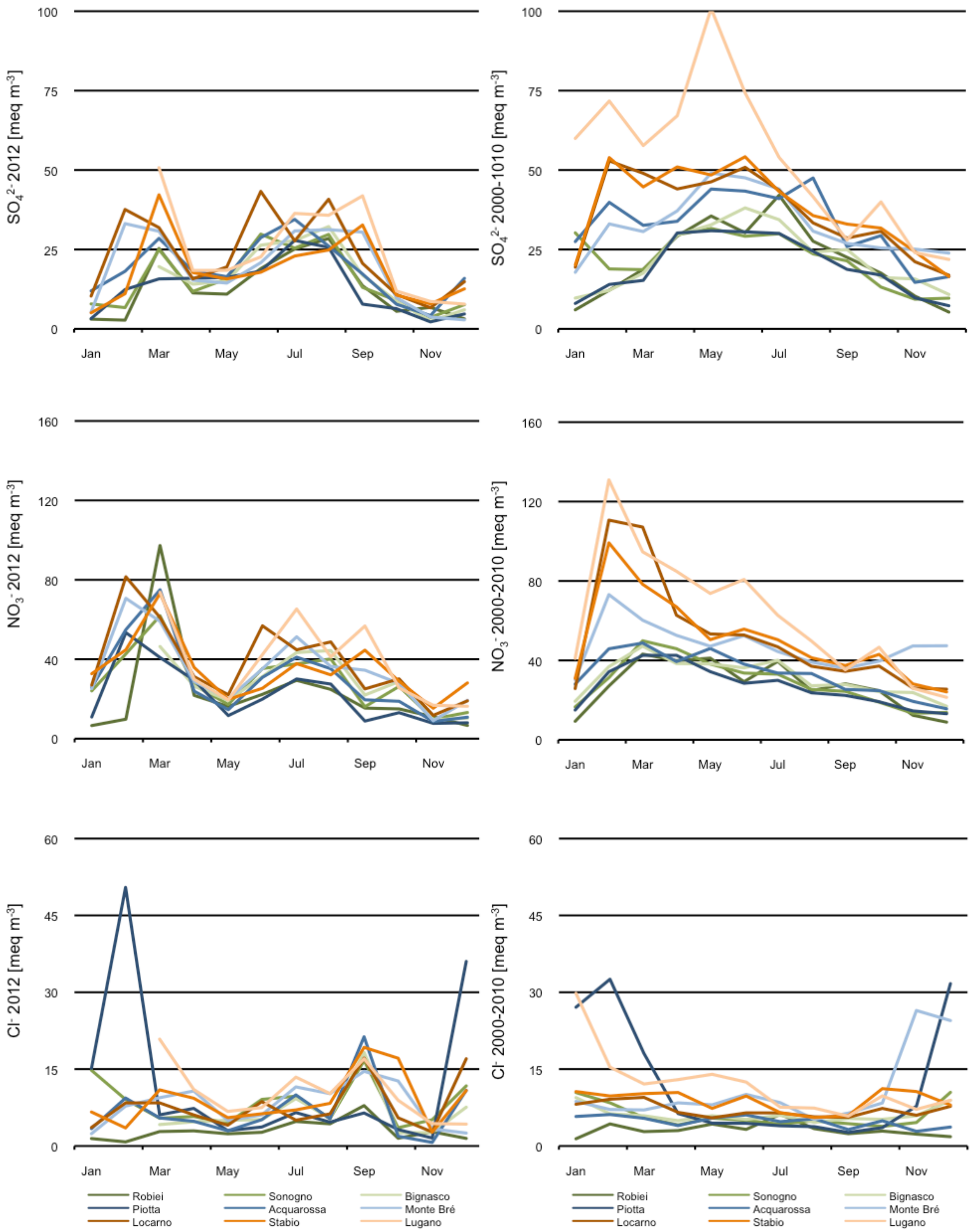
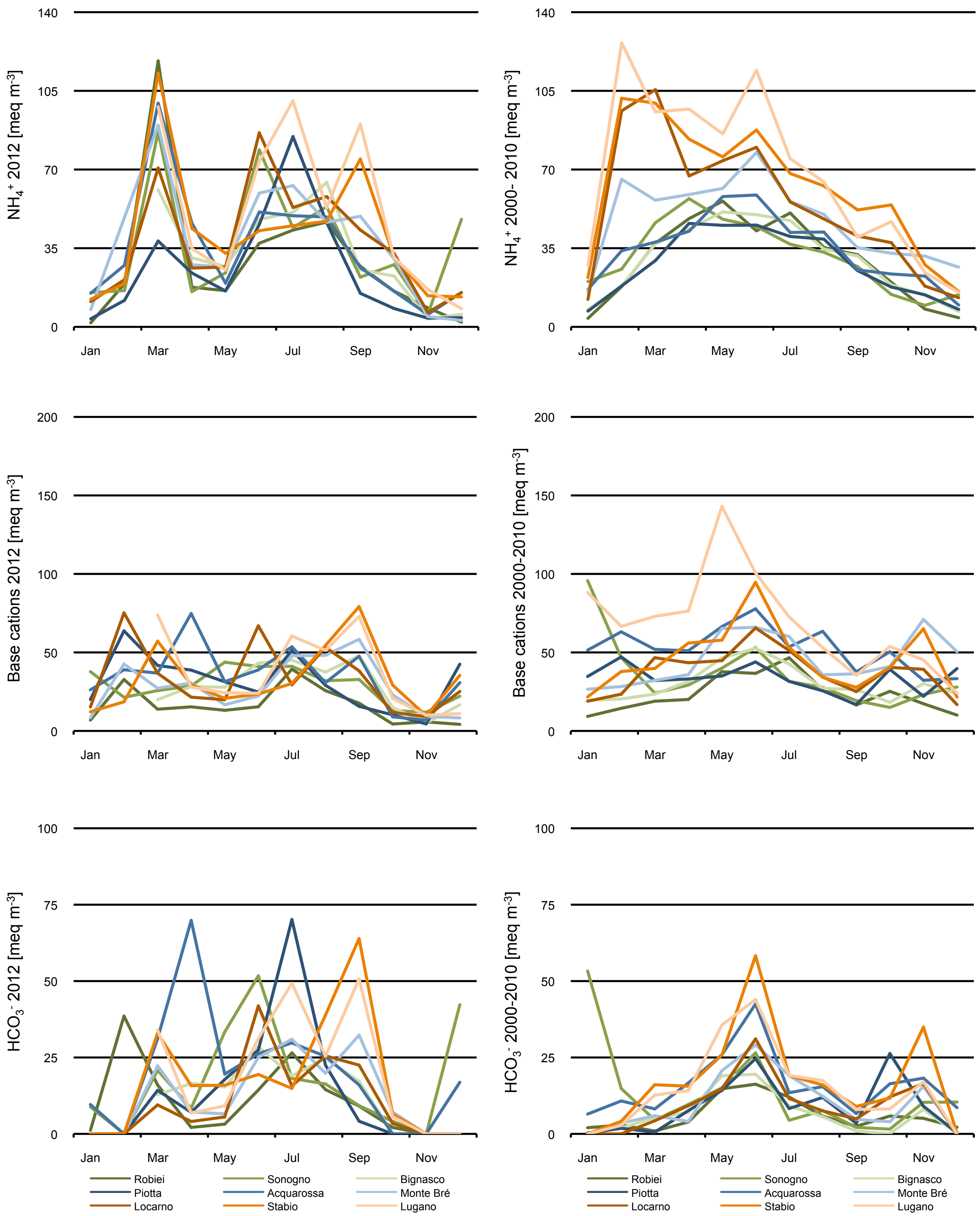


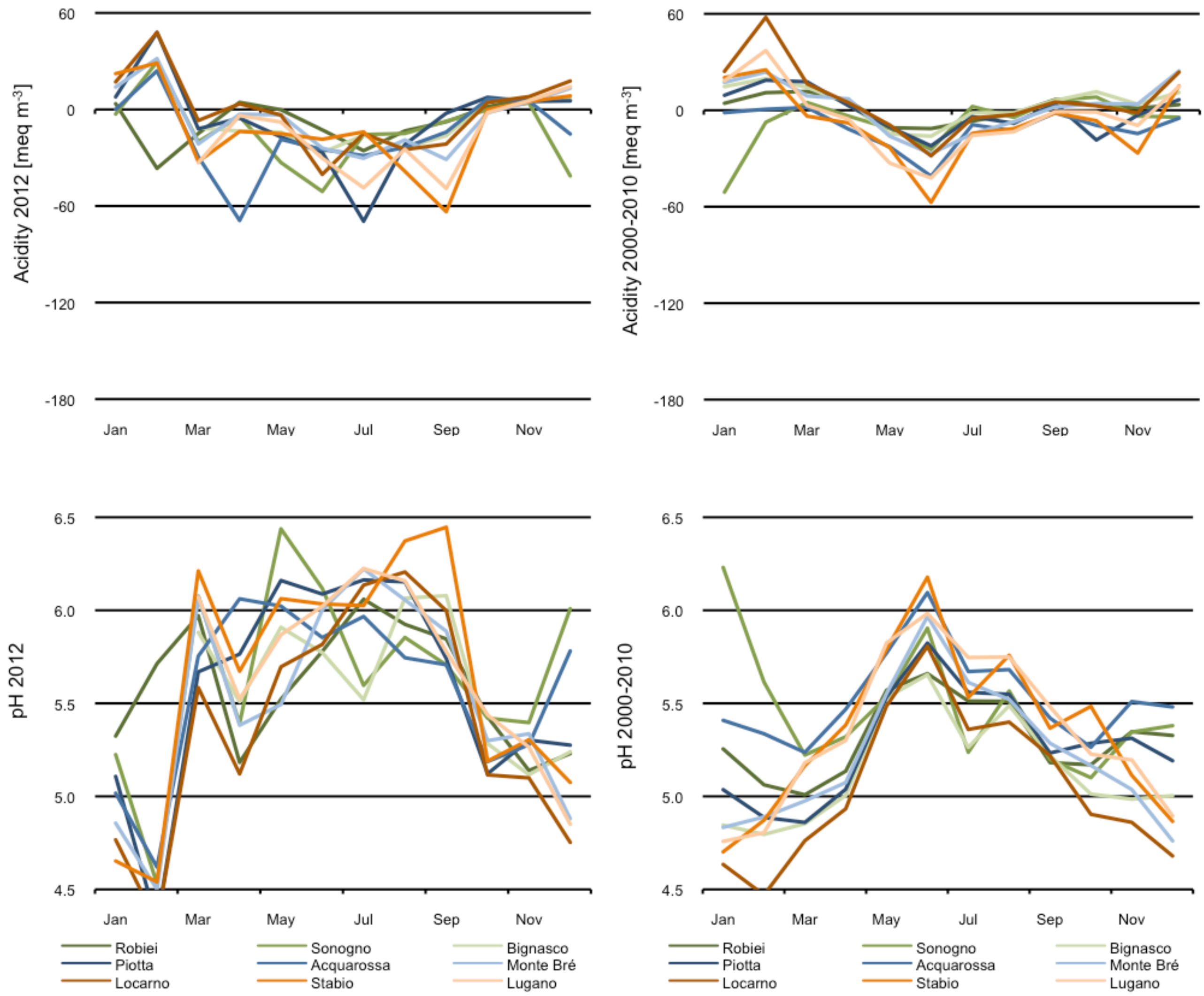
Figure 2.2 Seasonal variations of monthly average rain water concentrations

Base cations correspond to the sum of calcium, magnesium, sodium and potassium.





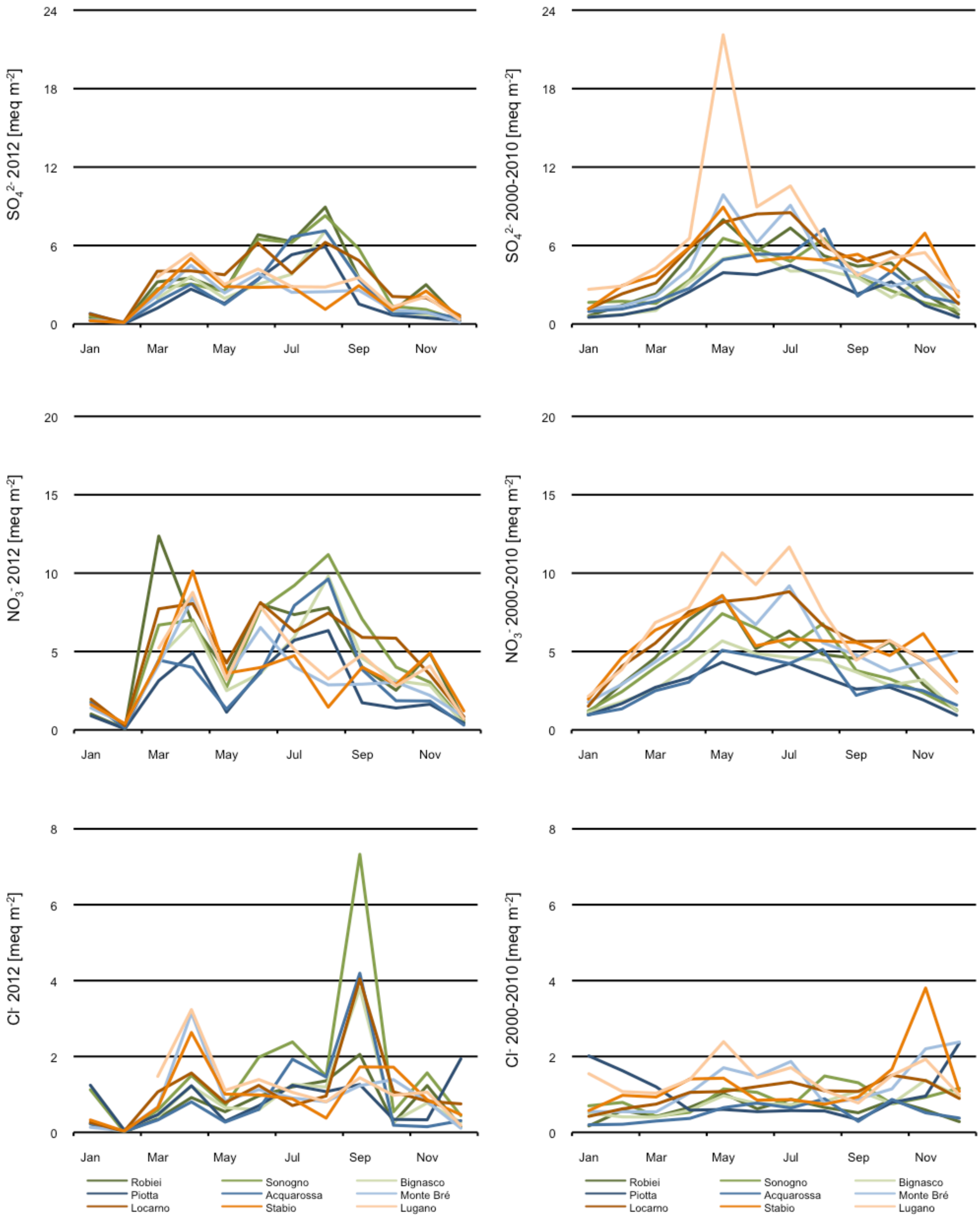
NH4+ 2012 [meq m-3]
NH4+ 2000- 2010 [meq m-3]
Base cations 2012 [meq m-3]
Base cations 2000-2010 [meq m-3]
HCO3- 2012 [meq m-3]
HCO3- 2000-2010 [meq m-3]
Jan
Mar
May
Jul
Sep
Nov
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano



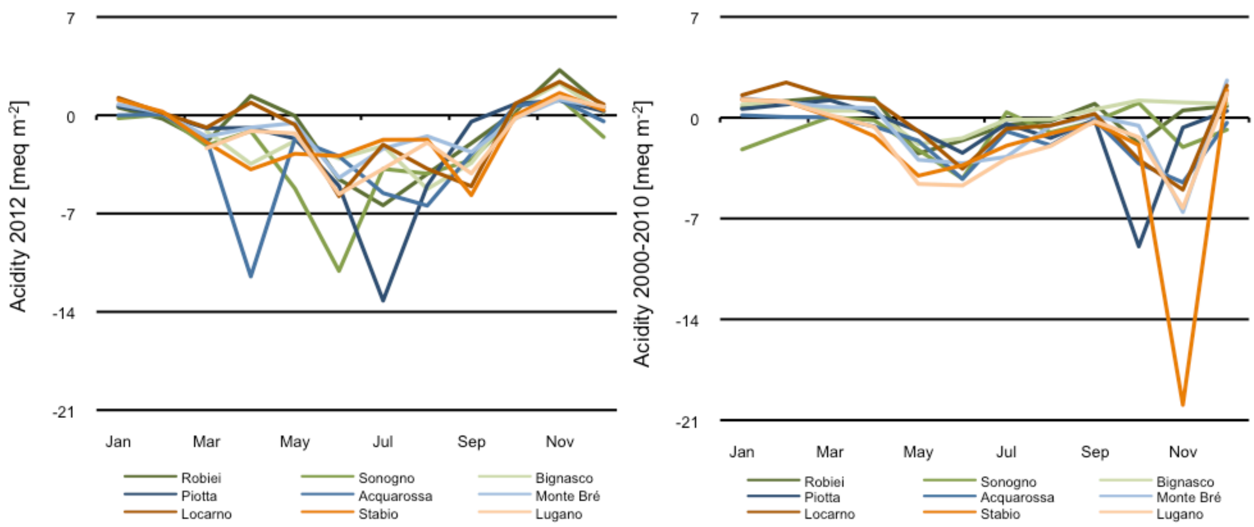
Depositions behaved similar to concentrations, with the difference that rain water volume gained further importance (Fig. 2.3). For sulphate, nitrate and ammonium, highest depositions during the period 2000-2010 occurred in summer and lowest in winter. During 2012 values were in the same range and seasonality was similar. Depositions of base cations and bicarbonate were also higher in summer compared to winter but differently to 2012 average values from the period 2000-2010 additionally peaked in November. Deposition of acidity behaved opposite to base cations and bicarbonate.

Figure 2.3 Seasonal variations of monthly wet deposition

Base cations correspond to the sum of calcium, magnesium, sodium and potassium.




NH$_4^+$ 2012 [meq m^{-2}]
NH$_4^+$ 2000-2010 [meq m^{-2}]
Base cations 2012 [meq m^{-2}]
Base cations 2000-2010 [meq m^{-2}]
HCO$_3^-$ 2012 [meq m^{-2}]
HCO$_3^-$ 2000-2010 [meq m^{-2}]
0
5
10
15
20
8
16
24
32
6
12
18
Jan
Mar
May
Jul
Sep
Nov
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano



Temporal variations

The amount of yearly precipitation at each sampling site is reported in Fig. 2.4, while variation of yearly average rainwater concentrations and deposition rates of the main chemical parameters since 1988 are shown in Fig. 2.5. Compared to the time series, precipitation during 2012 was higher than average at sites situated at higher latitudes (Acquarossa, Piotta, Robiei, Sonogno) but similar to average values at the other sites. In general, the measured concentrations and depositions were similar to values of the most recent years.

For some parameters temporal trends in concentrations are immediately visible. Sulphate concentrations and depositions decreased after 1990 at all sampling stations as a consequence of reduced SO_2 emissions. The sulphate peak at Lugano in 2012 was the consequence of the volcanic eruption at Eyafjellajokull (Iceland) in April 2010 (Steingruber and Colombo, 2011; UACER, 2011). The decrease in emissions of NO_x and NH_3 caused until to now only a slight decrease in concentrations, while their depositions are still much influenced by the precipitation volume, so that high deposition values still occur during wet years. Base cations also seem to slightly decrease, however their annual mean concentrations and depositions can vary greatly from year to year reaching high values during years with single events rich in base cations. Concentrations and depositions of acidity, that can be calculated as the difference between acid anions and base cations and ammonia, decreased significantly at most sites. In general, concentrations and depositions of acidity decreased from values around 30-40 meq/m^3 and 60 meq/m^2, respectively to values around - 10 meq/m^3 and - 15 meq/m^2 on average. However, it can happen that single particularly intense rain events with alkaline characteristics can heavily influence yearly mean acidity shifting it toward negative values. Such negative peaks can be observed at sampling stations Acquarossa, Locarno Monti and Piotta in 2000 (alkaline event in October) and at Monte Bré, Locarno Monti, Lugano and Stabio in 2002 (alkaline event in November) and are accompanied by peaks in concentrations of base cations and bicarbonate. We remember that both events lead to floods in the region. When and why such events appear is still not clear. Rogora et al. (2004) observed an increased frequency of alkaline rain events especially during the last decade, many of them caused by deposition of Saharan dust. It is possible that rain rich years increase the chance of the occurrence of alkaline rain events. In addition the reduction of sulphate concentrations during the last 2 decades probably decreased the capacity of rainwater to neutralize alkaline rain events making them more observable in rainwater chemistry. If climate change may also influence the occurrence of alkaline rain events by increased long distance transport of dust is not known. A more detailed trend analysis is described in Steingruber and Colombo (2010) and Steingruber and Colombo

(2011). The described decrease of acidity gets obviously reflected in an increase of pH from average values around 4.3 in the 1990’s to values ranging between 5.2 and 5.6 today.

Figure 2.4 Yearly precipitations

Da Precipitation at the sampling stations estimated with data from MeteoSwiss (Acquarossa-Comprovasco, Locarno Monti, Lugano, Piotta, Robiei, Sonogno, Stabio) and from Canton of Ticino (Bignasco).

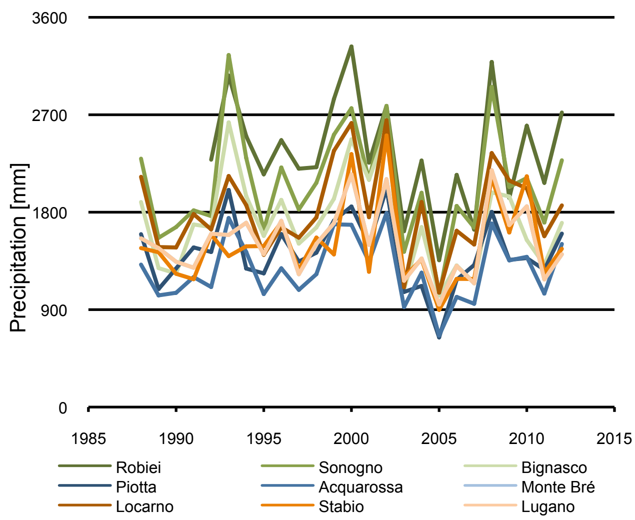
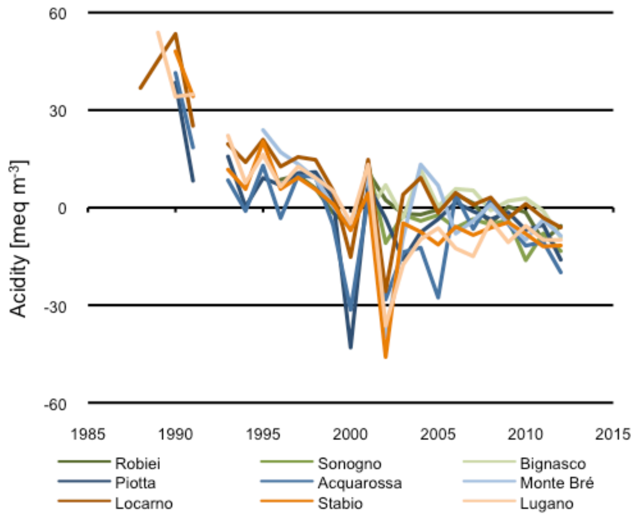
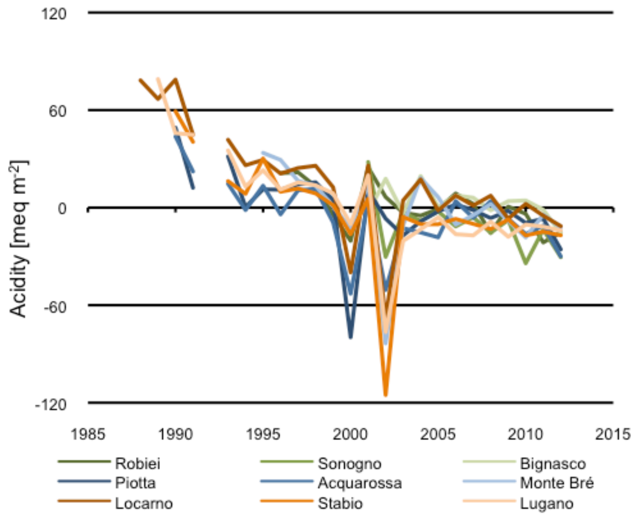


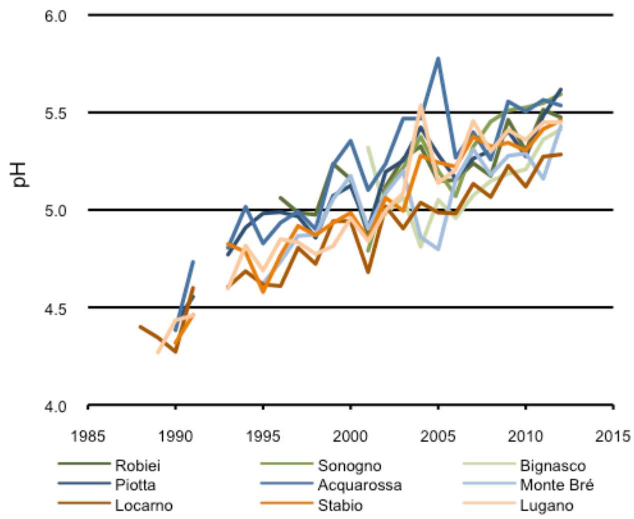
Figure 2.5 Temporal variations of annual mean rain water concentrations, deposition rates and pH

Base cations correspond to the sum of calcium, magnesium, sodium and potassium.


NH4+ [meq m-3]
NH4+ [meq m-2]
Base cations [meq m-3]
Base cations [meq m-2]
HCO3- [meq m-3]
HCO3- [meq m-2]
1985 1990 1995 2000 2005 2010 2015
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano


60
30
0
-30
-60
Acidity [meq m-3]
1985
1990
1995
2000
2005
2010
2015
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano


120
60
0
-60
-120
Acidity [meq m-2]
1985
1990
1995
2000
2005
2010
2015
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano


6.0
5.5
5.0
4.5
4.0
pH
1985
1990
1995
2000
2005
2010
2015
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano

2.5.2 Alpine rivers

Spatial variations

During 2012 river water was sampled at the following days: 16.1, 13.2, 12.3, 16.4, 14.5, 11.6, 9.7, 6.8, 3.9, 15.10, 12.11, 10.12. Annual mean concentrations of the chemical parameters measured in river Maggia, Vedeggio and Verzasca during 2012 are shown in Tab. 2.5. Conductivity, concentrations of calcium, sodium, potassium, sulphate, chloride, alkalinity and pH were highest in river Maggia, followed by Vedeggio and Verzasca. As discussed in Steingruber and Colombo (2006), differences in catchments areas and geology are the main cause for differences in concentrations among rivers. In fact, the catchment area of river Maggia is 7 and 10 times larger than the watersheds of river Verzasca and Vedeggio, respectively, implying a longer average water residence time and higher average weathering rate related to increased buffering capacity in the watershed of river Maggia. Differences in water chemistry of rivers Vedeggio and Verzasca are more related to their different catchment geology. Similarly to the catchment of river Maggia, the watersheds of river Vedeggio and Verzasca are very poor in carbonate containing rocks, but while the catchment of river Verzasca is characterized by the presence of rather new rocks that were formed during the orogenesis of the Alps (60 millions years ago), the geology of the catchment of river Vedeggio is much older (300 millions to 2.5 milliards years) and therefore much more weathered and fractured, increasing the surface that can interact with water from precipitations. Interestingly, highest and lowest nitrate concentrations were measured in rivers Vedeggio and Maggia, respectively. The low nitrate concentrations in river Maggia may be a consequence of its large watershed, being able to retain more nitrogen.

During 2012 average alkalinity was 281 meq m^{-3} in river Maggia, 161 meq m^{-3} in river Vedeggio and 60 meq m^{-3} in river Verzasca. Based on these data river Verzasca and river Vedeggio have low alkalinities (50-200 meq m^{-3}), but no river is sensitive to acidification. The same is suggested by their minimum alkalinities that were always > 0 meq m^{-3}. Average pH was 7.3 in river Maggia, 7.1 in river Vedeggio and 6.8 in river Verzasca. Their minimum pH's were not much lower (Maggia: 7.0, Vedeggio: 7.0, Verzasca: 6.6). As a consequence of the relatively high pH's, dissolved aluminium concentrations were on average low and mainly < 15 meq m^{-3}. However, higher aluminium concentrations up to 78 meq m^{-3} in river Maggia, 70 meq m^{-3} in river Vedeggio and 73 meq m^{-3} in river Verzasca occurred during a high flow event in October.

Table 2.5 Average concentrations in river water during 2012.
Average values with some or all single values below the quantification limit were preceded with <.

River name	pH	Conductivity 25°C (µS cm^{-1})	Alkalinity (µeq l^{-1})	Ca^{2+} (meq m^{-3})	Mg^{2+} (meq m^{-3})	Na^{+} (meq m^{-3})	K^{+} (meq m^{-3})	NH4+ (meq m^{-3})	SO_4^{2-} (meq m^{-3})	NO_3^{-} (meq m^{-3})	Cl^{-} (meq m^{-3})	SRP (µg P l^{-1})	DOC (mg C l^{-1})	SiO_2 (mg l^{-1})	$Al_{dissolved}$ (µg l^{-1})	Al_{tot} (µg l^{-1})	$Cu_{dissolved}$ (µg l^{-1})	Cu_{tot} (µg l^{-1})	$Zn_{dissolved}$ (µg l^{-1})	Zn_{total} (µg l^{-1})
Maggia	7.3	57	281	366	52	69	34	1	159	40	32	<2.9	1.0	4.9	17.8	20.0	<0.2	<0.3	1.6	1.8
Vedeggio	7.1	46	161	237	78	75	14	1	119	66	31	<3.2	1.0	7.3	13.9	14.8	<0.2	<0.2	<0.8	1.1
Verzasca	6.8	22	60	126	18	29	14	**1**	66	46	7	<2.5	0.8	3.8	13.9	15.0	<0.2	<0.3	<1.8	<2.2

Seasonal variations

Fig. 2.6 shows the daily mean discharges during 2012 and the monthly mean discharges in the period 2000-2010. In both graphs show low values during winter and higher values during the rest of the year, especially in spring and autumn. Sampling occurred simultaneously with increased discharge in June, August, October and November.

Concentrations of the main chemical parameters during 2012 were mostly very similar to their average values in the period 2000-2010. Concentrations of sulphate, chloride, base cations were lower from spring to autumn when river discharge is higher and higher during the rest of the year when discharge is lower. Because water quality of surface waters and rain differ greatly, Steingruber and Colombo (2006) suggested the following mechanisms occurring during rain events and/or snow melt: a dilution of sulphate, base cations, chloride and a combination of dilution and consumption of alkalinity. Because of rain acidity river pH clearly decreases during rain events. Nitrate concentrations seem to behave opposite to sulphate, chloride, base cations, alkalinity and pH and its variations are more difficult to understand. Highest concentrations in river Maggia and Verzasca normally occur from January to May and lowest during summer (Maggia, Verzasca). More than one factor probably determines its variation of concentrations e.g. higher values during the first months of the year because of higher concentrations in rainwater during that period (Fig. 2.2), increase during intense precipitation or snow melt because of leakage from soils, decrease during photosynthetic activity because of uptake by vegetation and algae during the vegetation period. Concentrations of aluminium seem to reach its highest concentrations during high flow events. In fact their average concentrations during 2000-2010 are highest during May and November when average daily discharge was also higher, suggesting leakage from soils, probably enhanced by lower pH values during these occasions. During 2012 highest values were measured during the high flow events in August, September and November.

Figure 2.6 Daily mean discharge during 2012.

Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2013). Discharge of river Verzasca at Sonogno and Maggia at Brontallo were estimated by discharge values of Verzasca at Lavertezzo and Maggia at Bignasco published by BWG (2001-2004) and BAFU (2005-2013). The vertical lines correspond to dates of sampling.

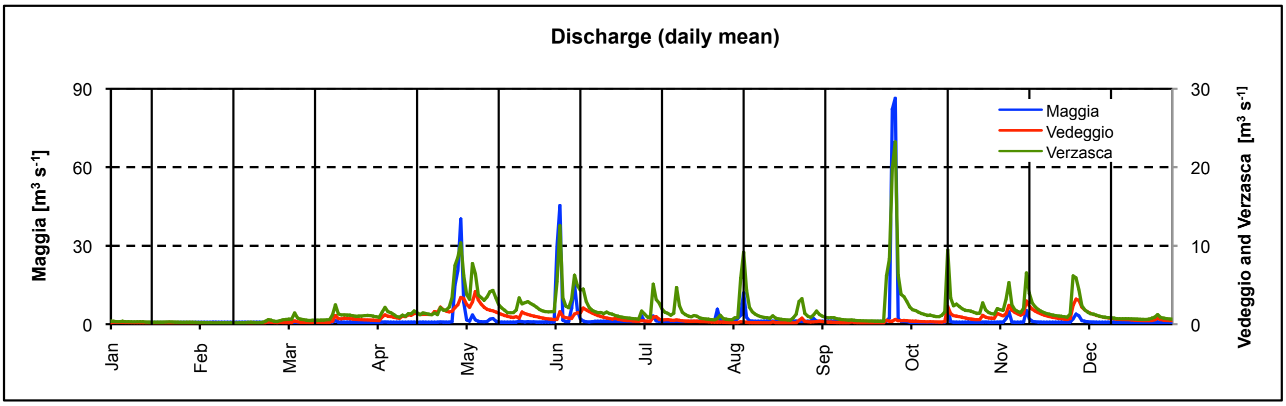
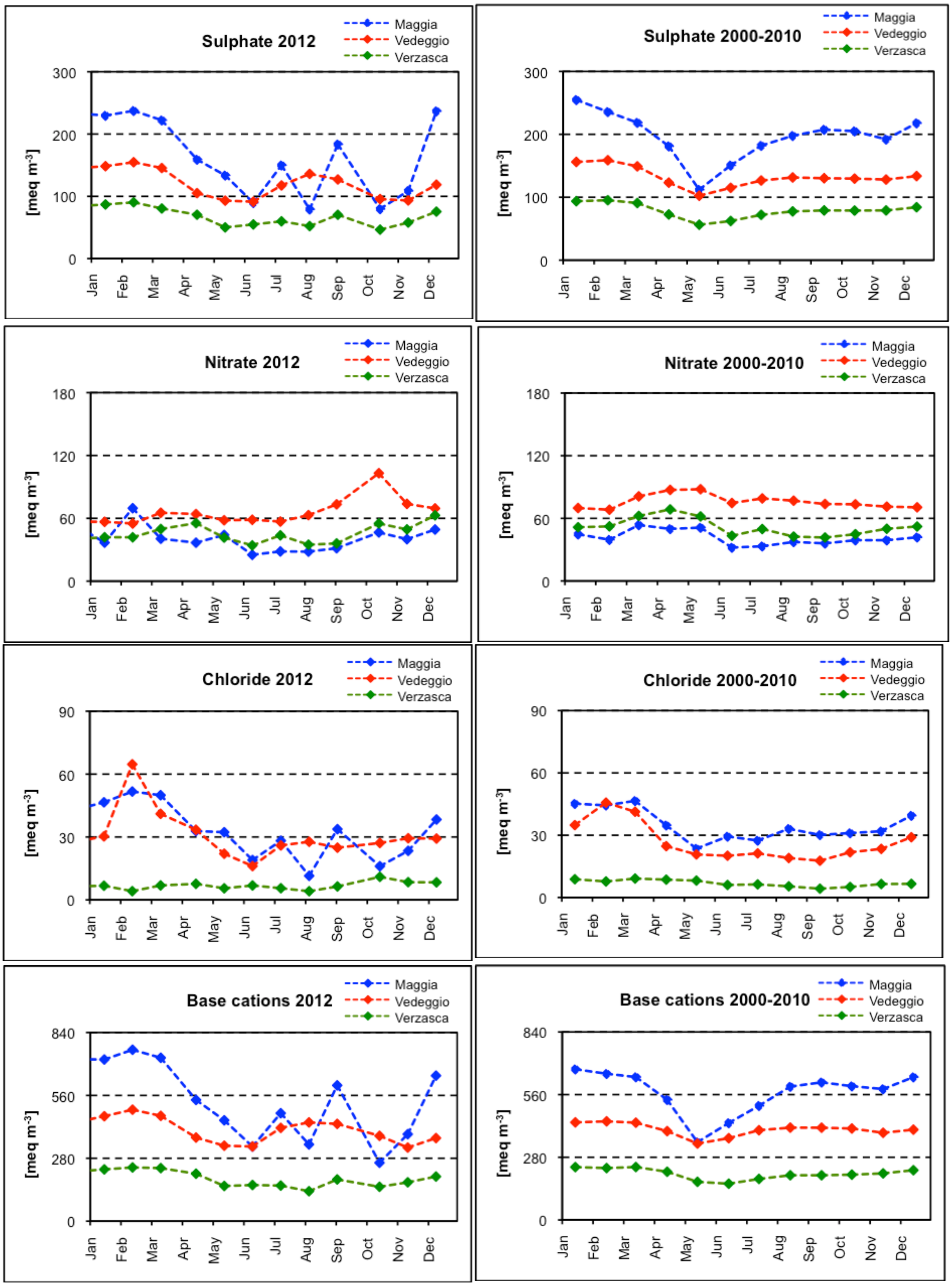
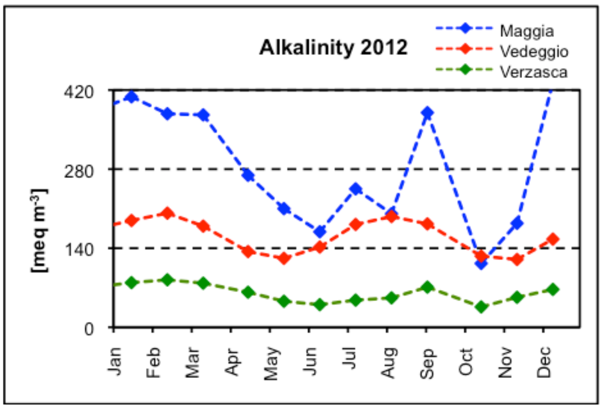
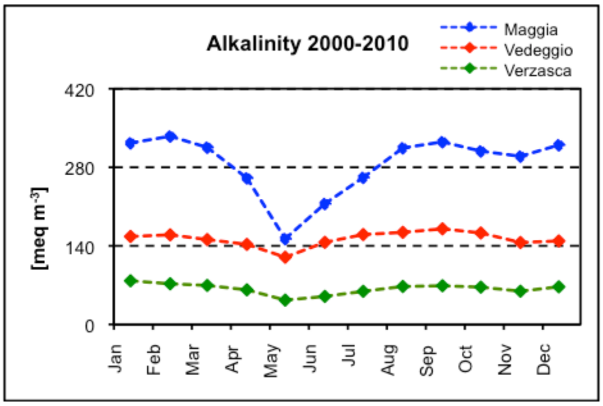


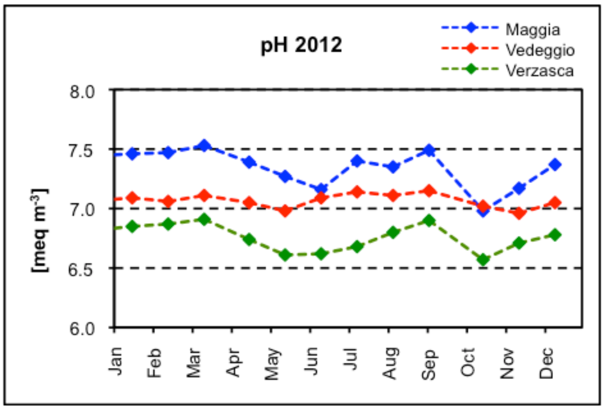
Figure 2.7 Concentrations of the main chemical parameters in river water during sampling days in 2012 and their average values from 2000 to 2010.

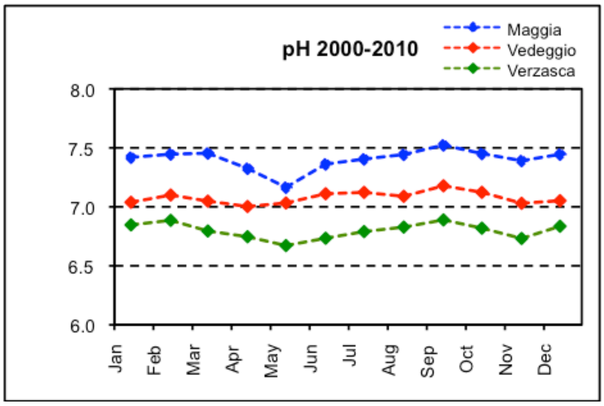
Base cations correspond to the sum of calcium, magnesium, sodium and potassium.

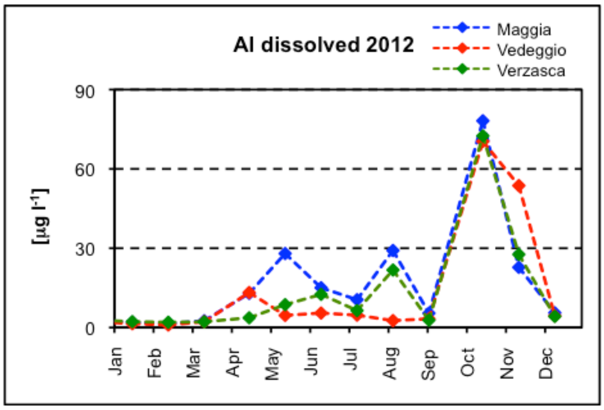


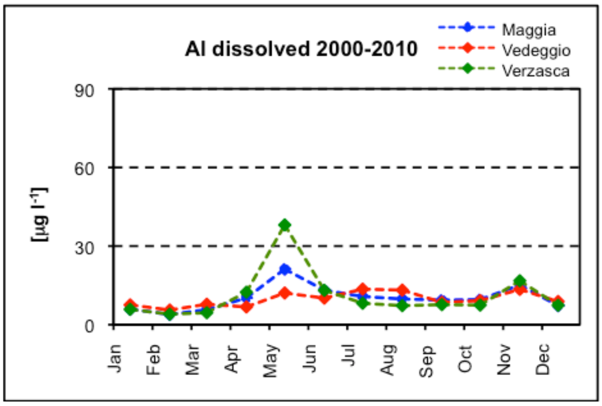

Alkalinity 2012
Maggia
Vedeggio
Verzasca
[meq m-3]
420
280
140
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

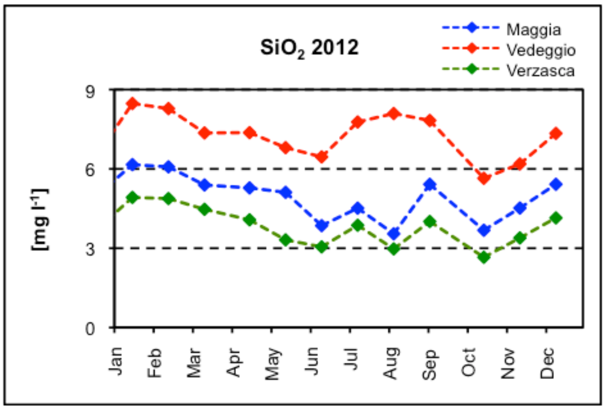

Alkalinity 2000-2010
Maggia
Vedeggio
Verzasca
[meq m-3]
420
280
140
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

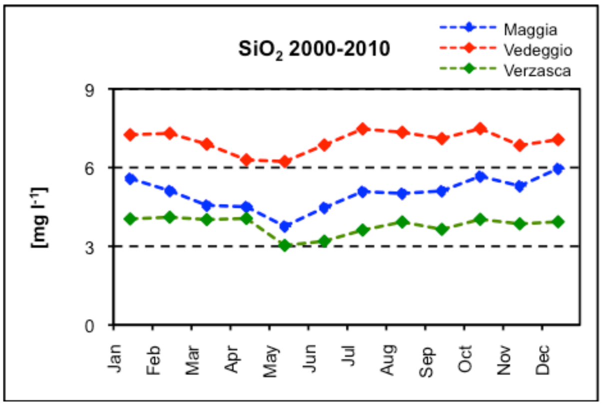

pH 2012
Maggia
Vedeggio
Verzasca
[meq m-3]
8.0
7.5
7.0
6.5
6.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


pH 2000-2010
Maggia
Vedeggio
Verzasca
8.0
7.5
7.0
6.5
6.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


Al dissolved 2012
Maggia
Vedeggio
Verzasca
[µg l-1]
90
60
30
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


Al dissolved 2000-2010
Maggia
Vedeggio
Verzasca
[µg l-1]
90
60
30
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


SiO2 2012
Maggia
Vedeggio
Verzasca
[mg l-1]
9
6
3
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


SiO2 2000-2010
Maggia
Vedeggio
Verzasca
[mg l-1]
9
6
3
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Temporal variations

Variations of monthly average discharges and concentrations of chemical parameters over time from 2000 to 2012 are presented graphically in Fig. 2.8 and 2.9, respectively. Since, as described for seasonal variations in river chemistry, concentrations are very much related to the river discharge, a yearly trend in river chemistry is difficult to detect at a glance. A more detailed time trend analysis of the period 2000-2010 with discharge as explanatory variable is described in Steingruber and Colombo (2011). Differently than what observed for precipitation, sulphate and nitrate concentrations in river water did not decrease significantly. Nevertheless, alkalinity decreased significantly in river Vedeggio and river Verzasca.

Figure 2.8 Monthly mean discharge in river water from 2000 to 2012

Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2013). Discharge of river Verzasca at Sonogno and Maggia at Brontallo were estimated by discharge values of Verzasca at Lavertezzo and Maggia at Bignasco published by BWG (2001-2004) and BAFU (2005-2013).

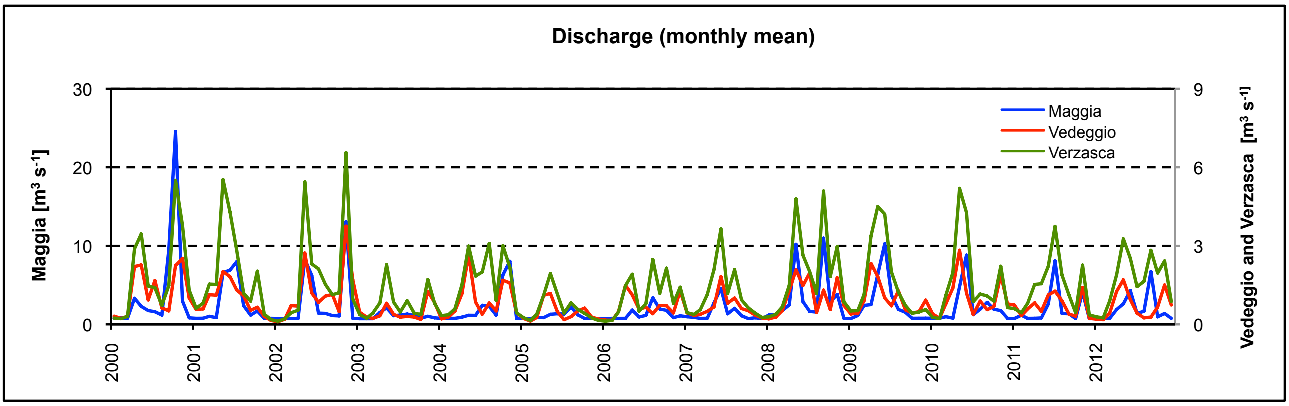
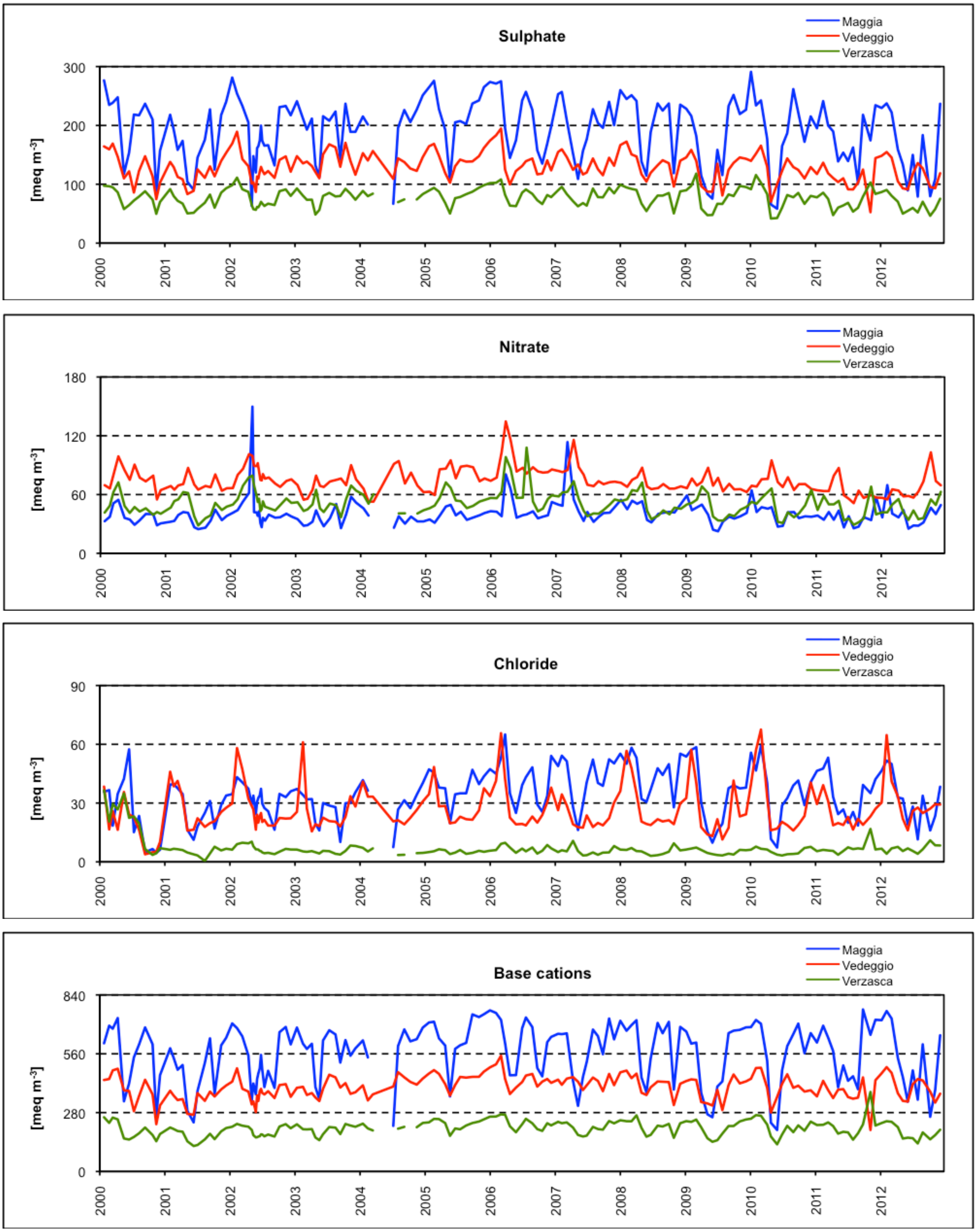
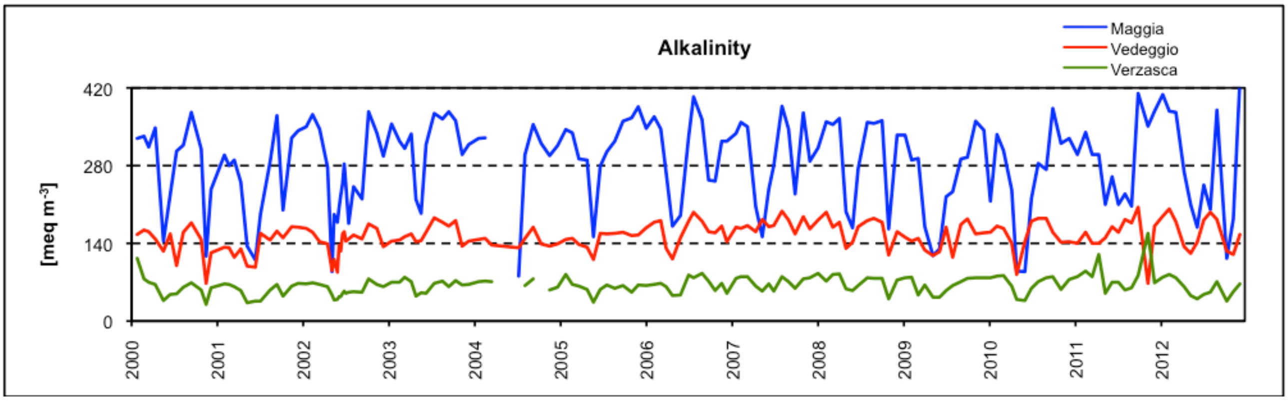
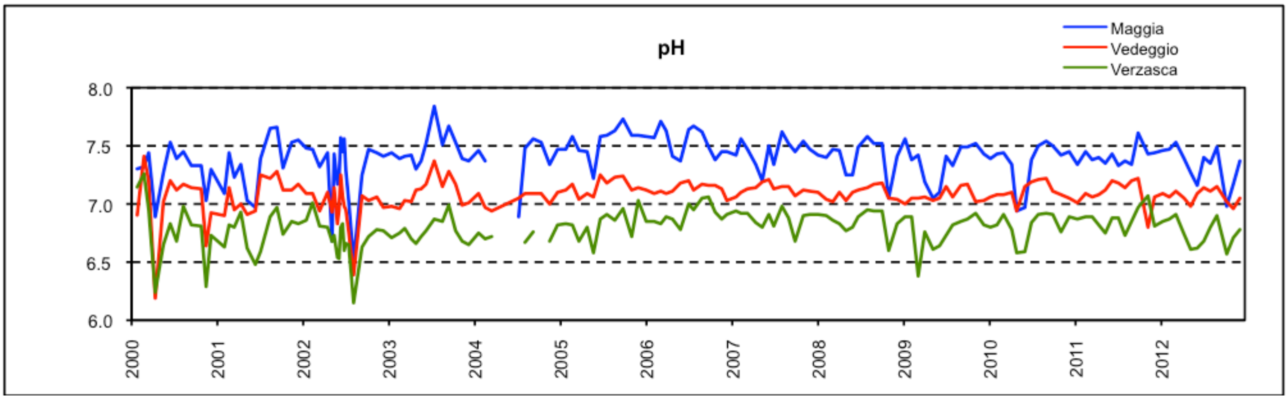


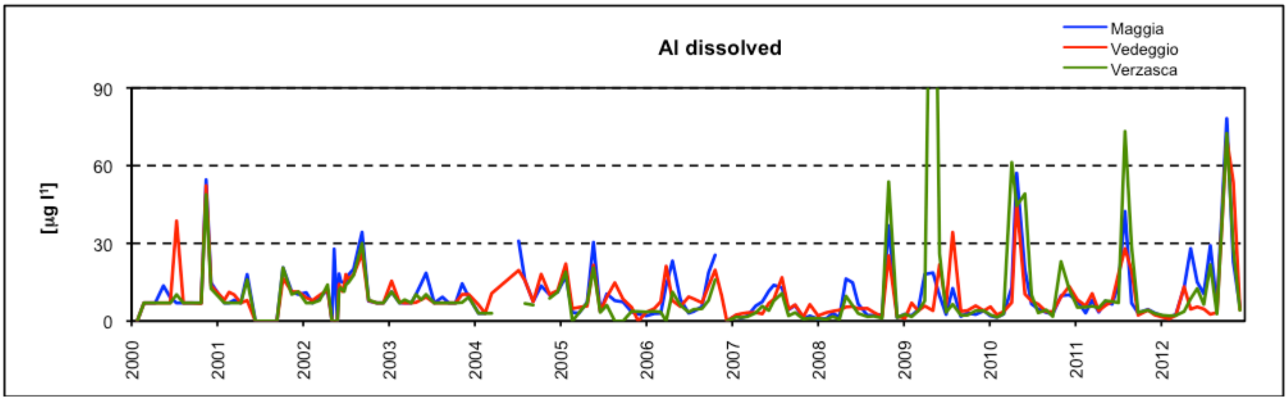
Figure 2.9 Concentrations of the main chemical parameters in river water from 2000 to 2012

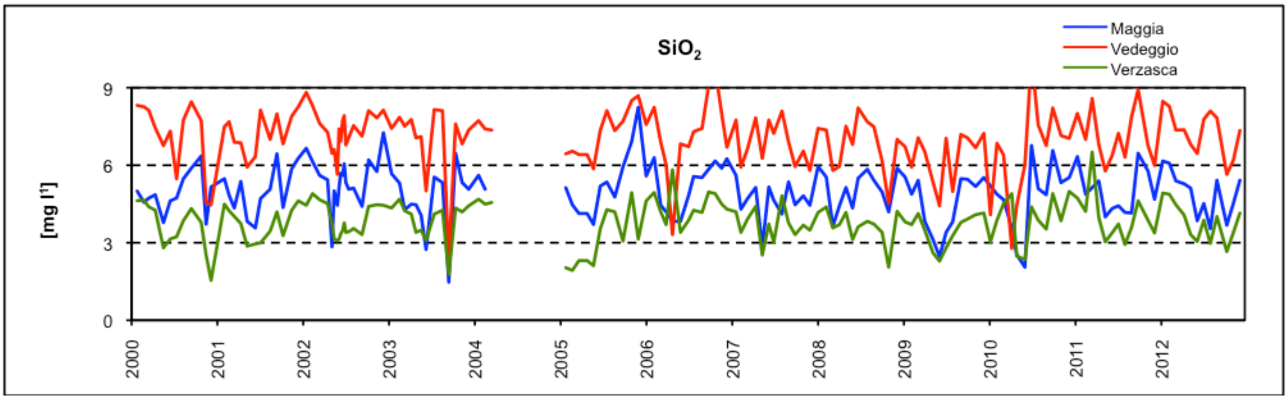
Base cations correspond to the sum of calcium, magnesium, sodium and potassium.




Alkalinity
Maggia
Vedeggio
Verzasca
[meq m-3]
420
280
140
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012


pH
Maggia
Vedeggio
Verzasca
8.0
7.5
7.0
6.5
6.0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012


Al dissolved
Maggia
Vedeggio
Verzasca
[µg l-1]
90
60
30
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012


SiO2
Maggia
Vedeggio
Verzasca
[mg l-1]
9
6
3
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

2.5.3 Alpine lakes

Spatial variations

During 2012 sampling of alpine lakes occurred at the following days: 3.7, 10.9, 8.10. Yearly mean concentrations of the main chemical parameters measured in lake surface water during 2012 are presented in Tab. 2.7. Means were calculated by averaging first the two autumn values and then the autumn with the summer value.

With exception of Lago Bianco, the chemical water composition is typical for carbonate poor mountain regions: low conductivity, alkalinity and pH and small nutrient and DOC concentrations. Average conductivity at 25°C varied between 7 and 19 $\mu S\ cm^{-1}$, alkalinity between -6 and 77 meq m^{-3}, pH between 5.3 and 6.9, sulphate between 15 and 104 meq m^{-3}, nitrate between 8 and 29 meq m^{-3}, dissolved organic carbon between 0.4 and 0.8 mg C l^{-1}, reactive dissolved silica between 0.8 and 2.4 mg SiO_2 l^{-1} and dissolved aluminium between 1 and 49 $\mu g\ l^{-1}$.

Table 2.7 Average lake surface water concentrations during 2012

Average values with some values below the quantification limit were preceded with <.

Lake name	Conductivity 25°C (µS cm^{-1})	pH	Alkalinity (meq m^{-3})	Ca^{2+} (meq m^{-3})	Mg^{2+} (meq m^{-3})	Na^{+} (meq m^{-3})	K^{+} (meq m^{-3})	NH_4^{+} (meq m^{-3})	SO_4^{2-} (meq m^{-3})	NO_3^{-} (meq m^{-3})	Cl^{-} (meq m^{-3})	DOC (mg C l^{-1})	SiO_2 (mg l^{-1})	$Al_{dissolved}$ (µg l^{-1})	Al_{tot} (µg l^{-1})	$Cu_{dissolved}$ (µg l^{-1})	Cu_{tot} (µg l^{-1})	$Zn_{dissolved}$ (µg l^{-1})	Zn_{total} (µg l^{-1})
Lago del Starlaresc da Sgiof	8.8	5.7	3	24	10	13	4	2	25	23	5	0.83	1.5	42.6	60.9	<0.2	<0.2	3.2	3.6
Lago di Tomè	9.1	5.7	5	38	5	13	4	1	26	28	4	0.46	1.7	19.6	25.3	<0.2	<0.2	1.8	2.0
Lago dei Porchieirsc	18.1	6.6	50	103	10	17	10	2	67	24	3	0.44	2.4	2.3	3.4	<0.2	<0.2	0.5	0.6
Lago Barone	9.2	6.1	14	42	5	10	4	2	32	19	3	0.45	1.4	2.8	4.0	<0.2	<0.2	1.0	1.1
Laghetto Gardiscio	7.7	5.3	-6	18	6	6	5	3	28	13	3	0.37	0.8	49.0	58.4	<0.3	<0.3	2.2	2.2
Lago della Capannina Leit	18.7	6.3	22	82	28	16	11	1	104	15	3	0.48	1.7	2.2	4.2	<0.2	<0.3	1.3	1.5
Lago di Morghirolo	12.5	6.5	35	57	13	13	10	1	47	14	2	0.43	1.7	1.0	2.2	<0.2	0.3	0.7	0.9
Lago di Mognòla	16.4	6.7	45	76	18	21	11	1	63	20	3	0.46	2.4	3.3	4.9	<0.2	<0.5	0.6	0.7
Laghetto Inferiore	9.5	6.5	29	44	7	11	8	1	24	20	2	0.58	1.3	4.5	7.8	<0.2	<0.2	0.7	0.8
Laghetto Superiore	9.2	6.5	33	44	7	10	7	1	22	17	2	0.65	1.2	5.1	8.5	<0.2	<0.2	0.4	0.5
Lago Nero	16.1	6.7	65	89	12	15	10	1	55	11	2	0.48	0.9	1.8	2.1	<0.2	<0.2	0.9	1.1
Lago Bianco	66.2	7.5	434	514	57	13	17	2	192	12	3	0.54	1.5	7.3	8.6	<0.2	<0.2	<0.3	0.4
Lago della Froda	12.1	6.6	42	72	6	10	5	1	35	16	2	0.52	1.2	2.7	4.3	<0.2	<0.2	0.5	0.7
Lago d'Antabia	12.1	6.8	59	71	5	16	6	1	18	20	2	0.48	2.1	3.0	4.3	<0.2	<0.2	<0.5	<0.5
Lago della Crosa	7.4	6.3	19	33	4	10	3	1	15	18	2	0.48	1.3	1.4	2.0	<0.2	<0.2	1.3	1.4
Lago d'Orsalìa	9.7	6.4	26	47	6	12	4	2	17	29	3	0.49	1.5	4.9	7.5	<0.2	<0.2	1.1	1.3
Schwarzsee	11.4	6.6	40	61	7	13	6	1	24	24	3	0.47	1.8	4.0	5.5	<0.2	<0.3	0.5	0.6
Laghi dei Pozzöi	8.5	6.5	35	40	7	14	4	1	21	8	3	0.84	1.9	9.2	13.6	<0.2	<0.2	0.6	0.7
Lago di Sfille	9.2	6.5	30	44	7	15	3	1	24	14	4	0.73	1.9	8.5	13.6	<0.2	<0.2	1.2	1.4
Lago di Sascòla	9.7	6.1	15	36	10	13	7	2	26	27	3	0.72	1.7	14.0	17.2	<0.2	<0.2	1.5	1.6
Lago d'Alzasca	15.9	6.9	77	82	15	20	11	2	36	18	4	0.65	2.4	4.0	4.2	<0.2	<0.2	0.5	0.5

In order to better compare chemistry of lakes with low alkalinities, values of the main parameters measured during 2012 and their mean values from 2000 to 2010 are shown graphically in Fig. 2.10.

In general values from 2012 are not much different from their of the period 2000-2010. During 2012 alkalinities below 0 meq m^{-3} were detected always in Laghetto Gardiscio and in late autumn in Lago del Starlaresc da Sgiof, while alkalinities constantly above 50 meq m^{-3} were measured only in Lago d'Alzasca. All other 17 lakes were at least temporary sensitive to acidification (0 < alkalinity < 50 meq m^{-3}). It also immediately appears that alkalinity correlates well with pH and concentrations of aluminium. Lakes with lowest alkalinities had also lowest pH and highest concentrations of aluminium. Particularly high concentrations of aluminium were mainly measured in lakes with pH's <= 6 like Lago del Starlaresc da Sgiof, Lago, Laghetto Gardiscio, Lago di Tomè where concentrations ranged from 14 to 79 $\mu g\ l^{-1}$. In general concentrations of base cations also correlate well with alkalinity, which is not surprising since in nature carbonate is often associated with calcium or magnesium. Differently, because of their mainly atmospheric origin, sulphate and nitrate concentrations do not correlate with alkalinity. Highest concentrations of sulphate occur in lakes with catchments probably rich in geogenic sulphate (Lago della Capannina Leit, Lago dei Porchieirsc, Lago di Mognòla, Lago Nero, Lago di Morghirolo, Lago della Froda). Because deposition of sulphate does not differ greatly between lakes, concentrations of sulphate in the other lakes are similar to each other. For nitrate, differences in concentrations among lakes are more difficult to understand. Similarly to sulphate, deposition of nitrate is probably similar for all lakes, so that differences in concentrations may result as a consequence of different retention capacity of the catchment.

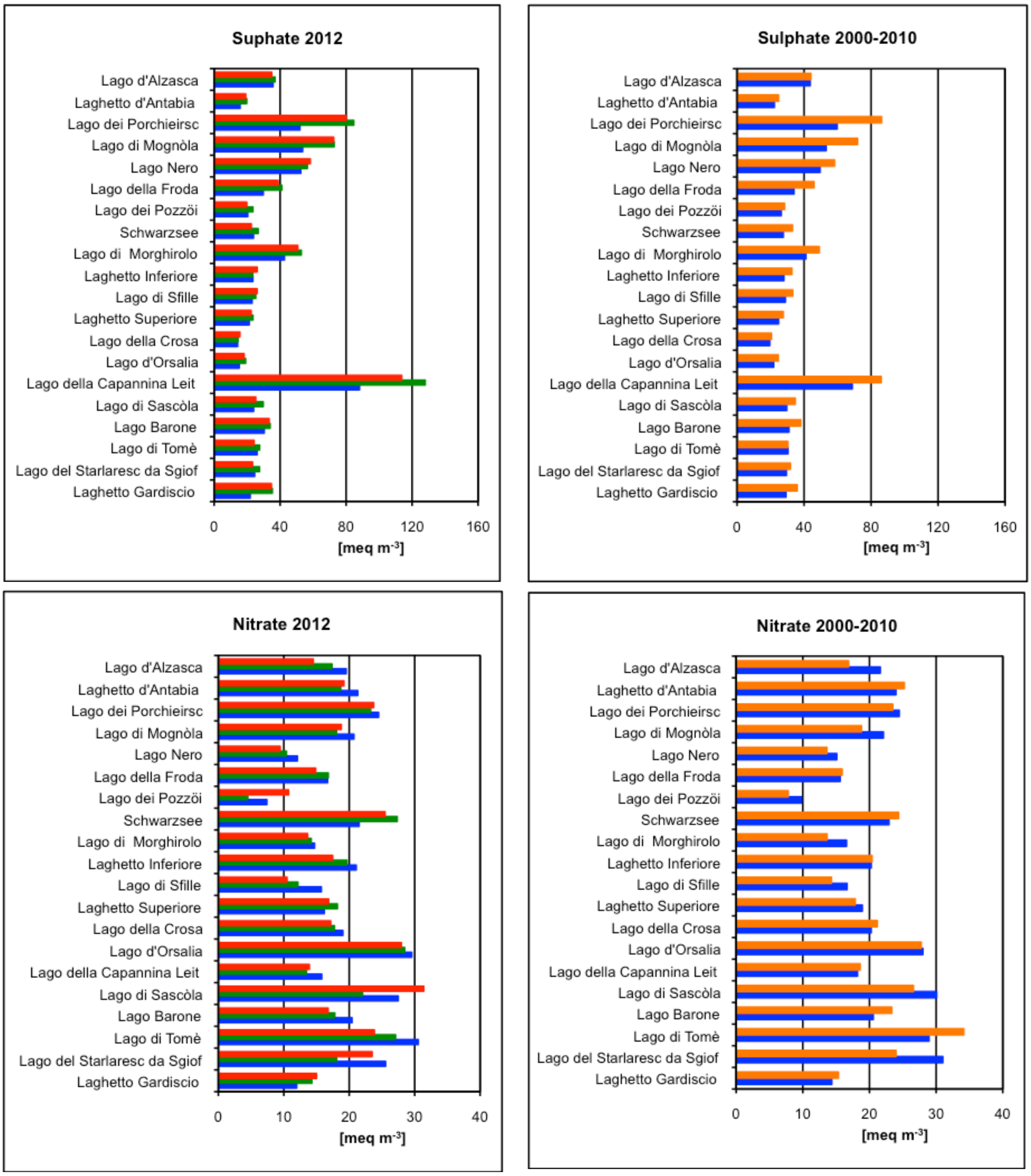
Seasonal variations

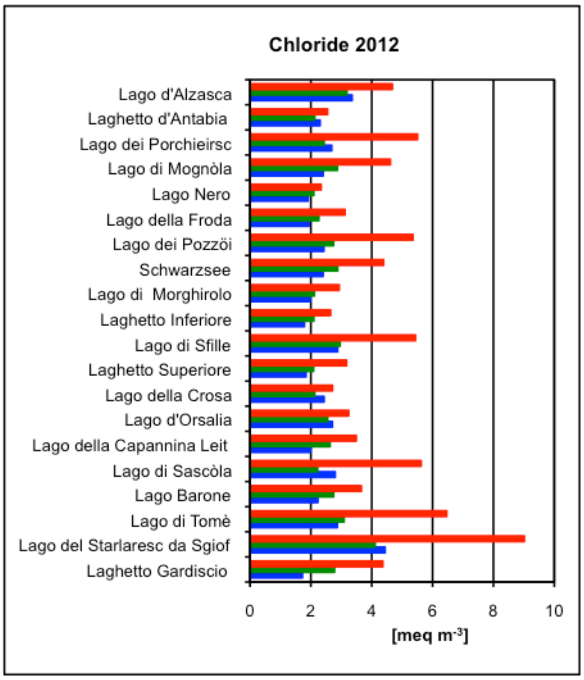
Fig. 2.10 also shows some seasonal differences. These are mostly in agreement with seasonal variations observed for rivers. In most lakes alkalinity and pH and concentrations of sulphate and base cations are lower in July than in September and October. As discussed for rivers, the elevated discharge in spring causes a dilution of sulphate, base cations and a combination of dilution and consumption of alkalinity. Differently, concentrations of nitrate are often higher at the beginning of the summer compared to fall. Since concentrations in precipitations are normally in the same range as in lakes, differences in nitrate concentrations between spring and summer may be caused by a combination of increased nitrate leaching during high discharge in spring and by increased assimilation and eventually also denitrification both in the catchment and in the lake itself during the warmer summer months.

Figure 2.10 Annual average concentrations of the main chemical parameters in 20 Alpine lakes during 2012 and their average values from 2000 to 2010.

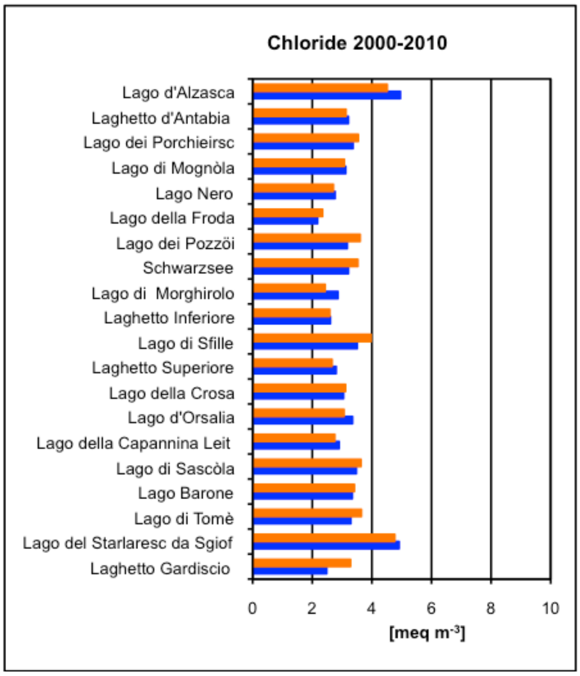
Blue: summer, green: autumn 1, red: autumn 2; orange: mean autumn.

Base cations correspond to the sum of calcium, magnesium, sodium and potassium.

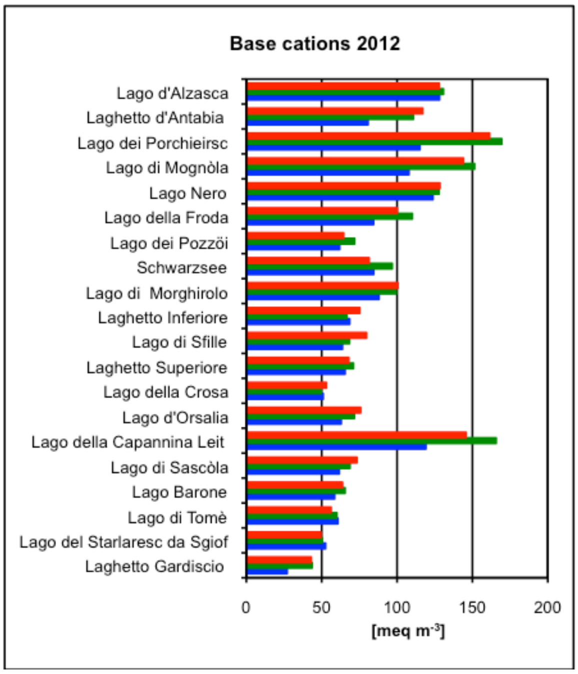




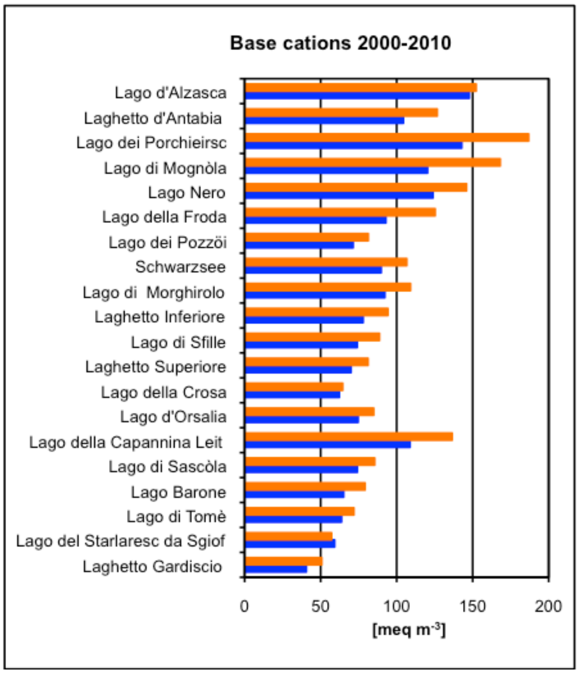
Chloride 2012
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0
2
4
6
8
10
[meq m-3]



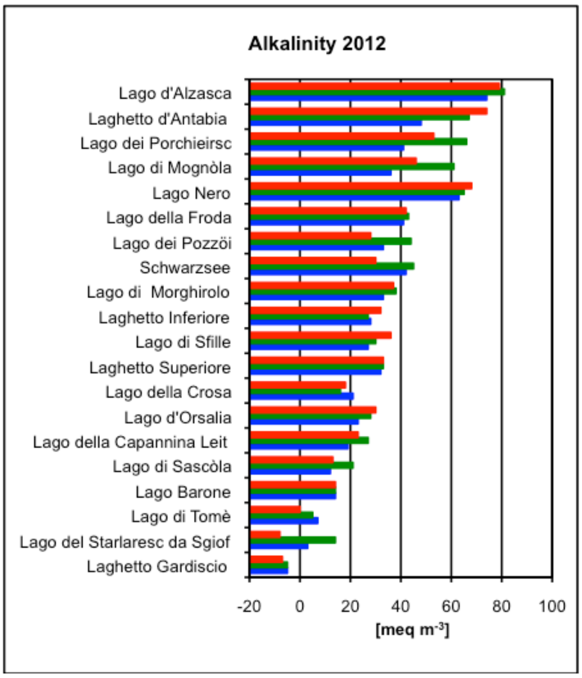
Chloride 2000-2010
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0
2
4
6
8
10
[meq m-3]

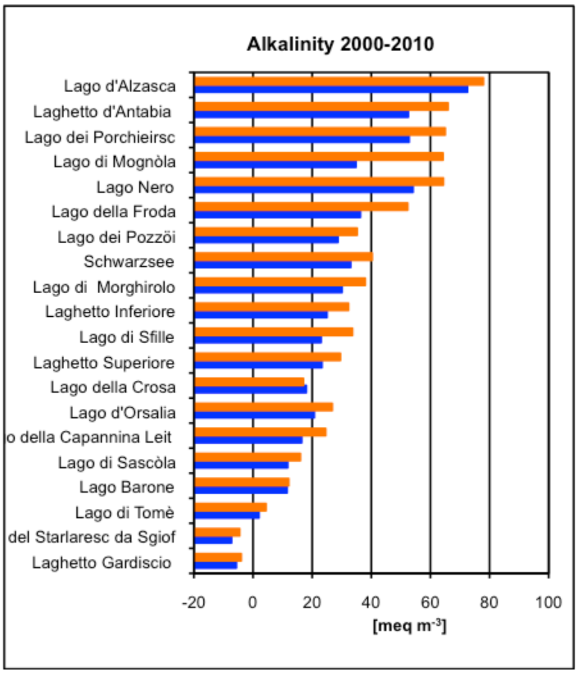


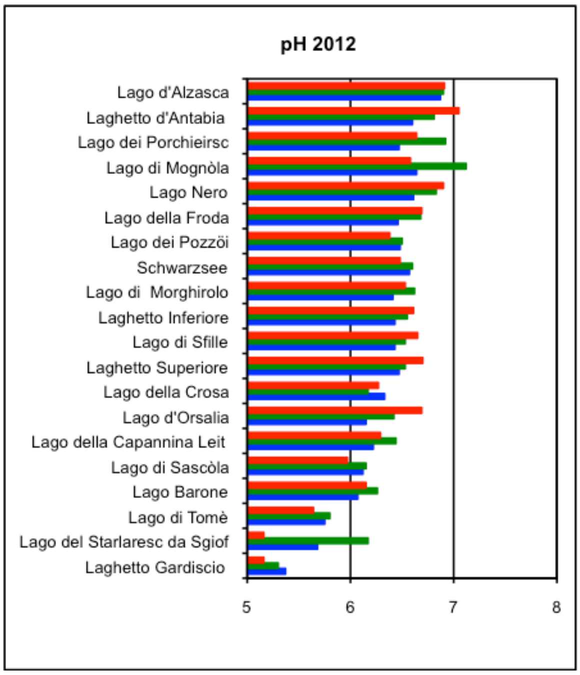
Base cations 2012
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0
50
100
150
200
[meq m-3]

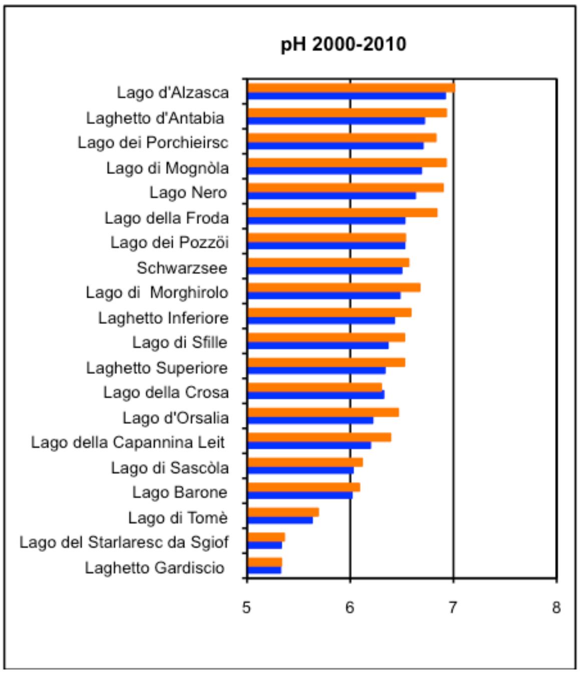


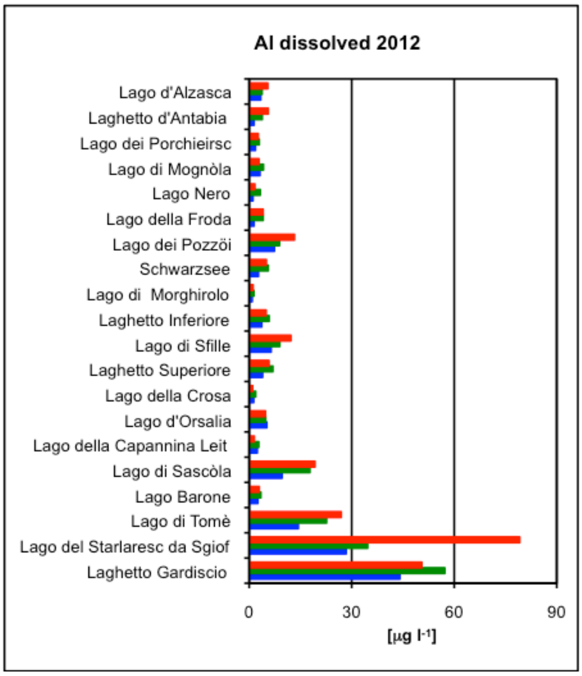
Base cations 2000-2010
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0
50
100
150
200
[meq m-3]

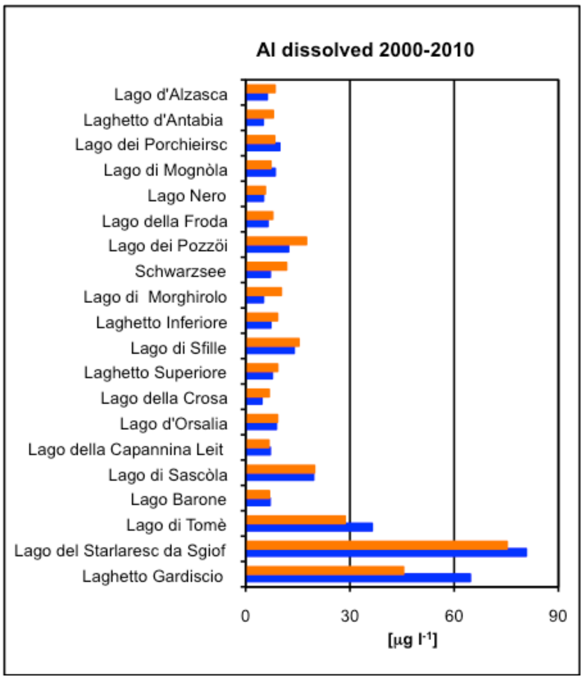

Alkalinity 2012
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
-20 0 20 40 60 80 100
[meq m-3]


Alkalinity 2000-2010
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
o della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
del Starlaresc da Sgiof
Laghetto Gardiscio
-20 0 20 40 60 80 100
[meq m-3]


pH 2012
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
5 6 7 8


pH 2000-2010
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
5 6 7 8


Al dissolved 2012
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0
30
60
90
[µg l-1]

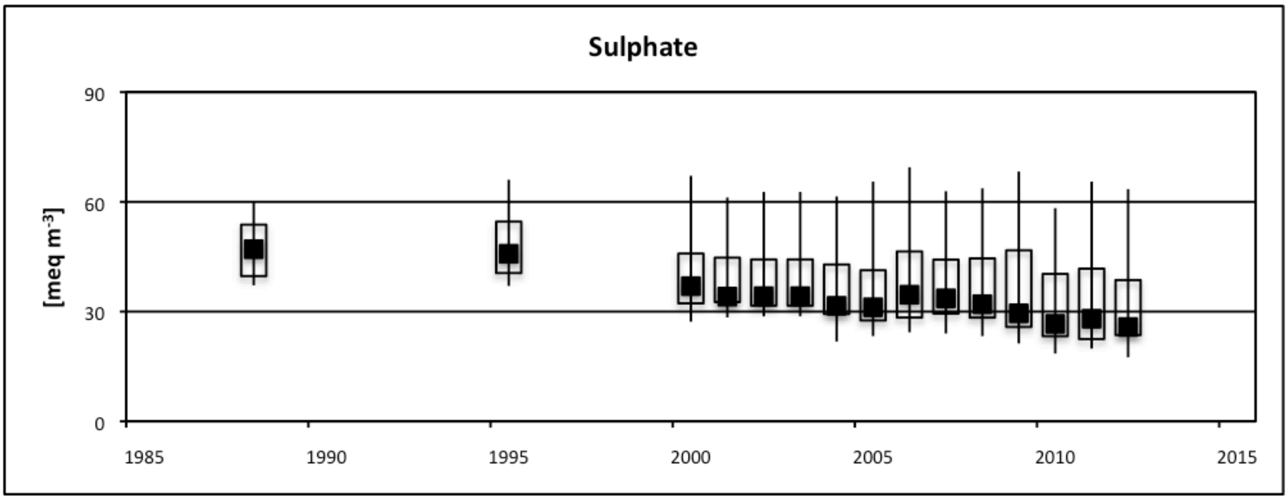

Al dissolved 2000-2010
Lago d'Alzasca
Laghetto d'Antabia
Lago dei Porchieirsc
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Pozzöi
Schwarzsee
Lago di Morghirolo
Laghetto Inferiore
Lago di Sfille
Laghetto Superiore
Lago della Crosa
Lago d'Orsalia
Lago della Capannina Leit
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0
30
60
90
[µg l-1]

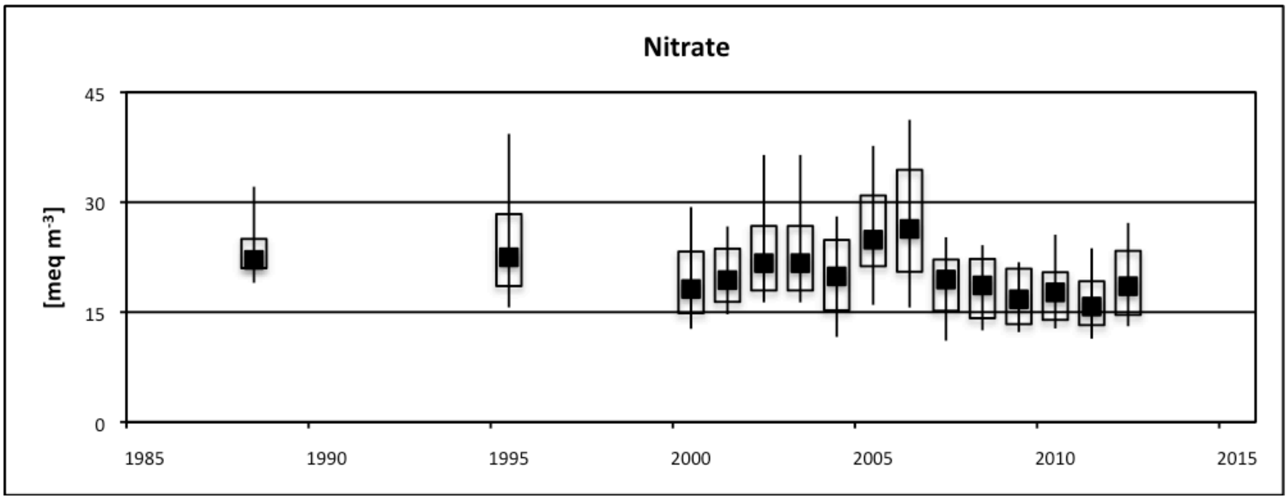
Temporal variations

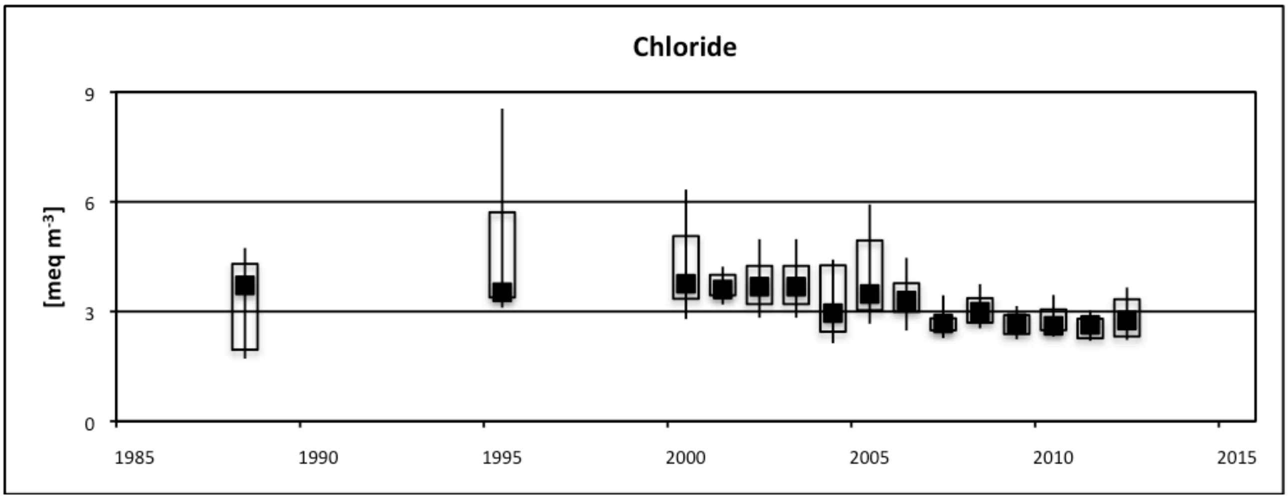
In order to show temporal variations of lake quality, annual median values of pH, alkalinity and concentrations of base cations, sulphate and nitrate of all lakes with their 10th, 25th, 75th and 90th percentile values are represented in Fig. 2.11. Only years, where all 20 alpine lakes have been monitored were chosen. As already discussed in Steingruber and Colombo (2006), after 1980's sulphate concentrations decreased, mainly because of the reduction of the sulphur content in heating oils and the partial substitution of sulphur rich combustibles with other fossil fuels. However, it is interesting to observed that in 3 lakes (Lago della Capannina Leit, Lago di Morghirolo and Lago di Mongòla concentrations of sulphate are increasing (data not shown). Melting of rock glaciers because of climate change present in all 3 lakes (Scapozza and Mari, 2010) might be the reason (Thies et al., 2007). However, in general as a consequence of sulphate decrease alkalinity and pH increased. Concentrations of nitrate also seem to have slightly decreased as a consequence of reduced emissions of NO_x. Aluminium concentrations of the 3 most acidic lakes are presented in Fig. 2.12. A clear decrease in concentrations can be observed only in Lago di Tomè from about 40 to 20 $\mu g\ l^{-1}$. In Lago del Starlaresc da Sgiof concentrations also decreased (from 80-100 to 60-80 $\mu g\ l^{-1}$) but with high annual fluctuations. No significant trend in concentrations of aluminium occurred in Laghetto Gardiscio, neither alkalinity significantly increased and sulphate only slightly increased. Interestingly, Laghetto Gardiscio is the highest lake here studied (2580 m a.s.l.), while its geology (mainly gneiss) and landuse seems not to be very different from the other lakes. However, together with the very small catchment (12 ha), steep catchment slope and the resulting short residence time it would explain the low pH. Instead, the almost missing time trends are related to the fact that deposition at this altitude have probably always been too low to show a time trend. In fact, Steingruber and Colombo (2010) showed that concentrations in rainwater decrease with altitude and the same happens for changes in concentrations with time. As a paradox, the most acidic lake may therefore have been also that less affected by acid deposition, showing only slight trend of pH and alkalinity in time.

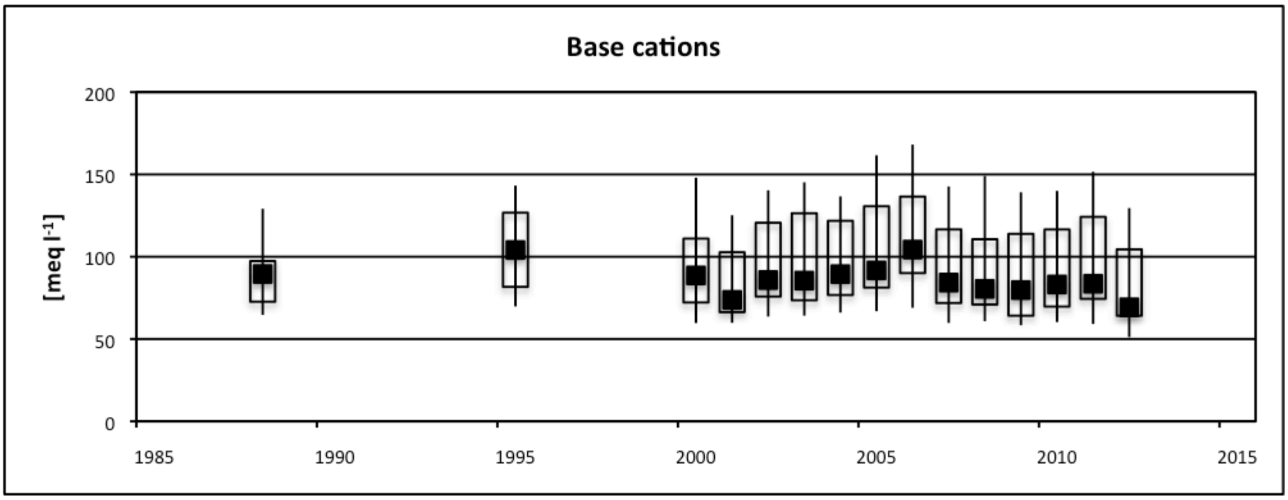
Figure 2.11 Temporal variations of annual median values and their 10th, 25th, 75th, 90th percentiles of parameters measured in 20 Alpine lakes from 1988 to 2012.

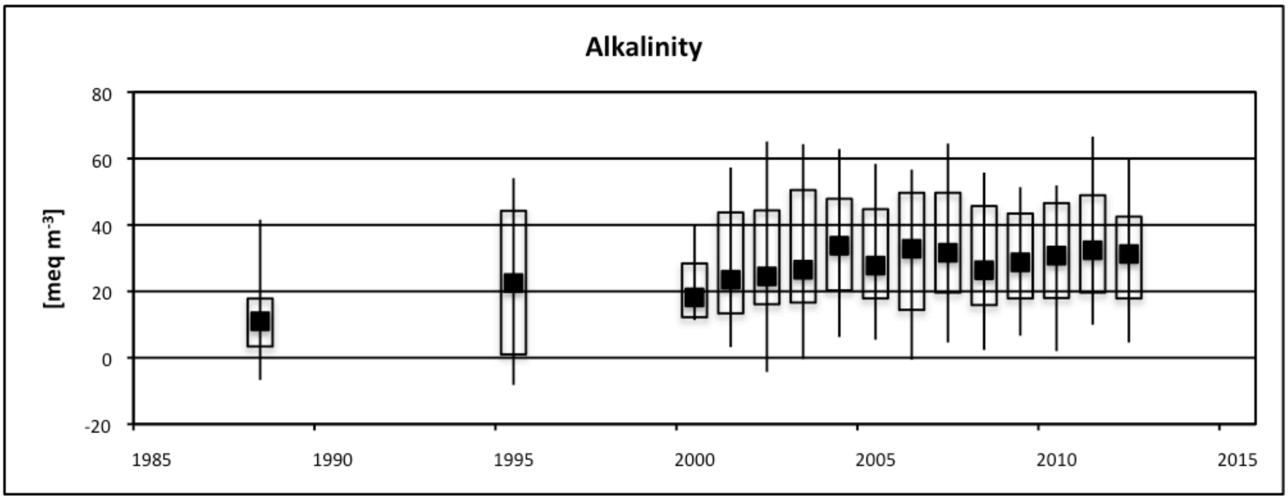
Base cations correspond to the sum of calcium, magnesium, sodium and potassium.








Base cations
[meq l-1]
200
150
100
50
0
1985
1990
1995
2000
2005
2010
2015


Alkalinity
[meq m-3]
80
60
40
20
0
-20
1985
1990
1995
2000
2005
2010
2015

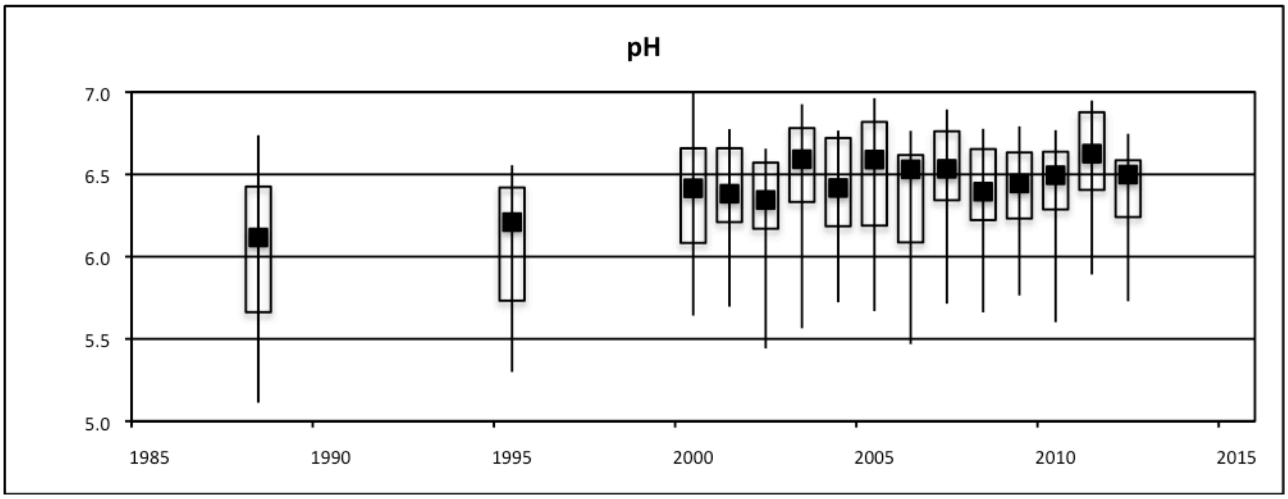
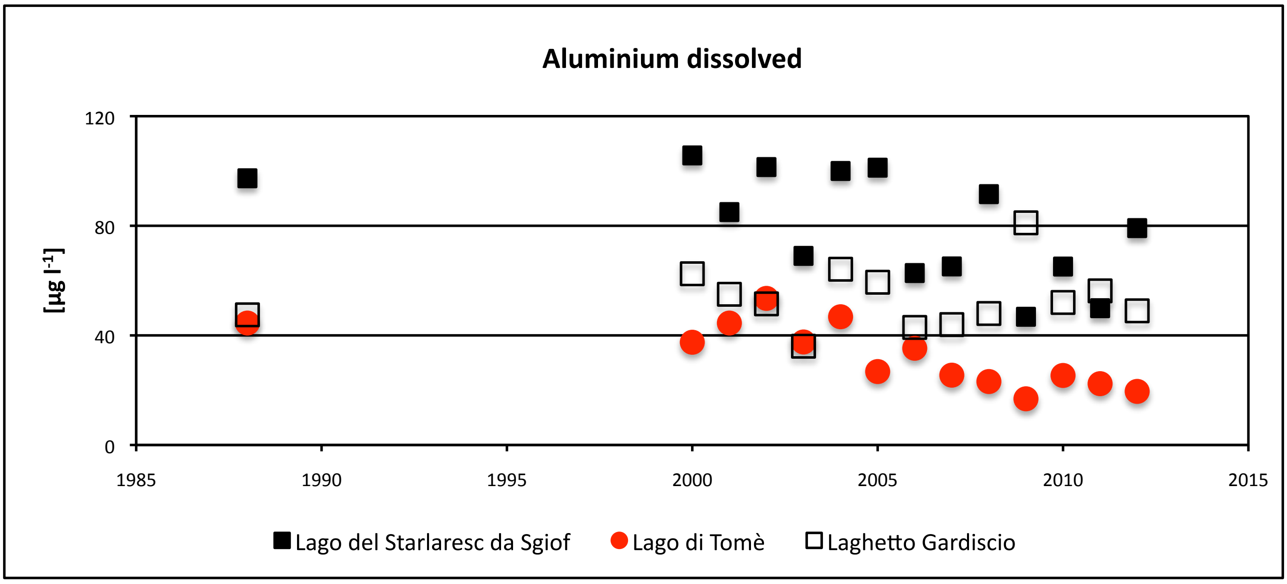

pH
7.0
6.5
6.0
5.5
5.0
1985
1990
1995
2000
2005
2010
2015

Figure 2.12 Temporal variations of dissolved aluminium in the 3 most acidic lakes from 1988 to 2012



3 Macroinvertebrates as bioindicators

3.1 Introduction

The ultimate goal of emission control programmes is biological recovery, e.g. the return of acid sensitive species that have disappeared and the restoration of biological functions that have been impaired during the course of acidification. Since concentrations of soluble aluminium increase with decreasing pH from a pH of ca. 6.3, it is generally assumed that first signs of changes in the biological communities as a consequence of acidification appear when pH drops below 6 (Wright et al. 1975). To study biological recovery at sites with acidification problems macroinvertebrates were included as bioindicators in the monitoring programme. Between 2000 and 2011 macroinvertebrates were monitored regularly in 4 lakes (Laghetto Inferiore, Laghetto Superiore, Lago di Tomè, Lago del Starlaresc da Sgiof) and 3 rivers (Maggia, Vedeggio, Verzasca). In order to better interpret results from Alpine lakes, from 2006 to 2011 the alkaline lake Lago Bianco was also added to the monitoring list. After 2012 because of financial reasons monitoring of macroinvertebrates was limited to the most acid sensitive sites (Laghetto Inferiore, Laghetto Superiore, Lago di Tomè, Lago del Starlaresc da Sgiof and river Verzasca). During 2012 average and minimum lake pH's were 6.5/6.4, 6.5/6.5, 5.7/5.6, 5.7/5.2 in lakes Inferiore, Superiore, Tomè and Starlaresc da Sgiof, respectively. Compared to Alpine lakes, river Verzasca is situated at much lower altitudes, having therefore a larger catchments area, that is responsible for higher average weathering rates. As a consequence river Verzasca is characterized by higher salinity and higher pH (average values during 2013 was 6.8). However, during high flow pH can decrease close to average pH values of lakes (6.7 during 2013).

3.2 Methods

Macroinvertebrate samples were collected by "kicksampling" according to the ICP Waters Manual (ICP Waters Programme Centre, 2010). Lake samples (Laghetto Inferiore, Laghetto Superiore, Lago di Tomè, Lago del Starlaresc da Sgiof, Lago Bianco) were collected from the littoral and the emissary 2-3 times a year. Sampling in river Maggia, Vedeggio and Verzasca occurred 3-8 times a year, after 2012 Verzasca was sampled separately in a pool and a run zone. Before 2012 for each site a mixed sample from different substrates was sampled. After 2012 for each site samples from fine and coarse substrates were collected separately. Macroinvertebrates were conserved in 70% ethanol. During the first 2 years (2000-2001) for mixed littoral and outlet samples were taken. For this reason results from 2000 and 2001 are difficult to compare with those after 2002, when littoral and outlet samples were collected separately and were therefore omitted in the temporal analysis. Instead, we used results from samples taken in the littorals and the outlets of Laghetto Inferiore and Superiore by the Institute for Ecosystem Studies in Pallanza during 1991 and results from samples taken in the littoral and the outlets of Laghetto Inferiore, Laghetto Superiore, Lago di Tomè, Lago del Starlaresc da Sgiof for EMERGE in 2000.

To study temporal trends the relative abundances of the main taxonomic groups are here shown. In addition, the total number of taxa, the number of taxa belonging to the orders of Ephemeroptera, Plecoptera and Trichoptera (EPT taxa), considered particularly sensitive to pollution, and the number of acid sensitive taxa (AS taxa) according to literature are presented. In order to avoid differences in the taxa number caused by different identifications levels used through time, for each taxonomic group a taxonomic identification level was defined and the results filtered through. The identification levels are the following: Annelida -> class, Arachnida -> subcohort, Coleoptera -> genus, Diptera -> family, Ephemeroptera -> genus, Heteroptera -> genus, Megaloptera -> genus, Odonata -> genus, Trichoptera -> genus, Mollusca -> class, Plathelminthes -> family. Moreover, since the sample sizes varied greatly from year to year and it is known that the number of taxa/species increases with the number of individuals, the yearly number of taxa were standardized. For each sampling site a potential regression was calculated between the annual total number of taxa and the annual number of sampled individuals. With this functions for each year the number of taxa were standardized to a sample size of 1000 individuals. For rivers the acidification class described in Braukmann and Biss (2004) was also calculated.

3.3 Results and discussion

3.3.1 Lakes

Sample sizes and the relative abundance of identified taxa with the most important taxa numbers (total, EPT, AS) in lakes during 2013 are shown in Tab. 3.1 and 3.2, respectively. At all sites Diptera was the most abundant order especially in the littoral, mainly represented by Chironomidae, but also by the current loving Simuliidae in the outlets and Ceratopogonidae in Lago del Starlaresc da Sgiof, probably because of the presence of wetland vegetation. Other quantitatively important taxonomic groups are Oligochaeta, with Tubificidae preferring fine substrates, Plecoptera (*Leuctra sp.*, *Nemoura sp.*, *Protonemoura sp.*) and Trichoptera (*Plectrocnemia sp.*, *Rhyacophila sp.*). The more acid sensitive Ephemeroptera were found only in Laghetto Inferiore (*Ecdyonurus sp.*), Heteroptera (Gerridae) and Odonata (*Aeshna sp.*, *Orthetrum sp.*), that are commun in wetlands, were observed only in Lago del Starlaresc da Sgiof, Bivalvia (mussels) were collected only in the littorals of Laghetto Inferiore and Laghetto Superiore and Turbellaria (probably the acid sensitive *Crenobia sp.*) were present in the outlets of Laghetto Inferiore, Laghetto Superiore and Lago di Tomè. Regarding the number of taxa, it can be observed that the total number of taxa were higher in fine substrates compared to coarse, in outlets compared to littorals. Lake outlets are in fact known to be unique aquatic environments that are inhabited by both lake and stream organisms (Hieber, 2002). Highest total taxa numbers were found in Laghetto Inferiore, while among the other lakes numbers differed little. Similar differences between outlet and littoral occurred also for the number of EPT taxa. The highest numbers of EPT taxa were also identified in Laghetto Inferiore, while lowest numbers characterized Lago del Starlaresc da Sgiof. Acid sensitive taxa were only found in Laghetto Inferiore (*Ecdyonurus sp.*). The still occasionally low pH of Lago del Starlaresc da Sgiof and its related high aluminium concentrations (up to 80 μg/l) may have been responsible for the low EPT taxa number and the absence of Turbellaria and Bivalvia in Lago del Starlaresc da Sgiof.

Table 3.1 Lake sample sizes during 2013.

LAKE	SITE	SUBSTRATE	JULY	OCTOBER
INF	Outlet	fine	715	904
		coarse	1320	1862
	Littoral	fine	543	587
		coarse	314	1050
SUP	Outlet	fine	853	180
		coarse	787	4903
	Littoral	fine	538	676
		coarse	448	826
TOM	Outlet	fine	169	39
		coarse	577	73
	Littoral	fine	172	148
		coarse	72	190
STA	Outlet	fine	362	35
		coarse	285	84
	Littoral	fine	304	770
		coarse	341	535

Table 3.2 Relative abundance and number of taxa in lakes during 2013.

TAXA	INF				SUP				TOM				STA			
	Outlet		Littoral		Outlet		Littoral		Outlet		Littoral		Outlet		Littoral	
	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
OLIGOCHAETA	**0.6%**	**0.3%**	**7.1%**		**2.4%**	**45.1%**	**9.3%**	**1.9%**	**7.7%**		**19.5%**		**11.4%**	**0.4%**	**16.1%**	**9.9%**
Naididae	0.4%	0.3%	1.4%		1.5%	45.1%	2.7%								1.6%	
Tubificidae	0.2%		5.7%		0.9%		6.7%	1.9%	7.7%		19.5%		11.4%	0.4%	14.5%	9.9%
HYDRACARINA	**0.1%**	**0.1%**		**0.4%**			**0.2%**	**0.2%**	**1.2%**		**12.4%**	**30.6%**	**8.2%**	**4.3%**	**2.0%**	
COLEOPTERA			**0.3%**				**0.3%**	**0.4%**		**1.4%**	**0.3%**	**0.3%**	**0.1%**	**0.4%**		
Hydroporinae			0.3%				0.3%	0.2%			0.3%	0.3%				
Lacophilinae								0.1%								
DIPTERA	**87.9%**	**93.8%**	**90.9%**	**98.5%**	**80.6%**	**50.3%**	**88.0%**	**92.7%**	**58.3%**	**94.9%**	**62.9%**	**60.6%**	**75.7%**	**62.4%**	**80.3%**	**84.3%**
Ceratopogonidae													26.4%	13.0%	16.1%	14.2%
Chironomidae	64.8%	71.9%	90.9%	98.5%	79.4%	46.4%	88.0%	92.7%	29.8%	50.9%	62.5%	60.6%	19.1%	49.1%	64.1%	70.1%
Limoniidae	0.3%															
Simuliidae	22.8%	21.8%			1.2%	3.9%			28.5%	44.0%	0.3%		30.1%	0.2%		
EPHEMEROPTERA	**0.3%**	**0.2%**														
Ecdyonurus sp.	0.3%	0.2%														
HETEROPTERA													**0.1%**		**0.8%**	**5.3%**
Gerridae													0.1%		0.8%	5.3%
ODONATA													**4.4%**	**1.1%**	**0.9%**	**0.4%**
Aeshna grandis																0.3%
Aeshna sp.													3.0%	1.1%	0.8%	0.1%
Orthetrum sp.													1.4%		0.1%	
PLECOPTERA	**2.2%**	**1.5%**	**1.3%**	**0.6%**	**13.1%**	**1.5%**	**0.5%**	**4.7%**	**26.3%**	**1.6%**	**1.3%**	**0.5%**		**31.5%**		
Leuctra sp.	0.2%	0.1%			3.5%	1.2%			18.5%	1.2%	0.3%					
Nemoura avicularis	0.1%															
Nemoura cinerea			0.1%	0.2%												
Nemoura mortoni	0.7%	0.1%												31.5%		
Nemoura sp.	0.7%	0.5%	1.2%	0.5%	9.7%	0.1%	0.5%	4.7%	5.1%		0.7%	0.5%				
Protonemoura sp.	0.6%	0.8%				0.3%			2.7%	0.3%	0.3%					
TRICHOPTERA	**0.7%**	**0.2%**	**0.3%**	**0.3%**	**2.1%**	**0.1%**	**0.4%**	**0.2%**	**2.9%**		**3.7%**	**8.1%**				
Limnephilidae					0.3%						3.0%	0.7%				
Plectrocnemia conspersa			0.3%	0.2%			0.4%	0.2%	2.9%		0.3%	7.4%				
Plectrocnemia sp.					1.8%						0.3%					
Rhyacophila dorsalis	0.1%															
Rhyacophila (Rhyacophila) sp.	0.6%	0.2%				0.1%										
BIVALVIA			**0.1%**				**1.2%**									
TURBELLARIA	**8.2%**	**4.0%**		**0.2%**	**1.8%**	**2.9%**			**3.6%**	**2.2%**						
Planariidae	8.2%	4.0%		0.2%	1.8%	2.9%			3.6%	2.2%						
Number total taxa	15	11	8	7	9	8	8	7	9	6	11	6	9	8	8	6
Number EPT taxa	8	6	3	4	4	4	2	2	4	2	6	3	0	1	0	0
Number AS taxa	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Temporal changes of the relative abundances and the number of taxa are presented in Tab. 3.3. Increasing relative abundances of Diptera, particularly Chironomidae can be observed in outlets of Laghetto Inferiore, Laghetto Superiore and Lago di Tomè. Simultaneously, at the same sites a decrease in the relative abundances of Plecoptera and to a minor extend also of Trichoptera seemd to have occurred. In the outlet of Lago del Starlaresc da Sgiof relative abundances of Diptera were already very high in 2000 and did not change greatly over the years. The relative abundances of acid sensitive taxa seemed also to have decreased in Laghetto Inferiore and Laghetto Superiore. Relative abundances of the main taxonomic groups in the littoral did not change significantly. Regarding the standardized number of taxa, total, EPT and AS taxa seem to decrease especially after 2004 in the outlets of Laghetto Inferiore and Laghetto Superiore. In the more acidic outlets of Lago di Tomè and Lago del Starlaresc da Sgiof only in the first the total number of taxa seem to decrease. The other values remained fairly constant over time. Trends in the littorals are more difficult to observe. Only the number of total taxa in Laghetto Inferiore, Lago di Tomè and Lago del Starlaresc da Sgiof seem to have slightly decreased over time.

Surprisingly, most of the trends here observed seem to suggest a worsening of lake water quality (increasing relative abundance of Chironomidae, decreasing relative abundance of Plecoptera, Trichoptera and decreasing numbers of total, EPT and AS taxa. Actually, results from lake water analysis do not support this conclusion. In fact, decreasing concentrations of sulphate and nitrate and increasing alkalinity and pH were observed for all lakes (see ch. 2.5.3), so that other factors may be responsible for the described biological changes. On the contrary, an improvement of the macroinvertebrate population would have been expected, especially in Lago di Tomè, where pH is still below 6 but concentrations of soluble aluminium decreased from about 40 to 20 μg/l. The only taxonomic group that seemed to have benefitted from this decrease is Turbellaria (probably the acid sensitive *Crenobia sp.*) that was regularly sampled in its outlet after 2006.

Table 3.3 Temporal variations of the relative abundances and the number of taxa in lakes.

0 indicate values >0 but < 0.5.

LAKE	SITE	PARAMETER	1991	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012
INF	Outlet	Sampling times	1	1	3	3	3	3	2	2	2	2	2	2
		Individuals	64	80	293	1216	2004	8338		7713	10515	5255	958	4801
		Rel. abundance OLIGOCHAETA (%)	22	6	11	25	36	30		30	23	23		18
		Rel. abundance HYDRACARINA (%)			1	0	0	0		0	0	0	1	0
		Rel. abundance COLEOPTERA (%)				0	0	0					0	
		Rel. abundance COLLEMBOLA (%)				0	0	0		0	0	0		
		Rel. abundance DIPTERA (%)	47	25	44	44	33	45		58	52	60	92	73
		Rel. abundance CHIRONOMIDAE (%)	*38*	*13*	*17*	*28*	*23*	*18*		*39*	*46*	*51*	*86*	*50*
		Rel. abundance EPHEMEROPTERA (%)				2	2	1		1	1	0	0	0
		Rel. abundance PLECOPTERA (%)	27	56	33	23	16	12		5	5	6	6	2
		Rel. abundance TRICHOPTERA (%)		8	1	3	3	3		0	1	1	1	0
		Rel. abundance BIVALVIA (%)	0	0	0	0	0	0		0	0	0	0	0
		Rel. abundance TURBELLARIA (%)	5	5	11	2	10	8		5	18	9	1	6
		Rel. abundance AS taxa		8		10	8	5		2	1	2	3	0
		Standardized number total taxa	13	13	14	21	17	16	13	15	14	13	13	8
		Standardized number EPT taxa	7	5	6	12	9	10	6	10	8	8	5	4
		Standardized number AS taxa	0	2	0	5	4	5	4	4	3	2	3	1
	Littoral	Sampling times	1	1	3	3	3	3	2	2	2	2	2	2
		Individuals	189	31	199	1239	1361	5123	3159	2483	6829	2914	1050	2494
		Rel. abundance OLIGOCHAETA (%)	13	32	36	13	18	17	12	14	7	22		4
		Rel. abundance HYDRACARINA (%)			3	0	0	1	2	3	1	0	0	0
		Rel. abundance COLEOPTERA (%)	1	3	1	1	3	1	1	1	0	0	1	0
		Rel. abundance COLLEMBOLA (%)					0	1	0	0	32	5		
		Rel. abundance DIPTERA (%)	86	29	59	82	75	76	79	78	57	70	92	95
		Rel. abundance CHIRONOMIDAE (%)	*71*	*3*	*52*	*81*	*73*	*75*	*78*	*77*	*57*	*70*	*82*	*95*
		Rel. abundance EPHEMEROPTERA (%)											0	
		Rel. abundance PLECOPTERA (%)	1	23	1	2	3	3	4	1	2	3	4	1
		Rel. abundance TRICHOPTERA (%)		10		1	1	0	1	2	0	0	0	0
		Rel. abundance BIVALVIA (%)				0		0		0	0	0		0
		Rel. abundance TURBELLARIA (%)		3		0	0	0	0				2	0
		Rel. abundance AS taxa			1	0	0	0	0				0	
		Standardized number total taxa	7	17	9	12	13	15	10	11	13	11	10	8
		Standardized number EPT taxa	1	6	1	5	4	6	3	3	3	5	5	3
		Standardized number AS taxa	0	0	1	1	1	1	1	0	0	0	1	0

LAKE	SITE	PARAMETER	1991	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012
SUP	Outlet	Sampling times	1	1	3	3	3	3	2	2	2	2	2	2
		Individuals	49	34	150	1533	1748	6631	5742	5348	4994	5474	963	6723
		Rel. abundance HIRUDINEA (%)												
		Rel. abundance OLIGOCHAETA (%)	6	3	6	21	20	38	50	64	43	29	1	24
		Rel. abundance HYDRACARINA (%)					0	0	0	0	0	0		
		Rel. abundance COLEOPTERA (%)				0		0			0	0	0	
		Rel. abundance COLLEMBOLA (%)				1	0	0	0	0	0	0		
		Rel. abundance DIPTERA (%)	63	6	50	34	49	47	38	30	49	49	81	65
		Rel. abundance CHIRONOMIDAE (%)	*59*	*6*	*42*	*30*	*36*	*31*	*27*	*19*	*44*	*43*	*65*	*63*
		Rel. abundance EPHEMEROPTERA (%)				9	7	1	0	0	0	0	1	
		Rel. abundance HETEROPTERA (%)					0							
		Rel. abundance PLECOPTERA (%)	18	68	38	29	17	11	10	3	6	21	13	7
		Rel. abundance TRICHOPTERA (%)	0	24	1	4	3	1	1	1	1	1	2	1
		Rel. abundance BIVALVIA (%)												
		Rel. abundance TURBELLARIA (%)	12		5	1	4	1	1	2	1	1	3	2
		Rel. abundance GASTROPODA (%)												
		Rel. abundance AS taxa		3		9	8	1	0	0	0	0	1	
		Standardized number total taxa	10	19	14	19	21	15	14	16	19	14	14	7
		Standardized number EPT taxa	3	16	7	12	13	8	8	11	9	8	8	4
		Standardized number AS taxa	0	2	0	5	6	3	3	2	2	1	2	0
	Littoral	Sampling times	1	1	3	3	3	3	2	2	2	2	2	2
		Individuals	654	49	331	1470	1722	7578	3366	3140	6778	3673	239	2488
		Rel. abundance HIRUDINEA (%)		2										
		Rel. abundance OLIGOCHAETA (%)	28	39	57	16	16	12	12	16	20	16		6
		Rel. abundance HYDRACARINA (%)	1		1	1	1	1	2	2	1	0	4	0
		Rel. abundance COLEOPTERA (%)		4	1	1	3	1	1	1	1	1	2	0
		Rel. abundance COLLEMBOLA (%)						0			0	0		
		Rel. abundance DIPTERA (%)	64	37	31	72	73	80	76	69	70	76	87	90
		Rel. abundance CHIRONOMIDAE (%)	59	37	30	72	72	79	76	68	69	76	86	90
		Rel. abundance EPHEMEROPTERA (%)												
		Rel. abundance HETEROPTERA (%)	0											
		Rel. abundance PLECOPTERA (%)	1	16	5	6	5	5	4	5	5	4	4	3
		Rel. abundance TRICHOPTERA (%)	0		4	3	1	1	4	6	2	0	3	0
		Rel. abundance BIVALVIA (%)	6	2	2	1	1	1	1	1	1	2	1	0
		Rel. abundance GASTROPODA (%)								0	0	0	0	1
		Rel. abundance TURBELLARIA (%)	1				0	0						
		Rel. abundance AS taxa						0		0	0			1
		Standardized number total taxa	14	12	9	10	10	12	8	12	15	13	12	7
		Standardized number EPT taxa	3	5	3	4	3	4	3	4	4	5	5	2
		Standardized number AS taxa	0	0	0	0	0	1	0	2	1	0	0	1

LAKE	SITE	PARAMETER	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012
TOM	Outlet	Sampling times	1	2	2	1	2	2	2	2	2	2	2
		Individuals	11	156	332	342	2139	3000	3998	4512	3746	230	858
		Rel. abundance OLIGOCHAETA (%)		7	1	0	0	0	0	1	1	42	4
		Rel. abundance HYDRACARINA (%)			1	1	0	2	1	0	0		1
		Rel. abundance COLEOPTERA (%)		1	3		0	0	0	0	0	1	1
		Rel. abundance COLLEMBOLA (%)			0	1	0	1	0	3	1		
		Rel. abundance DIPTERA (%)	36	28	34	39	84	58	64	88	87	53	77
		Rel. abundance CHIRONOMIDAE (%)	*36*	*14*	*33*	*36*	*75*	*38*	*57*	*60*	*65*	*26*	*40*
		Rel. abundance HETEROPTERA (%)			0		0	0					
		Rel. abundance MEGALOPTERA (%)	18	2	1	1	0		0	0	0		
		Rel. abundance PLECOPTERA (%)	36	60	57	57	13	36	34	8	10	3	14
		Rel. abundance TRICHOPTERA (%)	9	2	4	1	2	2	1	1	1	1	1
		Rel. abundance TURBELLARIA (%)						1	0	0	0		3
		Rel. abundance AS taxa					0	0	0	0			
		Standardized number total taxa	14	17	22	12	15	14	12	15	15	10	10
		Standardized number EPT taxa	7	8	8	4	7	7	5	8	8	3	4
		Standardized number AS taxa	0	0	0	0	1	1	1	1	0	0	0
	Littoral	Sampling times	1	2	2	2	2	2	2	2	2	2	2
		Individuals	9	227	236	428	1570	1518	1658	3420	1602	533	582
		Rel. abundance OLIGOCHAETA (%)		33	10	51	15	17	28	15	29	14	10
		Rel. abundance HYDRACARINA (%)		1	2		7	9	6	6	3	1	21
		Rel. abundance COLEOPTERA (%)		2	2	3	0	2	2	0	1	1	0
		Rel. abundance COLLEMBOLA (%)			0	0		0	0	0	1		
		Rel. abundance DIPTERA (%)	11	54	67	37	72	65	58	74	58	72	62
		Rel. abundance CHIRONOMIDAE (%)	11	54	67	37	71	65	58	73	58	72	62
		Rel. abundance HETEROPTERA (%)			0								
		Rel. abundance MEGALOPTERA (%)		0	1	2	0	0			0		
		Rel. abundance PLECOPTERA (%)	67	3	1	2	1	1	0	1	2	4	1
		Rel. abundance TRICHOPTERA (%)	22	7	16	4	5	7	6	4	6	7	6
		Rel. abundance TURBELLARIA (%)											
		Rel. abundance AS taxa	22										
		Standardized number total taxa	12	13	16	13	13	14	11	13	13	11	11
		Standardized number EPT taxa	2	3	3	2	2	2	1	2	2	1	1
		Standardized number AS taxa	2	0	0	0	0	0	0	0	0	0	0

LAKE	SITE	PARAMETER	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012
STA	Outlet	Sampling times	1	2	2	1	2	2	2	2	2	2	2
		Individuals	21	706	808	478	2634	6224	3451	3942	2847	604	766
		Rel. abundance OLIGOCHAETA (%)			1	3	3	1	0	2	10		6
		Rel. abundance HYDRACARINA (%)			1	1		0	0	1	2		6
		Rel. abundance COLEOPTERA (%)	14	2	0	0	0	0	0	0	0	1	0
		Rel. abundance COLLEMBOLA (%)						0		0	0		
		Rel. abundance DIPTERA (%)	29	85	91	66	89	96	85	87	74	95	69
		Rel. abundance CHIRONOMIDAE (%)	*29*	*69*	*85*	*56*	*75*	*93*	*79*	*70*	*56*	*63*	*34*
		Rel. abundance EPHEMEROPTERA (%)								0			
		Rel. abundance HETEROPTERA (%)			1	11	0	0	0	0	0	0	0
		Rel. abundance MEGALOPTERA (%)									0		
		Rel. abundance ODONATA (%)		6	0	13	5	1	3	2	2	2	3
		Rel. abundance PLECOPTERA (%)	24	2	2	5	1	1	9	8	12	1	16
		Rel. abundance TRICHOPTERA (%)	33	5	4		0	0	1	1	1		
		Rel. abundance AS taxa					0			0		25	
		Standardized number total taxa	13	9	14	14	12	10	13	16	14	14	11
		Standardized number EPT taxa	6	3	3	1	3	3	4	5	4	1	1
		Standardized number AS taxa	0	0	0	0	1	0	0	1	0	1	0
	Littoral	Sampling times	1	2	2	1	2	2	2	2	2	2	2
		Individuals	11	206	337	266	1392	2260	2682	3660	1197	135	1950
		Rel. abundance OLIGOCHAETA (%)		16	8	3	17	5	4	14	19		13
		Rel. abundance HYDRACARINA (%)			0		0	2	0	4	4		1
		Rel. abundance COLEOPTERA (%)				0							
		Rel. abundance COLLEMBOLA (%)						0					
		Rel. abundance DIPTERA (%)		75	85	80	78	91	92	82	77	98	82
		Rel. abundance CHIRONOMIDAE (%)		74	67	62	55	79	80	68	60	35	67
		Rel. abundance EPHEMEROPTERA (%)											
		Rel. abundance HETEROPTERA (%)		1	3	3	2	1	2		0		3
		Rel. abundance MEGALOPTERA (%)				0	0	0	0		0		
		Rel. abundance ODONATA (%)	36	4	3	12	2	1	1	1	1	2	1
		Rel. abundance PLECOPTERA (%)											
		Rel. abundance TRICHOPTERA (%)	64	4	0	0	0	0	0	0	0		
		Rel. abundance AS taxa							0				
		Standardized number total taxa	6	10	12	12	10	7	9	6	8	6	5
		Standardized number EPT taxa	0	3	1	1	1	1	1	1	0	0	0
		Standardized number AS taxa	0	0	0	0	0	0	1	0	0	0	0

3.3.2 Rivers

The number of identified individuals and the relative abundance of identified taxa with the most important taxa numbers (total, EPT, AS) and the Braukmann and Biss (2004) class of river Verzasca during 2013 are shown in Tab. 3.4 and 3.5, respectively. The most abundant taxonomic groups were Ephemeroptera and Diptera followed by Plecoptera and Coleoptera. Between pool and run sites relative abundances did not differ greatly, with exception of *Baetis sp.*, Plecoptera (*Leuctra sp.*, *Protonmura sp.*) and Simuliidae that were higher at the run sites and Chironomidae that were more abundant at the pool sites especially in the presence of fine substrate. Trichoptera and Turbellaria were also slightly more abundant at the run sites. All the taxa numbers (total, EPT AS) were higher at the run sites compared to the pool sites particularly at the sampling sites with coarse substrate. From the composition of the invertebrate population a Braukmann and Biss (2004) class of on average 2 can be calculated, corresponding to predominantly neutral to episodically weakly acidic waters with pH's normally around 6.8-7.0, status that is in agreement with the measured water chemistry (see ch. 2.5.3).

Similar to what observed for lakes the relative abundance of Diptera, particularly of Chironomidae, seem to have increased during the sampling period (Tab. 3.6) together with a decrease in the relative abundance of Ephemeroptera, Plecoptera, Trichoptera and AS species. Again this phenomena can not be explained by a degradation of waters quality (see ch. 2.5.3). This seems to be confirmed by the constant number of EPT and AS taxa and the acidification class of Braukmann and Biss (2004).

Table 3.4 River sample sizes during 2013.

RIVER	SITE	SUBSTRATE	MARCH	JULY	OCTOBER
VER	Pool	fine	849	534	178
		coarse	518	270	544
	Run	fine	1392	974	184
		coarse	1594	874	614

Table 3.5 Relative abundance and number of taxa in river Verzasca during 2013.

TAXA	Pool		Run	
	Fine	Coarse	Fine	Coarse
OLIGOCHAETA	**1.0%**	**0.4%**	**0.6%**	**0.1%**
HYDRACARINA	**0.6%**	**1.1%**	**0.6%**	**0.2%**
COLEOPTERA	**8.8%**	**13.6%**	**16.1%**	**5.7%**
Esolus sp.	8.7%	13.4%	15.8%	5.4%
Limnius sp.	0.1%			
Hydraena sp.		0.1%	0.2%	0.1%
Scirtidae				0.1%
DIPTERA	**67.1%**	**33.4%**	**19.8%**	**23.9%**
Athericidae		0.3%	0.2%	0.2%
Blephariceridae		0.1%		0.6%
Chironomidae	62.3%	32.3%	15.2%	17.2%
Empididae	0.1%		0.1%	0.2%
Limoniidae	4.4%	0.7%	0.7%	0.1%
Simuliidae	0.3%		3.7%	5.7%
EPHEMEROPTERA	**15.0%**	**42.7%**	**40.0%**	**51.4%**
Baetis sp.	1.7%	0.2%	18.7%	45.2%
Ecdyonurus sp.	9.2%	39.6%	8.7%	2.0%
Epeorus sp.			1.1%	0.5%
Heptageniidae	0.1%		0.9%	0.0%
Rhithrogena sp.	3.9%	2.9%	10.7%	3.7%
PLECOPTERA	**6.8%**	**8.0%**	**20.9%**	**16.5%**
Leuctra sp.	3.5%	3.5%	12.3%	10.3%
Amphinemoura sp.	1.6%		3.0%	1.2%
Nemouridae		3.5%		
Nemoura sp.	1.1%	0.8%	0.6%	0.3%
Protonemura sp.	0.2%		3.9%	3.0%
Perla bipunctata			0.0%	0.0%
Perla sp.		0.2%	1.0%	0.5%
Isoperla sp.	0.4%		0.1%	1.0%
TRICHOPTERA	**0.3%**	**0.5%**	**0.8%**	**1.7%**
Hydropsyche modesta				0.0%
Chaetopteryx gessneri	0.2%	0.1%		
Limnephilidae	0.1%	0.2%		0.1%
Monocentra lepidoptera		0.1%		
Philopotamus montanus				0.1%
Philopotamus sp.			0.5%	0.4%
Wormaldia sp.	0.0%	0.1%	0.1%	0.1%
Rhyacophila sp.				0.0%
Rhyacophila (Hyperrhyacophila) sp.			0.2%	0.6%
Rhyacophila (Hyporhyacophila) sp.				0.2%
BIVALVIA		**0.1%**		
TURBELLARIA	**0.4%**	**0.2%**	**1.2%**	**0.6%**
Planariidae	0.4%	0.2%	1.2%	0.6%
Number total taxa	21	21	26	32
Number EPT taxa	12	11	15	20
Number AS taxa	7	7	13	14
Acidification class (Braukmann & Biss)	2	2	2	3

Table 3.6 Temporal variations of the relative abundances and the number of taxa in river Verzasca.

RIVER	PARAMETER	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012
VER	Sampling times	8	6	6	6	5	4	4	4	4	4	4	3
	Individuals	1574	2258	2569	3760	4268	12900	15019	21054	20239	11691	4510	8570
	Rel. abundance OLIGOCHAETA (%)	0	1	0	0	0	1	0	3	1	5	0	1
	Rel. abundance HYDRACARINA (%)	2	1	1	2	0	1	1	1	2	1	1	1
	Rel. abundance COLEOPTERA (%)	18	22	23	14	18	16	24	19	17	8	22	11
	Rel. abundance COLLEMBOLA (%)	0	0	0	0	0	0	0	0	0	0	0	0
	Rel. abundance DIPTERA (%)	12	8	10	19	12	19	20	22	23	21	30	36
	Rel. abundance CHIRONOMIDAE (%)	*6*	*4*	*4*	*16*	*9*	*17*	*17*	*20*	*21*	*19*	*26*	*32*
	Rel. abundance EPHEMEROPTERA (%)	46	45	36	41	55	45	36	41	38	34	35	37
	Rel. abundance PLECOPTERA (%)	18	18	25	18	11	14	16	12	17	29	8	13
	Rel. abundance TRICHOPTERA (%)	3	4	3	4	2	2	2	1	1	2	2	1
	Rel. abundance AS taxa	52	54	47	46	62	49	40	43	40	40	36	38
	Standardized number total taxa	28	25	27	27	22	23	25	24	31	28	22	24
	Standardized number EPT taxa	17	16	16	17	13	14	16	15	20	18	13	14
	Standardized number AS taxa	10	9	9	11	9	8	9	9	11	9	10	9
	Acidification class (Braukmann & Biss)	2	2	2	2	2	2	2	2	2	2	2	2

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