Repubblica e Cantone Ticino
Dipartimento del territorio

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)

Annual report 2014

Ufficio dell'aria, del clima e delle energie rinnovabili
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Sampling and determination of macroinvertebrates	Fürst & Associati SA

Content

Abstract

Compared to previous years, precipitations during 2014 in southern Switzerland were higher than average. In general, because of the dilution effect, concentrations of the anthropogenic pollutants sulphate, nitrate and ammonium in rainwater were lower compared to values of the previous years, but deposition rates of the same parameters were comparable to the last years vales. For acidity concentrations did not greatly change, while depositions were slightly lower than average. For some parameters temporal trends in depositions are immediately visible. From 1990, as a consequence of reduced SO_2 emissions, yearly depositions 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 decades especially at the more polluted sites (Acquarossa, 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 and an increase of pH from around 4.3 to 5.4.

In agreement with wet deposition, from the 1980’s until present, concentrations of sulphate and nitrate decreased at most sites, 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) from values around 40 $\mu g\ l^{-1}$ to 20 $\mu g\ l^{-1}$ in the first and from 80-100 $\mu g\ l^{-1}$ to 40-60 $\mu g\ l^{-1}$ in the second.

Similarly to what observed for rainwater, in rivers, because of frequent precipitations and therefore higher discharges, during 2014 concentrations of sulphate, nitrate, base cations, alkalinity and pH were also slightly lower than average. The time trend analysis revealed that from 2000 to 2014 concentrations of sulphate decreased significantly in river Vedeggio and almost in river Maggia, concentrations of nitrate decreased in rivers Vedeggio and Verzasca, while alkalinity increased significantly only in river Verzasca.

The invertebrate population differed also slightly compared to previous years, responding to the increased discharge situation during 2014. Generally, in lake outlets and in river Verzasca chironomids were less abundant than usual and other more current loving taxa gained importance (simulids in lake outlets and mayflies in river Verzasca). Beside this, the invertebrate population did not change greatly and as regards acid sensitive (AS) indicators like the relative abundance of AS taxa and the standardized number of AS taxa almost no positive trend can be observed. The only early sign of recovery seems to be the reappearance of *Crenobia alpina* in Lago di Tomè after 2006.

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 recognized 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 harmonization of monitoring methods. The Programme is planned and coordinated by a Task Force under the leadership of Norway. Up to now data from about 200 catchments in 16 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 the Canton of Ticino.

In order to assess and monitor the effects of air pollution on rivers and lakes the Canton of Ticino monitors regularly wet deposition at 9 sampling sites, 21 high altitude lakes and 3 rivers. Next to water chemistry, also macroinvertebrates as indicators are sampled in 4 lakes and 1 river.

Meteorologically, 2014 has been characterized by extreme events. Exceptionally high precipitations occurred in winter 2013/2014. Snow depths of almost 7 meters were observed in southern Switzerland's mountains, the highest values measured since monitoring activity begun about one century ago. Temperature has been higher than average (1981-2010) during the first semester of the year. Differently, the summer months were rather fresh and rainy. Autumn was again warm but also very wet. Abundant precipitations occurred in October and November causing the overflow of lakes Ceresio and Verbano (MeteoSvizzera, 2015).

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 the Canton of 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 the Canton of 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 (Relief map: © Ufficio del catasto e dei riordini fondiari, 2015)

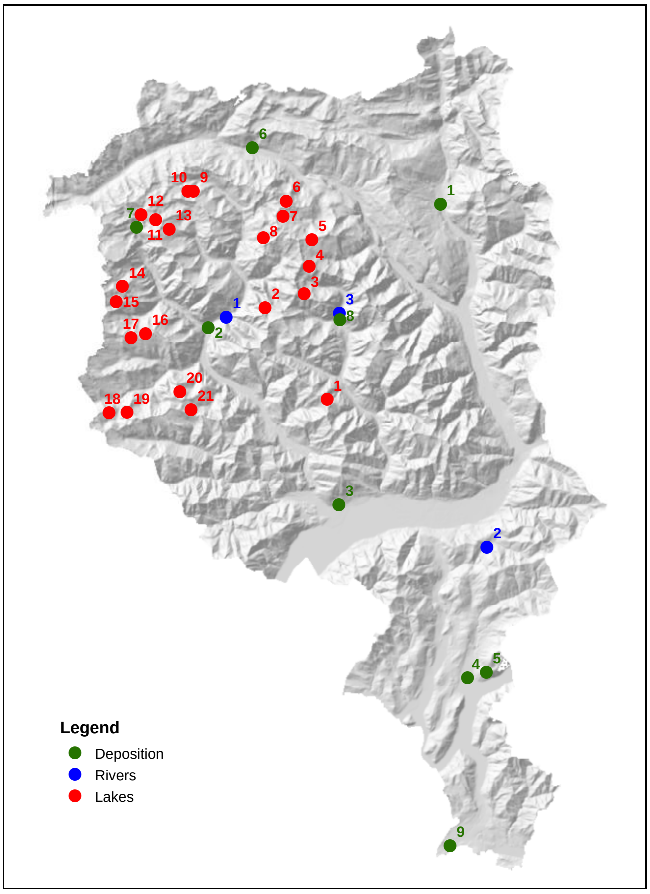


Table 1.1 Geographic and morphometric parameters of the wet deposition sampling sites

Sampling site number	Sampling site	CH1903 LV03 (m)		WGS84		Altitude
		Longitude	Latitude	Longitude	Latitude	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

Table 1.2 Geographic and morphometric parameters of the studied lakes

Lake number	Lake name	CH1903 LV03 (m)		WGS84		Altitude	Catchment area	Lake area	Max depth
		Longitude	Latitude	Longitude	Latitude	m a.s.l.	ha	ha	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 1.3 Geographic and morphometric parameters of the studied rivers

River number	River name	Sampling site	CH1903 LV03 (m)		WGS84		Altitude	Catchment area
			Longitude	Latitude	Longitude	Latitude	m a.s.l	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

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 the Canton of 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 the Canton of Ticino, wet deposition, water chemistry of 20 Alpine lakes (21 from 2006) and 3 rivers (Maggia, Vedeggio, Verzasca) have been monitored.

Rainwater has been sampled at weekly intervals with wet-only samplers since 1988. 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 the beginning of summer, twice in autumn). 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.

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.

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 and 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$_3$PO$_4$	UV-persulfate	0.05 mg C l^{-1}
soluble Al	PC filter	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.4 μg l^{-1}
total Al	No	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.4 μg l^{-1}
soluble Cu	PC filter	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.04 μg l^{-1}
total Cu	No	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.04 μg l^{-1}
soluble Zn	PC filter	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
total Zn	No	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
soluble Pb	PC filter	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.02 μg l^{-1}
total Pb	No	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.02 μg l^{-1}
soluble Cd	PC filter	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.01 μg l^{-1}
total Cd	No	acid washed PP bottle, +HNO$_3$, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.01 μg l^{-1}

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 depositions were calculated by multiplying monthly and yearly mean concentrations with the precipitation volume measured at a meteorological sampling station close to the sampling site. This procedure has been chosen in order to avoid underestimation of monthly and yearly depositions due to occasionally missing weekly samples. In particular, for our sampling sites, data from the pluviometric stations of MeteoSwiss (Acquarossa → Comprovasco, Locarno Monti → Locarno Monti, Lugano → Lugano, Monte Brè → Lugano, Piotta → Piotta, Robiei → Robiei, Stabio → Stabio) and of the Canton of Ticino (Bignasco → Cavergno, Sonogno → Sonogno) have been chosen.

2.5 Statistical methods used for trend analysis

Trend analyses were performed with the Mann-Kendall test to detect temporal trends in wet deposition and lake- and river water chemistry. For wet depositions a seasonal Mann-Kendall test (Hirsch et al., 1982) was performed on monthly mean depositions. For river chemistry a seasonal partial Mann-Kendall test was performed (Libiseller and Grimvall, 2002). As covariate the average daily discharge of the sampling day was included. For both wet deposition and river chemistry a correction among block was considered (Hirsch and Slack, 1984). For lake chemistry a simple Mann-Kendall test was performed on autumn concentrations (Mann, 1945). The two sided tests for the null hypothesis that no trend is present were rejected for p-values below 0.05. Estimates for temporal variations of wet depositions, river and lake water chemistry were quantified with the seasonal Kendall slope estimator (Gilbert, 1987). All trend analysis were calculated with the CRAN package “rkt 1.3” (Marchetto, 2014).

2.6 Results and discussion

2.6.1 Wet deposition

Spatial variation

Annual average rainwater concentrations of the main chemical parameters and their yearly deposition rates during 2014 are shown in Tab. 2.2.

Table 2.2 Yearly mean rain water concentrations and deposition rates during 2014

					Ca^{2+}		Mg^{2+}		Na^{+}		K^{+}		NH_4^{+}		HCO_3^{-}		SO_4^{2-}		NO_3^{-}		Cl^{-}		Acidity = $H^{+} - HCO_3^{-}$	
Sampling site	Precipitation (mm)	Analysed precipitation (mm)	Cond 25°C (µS cm^{-1})	pH	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	1678	1595	7	5.3	17	28	2	4	3	5	1	2	15	26	16	27	8	14	15	25	3	5	-12	-19
Bignasco	2107	1967	8	5.3	18	38	3	6	4	7	2	4	18	39	15	32	11	23	20	41	4	8	-10	-21
Locarno Monti	2781	2360	9	5.3	17	47	3	7	5	13	2	5	23	63	15	42	13	37	21	57	4	12	-10	-28
Lugano	2430	1775	8	5.5	14	35	3	6	5	11	2	5	23	56	12	29	13	31	19	47	5	12	-8	-21
Monte Brè	2430	2259	8	5.5	16	40	3	7	5	11	2	4	23	57	15	36	12	29	20	49	5	11	-12	-29
Piotta	1813	1522	7	5.4	16	29	3	5	6	11	2	4	15	28	18	33	8	15	12	22	6	11	-14	-26
Robiei	2738	2009	7	5.5	14	38	2	6	3	7	1	3	17	46	11	31	10	28	17	46	2	6	-8	-22
Sonogno	2604	2435	9	5.7	22	57	6	15	7	17	3	8	23	60	28	72	12	31	17	45	5	14	-25	-66
Stabio	2549	2349	9	5.5	15	37	3	7	6	15	1	4	29	73	16	41	13	33	22	57	5	13	-13	-32

In general, ion concentrations of anthropogenic origin (sulphate, nitrate, ammonia) decrease from sites with low to high latitude and from low to high altitude. During 2014 highest concentrations of the sum of sulphate, nitrate, ammonia were measured at Stabio and lowest at Piotta. 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.

Wet deposition of chemical parameters depends on both concentration and the amount of precipitation. Highest precipitation usually occurs in the north-western part of the Canton of Ticino. The reason for this distribution are 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 2014, highest deposition rates of the sum of ammonia, nitrate and sulphate occured at Locarno Monti and Stabio and lowest at Piotta and Acquarossa.

A detailed analysis on spatial distribution of rainwater quality and deposition rates is described in (Steingruber, 2015).

Seasonal variation

The amount of monthly precipitation at each sampling site during 2014 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 2014 and their mean values during the period 2000-2010 are compared 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 2014 was higher in February, July, August, October and November and lower in May and September.

Monthly average sulphate concentrations are usually higher in summer and lower in winter 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 Locarno Monti and Lugano 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). At high altitudes another explanation for the lower winter concentrations is the fact that in winter, the higher Alpine sites are generally not affected by polluted air masses from lower regions due to absence of vertical transport induced by thermal convection (Baltensperger et al. 1991). 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, the oxidation rate from SO_2 to SO_4^{2-} and at high altitude also the seasonality of thermal convection.

Monthly mean concentrations of nitrate are normally highest in February-March and lowest in December-January. Differently, concentrations of NO_2 in the air are highest in November-February and lowest in May-August. Dividing concentrations of nitrate with those of NO_2 maximum values occur during summer and minimum values during winter especially at Robiei (data not shown), suggesting that, as already observed for sulphate concentrations, 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, the already increasing oxidation rates of NO_x to NO_3^- in spring and at high altitudes the absence of vertical transport of pollutants induced by thermal convection.

The seasonality of monthly mean ammonium concentrations is usually 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.

Concentrations of base cations 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 behaves acidity, whose monthly mean concentrations are highest during winter and lowest during spring and autumn, indicating that the concentrations of base cations is the main responsible in determining the seasonality of acidity. As a consequence of decreased acidity during summer, pH values are highest in summer.

During 2014 concentrations of sulphate, nitrate, ammonium and base cations were in general lower than average. However, concentrations at most sites peaked in May and September when rainwater volume was particularly low. Differently, compared to average values, concentrations of acidity did not greatly change. The particularly high base cations and alkalinity peaks in May were caused by an alkaline rain event occurring between May 19-26. pH was higher than average during the last year. Only 4% of the monthly values were below pH 5, while the same percentage was on average 21% between 2000 and 2010. Similarly 57% of the monthly pH values were higher than 5.5 during 2014 and only 31% on average between 2000 and 2014.

Wet depositions in general behave similar to concentrations, with the difference that rainwater volume gain further importance (Fig. 2.3). For sulphate, nitrate and ammonium highest depositions normally occur during the warm months when both concentrations and precipitations are highest . Average depositions of base cations are also higher during summer but high values can also occur in October and November. Average deposition of acidity behave opposite to base cations. During 2014, depositions of sulphate, nitrate, ammonia and base cations were close to average values, while depositions of acidity were slightly lower. The already mentioned alkaline rain event in May 2014 was also clearly visible in the deposition charts of base cations and acidity.

Figure 2.1 Monthly precipitation

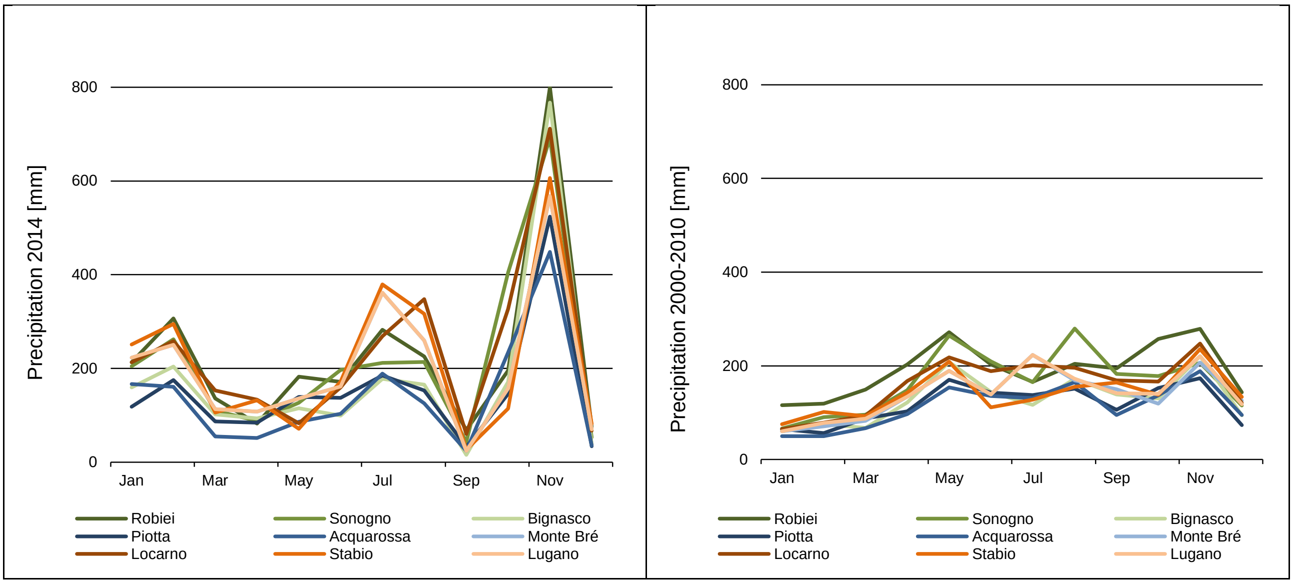
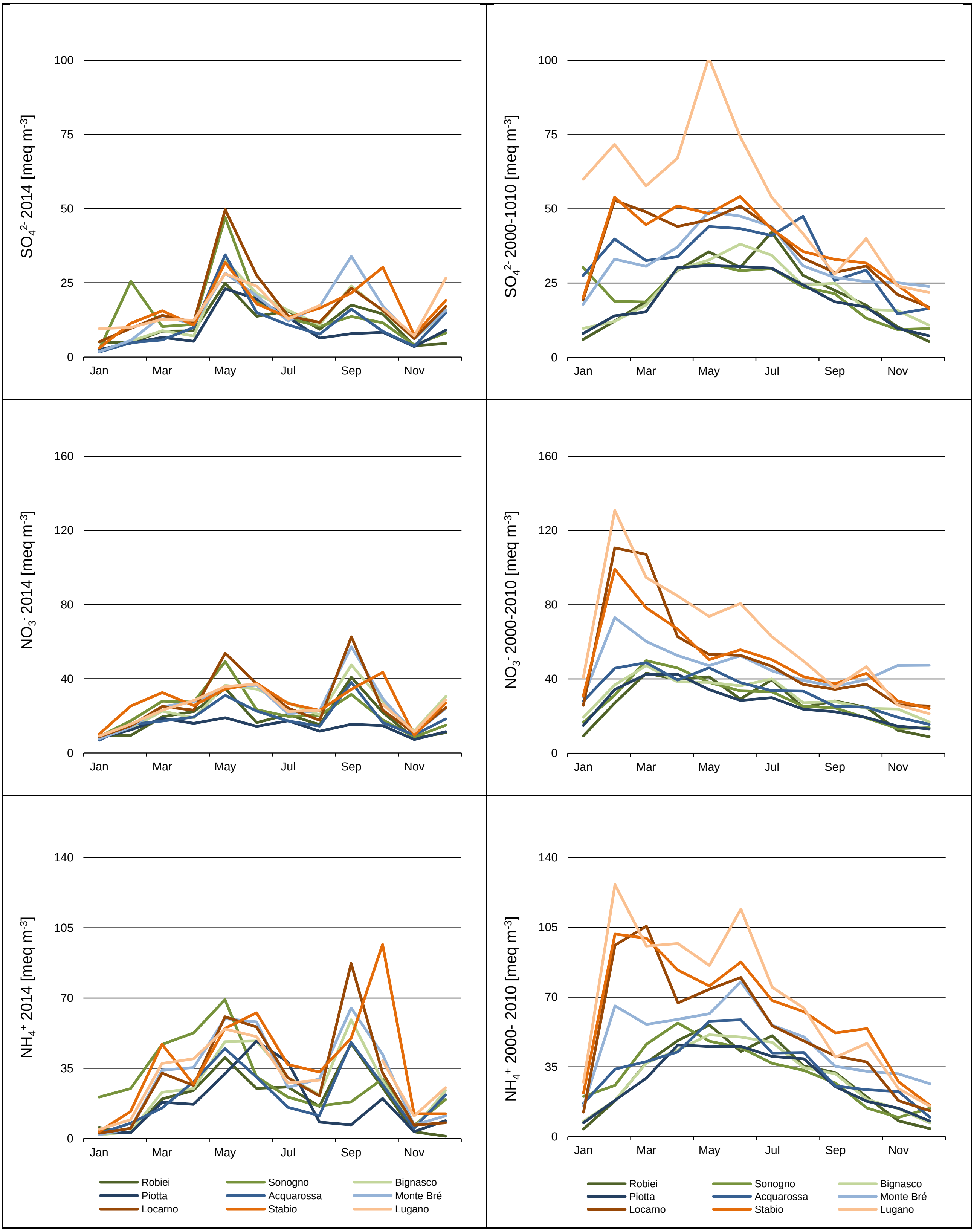


Figure 2.2 Seasonal variations of monthly average rain water concentrations



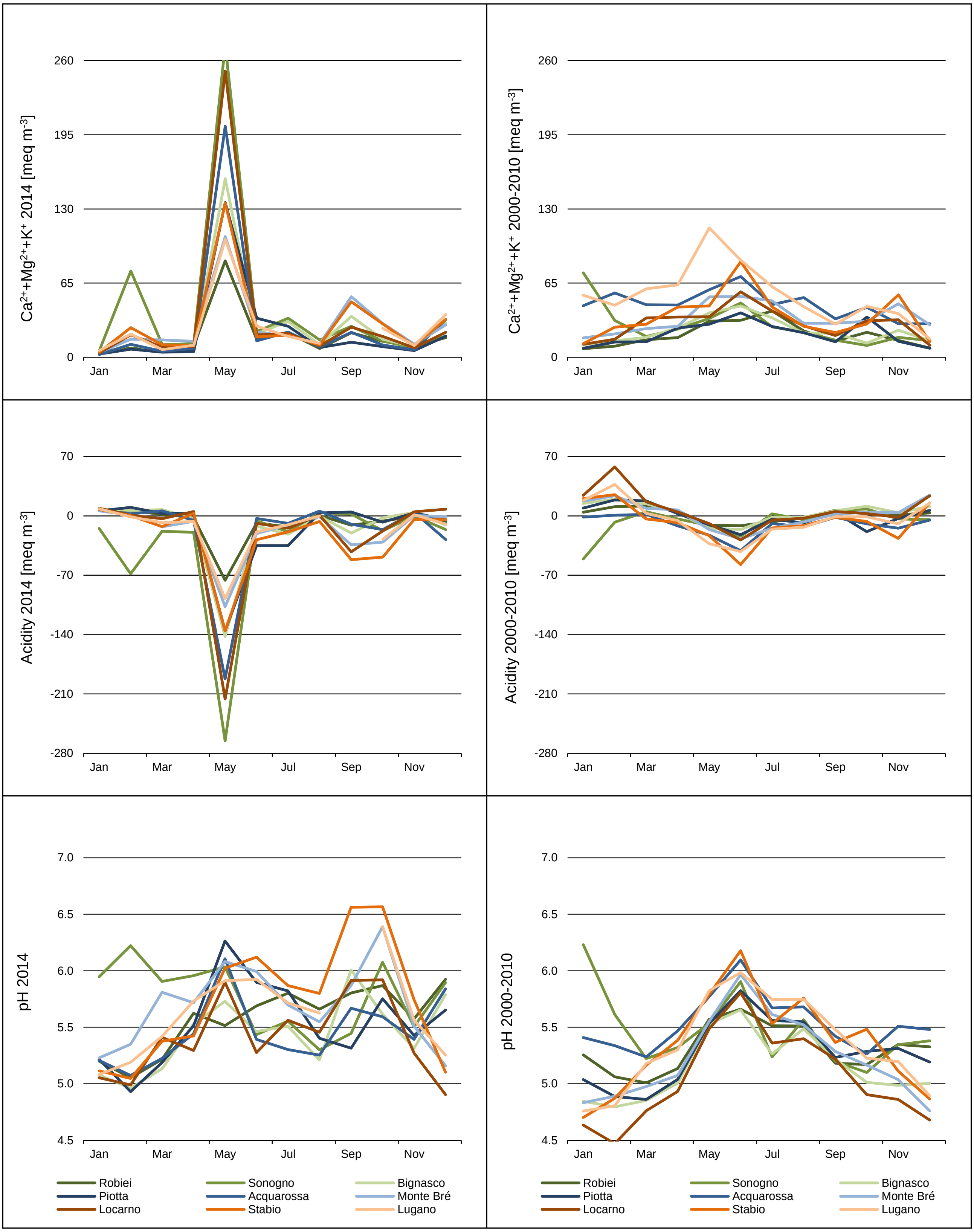
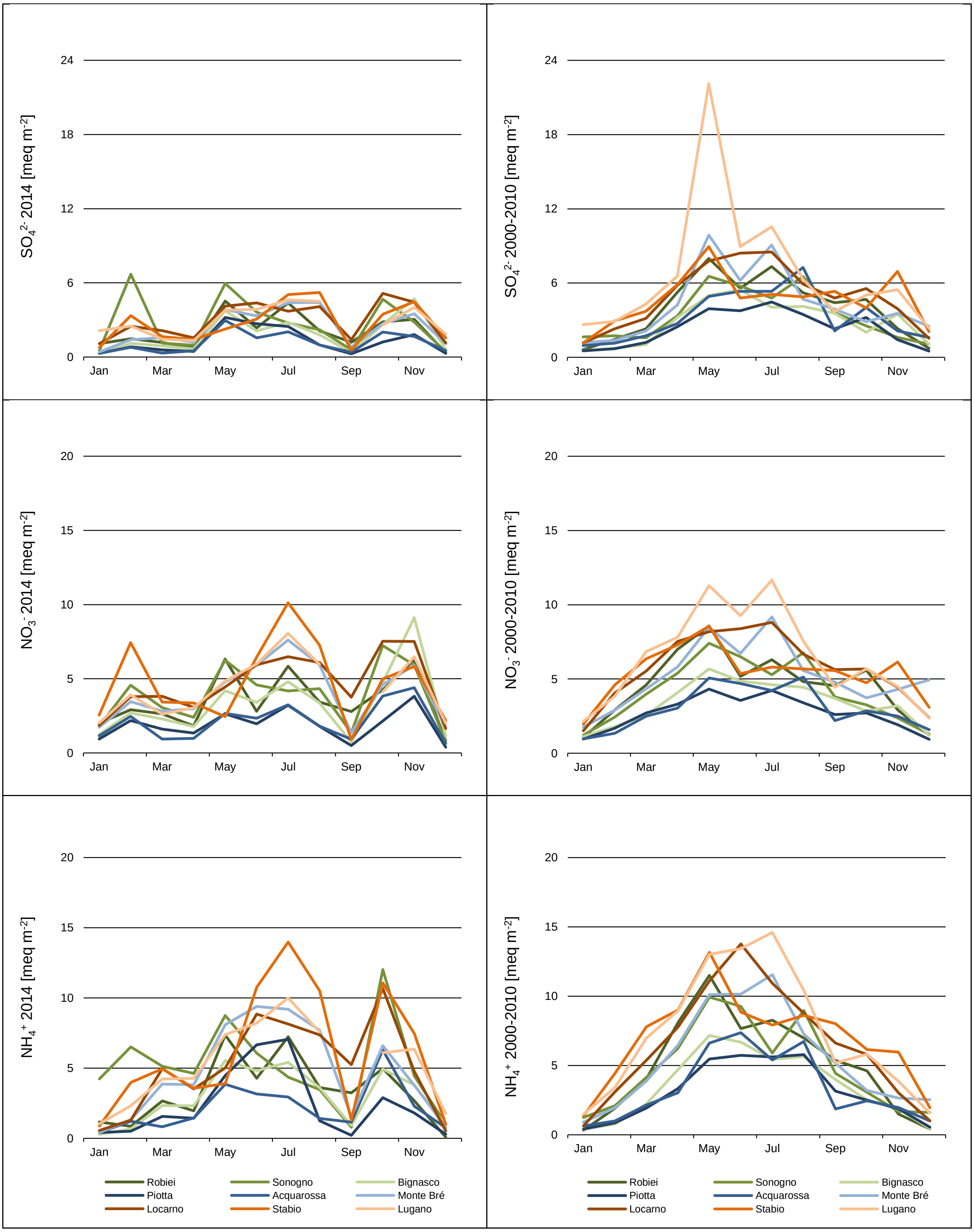

Ca^{2+}+Mg^{2+}+K^{+} 2014 [meq m^{-3}]
Ca^{2+}+Mg^{2+}+K^{+} 2000-2010 [meq m^{-3}]
260
195
130
65
0
Acidity 2014 [meq m^{-3}]
Acidity 2000-2010 [meq m^{-3}]
70
0
-70
-140
-210
-280
pH 2014
pH 2000-2010
7.0
6.5
6.0
5.5
5.0
4.5
Jan
Mar
May
Jul
Sep
Nov
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano

Figure 2.3 Seasonal variations of monthly wet deposition

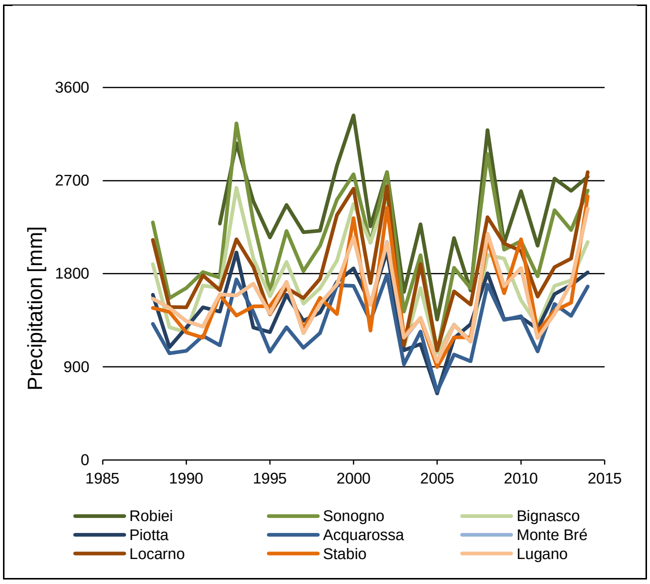



Ca²⁺+Mg²⁺+K⁺ 2014 [meq m⁻²]
Ca²⁺+Mg²⁺+K⁺ 2000-2010 [meq m⁻²]
Acidity 2014 [meq m⁻²]
Acidity 2000-2010 [meq m⁻²]
32
24
16
8
0
7
0
-7
-14
-21
Jan
Mar
May
Jul
Sep
Nov
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano

Temporal variations

The amount of yearly precipitation at each sampling site is reported in Fig. 2.4, while variations 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 volumes during 2014 were higher than average. Exceptionally high values were registered at Locarno Monti, Lugano and Stabio (from 147% to 168% of the MeteoSwiss norm period 1981-2010).

Figure 2.4 Yearly precipitations



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 2010 was the consequence of the volcanic eruption at Eyafjellajokull (Iceland) in April 2010 (Steingruber and Colombo, 2011; UACER, 2011).

As a consequence of decreased NO_x and NH_3 emissions, concentrations and depositions of nitrate and ammonium also slightly decreased.

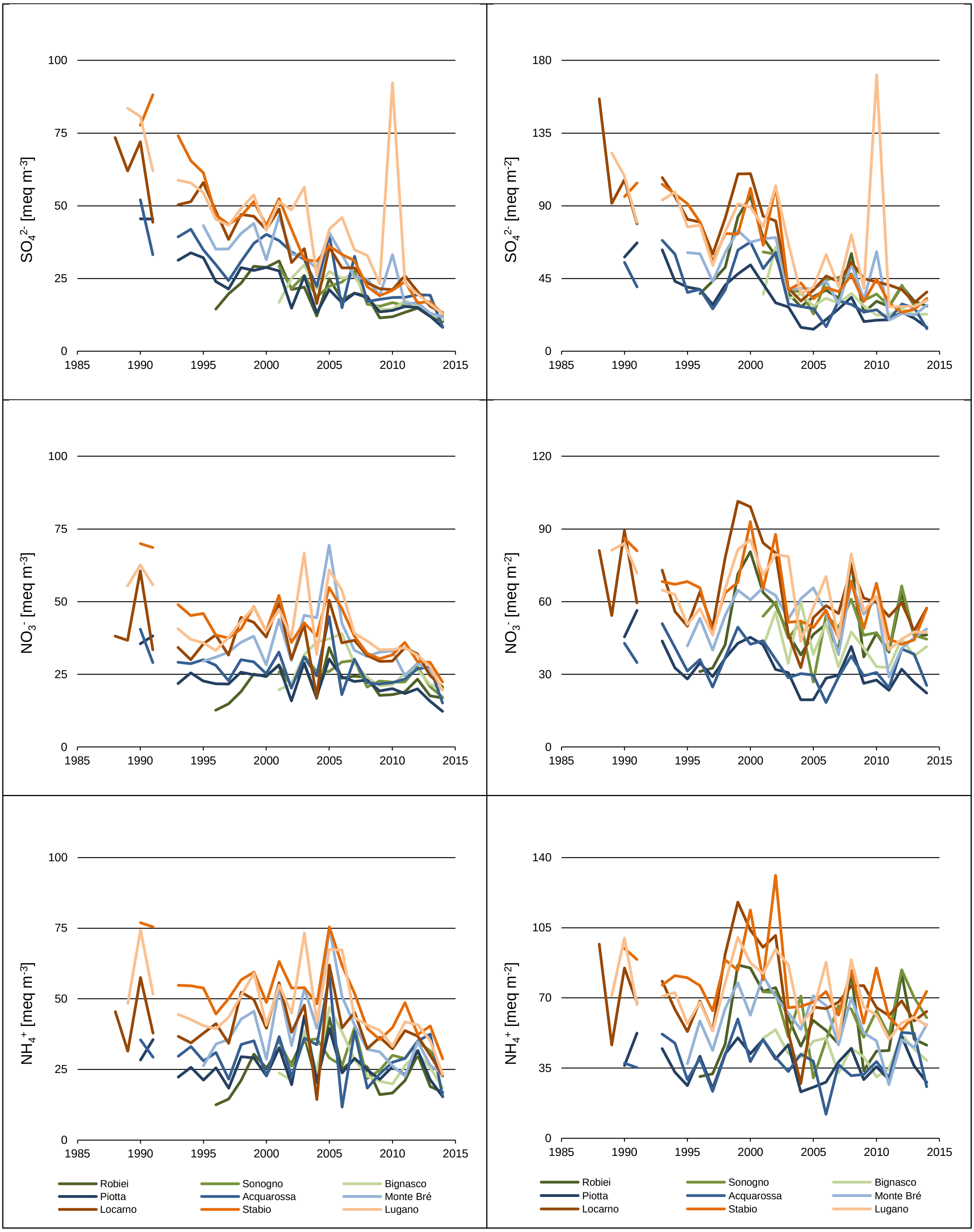
Base cations also seem to have slightly decreased, however their annual mean concentrations and depositions can vary greatly from year to year reaching high values during years with single events rich in base cations.

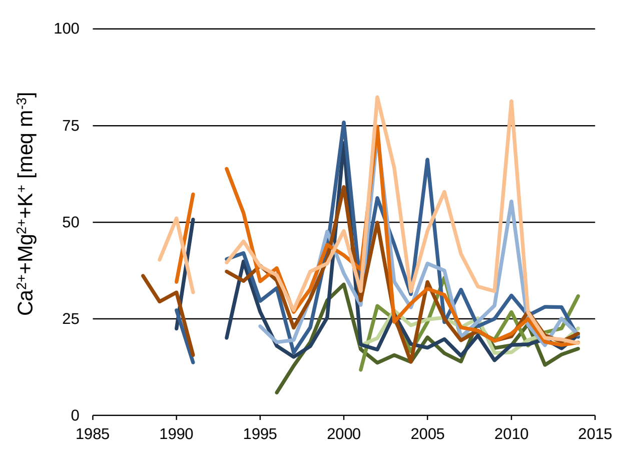
Concentrations and depositions of acidity, that can be calculated as the difference between acid anions and base cations and ammonia, decreased significantly at most sites. In general, concentrations and depositions of acidity decreased from values around 30-40 meq/m^3 and 60 meq/m^2, respectively to values around -15 meq/m^3 and -30 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. Both events lead to floods in the region. 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 5.3 and 5.6 today.

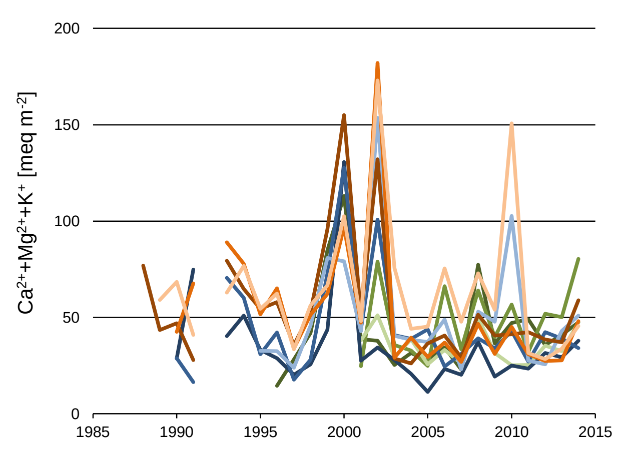
In order to evaluate the influence of wet deposition on surface water quality a trend analysis of monthly mean deposition from the beginning of sampling until 2014 was performed. Results from the trend analysis and estimates for the temporal variations in deposition using the Sen's slope are presented in Tab. 2.3.

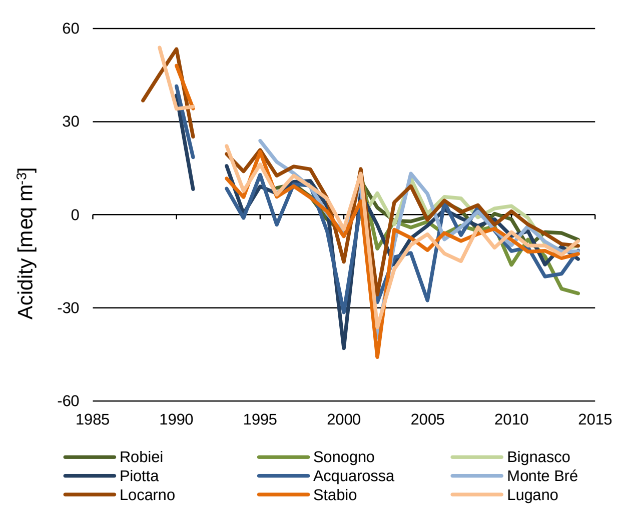
At almost all sites wet deposition of sulphate and acidity significantly decreased and pH increased. The improvement was particularly pronounced at the more polluted sites. At four sites wet deposition of nitrate also decreased significantly, while ammonium decreased significantly only at Locarno Monti.

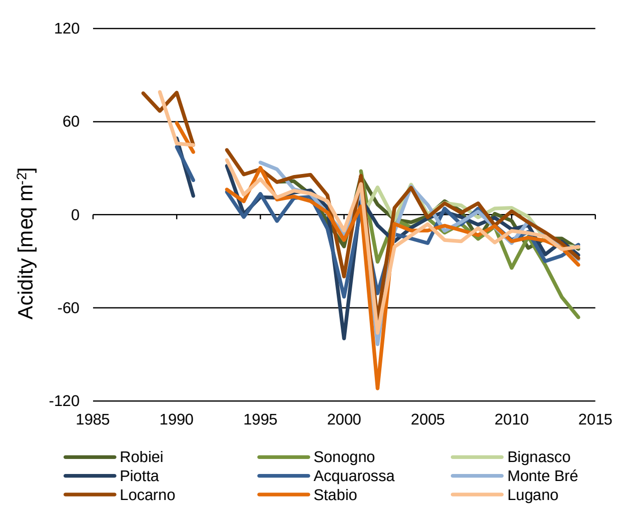
Figure 2.5 Temporal variations of annual mean rain water concentrations, deposition rates and pH




Ca^{2+}+Mg^{2+}+K^{+} [meq m^{-3}]
100
75
50
25
0
1985
1990
1995
2000
2005
2010
2015


Ca^{2+}+Mg^{2+}+K^{+} [meq m^{-2}]
200
150
100
50
0
1985
1990
1995
2000
2005
2010
2015


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


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

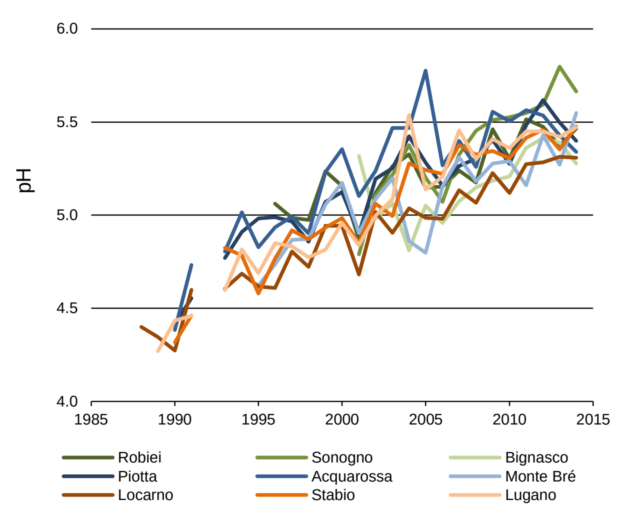

pH
6.0
5.5
5.0
4.5
4.0
1985
1990
1995
2000
2005
2010
2015
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano

Table 2.3 Results from trend analyses performed on mean monthly depositions during the monitoring period (significant trends in red). p corresponds to the probability level obtained with the seasonal Mann-Kendall test and the rate (meq m^{-2} yr^{-1}) to the seasonal Kendall slope estimator.

		Acquarossa 1990-2014	Bignasco 2001-2014	Monte Brè 1995-2014	Locarno Monti 1988-2014	Lugano 1989-2014	Piotta 1990-2014	Robiei 1996-2014	Sonogno 2001-2014	Stabio 1990-2014
SO_4^{2-}	p	0.000	0.024	0.000	0.000	0.000	0.000	0.007	0.074	0.000
	rate	-1.217	-0.809	-1.608	-2.660	-2.328	-0.768	-1.320	-0.795	-2.983
NO_3^-	p	0.010	0.620	0.084	0.022	0.326	0.007	0.379	0.645	0.005
	rate	-0.567	-0.213	-0.635	-0.840	-0.389	-0.411	-0.270	-0.180	-1.200
NH_4^+	p	0.222	0.803	0.102	0.022	0.895	0.155	0.170	0.925	0.065
	rate	-0.218	-0.067	-0.311	-0.495	-0.034	-0.120	0.345	0.142	-0.582
Base cations	p	0.631	1.000	0.666	0.024	0.632	0.025	0.989	0.153	0.005
	rate	-0.139	0.000	-0.109	-0.447	-0.192	-0.285	-0.012	0.740	-0.994
H^+	p	0.000	0.056	0.000	0.000	0.000	0.000	0.006	0.003	0.000
	rate	-0.600	-0.480	-0.944	-1.890	-1.376	0.600	-0.660	-0.497	-0.987
Total acidity	p	0.000	0.015	0.000	0.000	0.000	0.000	0.004	0.002	0.000
	rate	-1.254	-1.290	-2.024	-2.856	-2.640	-1.088	1.080	-2.520	-2.315

2.6.2 Alpine lakes

Spatial variations

During 2014 sampling of Alpine lakes occurred at the following days: 15.7, 15.9, 14.10. Yearly mean autumn concentrations of the main chemical parameters measured in lake surface water are presented in Tab. 2.4.

With exception of Lago Bianco, the chemical water composition was 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 23 µS cm^{-1}, alkalinity between -1 and 79 meq m^{-3}, pH between 5.5 and 7.0, sulphate between 13 and 136 meq m^{-3}, nitrate between 4 and 22 meq m^{-3}, dissolved organic carbon between 0.4 and 1.1 mg C l^{-1}, reactive dissolved silica between 1.1 and 3.2 mg SiO_2 l^{-1} and dissolved aluminium between 2 and 41 µg l^{-1}.

Table 2.4 Average lake surface water concentrations during autumn 2014 Average values with some values below the quantification limit were preceded with <.

Lake name	Lago del Starlaresc da Sgiof	Lago di Tomè	Lago dei Porchieirsc	Lago Barone	Laghetto Gardiscio	Lago della Capannina Leit	Lago di Morghirolo	Lago di Mognòla	Laghetto Inferiore	Laghetto Superiore	Lago Nero	Lago Bianco	Lago della Froda	Lago d’Antabia	Lago della Crosa	Lago d'Orsalia	Schwarzsee	Laghi dei Pozzöi	Lago di Sfille	Lago di Sascòla	Lago d'Alzasca
Cond 25°C (µS cm^{-1})	6.5	7.4	18.9	8.4	7.2	22.6	13.3	18.3	8.5	8.3	16.3	157.5	13.6	12.9	6.9	8.2	10.2	7.9	9.3	8.5	15.6
pH	5.7	5.9	6.8	6.3	5.5	6.4	6.7	6.9	6.6	6.7	6.9	7.8	6.8	7.0	6.5	6.6	6.6	6.6	6.7	6.1	6.9
Alkalinity (meq m^{-3})	2	9	65	16	-1	30	47	67	37	40	75	662	63	79	27	35	39	41	41	20	85
Ca^{2+} (meq m^{-3})	19	32	107	41	22	101	62	86	41	41	91	1103	82	76	33	42	55	38	47	34	80
Mg^{2+} (meq m^{-3})	6	5	11	6	8	35	14	20	6	6	13	173	7	5	5	5	7	7	7	9	15
Na^{+} (meq m^{-3})	9	12	18	10	8	20	14	25	11	10	16	32	12	18	10	11	12	14	16	12	20
K^{+} (meq m^{-3})	4	3	11	4	6	14	11	13	8	7	11	34	6	7	4	4	6	4	3	8	11
NH_4^{+} (meq m^{-3})	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SO_4^{2-} (meq m^{-3})	20	24	78	32	33	136	54	72	22	20	56	833	42	18	13	16	22	19	25	25	33
NO_3^{-} (meq m^{-3})	12	20	14	15	11	10	9	13	11	9	8	8	10	16	15	16	22	4	9	19	18
Cl^{-} (meq m^{-3})	3	3	2	3	3	4	2	3	2	2	2	3	2	2	2	2	3	3	3	2	3
DOC (mg C l^{-1})	1.12	0.59	0.50	0.45	0.35	0.65	0.51	0.52	0.62	0.70	0.50	0.37	0.56	0.52	0.45	0.51	0.57	1.04	0.83	0.91	0.68
SiO_2 (mg l^{-1})	1.6	1.8	2.7	1.4	1.1	2.1	2.0	3.0	1.4	1.3	1.6	3.2	1.5	2.5	1.6	1.7	1.8	2.2	2.2	1.9	2.7
$Al_{dissolved}$ (µg l^{-1})	40.9	20.8	4.2	3.4	25.5	4.8	3.3	5.9	6.9	6.7	1.9	8.8	4.3	4.3	2.1	5.9	9.5	17.4	15.0	24.5	7.5
Al_{tot} (µg l^{-1})	68.5	28.3	8.0	7.8	34.8	26.5	14.8	14.0	12.8	12.0	4.7	14.1	9.5	11.8	5.0	12.3	16.2	29.9	23.4	46.1	10.2
$Cu_{dissolved}$ (µg l^{-1})	0.28	0.13	0.17	0.11	0.21	0.34	0.25	0.28	0.14	0.13	0.12	0.08	0.14	0.07	0.04	0.07	0.08	0.12	0.08	0.22	0.09
Cu_{tot} (µg l^{-1})	0.27	0.21	0.17	0.11	0.28	0.45	0.35	0.31	0.14	0.13	0.11	0.09	0.15	0.15	0.04	0.07	0.09	0.12	0.10	0.24	0.09
$Zn_{dissolved}$ (µg l^{-1})	2.71	1.45	0.67	1.02	2.42	2.01	0.98	1.19	0.86	0.91	1.04	0.72	0.92	1.21	0.79	1.02	0.73	0.97	1.45	1.41	0.57
Zn_{total} (µg l^{-1})	*2.86*	1.67	0.68	1.06	2.47	2.14	1.06	1.33	0.93	1.13	1.22	0.92	0.95	1.34	0.83	1.12	0.73	1.01	1.47	1.48	0.80

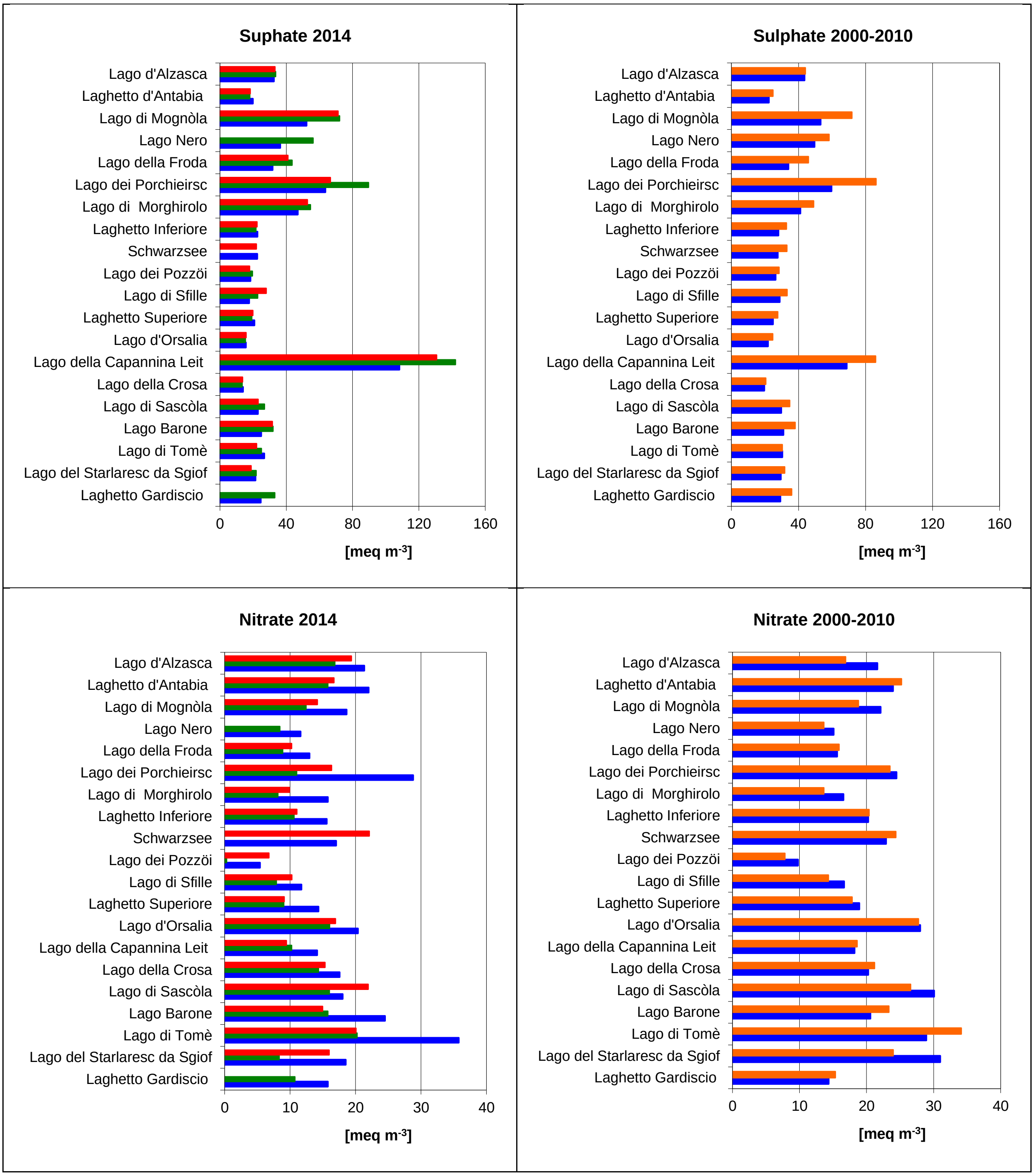
In order to better compare chemistry of lakes with low alkalinities, values of the main parameters measured during 2014 and their mean values from 2000 to 2010 are shown graphically in Fig. 2.6.

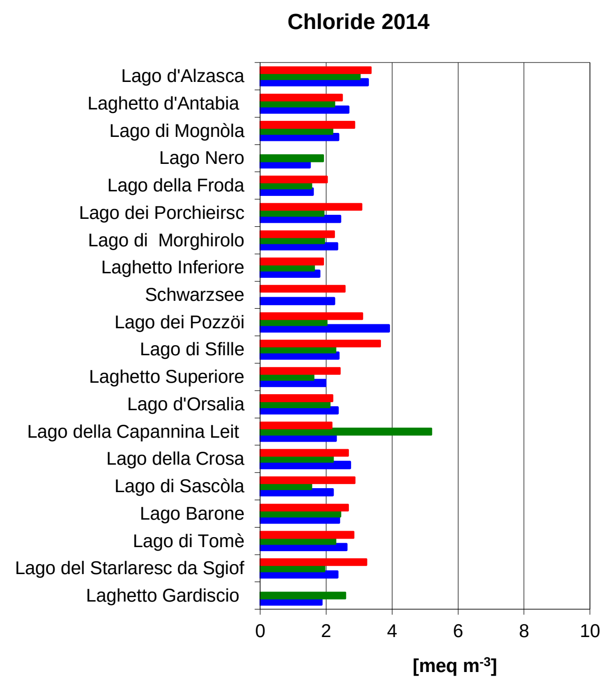
In general, values from 2014 were not much different from those of the period 2000-2010, but concentrations of sulphate, nitrate and base cations were in general slightly lower. During 2014 alkalinities below 0 meq m^{-3} were detected always in Laghetto Gardiscio and in spring in Lago di Tomè and Lago del Starlaresc da Sgiof, while alkalinities constantly above 50 meq m^{-3} were measured only in Lago dei Porchieirsc, Laghetto d’Antabia and Lago d’Alzasca. All other 14 lakes were at least temporary sensitive to acidification (0 < alkalinity < 50 meq m^{-3}). Alkalinity correlated well with pH and concentrations of aluminium. In fact, 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 57 µg l^{-1}. In general concentrations of base cations also correlated 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 did not correlate with alkalinity. Highest concentrations of sulphate occured 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 among lakes, concentrations of sulphate in the other lakes were similar to each other. For nitrate, differences in concentrations among lakes are more difficult to understand and may depend on different factors (nitrogen deposition, retention capacity of the catchment, presence of vegetation, microbial processes, …).

Seasonal variations

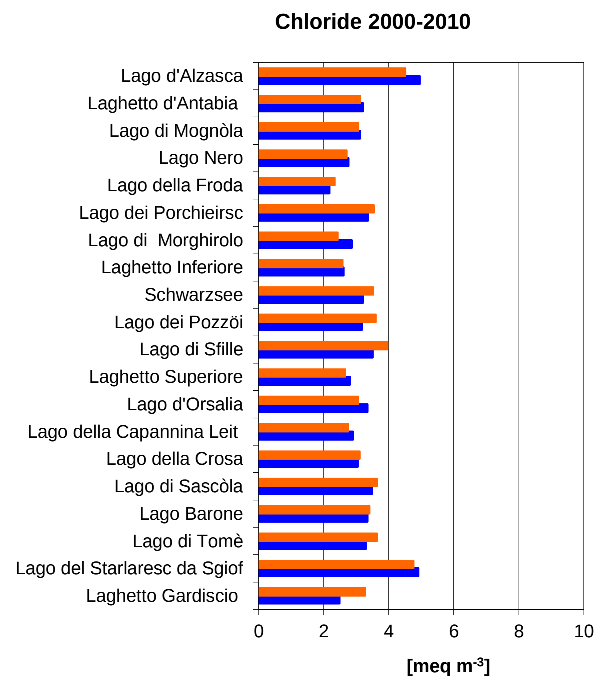
Fig. 2.6 also shows some seasonal differences. In most lakes alkalinity and pH and concentrations of sulphate and base cations are lower in July than in September and October. As discussed for rivers, the elevated discharge in spring causes a dilution of sulphate, base cations and a combination of dilution 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 2.6 Concentrations of the main chemical parameters in 20 Alpine lakes during 2014 and their average values from 2000 to 2010. ***Blue columns represent summer, green early autumn, red late autumn and orange mean autumn values.***

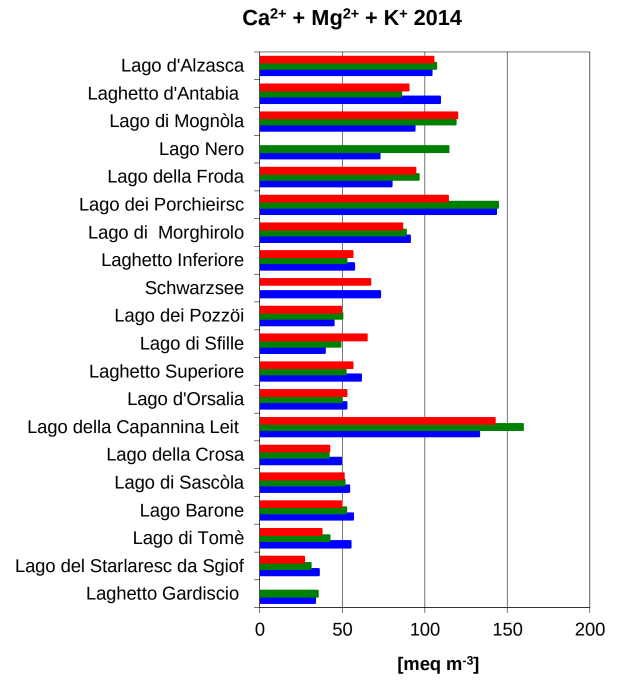




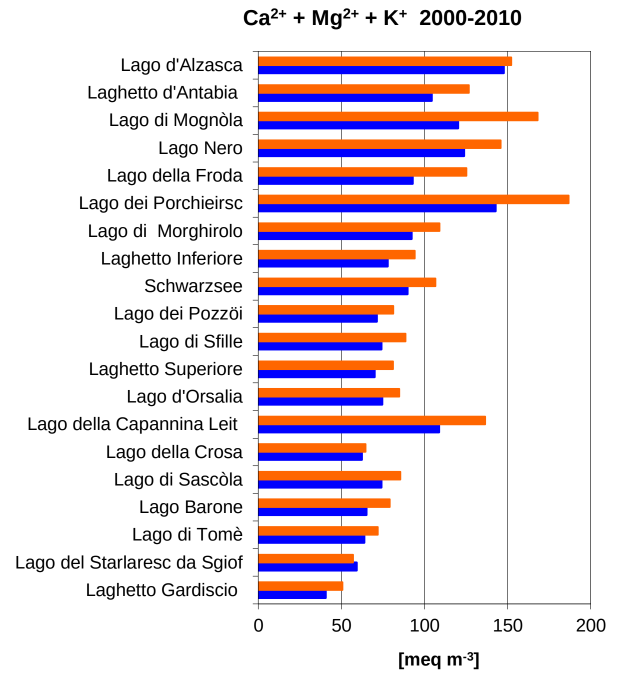
Chloride 2014



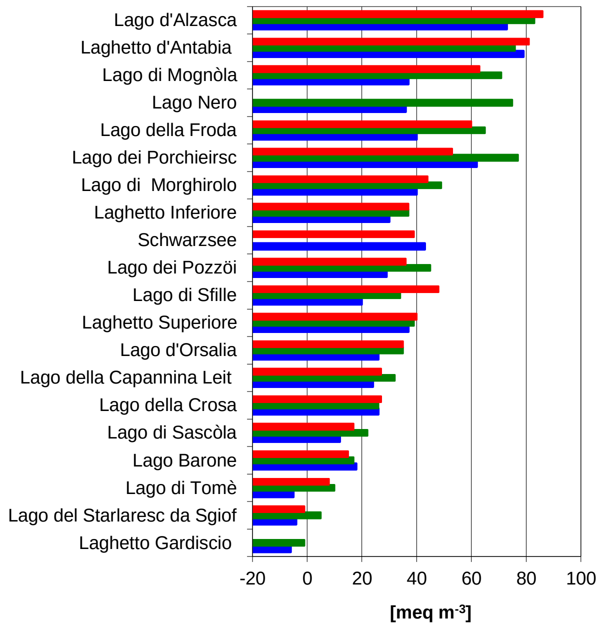
Chloride 2000-2010

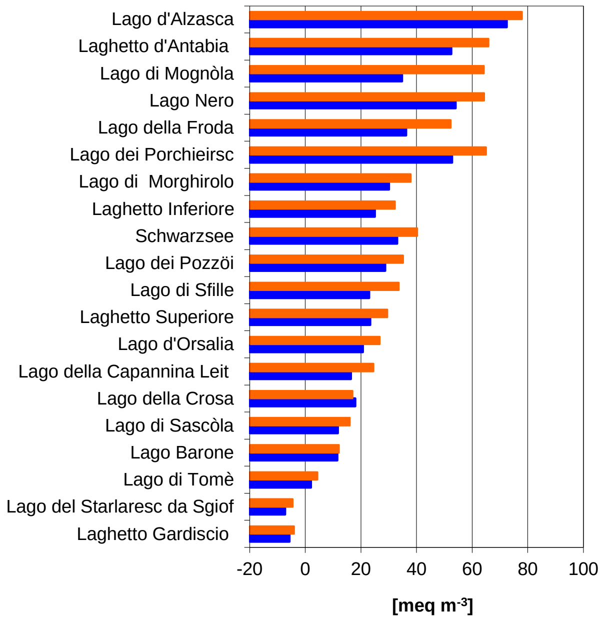


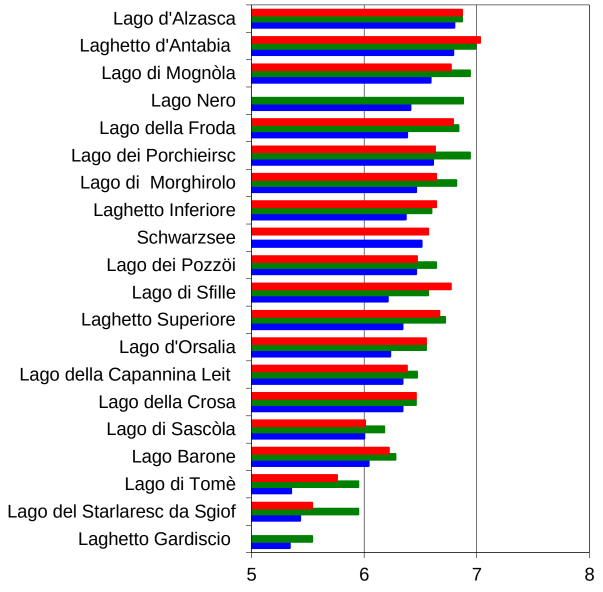
$Ca^{2+} + Mg^{2+} + K^{+}$ 2014

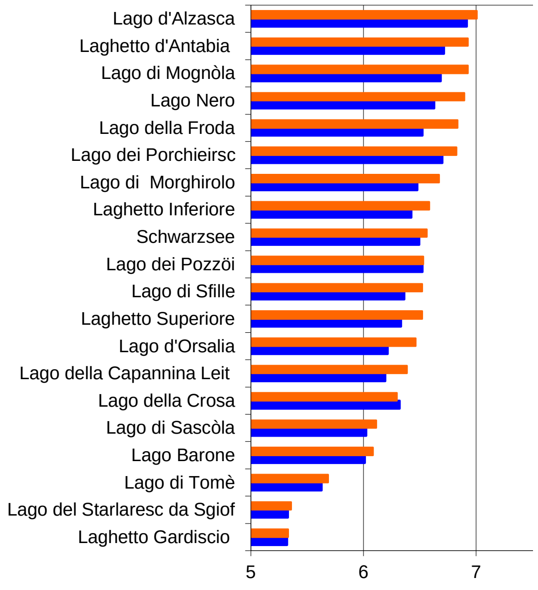


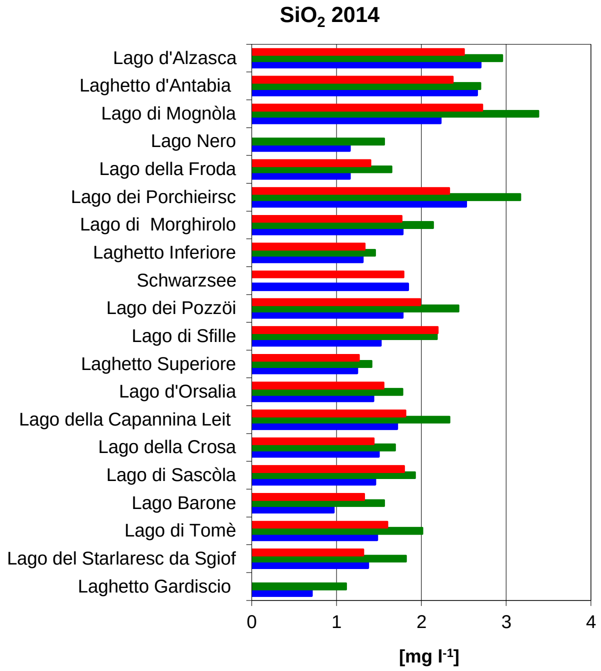
$Ca^{2+} + Mg^{2+} + K^{+}$ 2000-2010


Alkalinity 2014

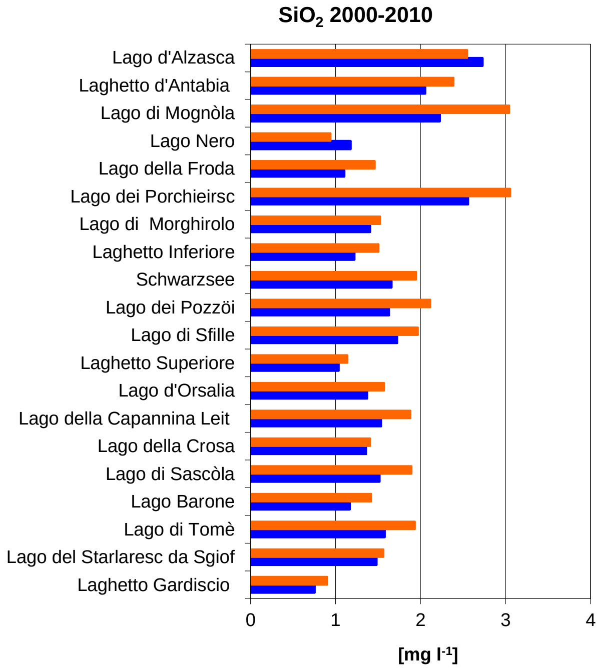

Alkalinity 2000-2010


pH 2014

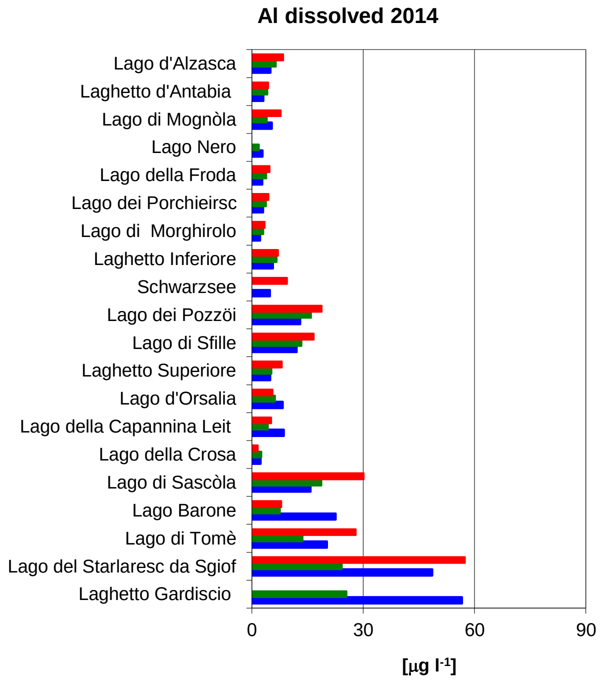

pH 2000-2010



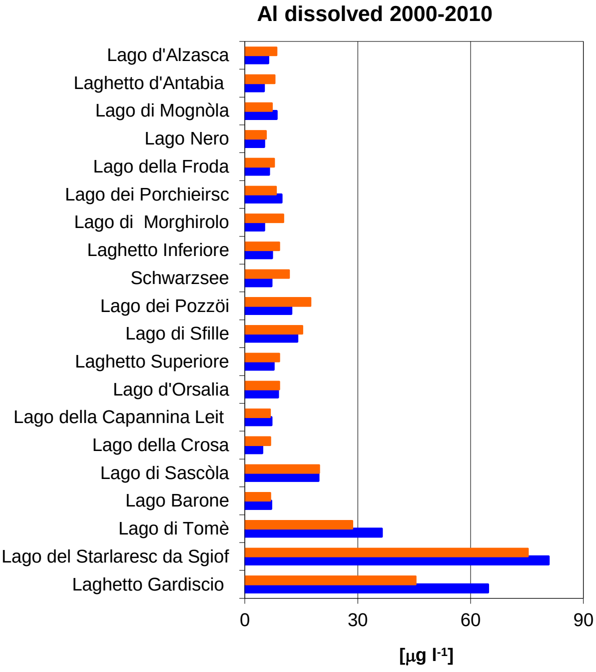
SiO$_2$ 2014



SiO$_2$ 2000-2010



Al dissolved 2014



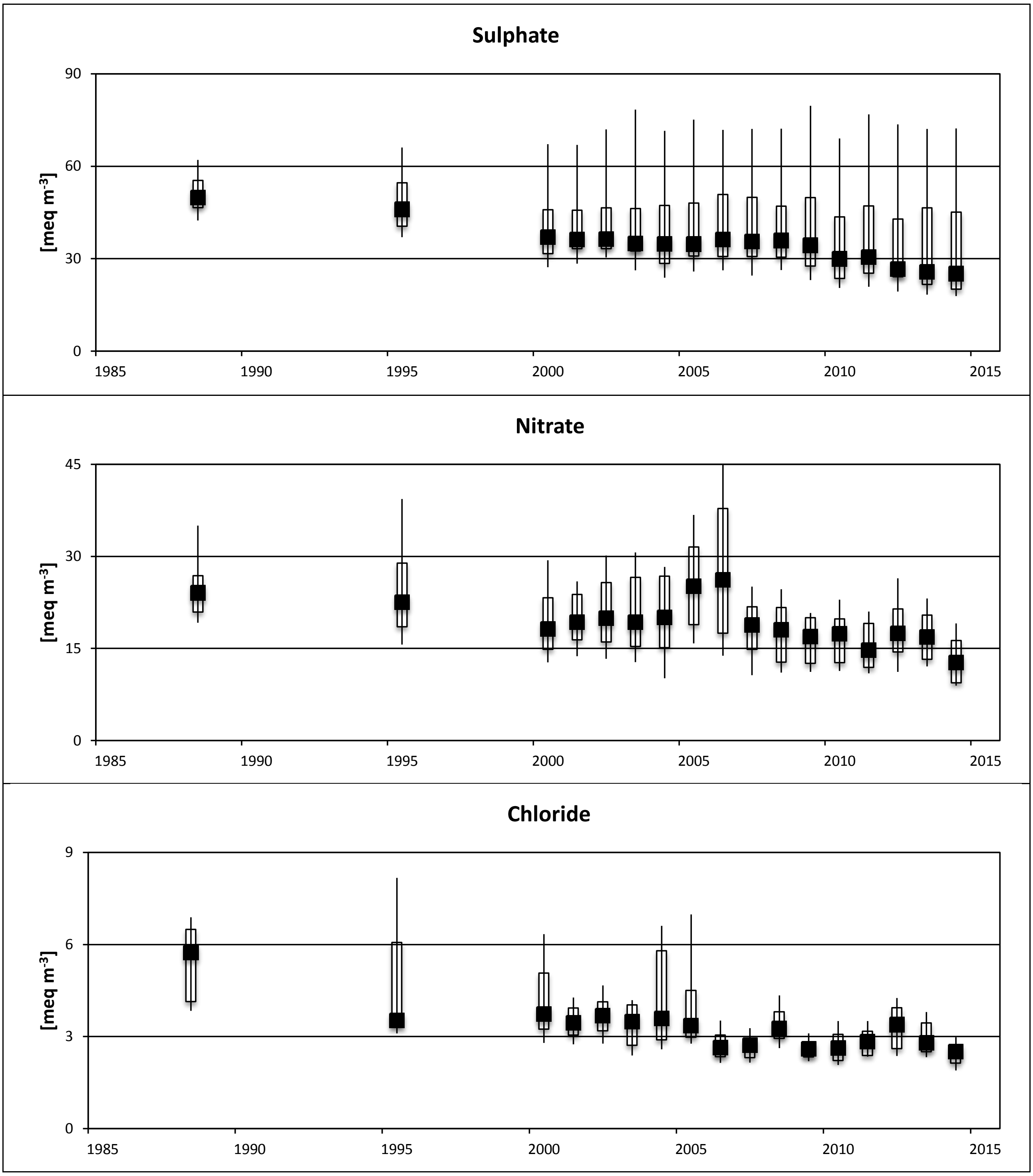
Al dissolved 2000-2010

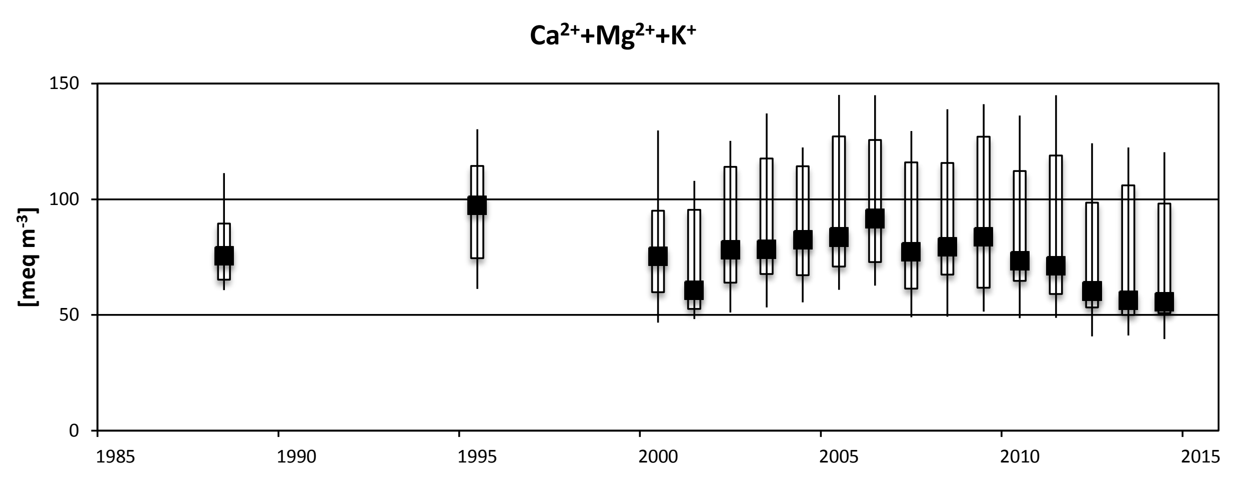
Temporal variations

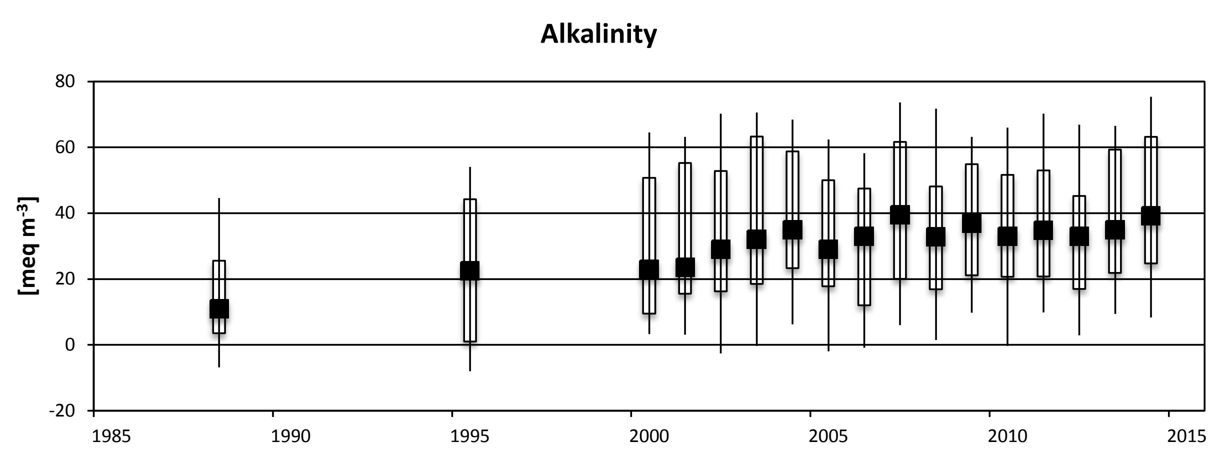
In order to show temporal variations of lake quality, annual median values of pH, alkalinity and concentrations of base cations, sulphate and nitrate of all lakes with their 10th, 25th, 75th and 90th percentile values are represented in Fig. 2.7. Only years, where all 20 Alpine lakes have been monitored were chosen. As already discussed in Steingruber and Colombo (2006), after 1980's sulphate concentrations decreased, because of reduced SO_x emissions and therefore also sulphate depositions. As a consequence of the sulphate decrease, alkalinity and pH increased. Concentrations of nitrate also slightly decreased as a consequence of reduced emissions of NO_x. Aluminium concentrations of the 3 most acidic lakes are presented in Fig. 2.8 (see also trends in Tab. 2.5). A clear decrease in concentrations could be observed only in Lago di Tomè from about 40 to 20 µg l^{-1} and in Lago del Starlaresc da Sgiof from 80-100 to 40-60 µg l^{-1}. No significant trend in concentrations of aluminium occurred in Laghetto Gardiscio, neither alkalinity significantly increased and sulphate only slightly decreased. Interestingly, Laghetto Gardiscio is the highest lake here studied (2580 m a.s.l.), while its geology (mainly gneiss) and land use 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.

Results of a detailed trend analysis of the main parameters are presented in Tab.2.5. Accordingly to what observed in the previous paragraph, sulphate decreased significantly in 15 lakes and alkalinity and pH increased significantly in 14 lakes. As a consequence of lower acid deposition base cations also decreased significantly in 7 lakes. Interestingly, differently to most lakes, concentrations of sulphate and base cations increased significantly in 3 lakes (Lago della Capannina Leit, Lago di Morghirolo and Lago di Mognòla). Climate change leading to increased weathering of sulphur containing rocks or melting of rock glaciers present in all 3 lakes (Scapozza and Mari, 2010) might be the reason (Thies et al., 2007). Differently to previous trend analysis (Steingruber et al. 2006), in agreement to what observed for atmospheric deposition, concentrations of nitrate also recently started to decrease (significantly in 13 lakes).

Figure 2.7 Temporal variations of annual median values and their 10th, 25th, 75th, 90th percentiles of parameters measured in 20 Alpine lakes from 1988 to 2014 (calculated from autumn mean values).




$Ca^{2+}+Mg^{2+}+K^+$
[meq m-3]
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

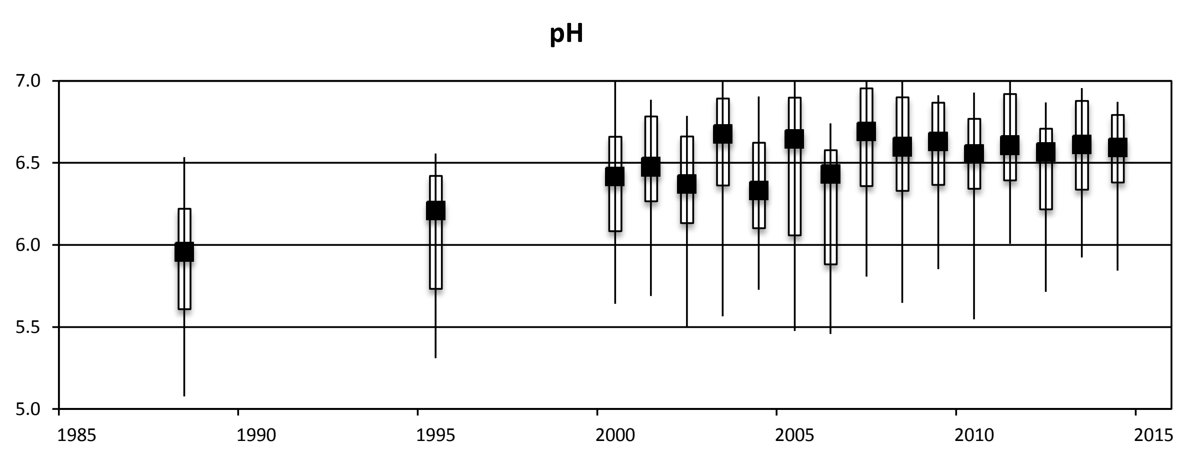

pH
7.0
6.5
6.0
5.5
5.0
1985
1990
1995
2000
2005
2010
2015

Figure 2.8 Temporal variations of dissolved aluminium in the 3 most acidic lakes from 1988 to 2014 (mean autumn values).

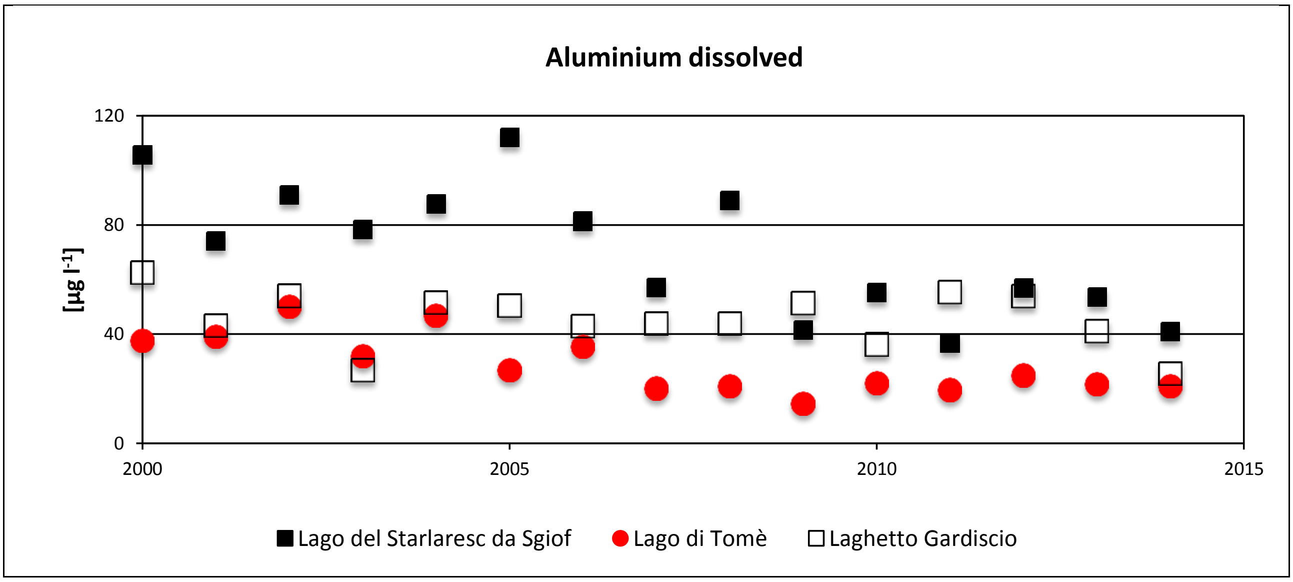


Table 2.5 Results from trend analyses. The analysis period is 1980-2014 for sulphate, nitrate, base cations, hydrogen ion, alkalinity and 2000-2014 for aluminium. p corresponds to the probability level obtained with the Mann-Kendall test and the rate (meq m^{-3} yr^{-1}for anions and cations, mg l^{-1} yr^{-1} for SiO$_2$) with the Kendall slope estimator.

Lake	SO_4^{2-}		NO_3^-		Base cations		H^+		Total alkalinity		Al_{dis}	
	p	rate	p	rate	p	rate	p	rate	p	rate	p	rate
Lago del Starlaresc da Sgiof	0.000	-1.32	0.042	-0.56	0.000	-1.00	0.000	-0.48	0.000	0.81	0.005	-4.00
Lago di Tomè	0.000	-0.92	0.193	-0.33	0.001	-1.03	0.014	-0.07	0.022	0.38	0.009	-1.67
Lago dei Porchieirsc	0.857	0.10	0.026	-0.35	0.620	-0.27	0.041	-0.01	0.241	0.55	0.305	-0.07
Lago Barone	0.000	-0.46	0.011	-0.20	0.174	-0.32	0.002	-0.04	0.001	0.55		
Laghetto Gardiscio	0.035	-0.21	0.055	-0.17	0.081	-0.25	0.069	-0.10	0.062	0.22		
Lago Leit	0.000	2.25	0.000	-0.25	0.000	2.32	0.025	-0.01	0.000	0.50		
Lago di Morghirolo	0.001	0.27	0.014	-0.13	0.029	0.69	0.056	0.00	0.000	0.75		
Lago di Mognòla	0.004	0.35	0.073	-0.12	0.239	0.44	0.154	0.00	0.762	-0.11		
Laghetto Inferiore	0.000	-0.94	0.006	-0.35	0.030	-0.96	0.043	-0.01	0.075	0.50		
Laghetto Superiore	0.000	-0.84	0.001	-0.34	0.487	-0.22	0.003	-0.02	0.000	0.90		
Lago Nero	0.799	0.00	0.005	-0.09	0.284	0.37	0.003	0.00	0.000	0.66		
Lago della Froda	0.043	-0.27	0.004	-0.26	0.203	0.45	0.003	-0.01	0.002	0.67		
Lago d'Antabia	0.000	-0.71	0.025	-0.25	0.544	-0.15	0.066	0.00	0.053	0.54		
Lago della Crosa	0.000	-0.83	0.013	-0.13	0.002	-0.47	0.001	-0.03	0.000	0.65		
Lago d'Orsalia	0.000	-1.00	0.103	-0.22	0.416	-0.19	0.000	-0.05	0.000	0.96		
Schwarzsee	0.000	-1.09	0.045	-0.25	0.006	-1.13	0.005	-0.01	0.147	0.50		
Laghi dei Pozzöi	0.000	-1.09	0.192	-0.16	0.001	-0.74	0.119	0.00	0.017	0.42		
Lago di Sfille	0.000	-0.94	0.004	-0.25	0.009	-0.76	0.001	-0.01	0.000	0.70		
Lago di Sascòla	0.000	-0.93	0.090	-0.20	0.001	-0.98	0.078	-0.02	0.001	0.40		
Lago d'Alzasca	0.000	-0.90	0.395	-0.05	1.000	0.00	0.009	0.00	0.000	0.93		

2.6.3 Alpine rivers

Spatial variations

During 2014 river water was sampled at the following days: 13.1, 18.2, 10.3, 7.4, 5.5, 2.6, 7.7, 4.8, 8.9, 6.10, 3.11, 1.12. Annual mean concentrations of the chemical parameters measured in river Maggia, Vedeggio and Verzasca during 2014 are shown in Tab. 2.6. Conductivity, alkalinity, pH, concentrations of calcium, and sulphate 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. 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.

During 2014 average alkalinity was 264 meq m^{-3} in river Maggia, 142 meq m^{-3} in river Vedeggio and 67 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, 7.0 in river Vedeggio and 6.8 in river Verzasca. Their minimum pH's were not much lower (Maggia: 6.9, Vedeggio: 7.0, Verzasca: 6.7).

Table 2.6 Average concentrations in river water during 2014. Average values with some or all single values below the quantification limit were preceded with <.

River name	pH	Cond 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})	NH_4^+ (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	52	264	321	40	64	32	1	142	31	31	<4.2	1.1	4.8	18.9	20.5	<0.5	0.5	2.8	3.0
Vedeggio	7.1	38	142	197	63	63	12	0	97	54	25	<2.6	1.2	6.5	18.8	35.7	0.5	0.6	1.8	2.2
Verzasca	6.8	20	67	110	15	28	14	0	58	34	10	<2.3	0.9	3.5	18.1	28.8	<0.4	<0.4	1.9	2.1

Seasonal variations

Fig. 2.9 shows the daily mean discharges during 2014. After the typical low values during winter, because of the frequent precipitations, discharges were elevated from March to mid of August and again from October to mid of December.

The seasonality of the concentrations of the main chemical parameters during 2014 was mostly very similar to that for average values in the period 2000-2010, however concentrations were mostly lower. Concentrations of sulphate, base cations, alkalinity, SiO_2 and pH are normally lower from spring to autumn when river discharge is higher and more elevated during the rest of the year. 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 are also higher in winter compared to summer but in addition concentrations can also increase during high flow events. More than one factor probably determines its variation of concentrations e.g. higher values during winter because of lower discharge (less dilution) and low photosynthetic activity (uptake by vegetation and algae) and occasionally higher values during precipitation events or snow melt because of leakage from soils. Concentrations of aluminium seem to reach their highest concentrations during high flow events. In fact, their average concentrations during 2000-2010 were 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 2014 because of frequent precipitation events concentrations of aluminium peaked more frequently than usual. Next to the usual peaks in spring and autumn, they could also be observed during summer.

Figure 2.9 Daily mean discharge during 2014. Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2014). 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 (2005-2014). The vertical lines correspond to dates of sampling.

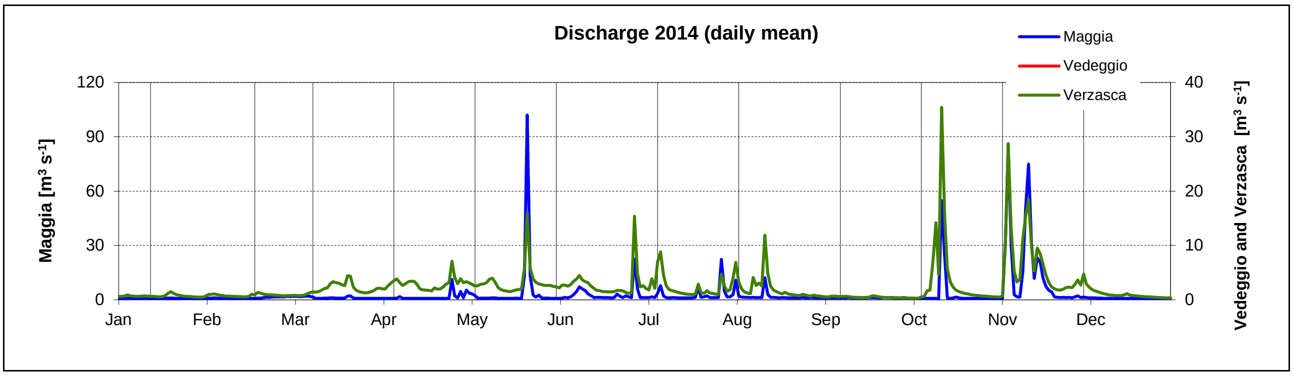
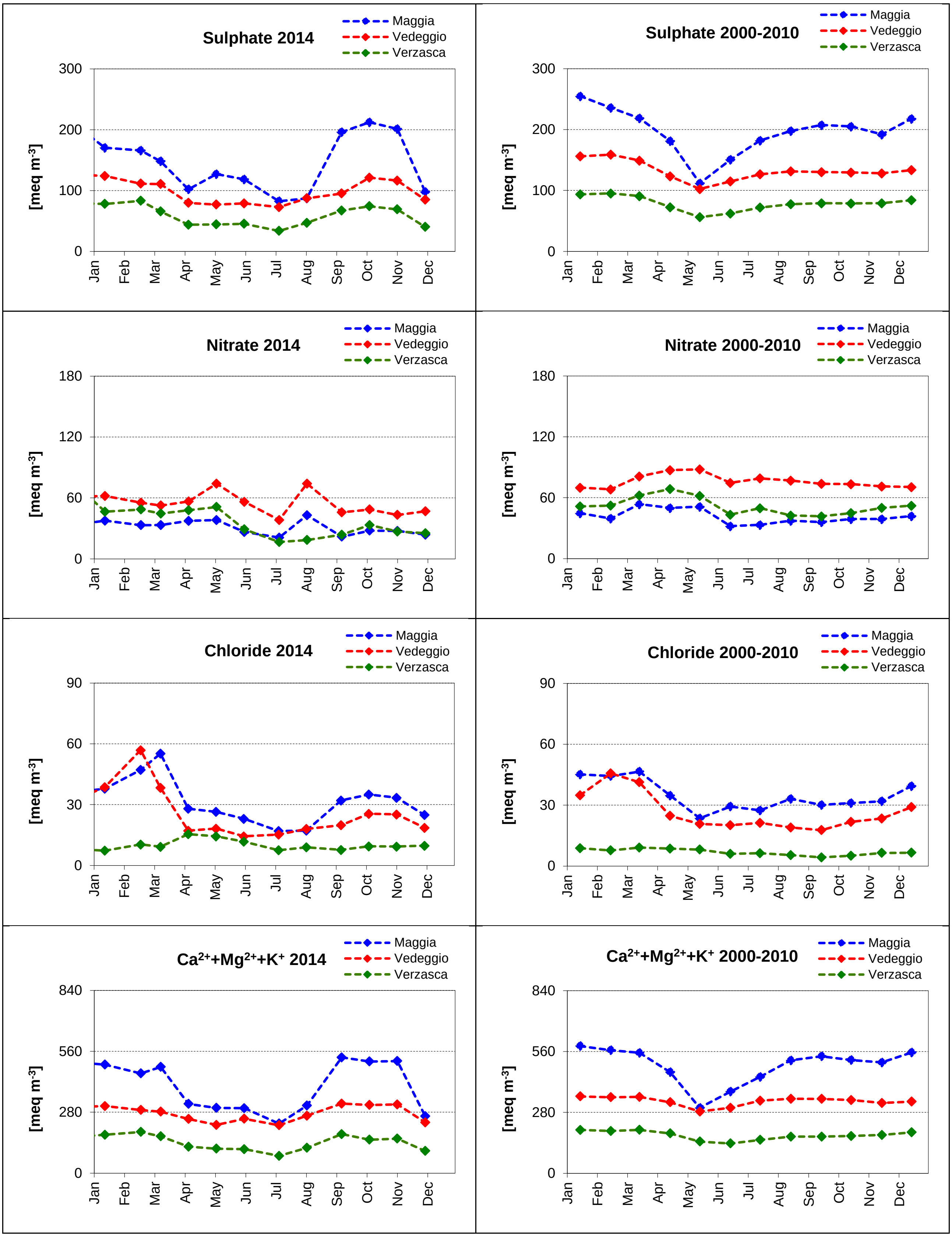
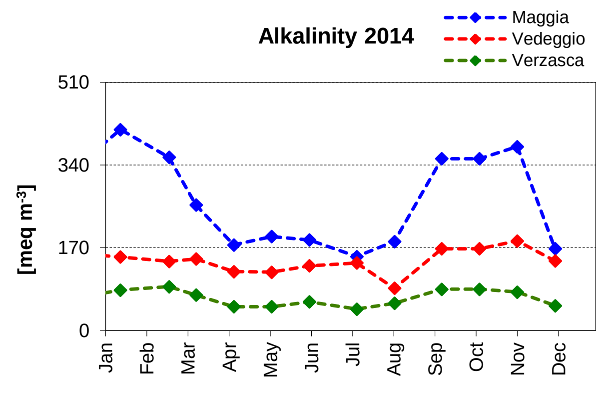
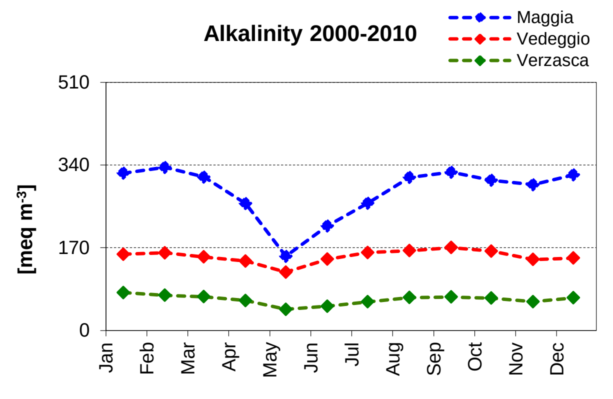
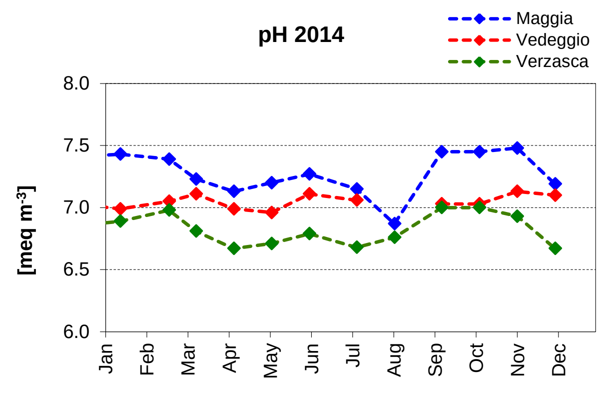


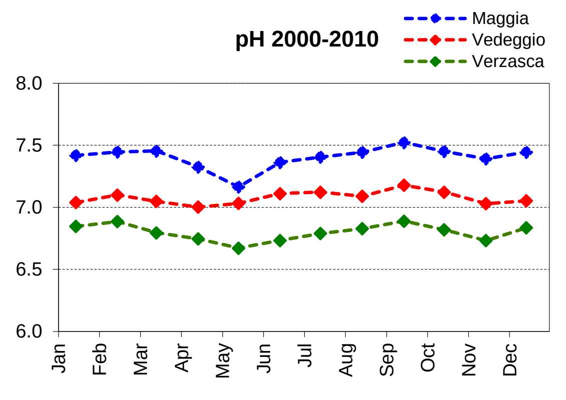
Figure 2.10 Concentrations of the main chemical parameters in river water during sampling days in 2014 and their average values from 2000 to 2010.




Alkalinity 2014
Maggia
Vedeggio
Verzasca
[meq m-3]
510
340
170
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Alkalinity 2000-2010
Maggia
Vedeggio
Verzasca
[meq m-3]
510
340
170
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


pH 2014
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
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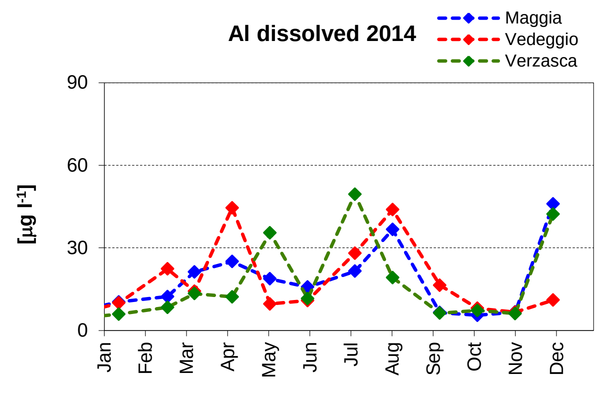
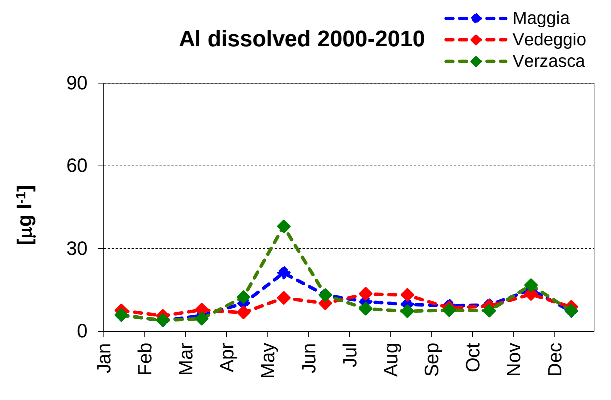
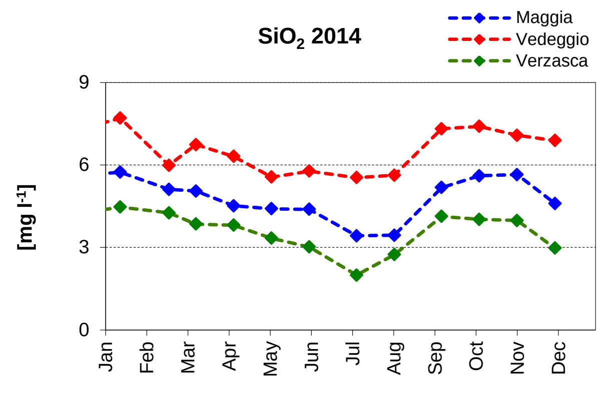
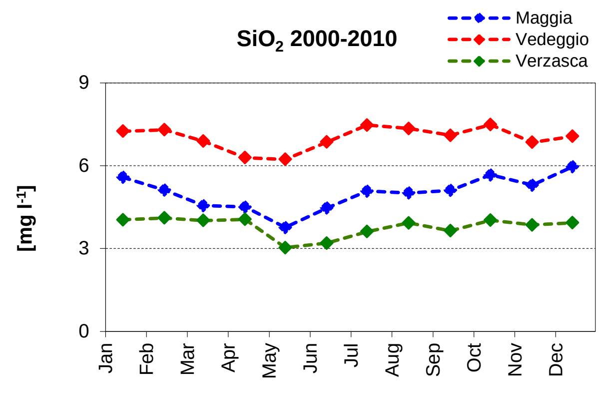
Jul
Aug
Sep
Oct
Nov
Dec


Al dissolved 2014
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


SiO_2 2014
Maggia
Vedeggio
Verzasca
[mg l-1]
9
6
3
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SiO_2 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 2014 are presented graphically in Fig. 2.11 and 2.12, respectively.

Because of the 2014's frequent precipitations discharges were higher than average. In particular, yearly average discharges during sampling days were the highest measured since the beginning of chemical monitoring of rivers in 2000. Consequently, concentrations of sulphate, nitrate, base cations, alkalinity, pH and SiO_2 were diluted and lower than average.

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. We therefore performed a seasonal partial Mann-Kendall test for the period 2000-2014. Results of the trend analysis are shown in Tab. 2.7. Concentrations of sulphate decreased significantly only in river Vedeggio. However, trends were almost significant also in river Maggia, as well. Concentrations of nitrate decreased significantly only in river Vedeggio and Verzasca and alkalinity only in river Verzasca. Interestingly, trend analysis of data from river Maggia at Solduno (submitted by CNR-ISE Pallanza-Italy), about 30 km downstream from Bignasco, produced a significant decreasing nitrate trend ($p=0.004$) for the period 2000-2014 but not for 1985-2014 ($p=0.675$), while for sulphate the trend was significant for both periods: 2000-2014 ($p=0.005$) and 1985-2014 ($p=0.000$). It therefore seems that the absence of significant decreasing sulphate trends may be related to the short analysis period, in fact, the highest decrease in sulphate deposition occurred between 1980's and 1990's (Fig. 2.4), while the reduction in nitrate concentrations seems to be a more recent phenomena.

Figure 2.11 Monthly mean discharge in river water from 2000 to 2014. Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2014). 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 (2005-2014).

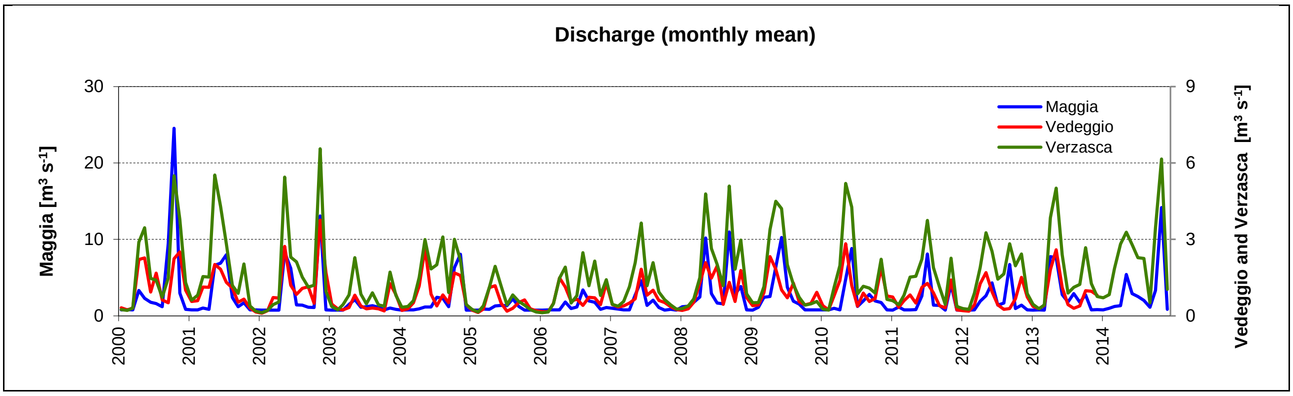
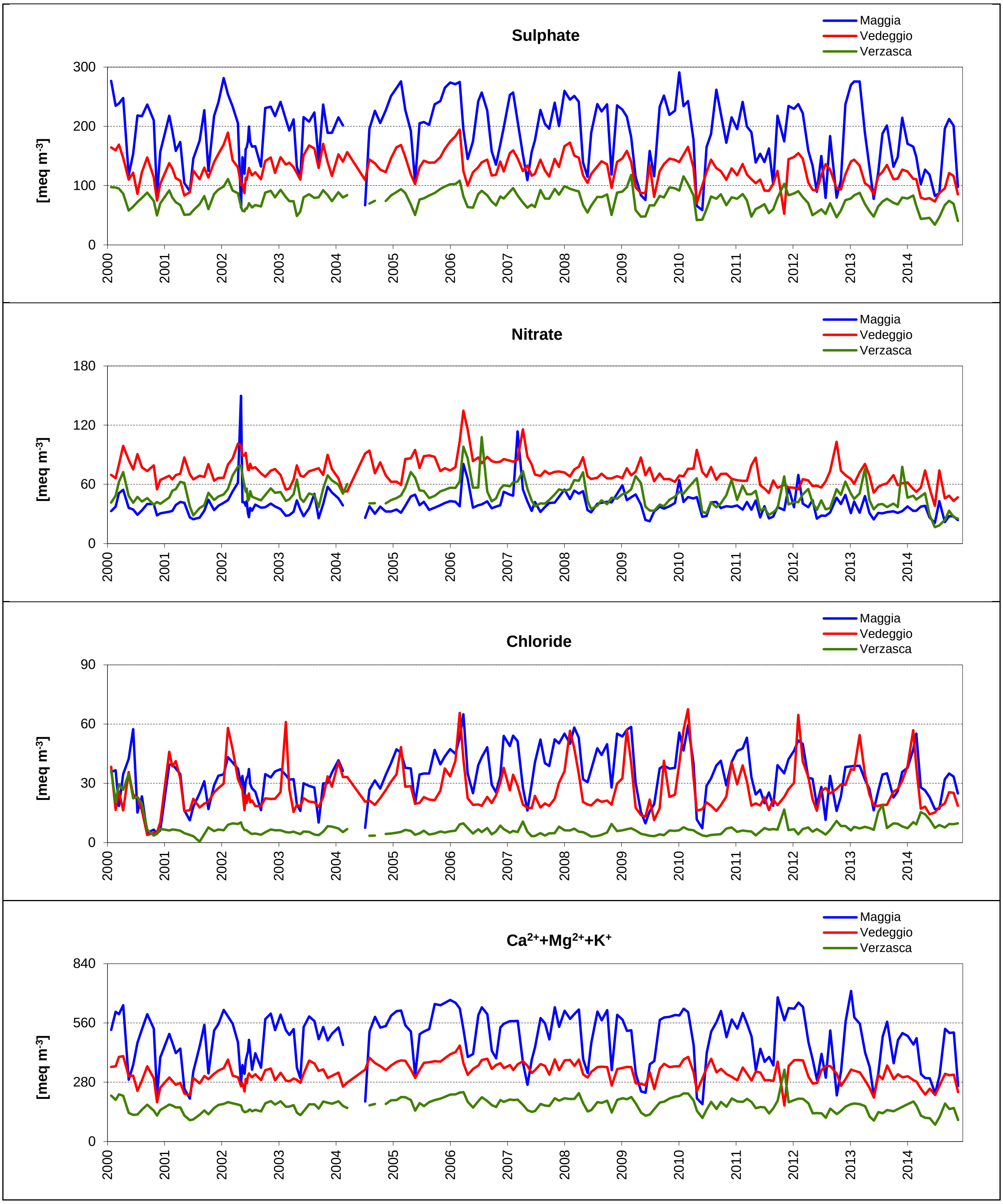
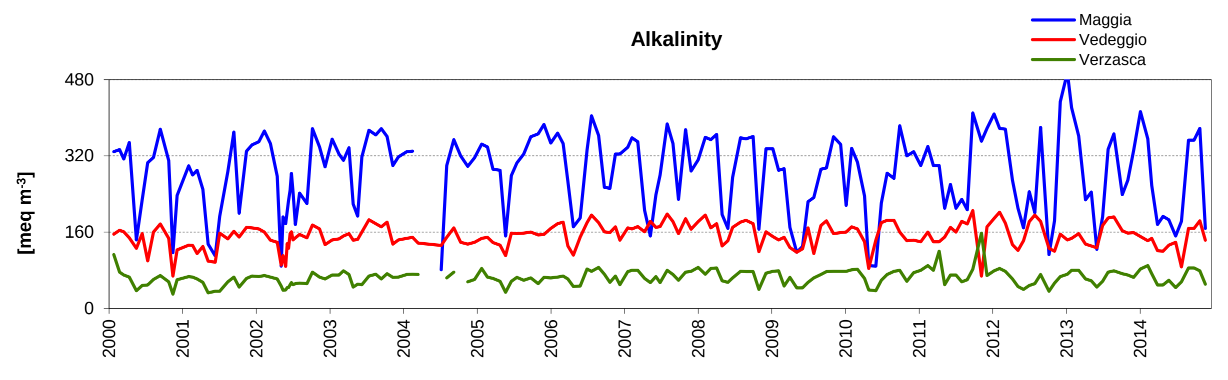
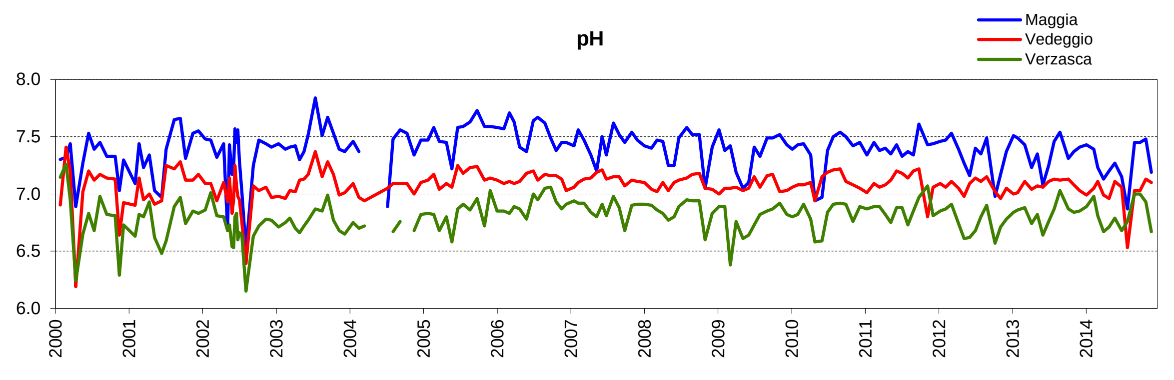
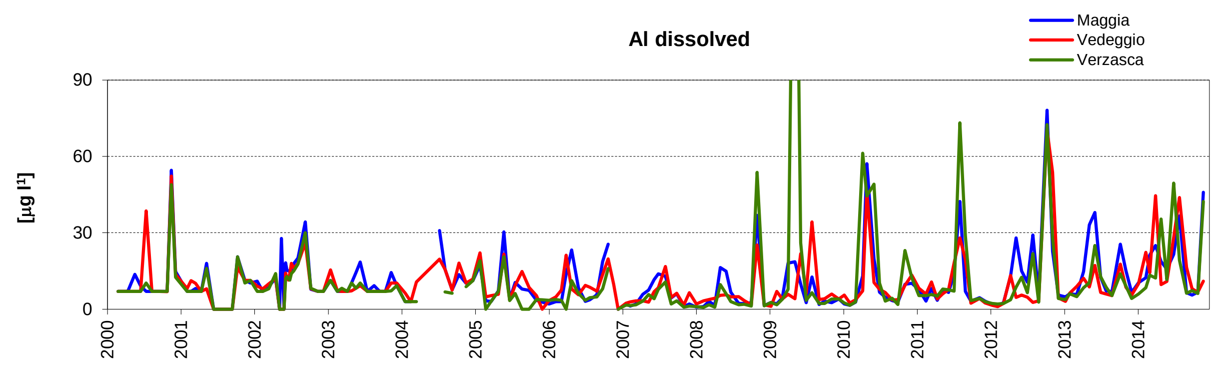


Figure 2.12 Concentrations of the main chemical parameters in river water from 2000 to 2014




Alkalinity
Maggia
Vedeggio
Verzasca
[meq m-3]
480
320
160
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014


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
2013
2014


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
2013
2014

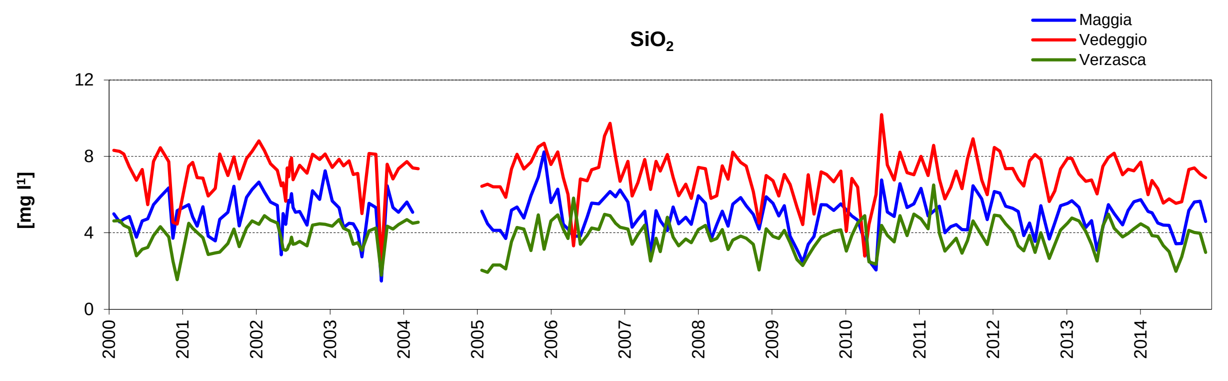

SiO2
Maggia
Vedeggio
Verzasca
[mg l-1]
12
8
4
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

Table 2.7 Results from trend analyses (significant trends in red) during the period 2000-2014. p corresponds to the probability level obtained with the seasonal partial Mann-Kendall test and the rate (meq m^{-3} $yr^{-1}$for anions and cations, mg l^{-1} yr^{-1} for SiO_2) with the seasonal Kendall slope estimator.

River	SO_4^{2-}		NO_3^-		Base cations		H^+		Alkalinity	
	p	rate	p	rate	p	rate	p	rate	p	rate
Maggia	0.087	-2.00	0.328	-0.25	0.604	-1.50	0.326	0.00	0.920	0.33
Vedeggio		-1.75		-1.15		-0.75		0.00		1.00
Verzasca	0.189	-0.86	0.006	-0.80	0.694	-0.29	0.179	-0.00	0.002	0.78

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 2014 autumn average and minimum (spring) lake pH's were 6.6/6.4, 6.7/6.3, 5.7/5.4, 5.9/5.4 in lakes Inferiore, Superiore, Starlaresc da Sgiof and Tomè, 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. During 2014 values ranged between 6.7 and 7.0.

During the macroinvertebrate monitoring period (from 2000 to present) autumn pH and alkalinity increased significantly only in lakes Superiore and Starlaresc da Sgiof. However, for Laghetto Inferiore the increasing alkalinity trend was also almost significant. In Laghetto Inferiore pH and alkalinity increased from about 6.5 and 28 µeq l^{-1} (average 2000-2003) to 6.7 and 33 µeq l^{-1} (average 2011-2014), in Laghetto Superiore from 6.4 and 24 µeq l^{-1} to 6.7 and 35 µeq l^{-1}, in Lago del Starlaresc da Sgiof from 5.2 and -9 µeq l^{-1} to 5.8 and 6 µeq l^{-1} and in Lago di Tomè from 5.7 and 2 µeq l^{-1} to 5.8 and 5 µeq l^{-1}. Concentrations of dissolved aluminium decreased significantly only in Lago del Starlaresc da Sgiof and Lago di Tomè. Values decreased from about 87 to 47 µg l^{-1} in the first and from 40 to 22 µeq l^{-1} in the second. In river Verzasca only alkalinity showed a significant improvement increasing from about 59 to 67 µg l^{-1}.

3.2 Methods

Macroinvertebrate samples were collected by “kicksampling” according to the ICP Waters Manual (ICP Waters Programme Centre, 2010). Until 2013 lake samples (Laghetto Inferiore, Laghetto Superiore, Lago di Tomè, Lago del Starlaresc da Sgiof) were collected from the littoral and the emissary 2-3 times a year. From 2014 because of financial reasons only emissaries have been sampled. Emissaries were preferred to littorals because known to be inhabited more often by indicator species for acidity (Steingruber et al. 2013). In fact, many of these species were determined for rivers and are therefore current loving. Sampling in river 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, usually, for each site samples from fine and coarse substrates were collected separately. However, during 2014 discharges were often elevated. As a consequence it was often not possible to find locally sampling sites that could be representative for coarse respectively fine substrates. Macroinvertebrates were conserved in 70% ethanol. During the first 2 years (2000-2001) for lakes 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 (European Mountain lake Ecosystems: Regionalisation, diaGnostic & socio-economic Evaluation).

To study temporal trends for each year the relative abundances of the main taxonomic groups are here shown (average values). 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 numbers 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 and taxa groups (EPT, AS) with the most important taxa numbers (total, EPT, AS) in lakes during 2014 are shown in Tab. 3.1 and 3.2, respectively. At all sites Diptera was the most abundant order. However, differently to other years Chironomidae did not always prevail. With exception of October samples of Laghetto Inferiore and Superiore, the current loving Simuliidae were at least as abundant as Chironomidae. This might be attributed to the frequent high discharge situations during 2014.

As usual Ceratopogonidae were abundant in Lago del Starlaresc da Sgiof (but only in July), probably because of the presence of wetland vegetation. Another probably consequence of the 2014's high current situation, is the absence of Tubificidae, that normally prefer fine substates. It is possible that they have been washed away. Other quantitatively important taxonomic groups were Plecoptera (*Leuctra sp.*, *Nemoura sp.*, *Protonemoura sp.*) and Trichoptera (*Limnephilus sp.*, *Oligotricha striata*, *Plectrocnemia sp.*, *Rhyacophila sp.*). The more acid sensitive Ephemeroptera were found only in Laghetto Inferiore and Laghetto Superiore (*Ecdyonurus sp.*), Odonata (*Aeshna sp., Libellula sp.*), that are common in wetlands, were observed only in Lago del Starlaresc da Sgiof and Turbellaria (probably the acid sensitive *Crenobia sp.*) were present in the outlets of Laghetto Inferiore, Laghetto Superiore and Lago di Tomè. Highest total taxa numbers were found in Laghetto Inferiore (16), followed by Lago di Tomè (11), Laghetto Superiore (13) and Lago del Starlaresc da Sgiof (9). Regarding EPT, the highest number of taxa was identified in Laghetto Inferiore (9), then in Laghetto Superiore (5) and Lago di Tomè (6) and at last in Lago del Starlaresc da Sgiof (2).

Only few acid sensitive taxa were determined: *Ecdyonurus sp.* in Laghetto Inferiore and Laghetto Superiore, probably *Crenobia alpina* in Laghetto Inferiore, Laghetto Superiore and Lago di Tomè and Empididae in Lago di Tomè. However, compared to Laghetto Inferiore and Laghetto Superiore the abundance of acid sensitive species in Lago di Tomè was low. These results are not surprising since pH's of both Lago di Tomè and Lago del Starlaresc da Sgiof, but especially of the latter during 2014 have always been below 6.

Table 3.1 Lake sample sizes during 2014

LAKE OUTLETS	MONTH	SAMPLE A	SAMPLE B
INF	July (14.7.2014)	696	1898
	October (15.10.2014)	491	430
SUP	July (14.7.2014)	371	292
	October (15.10.2014)	151	435
TOM	July (15.7.2014)	3605	472
	October (14.10.2014)	36	24
STA	July (15.7.2014)	146	211
	October (15.7.2014)	1053	102

Table 3.2 Relative abundance and number of taxa in lake outlets during 2014. ***0.0% indicate values >0.0% but < 0.05%.***

TAXA	INF		SUP		TOM		STA	
	14.7.14	**15.10.14**	**14.7.14**	**15.10.14**	**14.7.14**	**15.10.14**	**14.7.14**	**15.10.14**
OLIGOCHAETA	**3.7%**	**13.7%**	**0.3%**	**51.7%**	**0%**	**29.2%**		
Naididae	1.6%	12.4%		51.7%				
HYDRACARINA								**0.2%**
COLEOPTERA						**2.8%**		**0.5%**
Agabus sp.								0.5%
DIPTERA	**80.7%**	**73.4%**	**81.5%**	**31.1%**	**94.2%**	**45.1%**	**98.0%**	**47.9%**
Ceratopogonidae							15.8%	0.4%
Chironomidae	38.2%	70.5%	46.6%	29.9%	16.6%	20.8%	7.6%	23.7%
Empididae					0.0%			
Limoniidae	0.1%			1.3%				
Simuliidae	42.4%	2.9%	34.8%	0.1%	77.6%	24.3%	74.6%	23.7%
EPHEMEROPTERA	**0.1%**	**0.8%**		**0.1%**				
Ecdyonurus sp.	0.1%	0.8%		0.1%				
HETEROPTERA	**0.0%**		**0.2%**			**1.4%**		
Mesoveliidae						1.4%		
ODONATA								**1.1%**
Aeshna sp.								0.4%
Libellula sp.								0.6%
PLECOPTERA	**10.0%**	**7.6%**	**12.4%**	**12.2%**	**4.5%**	**15.3%**	**2.0%**	**50.1%**
Leuctra sp.	1.6%		5.9%		1.8%	6.3%		
Nemoura sp.	4.4%	7.5%	4.3%	12.2%		9.0%	2.0%	50.1%
Protonemoura sp.	4.0%	0.1%	2.2%		2.7%			
TRICHOPTERA	**0.9%**	**1.0%**	**0.5%**	**0.2%**	**0.1%**	**6.3%**		**0.3%**
Limnephilus sp.	0.1%				0.0%	6.3%		
Oligotricha striata								0.3%
Plectrocnemia conspersa	0.1%							
Plectrocnemia sp.	0.0%							
Rhyacophila (Rhyacophila) sp.	0.5%	1.0%	0.5%	0.2%	0.1%			
Rhyacophila sp.	0.1%							
TURBELLARIA	**4.5%**	**3.4%**	**5.1%**	**4.6%**	**1%**			
Planariidae	4.5%	3.4%	5.1%	4.6%	1%			
Rel. abundance EPT taxa	11%	9%	13%	13%	5%	22%	2%	51%
Rel. abundance AS taxa	5%	4%	5%	5%	1%	0%	0%	0%
Number total taxa	7	6	6	6	5	6	2	6
Number EPT taxa	3	3	2	3	2	2	1	2
Number AS taxa	2	2	1	2	2	0	0	0

Temporal changes of the relative abundances of the main taxa and taxa groups (EPT, AS) and most important taxa numbers (total, EPT, AS) are presented in Tab. 3.3. Increasing relative abundances of Diptera, particularly Chironomidae can be observed in outlets of Laghetto Inferiore and Lago di Tomè. Simultaneously, at the same sites and in Laghetto Superiore a decrease in the relative abundance of Plecoptera and consequently also of the relative abundance of EPT taxa occurred.

Regarding acid sensitive indicators like the relative abundance of AS taxa and the standardized number of AS almost no positive trend can be observed. The only early sign of recovery seems to be the reappearance of *Crenobia alpina* in Lago di Tomè after 2006.

Table 3.3 Temporal variations of the relative abundances and the number of taxa in lake outlets. ***0% indicate values >0% but < 0.5%.***

LAKE	PARAMETER	1991	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014
INF	Sampling times	1	1	3	3	3	3	2	2	2	2	2	2	2	2
	Individuals	64	80	293	1216	2004	8338		7713	10515	5255	958	4801	4587	3515
	Rel. abundance OLIGOCHAETA (%)	22	6	11	25	36	30		30	23	23		18	1	9
	Rel. abundance HYDRACARINA (%)			1	0	0	0		0	0	0	1	0	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	93	77
	Rel. abundance CHIRONOMIDAE (%)	*38*	*13*	*17*	*28*	*23*	*18*		*39*	*46*	*51*	*86*	*50*	*70*	*54*
	Rel. abundance EPHEMEROPTERA (%)				2	2	1		1	1	0	0	0	0	0
	Rel. abundance HETEROPTERA (%)														0
	Rel. abundance PLECOPTERA (%)	27	56	33	23	16	12		5	5	6	6	2	1	9
	Rel. abundance TRICHOPTERA (%)		8	1	3	3	3		0	1	1	1	0	0	1
	Rel. abundance BIVALVIA (%)											0			
	Rel. abundance TURBELLARIA (%)	5	5	11	2	10	8		5	18	9	1	6	4	4
	Rel. abundance EPT taxa	27	64	34	28	21	16	14	7	6	8	6	2	2	10
	Rel. abundance AS taxa	5	13	11	12	18	13	9	7	20	11	4	6	5	4
	Standardized number total taxa	12	12	13	20	16	16	12	15	13	13	12	8	8	9
	Standardized number EPT taxa	6	5	6	12	9	11	6	10	8	8	5	4	4	6
	Standardized number AS taxa	2	3	1	6	5	6	4	5	3	3	4	2	2	2
SUP	Sampling times	1	1	3	3	3	3	2	2	2	2	2	2	2	2
	Individuals	49	34	150	1533	1748	6631	5742	5348	4991	5474	963	6723	1711	1249
	Rel. abundance OLIGOCHAETA (%)	6	3	6	21	20	38	50	64	43	29	1	24	7	26
	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	88	56
	Rel. abundance CHIRONOMIDAE (%)	*59*	*6*	*42*	*30*	*36*	*31*	*27*	*19*	*44*	*43*	*65*	*63*	*83*	*38*
	Rel. abundance EPHEMEROPTERA (%)				9	7	1	0	0	0	0	1		1	0
	Rel. abundance HETEROPTERA (%)					0									0
	Rel. abundance PLECOPTERA (%)	18	68	38	29	17	11	10	3	6	21	13	7	2	12
	Rel. abundance TRICHOPTERA (%)	0	24	1	4	3	1	1	1	1	1	2	1	0	0
	Rel. abundance TURBELLARIA (%)	12		5	1	4	1	1	2	1	1	3	2	1	5
	Rel. abundance EPT taxa	18	91	39	43	27	13	11	4	7	21	15	8	3	13
	Rel. abundance AS taxa	12	3	5	11	12	2	1	3	1	1	4	2	2	5
	Standardized number total taxa	10	19	14	19	21	15	14	16	19	14	14	7	10	9
	Standardized number EPT taxa	3	15	7	12	13	8	8	11	9	8	8	4	6	5
	Standardized number AS taxa	2	2	1	6	7	4	4	2	2	2	3	1	2	2

LAKE	PARAMETER	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014
TOM	Sampling times	1	2	2	1	2	2	2	2	2	2	2	2	2
	Individuals	11	156	332	342	2139	3000	3998	4512	3746	230	858	319	4137
	Rel. abundance OLIGOCHAETA (%)		7	1	0	0	0	0	1	1	42	4	1	15
	Rel. abundance HYDRACARINA (%)			1	1	0	2	1	0	0		1		
	Rel. abundance COLEOPTERA (%)		1	3		0	0	0	0	0	1	1		1
	Rel. abundance COLLEMBOLA (%)			0	1	0	1	0	3	1				0
	Rel. abundance DIPTERA (%)	36	28	34	39	84	58	64	88	87	53	77	72	70
	Rel. abundance CHIRONOMIDAE (%)	*36*	*14*	*33*	*36*	*75*	*38*	*57*	*60*	*65*	*26*	*40*	*68*	*19*
	Rel. abundance HETEROPTERA (%)			0		0	0							1
	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	27	10
	Rel. abundance TRICHOPTERA (%)	9	2	4	1	2	2	1	1	1	1	1	1	3
	Rel. abundance TURBELLARIA (%)						1	0	0	0		3		0
	Rel. abundance EPT taxa	45	62	61	58	15	38	35	8	11	4	15	27	13
	Rel. abundance AS taxa					0	1	0	0	0		3		0
	Standardized number total taxa	13	16	21	12	15	14	13	16	15	10	10	9	9
	Standardized number EPT taxa	6	8	8	4	7	7	6	8	8	3	4	5	3
	Standardized number AS taxa	0	0	0	0	1	2	1	2	1	0	1	0	1
STA	Sampling times	1	2	2	1	2	2	2	2	2	2	2	2	2
	Individuals	21	706	808	478	2634	6224	3451	3942	2847	604	766	929	1512
	Rel. abundance OLIGOCHAETA (%)			1	3	3	1	0	2	10		6	6	
	Rel. abundance HYDRACARINA (%)			1	1		0	0	1	2		6	7	0
	Rel. abundance COLEOPTERA (%)	14	2	0	0	0	0	0	0	0	1	0		0
	Rel. abundance COLLEMBOLA (%)						0		0	0				
	Rel. abundance DIPTERA (%)	29	85	91	66	89	96	85	87	74	95	69	87	73
	Rel. abundance CHIRONOMIDAE (%)	*29*	*69*	*85*	*56*	*75*	*93*	*79*	*70*	*56*	*63*	*34*	*59*	*16*
	Rel. abundance EPHEMEROPTERA (%)								0					
	Rel. abundance HETEROPTERA (%)			1	11	0	0	0	0	0	0	0	0	
	Rel. abundance MEGALOPTERA (%)									0				
	Rel. abundance ODONATA (%)		6	0	13	5	1	3	2	2	2	3	0	1
	Rel. abundance PLECOPTERA (%)	24	2	2	5	1	1	9	8	12	1	16		26
	Rel. abundance TRICHOPTERA (%)	33	5	4		0	0	1	1	1				0
	Rel. abundance EPT taxa	57	7	6	5	2	1	10	9	13	1	16		26
	Rel. abundance AS taxa					0			0		25			
	Standardized number total taxa	12	9	14	14	12	10	13	16	14	14	11	7	8
	Standardized number EPT taxa	6	3	3	1	3	3	4	5	4	1	1	0	2
	Standardized number AS taxa	0	0	0	0	1	0	0	1	0	1	0	0	0

3.3.2 Rivers

The number of identified individuals and the relative abundance of identified taxa and taxa groups (EPT, AS) with the most important taxa numbers (total, EPT, AS) and the Braukmann and Biss (2004) class of river Verzasca during 2014 are shown in Tab. 3.4 and 3.5, respectively. The most abundant taxonomic groups were Ephemeroptera and Plecoptera. Different to other years, the abundance of Chironomidae was low, probably because of the frequent high discharge situation during the year. 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 6.5-7.0, corresponding quite well with the measured water chemistry.

Tab. 3.6 shows the temporal variation of the relative abundances of the main taxa and taxa groups, taxa numbers (total, EPT, AS) and acidification class according to Braukmann and Biss (2004). A significant temporal trend cannot be observed.

Table 3.4 River Verzasca sample sizes during 2014.

MONTH	SUBSTRATE	Individuals
March	pool-fine	484
	run-fine	1550
	run-coarse a	694
	run-coarse a	1155
July	pool-fine	215
	pool-coarse	384
	run-fine	231
	run-coarse	142
July	A	238
	B	335
	C	251
	D	206

Table 3.5 Relative abundance and number of taxa in river Verzasca during 2014. ***0.0% indicate values >0.0% but < 0.05%.***

TAXA	MARCH	JULY	OCTOBER
OLIGOCHAETA	**0.1%**		**0.1%**
HYDRACARINA	**0.2%**	**0.2%**	**0.1%**
COLEOPTERA	**11.8%**	**3.0%**	**0.4%**
Curculionidae		*0.1%*	
Esolus sp.	11.7%	2.6%	0.2%
Hydraena sp.	0.1%	0.3%	0.1%
DIPTERA	**8.9%**	**5.7%**	**0.4%**
Athericidae	0.1%		
Aherix ibis	0.3%	1.1%	
Liponeura sp.		0.1%	
Chironomidae	7.5%	1.0%	0.3%
Limoniidae	1.1%	1.4%	0.1%
Simuliidae		2.2%	
EPHEMEROPTERA	**44.6%**	**58.4%**	**74.2%**
Baetis alpinus		0.3%	
Baetis sp.	28.3%	21.7%	7.6%
Ecdyonurus helveticus-Gr.		0.1%	
Ecdyonurus sp.	1.9%	9.4%	14.5%
Epeorus alpinus			0.4%
Epeorus sp.		2.1%	0.5%
Rhithrogena sp.	14.3%	24.9%	51.3%
PLECOPTERA	**31.3%**	**31.4%**	**20.8%**
Leuctra sp.	22.3%	13.3%	12.1%
Amphinemoura sp.	6.3%	0.2%	0.7%
Nemoura mortoni		0.3%	0.3%
Nemoura sp.	0.5%	3.2%	2.0%
Protonemura nimborum			0.2%
Protonemura sp.	0.7%	13.4%	3.0%
Perla grandis.		0.1%	0.2%
Perla sp.	1.3%	0.7%	0.6%
Perlodidae		0.1%	
Isoperla sp.	0.0%		0.3%
Rhabdiopteryx alpina			0.1%
Rhabdiopteryx sp.	0.1%		1.1%
TRICHOPTERA	**2.7%**	**1.0%**	**2.5%**
Hydropsyche modesta	0.0%	0.1%	0.1%
Hydropsyche *sp.*	0.1%		0.1%
Stacobia moselyi			0.1%
Limnephilidae		0.1%	
Limnephilus coenosus			0.1%
Limnephilus sp.			0.4%
Odontoceridae			0.1%
Philopotamus ludificatus			0.1%
Philopotamus sp.	0.3%		0.1%
Wormaldia copiosa		0.1%	
Wormaldia sp.	1.0%	0.3%	
Rhyacophila sp.			0.8%
Rhyacophila (Hyperrhyacophila) sp.	1.0%		
Rhyacophila torrentium			0.2%
Rhyacophila (Hyporhyacophila) sp.		0.2%	0.1%
Rhyacophila (Pararhyacophila) sp.			0.3%
Rhyacophila (Rhyacophila) sp.	0.2%	0.1%	
Sericostoma sp.			0.1%
BIVALVIA			
TURBELLARIA	**0.5%**	**0.3%**	**1.5%**
Planariidae	0.5%	0.2%	0.8%
Polycelis sp.		0.1%	0.7%

TAXA	MARCH	JULY	OCTOBER
Rel. abundance EPT taxa	79	91	98
Rel. abundance AS taxa	48	61	77
Number total taxa	25	31	38
Number EPT taxa	16	20	29
Number AS taxa	13	15	16
Acidification class (Braukmann & Biss)	2	2	2

Table 3.6 Temporal variations of the relative abundances and the number of taxa in river Verzasca. ***0% indicate values >0% but < 0.5%.***

RIVER	PARAMETER	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014
VER	Sampling times	8	6	6	6	5	4	4	4	4	4	4	3	3	3
	Individuals	1574	2258	2569	3760	4268	12900	15019	21054	20239	11691	4510	8570	8404	5885
	Rel. abundance OLIGOCHAETA (%)	0	1	0		0	1	0	3	1	5	0	1	0	0
	Rel. abundance HYDRACARINA (%)	2	1	1	2	0	1	1	1	2	1	1	1	1	0
	Rel. abundance COLEOPTERA (%)	18	22	23	14	18	16	24	19	17	8	22	11	12	5
	Rel. abundance COLLEMBOLA (%)				0	0	0	0	0	0	0				
	Rel. abundance DIPTERA (%)	12	8	10	19	12	19	20	22	23	21	30	36	38	5
	Rel. abundance CHIRONOMIDAE (%)	*6*	*4*	*4*	*16*	*9*	*17*	*17*	*20*	*21*	*19*	*26*	*32*	*35*	*3*
	Rel. abundance EPHEMEROPTERA (%)	46	45	36	41	55	45	36	41	38	34	35	37	33	59
	Rel. abundance PLECOPTERA (%)	18	18	25	18	11	14	16	12	17	29	8	13	14	28
	Rel. abundance TRICHOPTERA (%)	3	4	3	4	2	2	2	1	1	2	2	1	1	2
	Rel. abundance BIVALVIA (%)												0		
	Rel. abundance GASTROPODA (%)				0					0					
	Rel. abundance TURBELLARIA (%)		0	0	0	0	3	1	0	1	0	2	1	1	1
	Rel. abundance EPT taxa	52	54	45	46	62	51	40	43	41	36	40	39	35	62
	Rel. abundance AS taxa	52	54	45	46	62	51	40	43	41	36	40	39	35	62
	Standardized number total taxa	29	26	27	27	22	22	24	24	31	28	23	24	21	24
	Standardized number EPT taxa	18	16	16	17	13	14	16	16	20	19	14	14	12	16
	Standardized number AS taxa	10	9	10	11	9	8	9	9	12	10	10	9	9	9
	Acidification class (Braukmann & Biss)	2	2	2	2	2	2	2	2	2	2	2	2	3	2

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