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 2015

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Sampling and determination of macroinvertebrates	Fürst & Associati SA

Content

Abstract

During 2015 precipitations in southern Switzerland were lower than average and as a consequence concentrations of the anthropogenic pollutants sulphate, nitrate and ammonium in rainwater were slightly higher compared to the most recent years. Differently, deposition rates of the same parameters were comparable to the last years values. Similar conditions can be observed for concentrations and depositions of acidity.

For some parameters temporal trends were observed. From 1990, as a consequence of reduced SO_2 emissions, annual mean concentrations of sulphate decreased below 25 meq m^{-3} at all stations. The time trend analysis showed a significant decrease of sulphate concentrations at all sites particularly before 2000. Because of the reduction of the emissions of NO_x and NH_3, concentrations of especially nitrate but also of ammonium also slightly decreased. Significant decreasing nitrate and ammonium trends were detected at most sites after 2000. As a consequence a significant reduction of rainwater acidity at all sites from around 30-60 meq m^{-3} to below 0 meq m^{-3} and an increase of pH from around 4.3 to 5.4 took place. Trends in depositions were similar but less pronounced. The period after 2010 is too short for a representative time trend analysis, however concentrations of sulphate, nitrate and acidity seem to have decreased further, while concentrations of ammonium, base cations and pH remained stable.

In agreement with wet deposition, from the 1980's until present, concentrations of sulphate and nitrate decreased in most lakes, leading to an increase of alkalinity and pH. While for sulphate the calculated concentration trend rates were similar for the two analyzed time periods (1980's-2015 and 2000-2015), concentration rates of nitrate were higher after 2000, indicating a more pronounced decrease more recently. As a consequence also a significant decrease of concentrations of aluminium tool palce, especially after 2005 in the most acidic lakes Lago Tomé and Lago del Starlaresc da Sgiof (pH < 6) from annual mean 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.

The time trend analysis and river chemistry revealed that from 2000 to 2015 concentrations of sulphate decreased significantly in all 3 rivers. Concentrations of nitrate decreased significantly in the rivers Vedeggio and Verzasca and almost significantly in the river Maggia, while for alkalinity significant increasing trends were detected in the Vedeggio and in the Verzasca river and almost in the Vedeggio river.

The invertebrate population did not change greatly over time 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.

1 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 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 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, 2015 was an extreme year in Southern Switzerland. Winter and summer were the second warmest since the beginning of measurements in 1864 and the period November-December was the driest ever (MeteoSvizzera, 2016).

2 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. 2.1, while their main geographic and morphometric parameters are resumed in Tab. 2.1, 2.2 and 2.3.

Figure 2.1 Sampling sites (Relief map: © Ufficio del catasto e dei riordini fondiari, 2015)

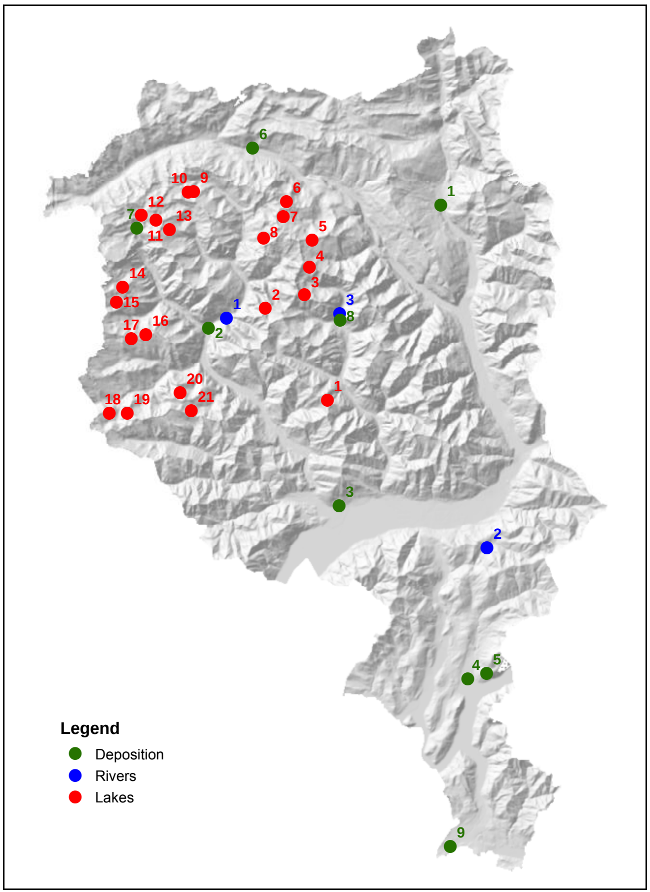


Table 2.1 Geographic and morphometric parameters of the wet deposition sampling sites

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 2.2 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 2.3 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

3 Water chemistry analysis

3.1 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 and low temperatures) 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.

3.2 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.

3.3 Analytical methods

Measured parameters, conservation methods, analytical methods and quantification limits are resumed in Tab. 3.1. 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 3.1 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_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)	0.4 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}

3.4 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.

3.5 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 concentrations and depositions. For river chemistry the seasonal Mann-Kendall test was performed on monthly measurements. 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).

3.6 Results and discussion

3.6.1 Wet deposition

Spatial variation

Annual average rainwater concentrations of the main chemical parameters and their yearly deposition rates during 2015 are shown in Tab. 3.2.

Table 3.2 Yearly mean rain water concentrations and deposition rates during 2015

					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	1157	1074	10	5.3	17	20	3	4	5	6	2	2	34	39	18	21	16	18	26	30	6	7	-13	-15
Bignasco	1287	1344	10	5.3	19	24	3	4	8	10	2	3	29	37	14	19	16	20	28	35	7	8	-9	-12
Locarno Monti	1345	1195	13	5.2	17	22	3	5	8	11	1	2	45	60	17	23	21	28	36	48	8	10	-10	-14
Lugano	1232	945	12	5.4	14	17	3	4	8	10	2	3	45	56	19	23	19	23	32	40	8	10	-15	-18
Monte Brè	1232	1129	12	5.6	19	24	5	6	10	12	3	4	42	52	21	26	20	25	34	42	10	13	-18	-23
Piotta	1189	923	9	5.6	14	17	3	3	7	8	4	4	31	36	18	21	16	19	19	23	7	9	-15	-18
Robiei	2279	1894	9	5.4	14	33	3	6	4	9	1	3	27	61	7	15	14	33	29	66	4	8	-2	-5
Sonogno	1694	1447	11	5.6	17	29	3	5	9	15	3	5	44	74	20	33	18	30	32	54	8	14	-17	-29
Stabio	1414	1368	13	5.4	16	22	4	6	8	12	2	3	48	69	22	31	22	31	33	46	7	10	-18	-25

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 2015 highest concentrations of the sum of sulphate, nitrate, ammonia were measured at Stabio and Locarno Monti 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 2015, highest deposition rates of the sum of ammonia, nitrate and sulphate occured at Robiei and Sonogno and lowest at Piotta.

A detailed analysis on the 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 2015 and their average values during the period 2000-2015 are reported in Fig. 3.1. Similarly, seasonal variations of monthly mean rainwater concentrations of the main chemical parameters during 2015 and their mean values during the period 2000-2015 are compared in Fig. 3.2.

Average monthly precipitation is normally low from December to March and higher from May to November. Highest precipitation volumes normally occur in May, August and November. Compared to average values, precipitation of 2015 was higher in September, and lower in April, July, November, December.

During 2000-2015 average sulphate concentrations were 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 started 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 of 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 during 2000-2015 were 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 concentrations of ammonium during 2000-2015 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.

Average concentrations of base cations during 2000-2015 were 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 behaved acidity, whose monthly mean concentrations were 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 were highest in summer.

Similarly to what observed for the most recent years, during 2015 concentrations of particularly sulphate, nitrate and base cations were in general lower than average values of 2000-2015, especially at the usually more polluted sites (low latitude and low altitude). Consequently, differences in concentrations among sampling stations became less significant. Compared to 2000-2015 average values, concentrations of acidity did not greatly change. The negative peaks in March and June correspond to the two peaks in concentrations of base cations. The particularly high base cations and alkalinity peaks in June were caused by an alkaline rain event that occurred during the 24^{th} week (8.6.15-15.6.15). Monthly pH's of 2015 were higher compared to 2000-2015 averages. Only 11% of the monthly values were below pH 5, while the same percentage was 17% for 2000-2015 averages. Similarly, during the last year 57% and 27% of the monthly pH values were higher than 5.5 and 6.0, respectively. The same percentages were only 43% and 5%, respectively for 2000-2015 monthly average values.

Wet depositions behave in general similar to concentrations, with the difference that rainwater volume gain further importance (Fig. 3.3). During 2000-2015 average monthly sulphate, nitrate and ammonium depositions were normally higher during the warm months when both concentrations and precipitations are highest. For the same time period average monthly depositions of base cations were also higher during summer but high values were also typical for October and November. Average monthly deposition of acidity behaved opposite to base cations.

During 2015, depositions of sulphate, nitrate and ammonium were in general slightly lower than 2000-2015 average values. However, higher depositions occurred during May and September when precipitations were also higher. For base cations and acidity highest resp. lowest values were observed during the already mentioned alkaline rain event in June 2015. This event contributed with 20-32% to the total yearly alkalinity load at all sites.

Figure 3.1 Monthly precipitations

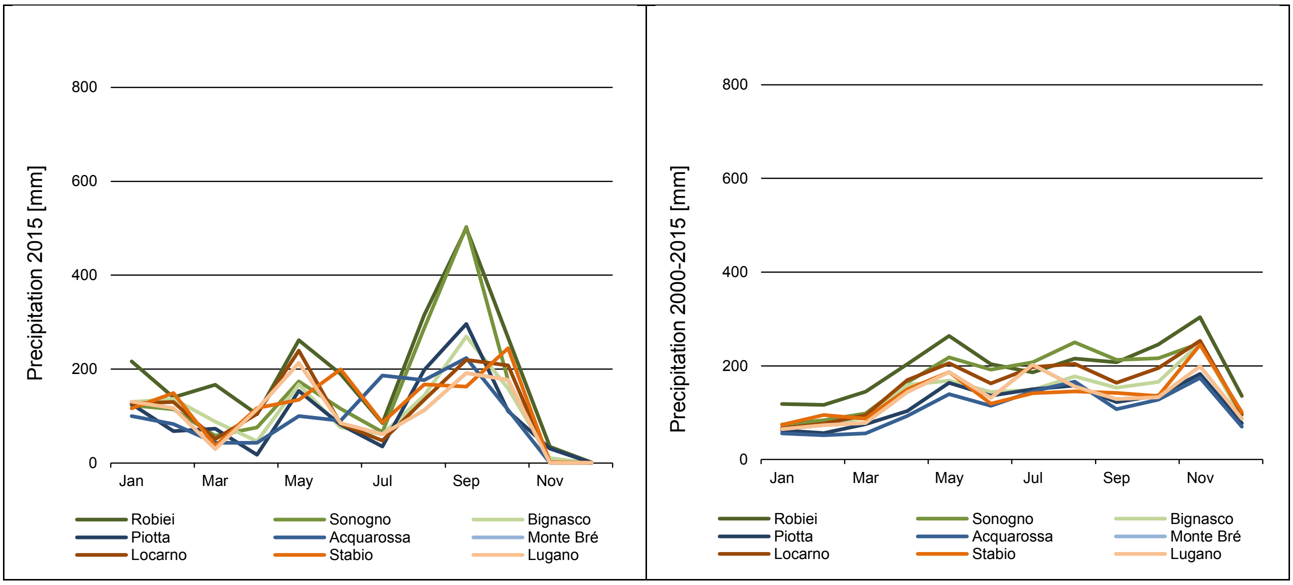
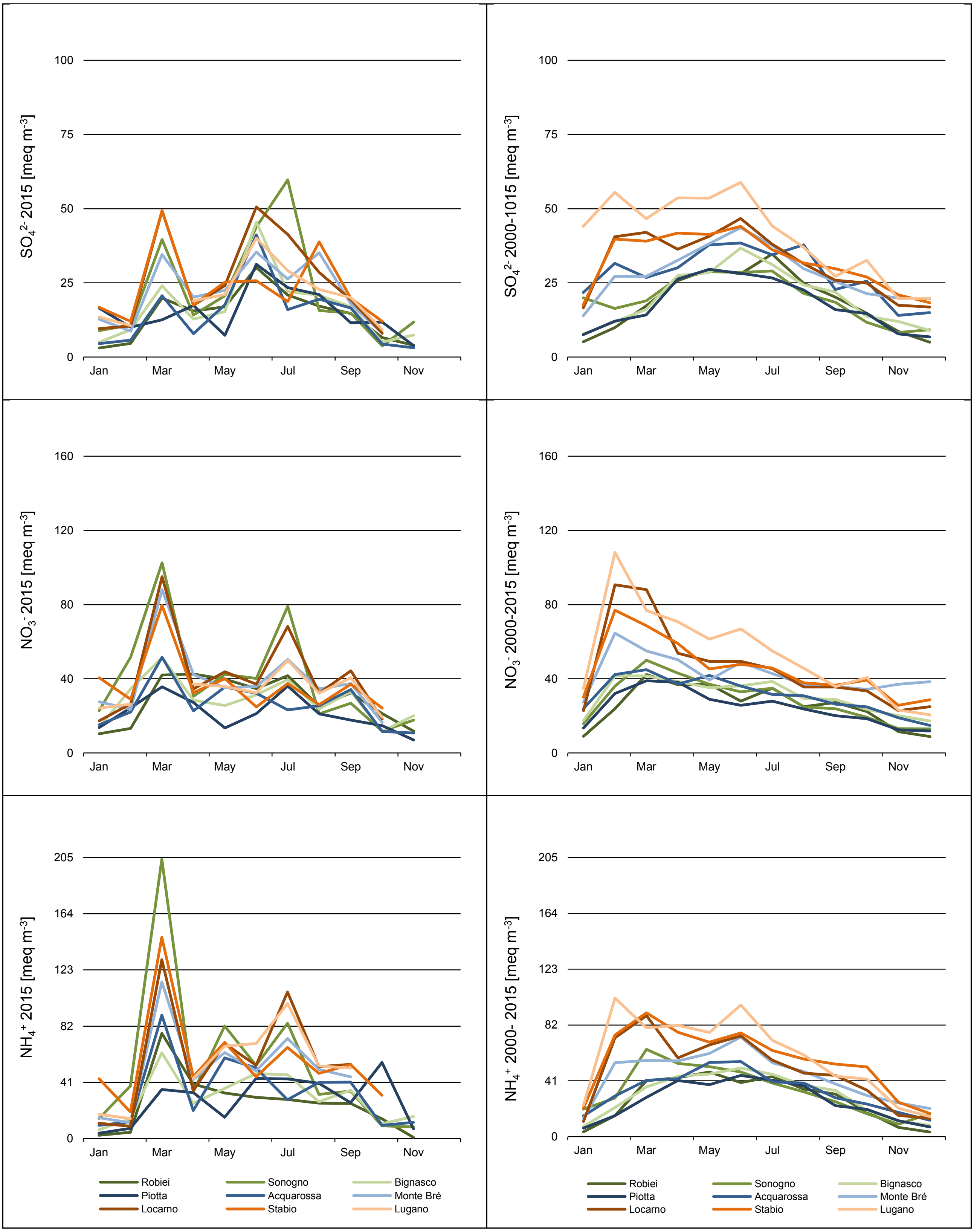
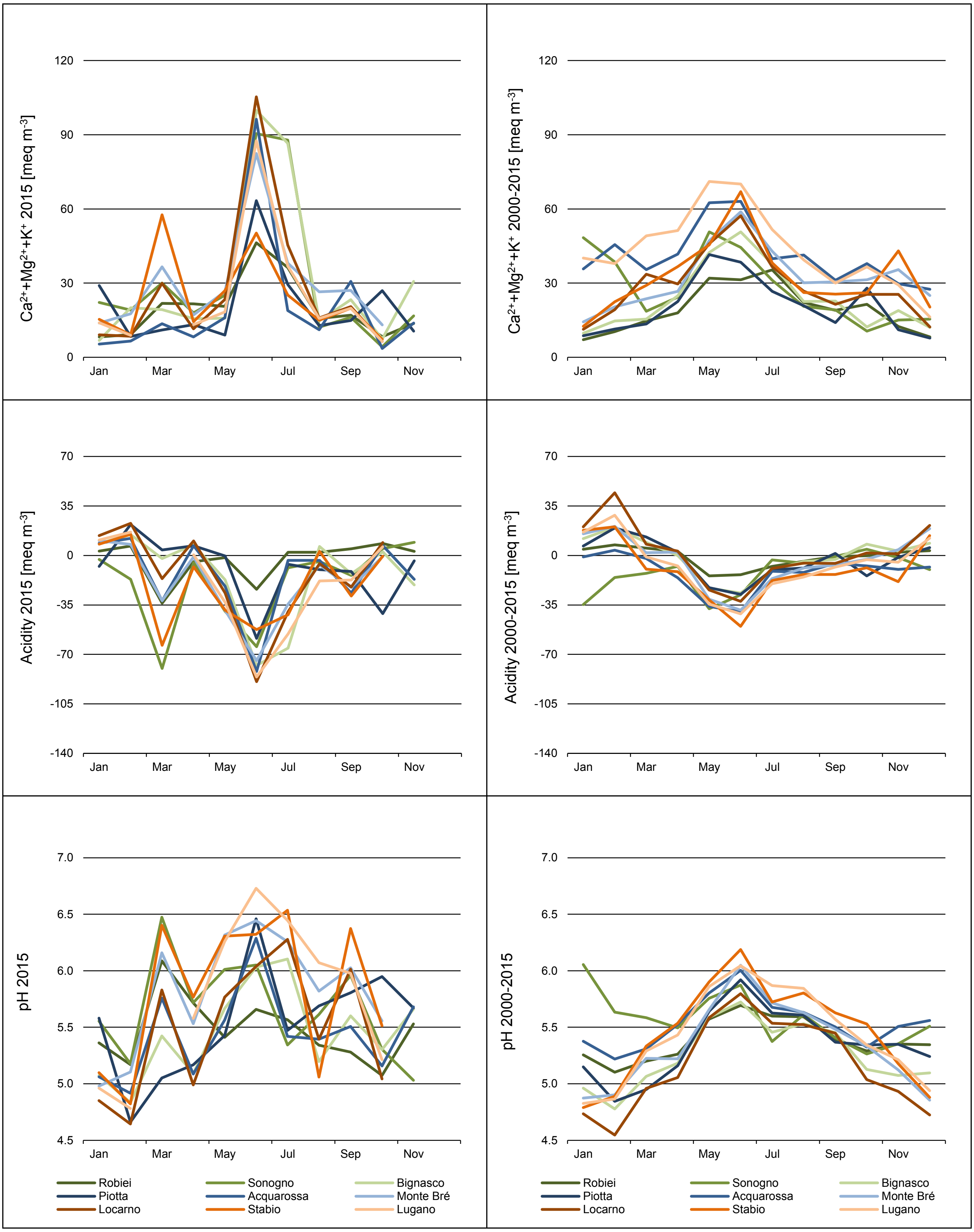


Figure 3.2 Seasonal variations of monthly average rain water concentrations

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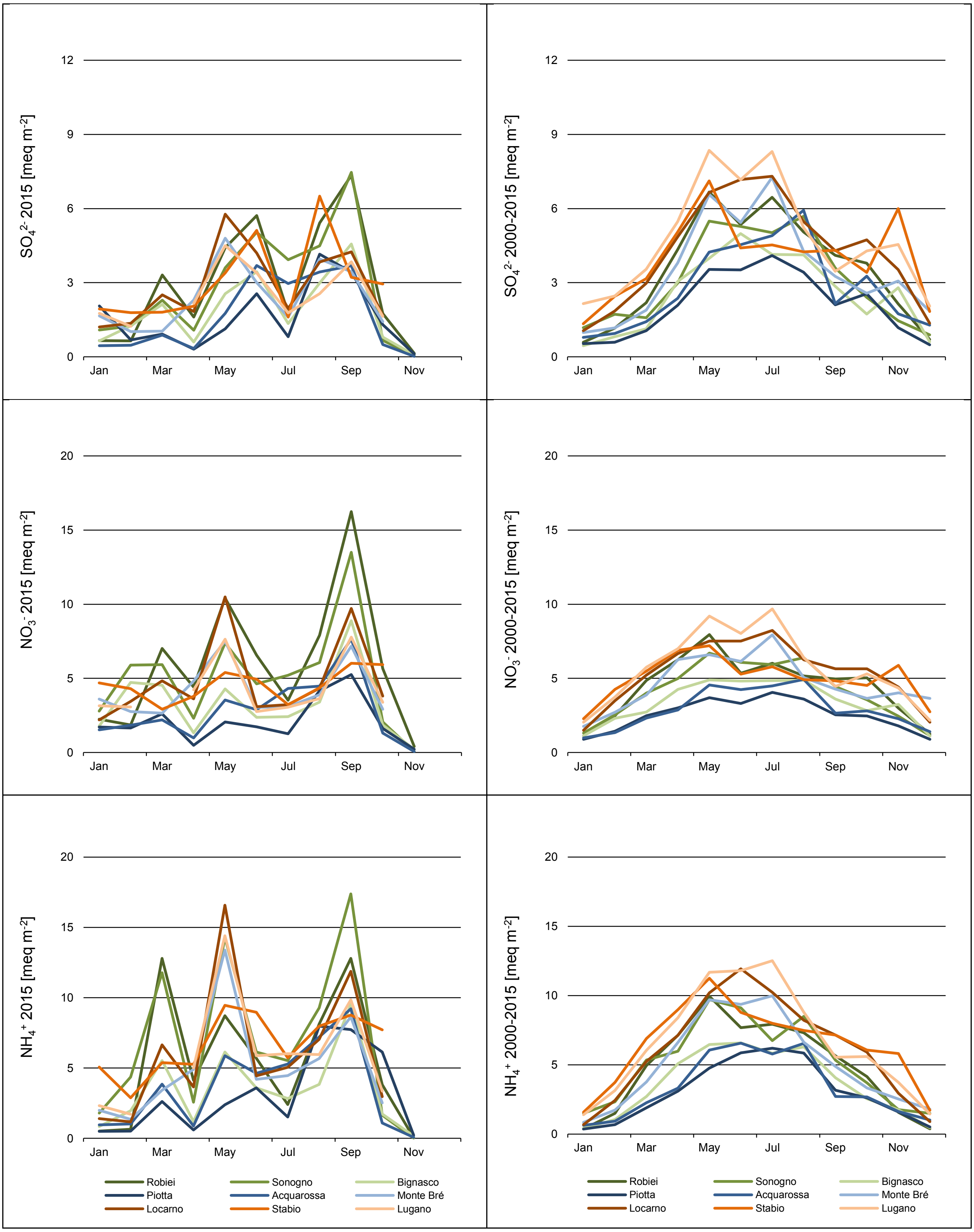
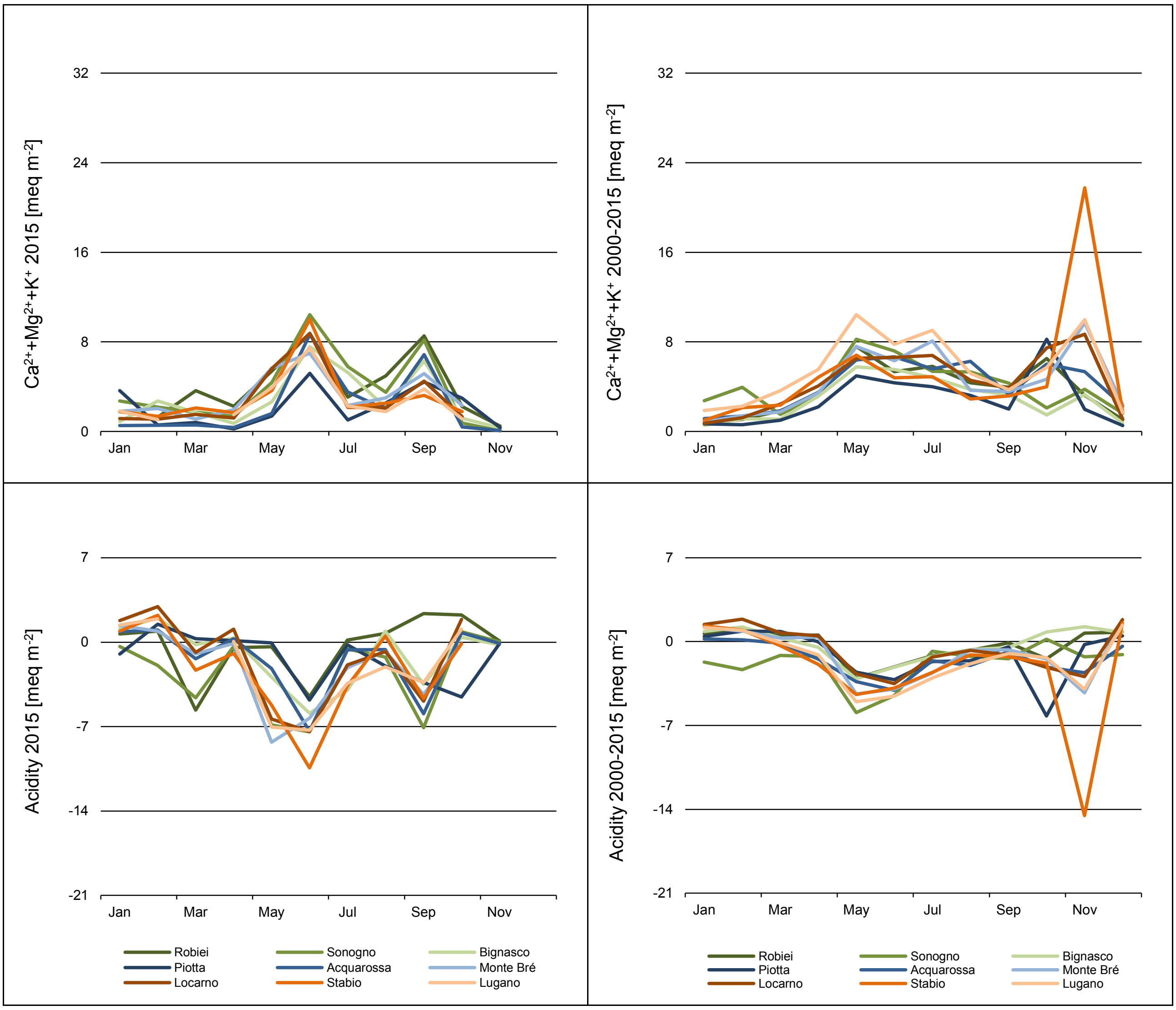
Locarno
Stabio
Lugano

Figure 3.3 Seasonal variations of monthly wet deposition

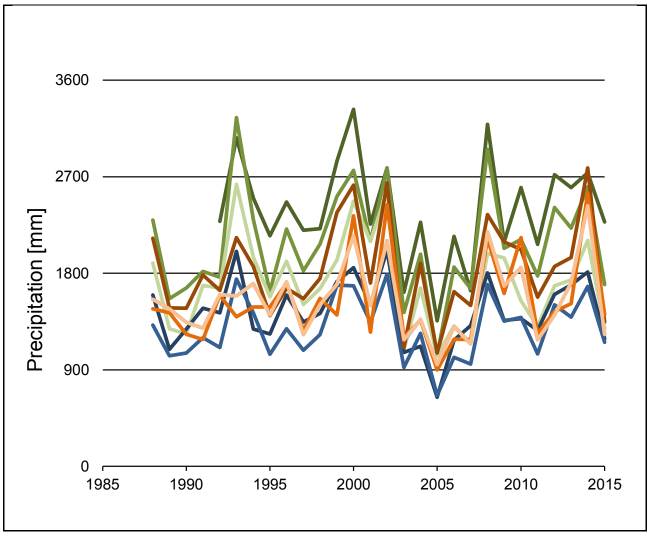



Ca²⁺+Mg²⁺+K⁺ 2015 [meq m⁻²]
Ca²⁺+Mg²⁺+K⁺ 2000-2015 [meq m⁻²]
Acidity 2015 [meq m⁻²]
Acidity 2000-2015 [meq m⁻²]
Jan
Mar
May
Jul
Sep
Nov
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano

Temporal variations

The amount of yearly precipitation at each sampling site is reported in Fig. 3.4, while variations of yearly average rainwater concentrations and deposition rates of the main chemical parameters since 1988 are shown in Fig. 3.5. Compared to MeteoSwiss norm values (1981-2010), precipitations during 2015 were between 5% and 29% lower.

Figure 3.4 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.

Because of decreased NO_x and NH_3 emissions, concentrations and depositions of nitrate and ammonium also slightly decreased.

Compared to the previous year (2014), concentrations of sulphate, nitrate and ammonium were slightly higher because of the lower precipitation amount during 2015.

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 -10 meq/m^3 and -20 meq/m^2 on average over the last 30 years. 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 5.2 and 5.6 today.

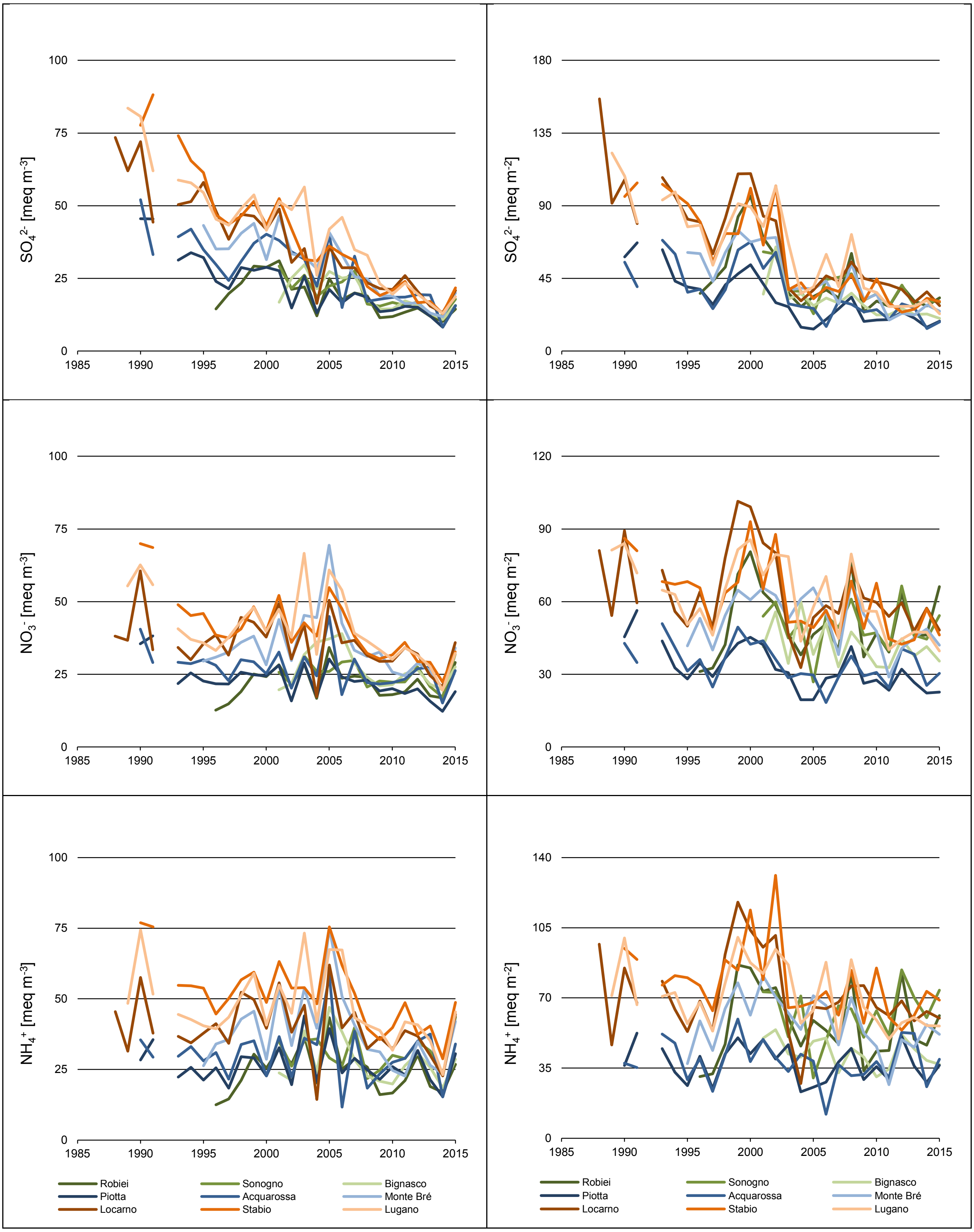
Trends of rainwater concentrations were analyzed for two different time periods: from 1988-1991 until 2000 and from 2000 until 2015. Since trends of depositions are "disturbed" by the precipitation volumes that vary irregularly through time, trends in depositions were calculated only for the entire monitoring period in order to level out as much as possible the influence of rainwater volume. Tab. 3.3 reports variations in concentrations and depositions using the Sen's slope. Red values correspond to significant trends.

Sulphate concentrations decreased at all sites and with exceptions of Acquarossa rates were higher before 2000. Differently, the decrease of nitrate, ammonium and base cations was more pronounced after 2000. In fact, after 2000 at most stations (7 out of 9) concentrations of nitrate decreased significantly, while before a significant decrease could only be observed at Stabio. Similarly, concentrations of ammonium and base cations decreased significantly only after 2000 (at 5 sites for ammonium and at 7 sites for base cations). Because of the decrease in sulphate but also in nitrate concentrations, concentrations of hydrogen ions and total acidity decreased significantly at all sites. This decrease was more pronounced before 2000.

The period after 2010 is too short for a representative time trend analysis, however concentrations of sulphate, nitrate and acidity seem to have decreased further, while concentrations of ammonium, base cations and pH remained stable.

Trends in deposition are similar but less pronounced. The decrease in depositions of sulphate was almost significant at Sonogno (p=0.074) and significant at all other sites. Depositions of nitrate decreased significantly at Acquarossa, Locarno Monti, Piotta, Stabio and almost at Monte Brè (p=0.053). Less significant were trends for ammonium and base cations. Depositions of ammonium decreased significantly only at Locarno Monti and of base cations at Locarno Monti, Piotta and Stabio. Similar to concentrations, depositions of hydrogen ions and total acidity decreased significantly at all sites.

Figure 3.5 Temporal variations of annual mean rainwater concentrations, deposition rates and pH



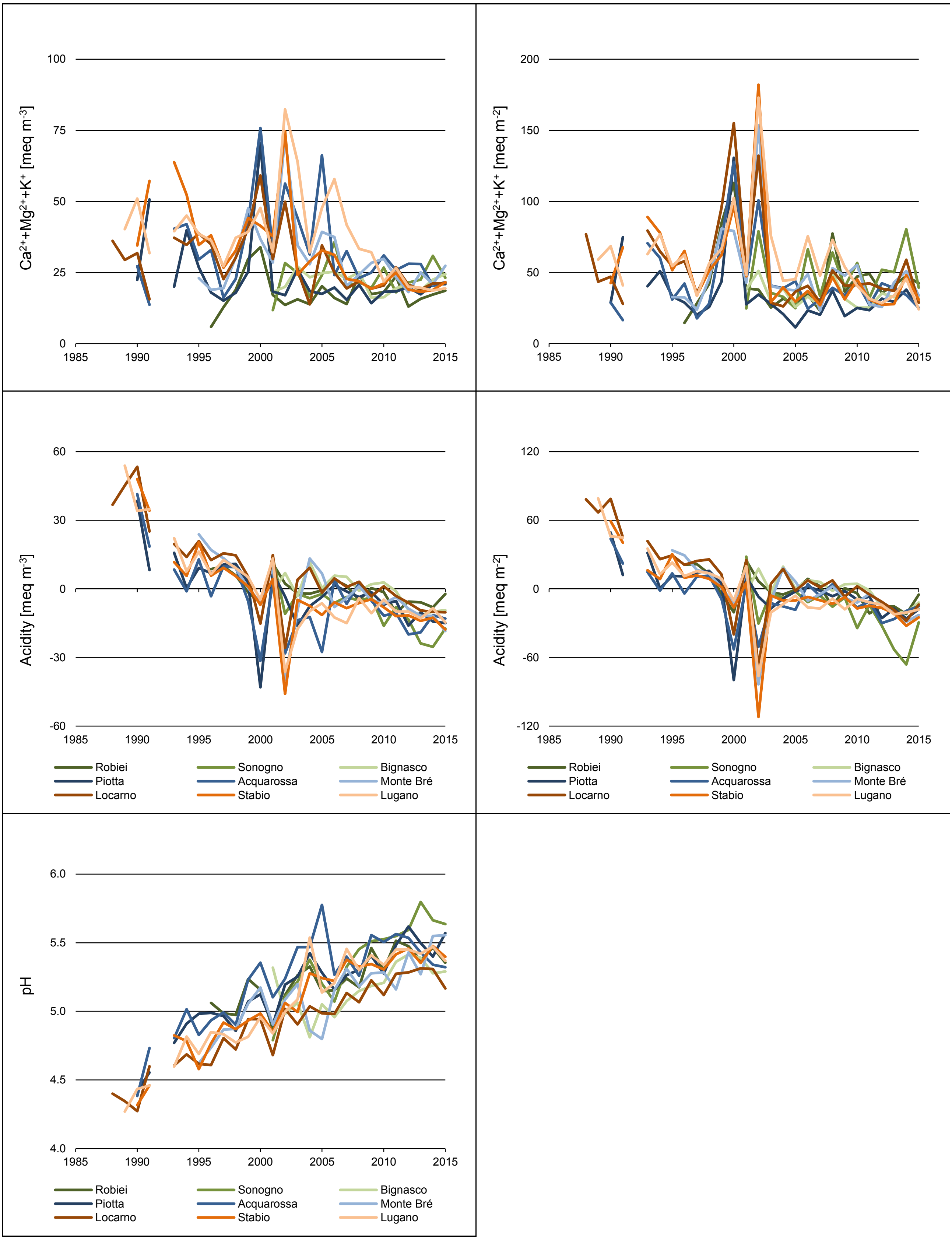

Ca2++Mg2++K+ [meq m-3]
100
75
50
25
0
1985
1990
1995
2000
2005
2010
2015
Ca2++Mg2++K+ [meq m-2]
200
150
100
50
0
Acidity [meq m-3]
60
30
0
-30
-60
Acidity [meq m-2]
120
60
0
-60
-120
pH
6.0
5.5
5.0
4.5
4.0
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano

Table 3.3 Results from trend analyses performed on monthly mean concentrations and depositions during the indicated time periods. Red values of concentrations- and depositions rates indicate significant trends.

CONCENTRATIONS	SO_4^{2-}		NO_3^-		NH_4^+		Base cations		H^+		Total acidity	
(meq m^{-3} yr^{-1})	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate
	'80/'90-00	'00-15	'90-00	'00-15	'90-00	'00-15	'90-00	'00-15	'90-00	'00-15	'90-00	'00-15
Acquarossa	-1.41	-1.60	-1.04	-0.51	-1.04	-0.37	0.46	-1.93	-2.29	-0.02	-4.53	-0.09
Bignasco		-0.93		-0.58		-0.31		-0.19		-0.55		-1.21
Monte Brè		-1.33		-0.75		-0.54		-0.54		-0.45		-1.61
Locarno Monti	-3.20	-1.65	-0.78	-1.22	-0.54	-0.98	0.07	-0.63	-3.48	-0.63	-4.38	-1.31
Lugano	-2.79	-2.63	-1.22	-1.70	-0.10	-1.43	0.08	-1.92	-2.85	-0.26	-4.28	-1.07
Piotta	-1.43	-0.76	-0.62	-0.60	-0.11	-0.43	-0.88	-0.40	-1.63	-0.30	-2.14	-0.60
Robiei		-0.87		-0.27		-0.53		-0.24		-0.30		-0.56
Sonogno		-0.63		-0.30		0.03		0.06		-0.31		-1.40
Stabio	-3.44	-2.00	-2.08	-1.21	-0.85	-1.21	-2.16	-0.84	-2.65	-0.27	-3.83	-1.34

DEPOSITIONS	SO_4^{2-}	NO_3^-	NH_4^+	Base cations	H^+	Total acidity
(meq m^{-2} yr^{-1})	rate	rate	rate	rate	rate	rate
	beginning-15	beginning-15	beginning-15	beginning-15	beginning-15	beginning-15
Acquarossa	-1.22	-0.54	-0.22	-0.26	-0.54	-1.18
Bignasco	-0.75	-0.31	-0.07	0.00	-0.46	-1.28
Monte Brè	-1.60	-0.66	-0.35	-0.13	-0.87	-1.89
Locarno Monti	-2.62	-0.84	-0.47	-0.45	-1.79	-2.75
Lugano	-2.46	-0.45	-0.07	-0.39	-1.28	-2.57
Piotta	-0.77	-0.42	-0.12	-0.29	-0.58	-1.08
Robiei	-1.26	-0.15	-0.33	0.05	-0.59	-1.28
Sonogno	-0.76	-0.12	0.25	0.63	-0.46	-2.38
Stabio	-2.80	-1.12	-0.50	-0.91	-0.15	-2.25

3.6.2 Alpine lakes

Spatial variations

During 2015 sampling of Alpine lakes occurred at the following days: 13.7, 7.9, 5.10. Yearly mean autumn concentrations of the main chemical parameters measured in lake surface water are presented in Tab. 3.4.

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 25 µS cm^{-1}, alkalinity between 0 and 81 meq m^{-3}, pH between 5.4 and 7.1, sulphate between 12 and 153 meq m^{-3}, nitrate between 4 and 20 meq m^{-3}, dissolved organic carbon between 0.5 and 1.2 mg C l^{-1}, reactive dissolved silica between 0.9 and 2.7 mg SiO_2 l^{-1} and dissolved aluminium between 3 and 62 µg l^{-1}.

Table 3.4 Average lake surface water concentrations during autumn 2015 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 ($\mu S\ cm^{-1}$)	7.8	7.4	22.1	8.4	7.6	24.8	13.8	18.7	8.4	8.2	16	68.7	12.3	13	6.8	8.9	10.2	7.8	9.3	8.1	14.8
pH	5.7	5.8	6.9	6.3	5.4	6.4	6.7	6.8	6.7	6.6	6.9	7.6	6.8	7.1	6.5	6.6	6.6	6.5	6.6	6.1	6.9
Alkalinity (meq m^{-3})	7	6	69	17	0	28	42	56	36	38	70	482	55	79	26	37	41	35	39	17	81
Ca^{2+} (meq m^{-3})	22	30	132	42	21	116	59	87	40	40	89	559	76	77	33	47	54	36	45	29	76
Mg^{2+} (meq m^{-3})	8	4	13	5	8	44	14	23	6	6	13	64	7	5	4	5	7	7	8	8	15
Na^{+} (meq m^{-3})	11	11	20	10	7	21	13	23	11	11	15	15	11	19	10	12	12	13	16	11	19
K^{+} (meq m^{-3})	4	3	12	4	6	15	11	13	9	7	11	20	6	7	4	4	6	4	3	7	11
NH_4^{+} (meq m^{-3})	2.6	0.3	0.4	0.4	1.5	1.6	0.6	0.6	0.3	0.4	0.7	0.4	0.3	0.3	0.6	0.5	0.3	0.7	0.4	0.6	1.1
SO_4^{2-} (meq m^{-3})	19	23	98	33	34	153	60	80	21	19	60	184	36	17	12	15	21	17	23	21	31
NO_3^{-} (meq m^{-3})	20	19	15	14	11	10	10	15	10	9	8	7	10	17	14	20	21	8	12	20	16
Cl^{-} (meq m^{-3})	4	3	3	2	2	4	2	3	2	2	2	3	2	2	2	2	2	3	3	2	3
SRP (μg P l^{-1})	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9
DOC (mg C l^{-1})	1.2	0.6	0.5	0.5	0.4	0.6	0.6	0.6	0.7	0.9	0.5	0.6	0.5	0.5	0.7	0.7	0.7	1.0	0.7	0.7	0.7
SiO_2 (mg l^{-1})	1.6	1.6	2.7	1.3	0.9	1.9	1.7	2.7	1.3	1.2	1.4	1.6	1.3	2.5	1.4	1.6	1.8	2.0	2.0	1.8	2.6
$Al_{dissolved}$ ($\mu g\ l^{-1}$)	62	20	3	4	31	10	7	6	7	8	3	8	6	6	3	6	8	20	16	23	9
Al_{tot} ($\mu g\ l^{-1}$)	70	25	5	8	36	45	33	20	14	16	7	15	11	9	7	14	12	27	26	31	15
$Cu_{dissolved}$ ($\mu g\ l^{-1}$)	0.25	0.13	0.15	0.08	0.26	0.39	0.35	0.31	0.11	0.20	0.14	0.18	0.12	<0.03	<0.03	0.05	0.08	0.09	0.06	0.16	0.10
Cu_{tot} ($\mu g\ l^{-1}$)	0.25	0.14	0.17	0.09	0.26	0.65	0.42	0.37	0.13	0.17	0.15	0.18	0.13	0.05	<0.04	0.05	0.08	0.09	0.07	0.17	0.11
$Zn_{dissolved}$ ($\mu g\ l^{-1}$)	3.03	1.29	0.53	0.86	1.66	2.76	2.30	1.03	0.71	9.15	0.98	0.72	0.97	0.55	0.61	0.56	0.71	0.94	1.18	1.37	1.15
Zn_{total} ($\mu g\ l^{-1}$)	*3.35*	1.44	0.68	0.85	1.72	3.10	2.46	1.09	0.86	9.56	1.09	0.99	1.01	0.58	0.67	0.60	0.74	0.96	1.23	1.43	1.17

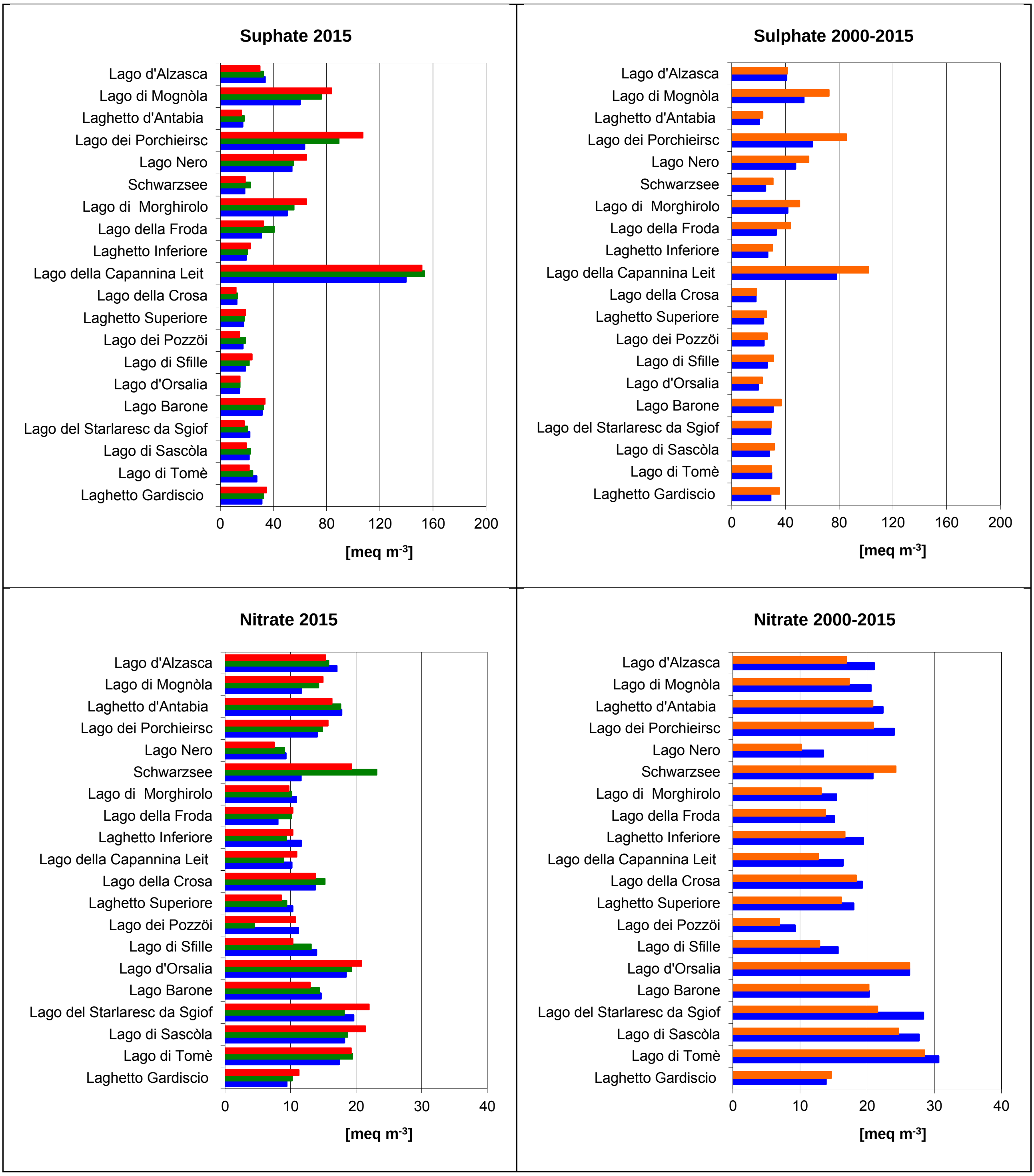
In order to better compare chemistry of lakes with low alkalinities, values of the main parameters measured during 2015 and their mean values from 2000 to 2015 are shown graphically in Fig. 3.6.

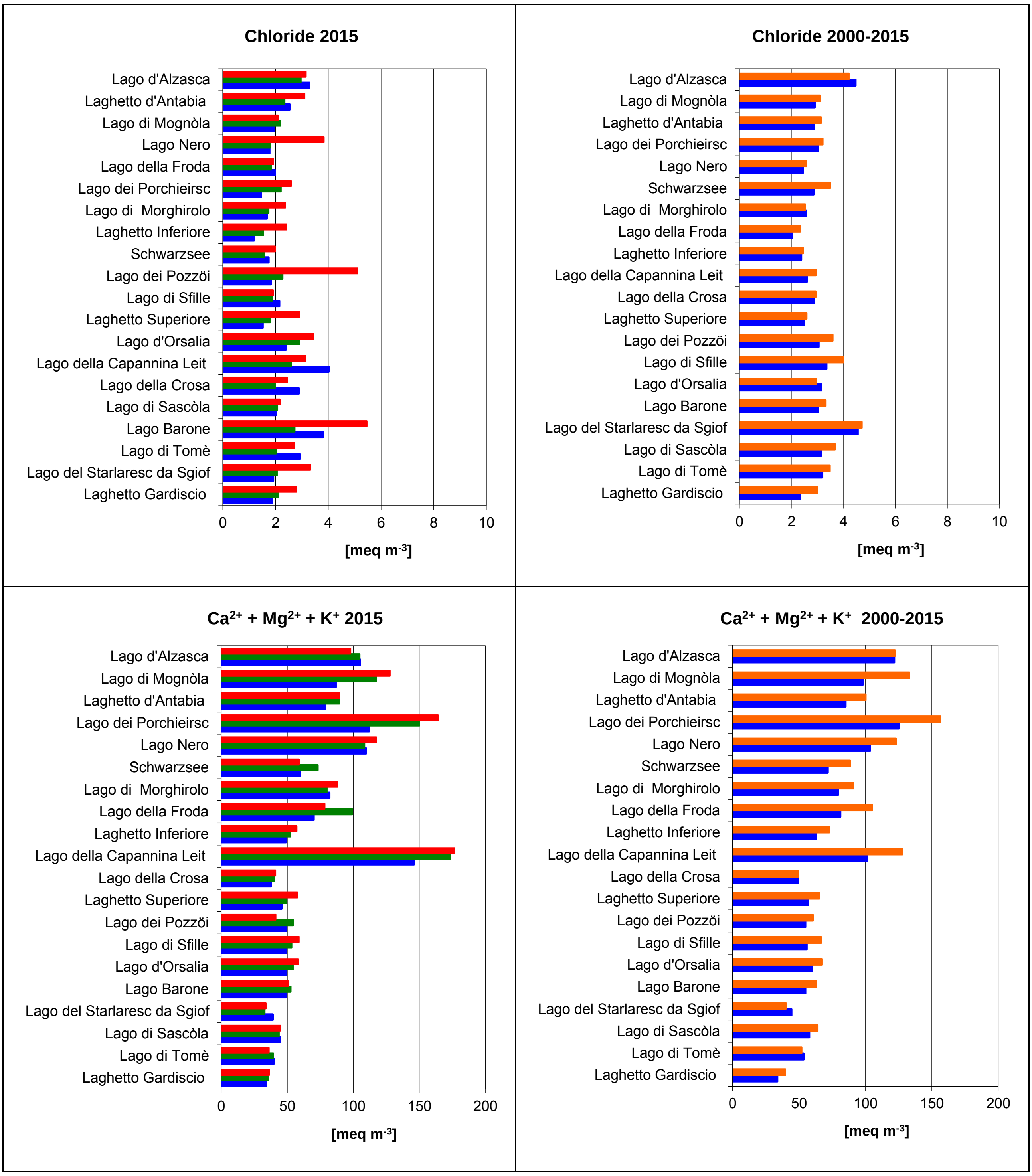
In general, values from 2015 were not much different from those of the period 2000-2015, but concentrations of sulphate, nitrate, chloride and base cations were in general slightly lower. During 2015 alkalinities below 0 meq m^{-3} were detected in July and September in Laghetto Gardiscio, while alkalinities constantly above 50 meq m^{-3} were measured only in Lago Nero, 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. Relatively, high concentrations of aluminium were mainly measured in Lago del Starlaresc da Sgiof, and Laghetto Gardiscio where concentrations ranged from 26 to 68 $\mu g\ l^{-1}$. 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). 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, …).

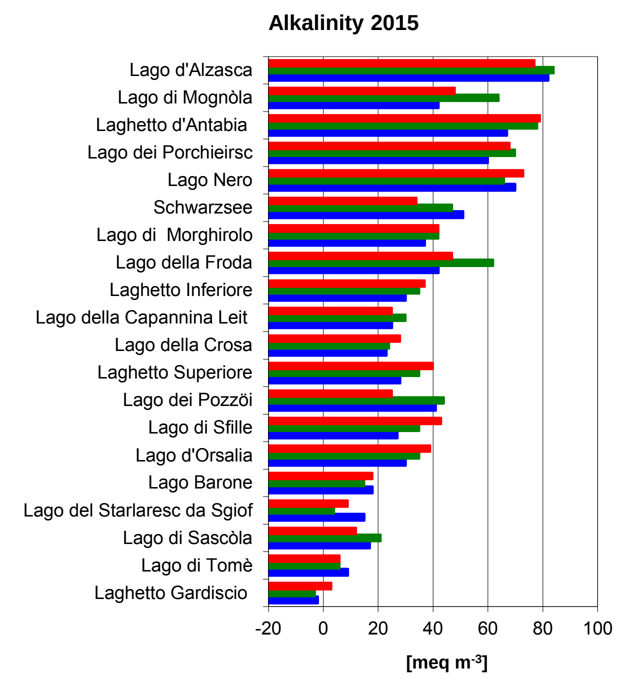
Seasonal variations

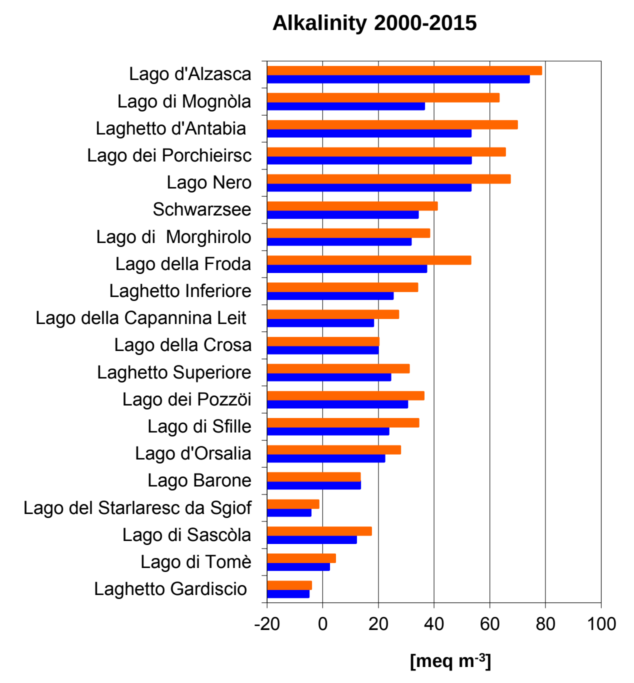
Fig. 3.6 also shows some seasonal differences. In most lakes alkalinity and pH and concentrations of sulphate and base cations tend to be lower in July than in September and October. The reason is the elevated discharge in spring that causes a dilution of sulphate, base cations and a combination of dilution and consumption of alkalinity. However, because of the last year warm spring/summer, the July samples were not greatly influenced by ice melt anymore and only in 9 lakes concentrations were lower than in autumn. 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. Nevertheless, as discussed for the other parameters, also for nitrate the effect of snow melt was not evident anymore in most samples. In fact, concentrations of only 9 lakes were higher in spring compared to autumn.

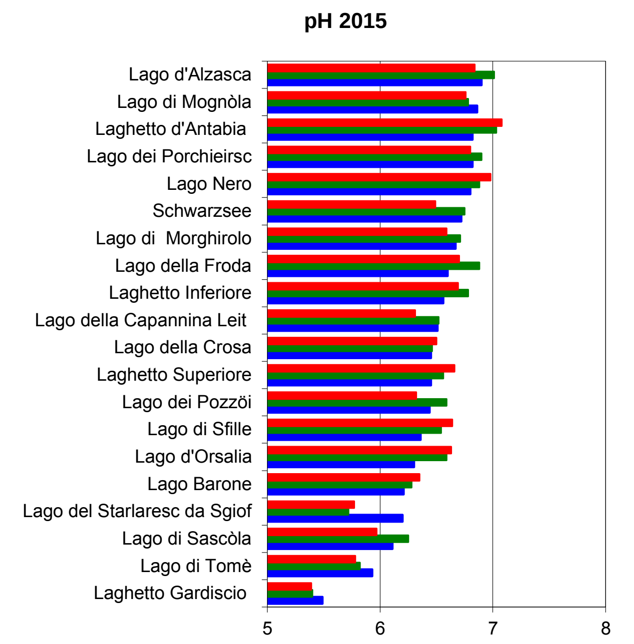
Figure 3.6 Concentrations of the main chemical parameters in 20 Alpine lakes during 2015 and their average values from 2000 to 2015. Blue columns represent summer, green early autumn, red late autumn and orange mean autumn values.

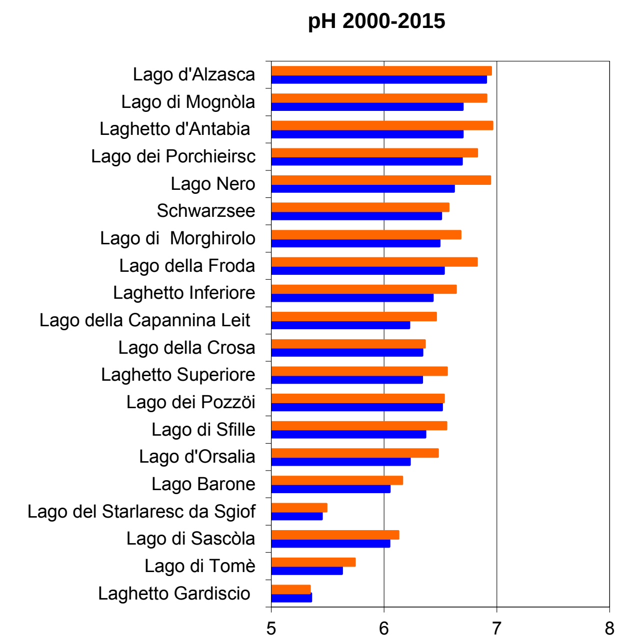


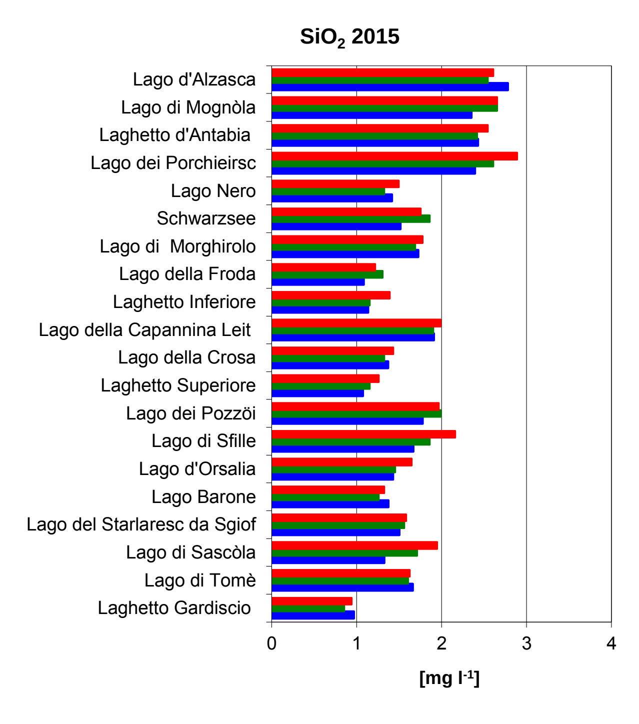

Chloride 2015
Lago d'Alzasca
Laghetto d'Antabia
Lago di Mognòla
Lago Nero
Lago della Froda
Lago dei Porchieirsc
Lago di Morghirolo
Laghetto Inferiore
Schwarzsee
Lago dei Pozzöi
Lago di Sfille
Laghetto Superiore
Lago d'Orsalia
Lago della Capannina Leit
Lago della Crosa
Lago di Sascòla
Lago Barone
Lago di Tomè
Lago del Starlaresc da Sgiof
Laghetto Gardiscio
0 2 4 6 8 10
[meq m-3]
Chloride 2000-2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0 2 4 6 8 10
[meq m-3]
Ca2+ + Mg2+ + K+ 2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0 50 100 150 200
[meq m-3]
Ca2+ + Mg2+ + K+ 2000-2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0 50 100 150 200
[meq m-3]

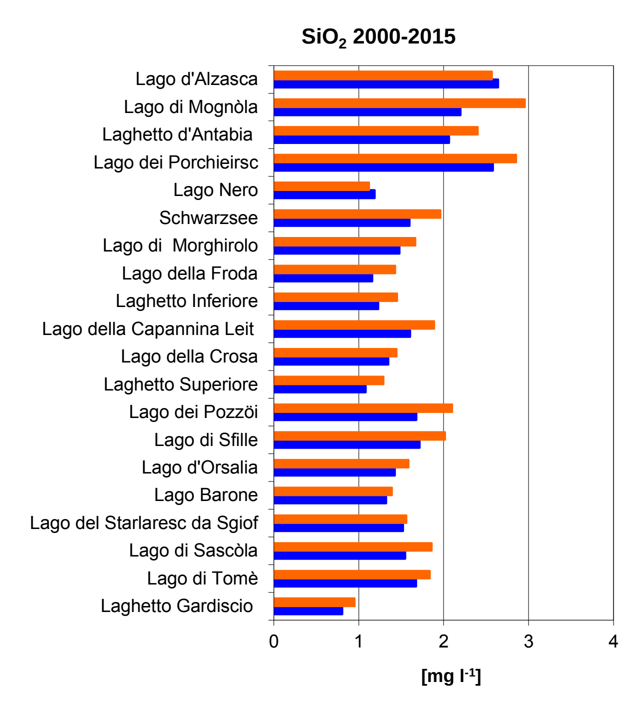

Alkalinity 2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
-20 0 20 40 60 80 100
[meq m-3]


Alkalinity 2000-2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
-20 0 20 40 60 80 100
[meq m-3]


pH 2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
5 6 7 8


pH 2000-2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
5 6 7 8


SiO$_2$ 2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0
1
2
3
4
[mg l-1]


SiO$_2$ 2000-2015
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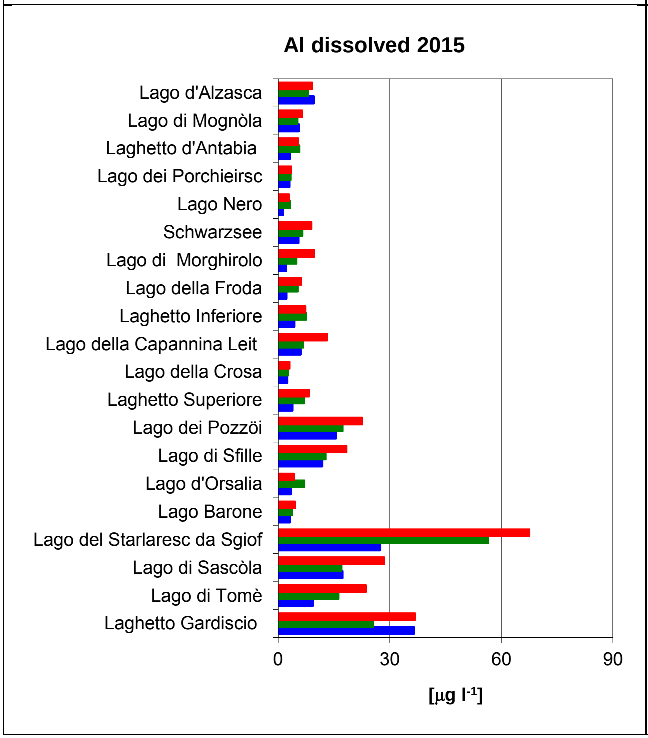
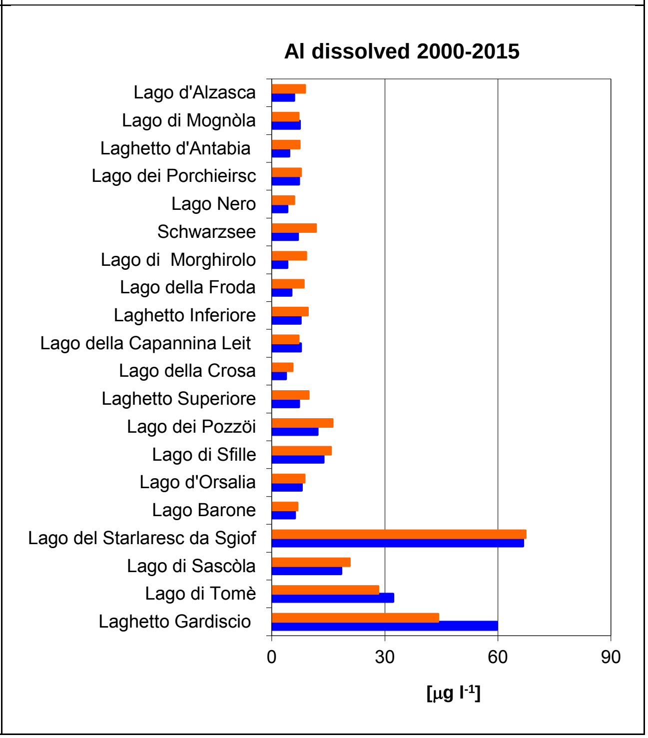
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0
1
2
3
4
[mg l-1]


Al dissolved 2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0
30
60
90
[µg l-1]


Al dissolved 2000-2015
Lago d'Alzasca
Lago di Mognòla
Laghetto d'Antabia
Lago dei Porchieirsc
Lago Nero
Schwarzsee
Lago di Morghirolo
Lago della Froda
Laghetto Inferiore
Lago della Capannina Leit
Lago della Crosa
Laghetto Superiore
Lago dei Pozzöi
Lago di Sfille
Lago d'Orsalia
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Sascòla
Lago di Tomè
Laghetto Gardiscio
0
30
60
90
[µg l-1]

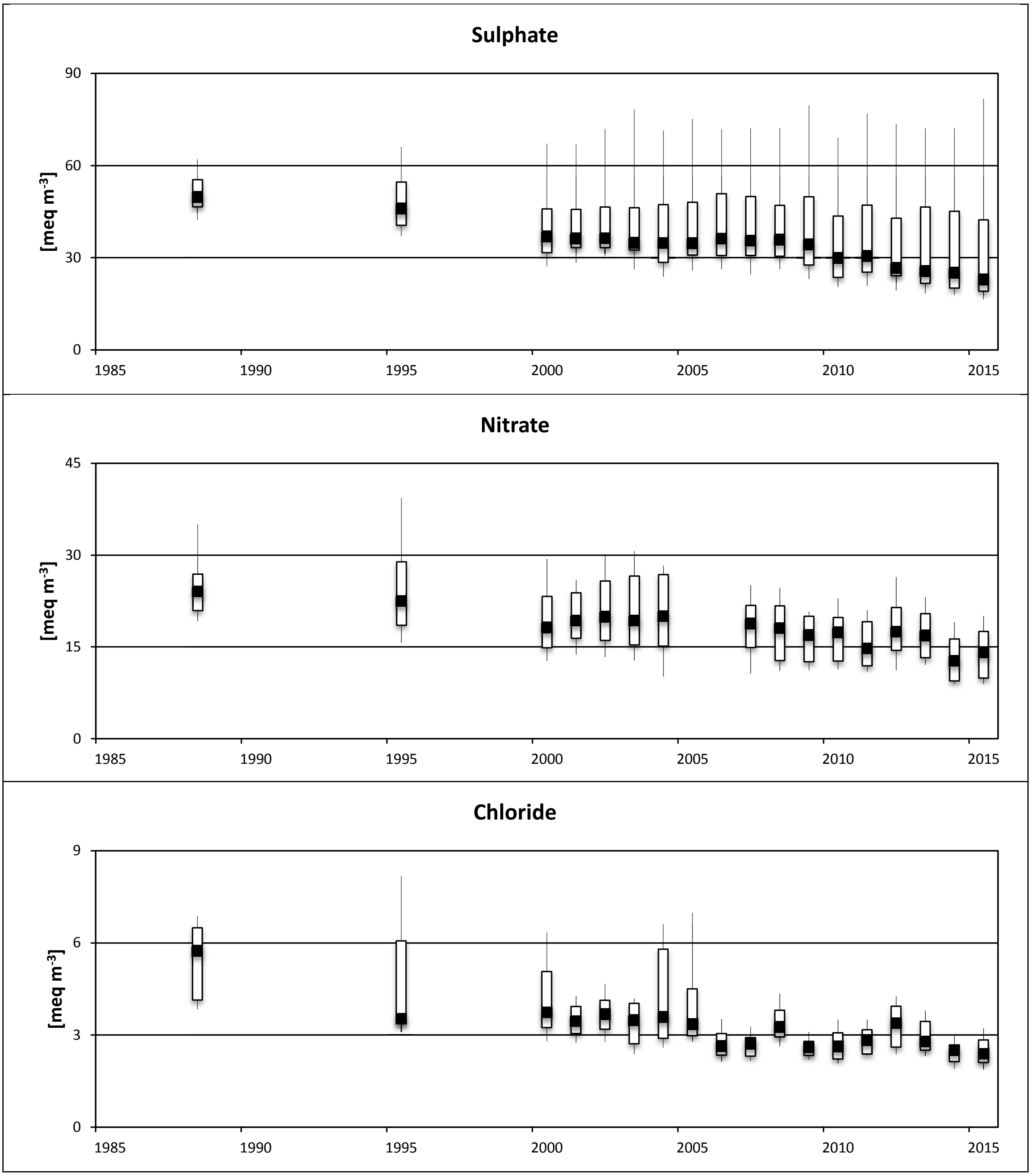
Temporal variations

In order to show temporal variations of lake quality, autumn 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. 3.7. 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. 3.8 (see also trends in Tab. 3.5). 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}. Concentrations of aluminium in Laghetto Gardiscio seems to have slightly decreased only during the last years. 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, the very small catchment (12 ha), the steep catchment slope and the resulting short residence time that inhibits buffering of rainwater may explain the low pH.

Results of a detailed trend analysis of the main parameters are presented in Tab. 3.5. Trends were calculated for the entire monitoring period and after 2000, when sampling occurred more regularly and frequently. Thanks to decreasing sulphate and nitrate depositions, since the 1980s concentrations of sulphate and nitrate decreased significantly in 15 and 16 lakes, respectively. In other 2 lakes concentrations of nitrate decreased almost significantly (Lago di Tomè with p=0.051 and Lago d'Orsalìa with p=0.063). While for sulphate the calculated concentration rates were similar for the two analyzed time periods, concentration rates of nitrate were higher after 2000, indicating a more pronounced decrease more recently. The decrease in anthropogenic sulphate and nitrate also caused decreasing concentrations of hydrogen ions that were significant in 16 lakes and almost significant in other 2 lakes (Lago dei Porchieirsc and Lago di Morghirolo) and increasing concentrations of total alkalinity (significant in 15 lakes). A significant decrease in dissolved aluminium could only be detected in Lago del Starlaresc da Sgiof and Lago di Tomè.

Interestingly, differently to most lakes, concentrations of sulphate increased significantly in 3 lakes (Lago della Capannina Leit, Lago di Morghirolo and Lago di Mognòla). For Lago Leit and Lago Morghirolo this increase is higher after 2000 and for Lago Leit even more pronounced after 2005 (9.5 meq m^{-3} yr^{-1}, data not shown). 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).

Figure 3.7 Temporal variations of annual median values and their 10th, 25th, 75th, 90th percentiles of parameters measured in 20 Alpine lakes from 1988 to 2015 (calculated from autumn mean values).



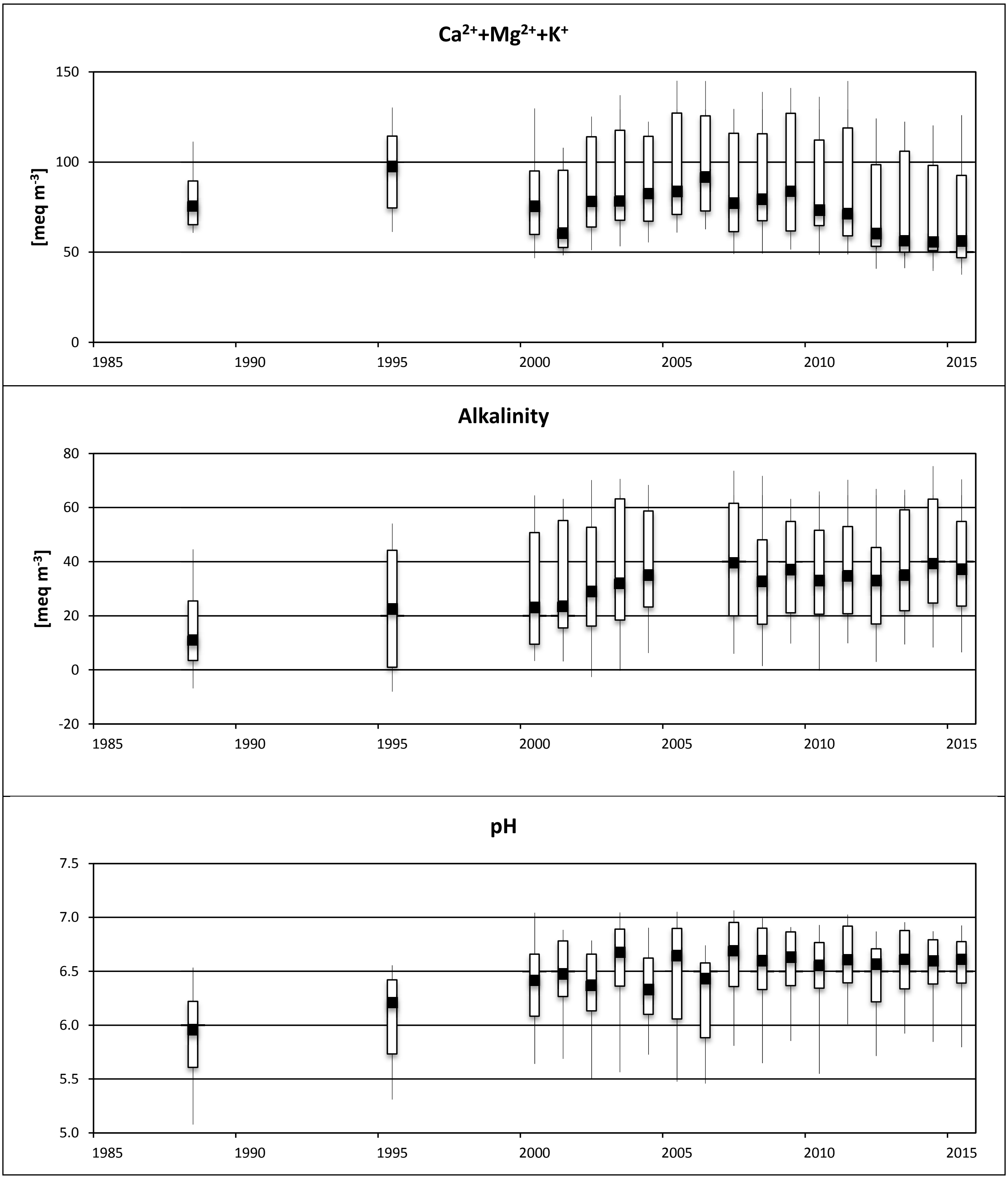

$Ca^{2+}+Mg^{2+}+K^{+}$
[meq m-3]
150
100
50
0
1985
1990
1995
2000
2005
2010
2015
Alkalinity
[meq m-3]
80
60
40
20
0
-20
1985
1990
1995
2000
2005
2010
2015
pH
7.5
7.0
6.5
6.0
5.5
5.0
1985
1990
1995
2000
2005
2010
2015

Figure 3.8 Temporal variations of dissolved aluminium in the 3 most acidic lakes from 1988 to 2015 (mean autumn values).

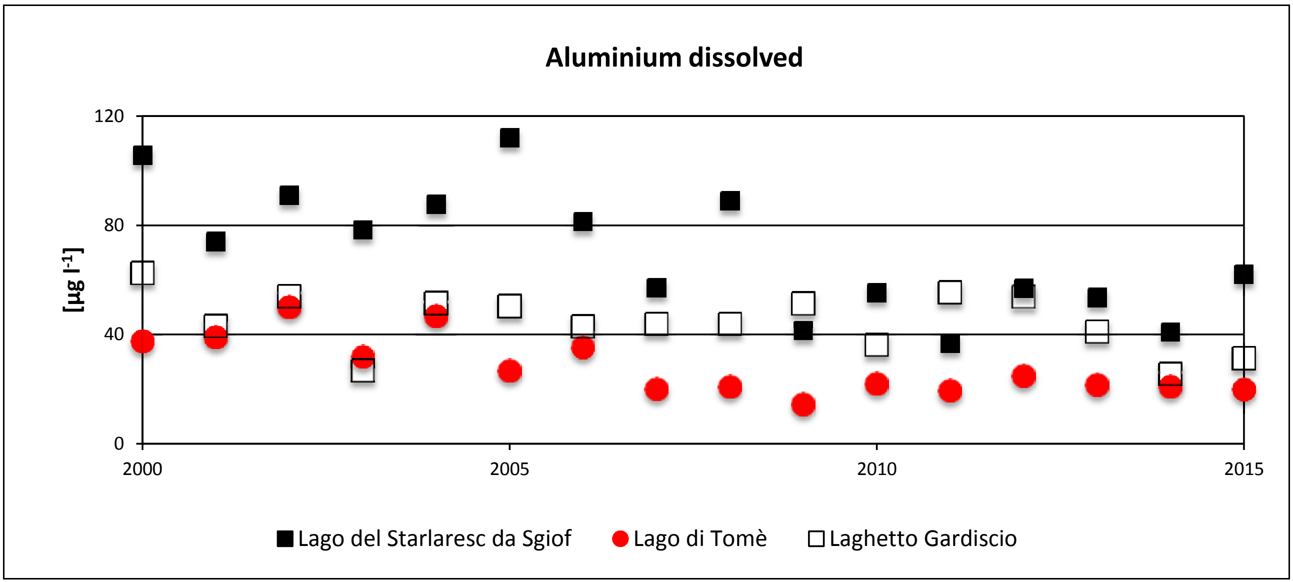


Table 3.5 Results from trend analyses during the indicated time periods. Red values of concentration rates indicate significant trends.

Lake	SO_4^{2-}		NO_3^-		Base cations		H^+		Total alkalinity		Al_{dis}	
	rate '80-15	rate 00-15	rate '80-15	rate 00-15	rate '80-15	rate 00-15	rate '80-15	rate 00-15	rate '80-15	rate 00-15	rate '80-15	rate 00-15
Lago del Starlaresc da Sgiof	-1.34	-1.28	-0.50	-0.75	-0.92	-1.07	-0.48	-0.35	0.00	0.23		-3.63
Lago di Tomè	-0.93	-0.83	-0.41	-1.00	-1.15	1.60	-0.07	-0.01	0.18	0.14		-1.41
Lago dei Porchieirsc	0.42	0.10	-0.41	-0.50	-0.21	-1.42	-0.01	0.00	0.57	0.25		
Lago Barone	-0.46	-0.40	-0.25	-0.50	-0.41	-0.65	-0.04	-0.02	0.52	0.50		
Laghetto Gardiscio	-0.20	0.17	-0.20	-0.29	-0.31	0.00	-0.10	-0.06	0.00	0.00		-0.96
Lago Leit	2.68	4.58	-0.25	-0.32	2.44	4.13	-0.01	0.00	0.47	0.25		
Lago di Morghirolo	0.29	0.66	-0.17	-0.25	0.57	-0.11	-0.00	0.00	0.73	0.61		
Lago di Mognòla	0.36	0.25	-0.17	-0.19	0.33	-0.71	0.00	0.00	-0.25	-0.67		
Laghetto Inferiore	-0.93	-0.96	-0.35	-0.63	-1.00	-1.55	-0.01	-0.00	0.38	0.46		
Laghetto Superiore	-0.87	-0.86	-0.38	-0.75	-0.40	-0.83	-0.01	-0.01	0.89	0.95		
Lago Nero	0.03	0.22	-0.11	-0.17	0.19	-0.50	-0.00	0.00	0.66	0.50		
Lago della Froda	-0.34	-0.33	-0.28	-0.33	0.17	-0.18	-0.01	0.00	0.66	0.28		
Lago d'Antabia	-0.73	-0.75	-0.30	-0.55	-0.30	-1.75	-0.00	0.00	0.57	0.50		
Lago della Crosa	-0.83	-0.80	-0.13	-0.28	-0.47	-1.00	-0.02	-0.01	0.64	0.56		
Lago d'Orsalia	-0.94	-0.92	-0.22	-0.65	-0.15	-1.18	-0.04	-0.01	0.96	0.83		
Schwarzsee	-1.11	-1.19	-0.30	-0.36	-1.29	-2.31	-0.01	0.00	0.48	-0.25		
Laghi dei Pozzöi	-1.09	-1.00	-0.18	-0.17	-0.84	-1.50	-0.00	0.00	0.32	0.21		
Lago di Sfille	-0.94	-0.89	-0.24	-0.29	-0.81	-1.00	-0.01	-0.00	0.69	0.69		-0.64
Lago di Sascòla	-1.00	-1.00	-0.21	-0.65	-1.18	-2.05	-0.02	0.00	0.38	0.27		-0.86
Lago d'Alzasca	-0.96	-1.00	-0.06	-0.13	-0.21	-1.71	-0.00	0.00	0.90	0.75		-0.21

3.6.3 Alpine rivers

Spatial variations

During 2015 river water was sampled at the following days: 19.1, 2.2, 16.3, 20.4, 18.5, 15.6, 20.7, 17.8, 14.9, 12.10, 9.11, 9.12. Annual mean concentrations of the chemical parameters measured in river Maggia, Vedeggio and Verzasca during 2015 are shown in Tab. 3.6. 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 concentrations of nitrate were measured in river Vedeggio followed by river Verzasca and Maggia. Differences in average rainwater nitrogen concentrations together with different nitrogen retention capacities of the watersheds, might be the reason. In fact, during 2008-2012 average nitrogen rainwater concentrations in the watershed of river Vedeggio, Verzasca and Maggia were 61, 41 and 37 meq m^{-3}, respectively and highest nitrogen retention during the same time period occurred in the larger river Maggia (36%) followed by river Vedeggio (31%) and Verzasca (29%).

During 2015 average alkalinity was 278 meq m^{-3} in river Maggia, 169 meq m^{-3} in river Vedeggio and 69 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 7.4 in river Maggia, 7.1 in river Vedeggio and 6.8 in river Verzasca. Their minimum pH's were not much lower (Maggia: 6.9, Vedeggio: 7.0, Verzasca: 6.6).

Table 3.6 Average concentrations in river water during 2015. 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	7.4	55	278	319	44	68	34	0.6	158	27	28	<3.9	0.9	4.8	19.8	25.0	0.4	0.4	2.8	3.4
Vedeggio	7.1	41	169	200	67	68	13	0.5	108	51	23	<2.3	1.0	7.2	12.3	21.9	0.5	0.5	1.5	1.6
Verzasca	6.8	21	69	103	15	31	14	0.5	60	34	11	<2.3	0.7	3.9	17.7	24.6	0.3	0.3	1.3	1.5

Seasonal variations

Fig. 3.9 shows the daily mean discharges during 2015. After the typical low values during winter, because of frequent precipitations, discharges were elevated in May/June and again in September/October.

Concentrations of the main chemical parameters in river water during sampling days in 2015 and their average values during 2000-2015 are shown in Fig. 3.10. Concentrations during 2015 were in general in the same range as average values measured during 2000-2015. Only nitrate and base cations were slightly lower.

During 2000-2015 the seasonality was characterized by concentrations of sulphate, base cations, alkalinity, SiO_2 and pH that 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 2000-2015 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.

Similarly behaved the seasonality of the measured parameters during 2015. Only in September, that was characterized by higher rainfalls than average, concentrations of sulphate, base cations, chloride and SiO_2 were lower and concentrations of aluminium peaked during this month.

Figure 3.9 Daily mean discharge during 2015. Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2016). Discharge of river Verzasca at Sonogno was estimated by discharge values of Verzasca at Lavertezzo by BWG (2001-2004) and BAFU (2005-2016) and discharge of river Maggia at Brontallo was measured by OFIMA.

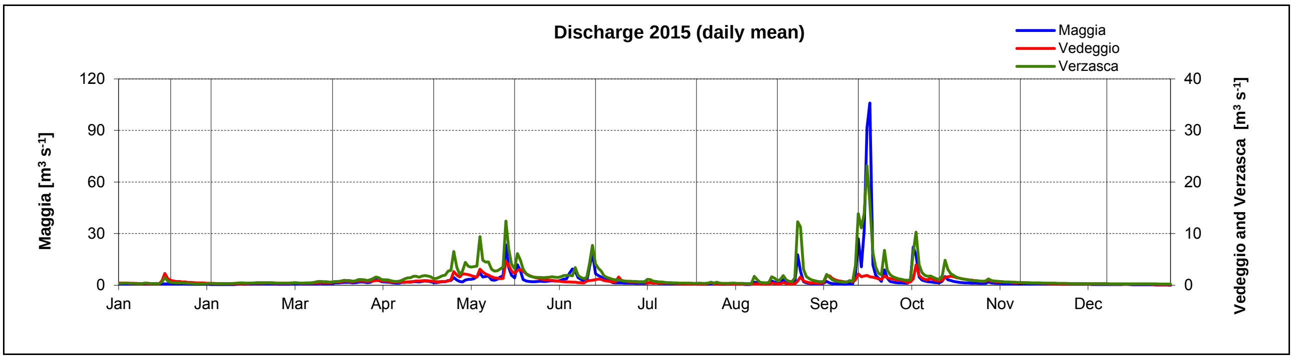
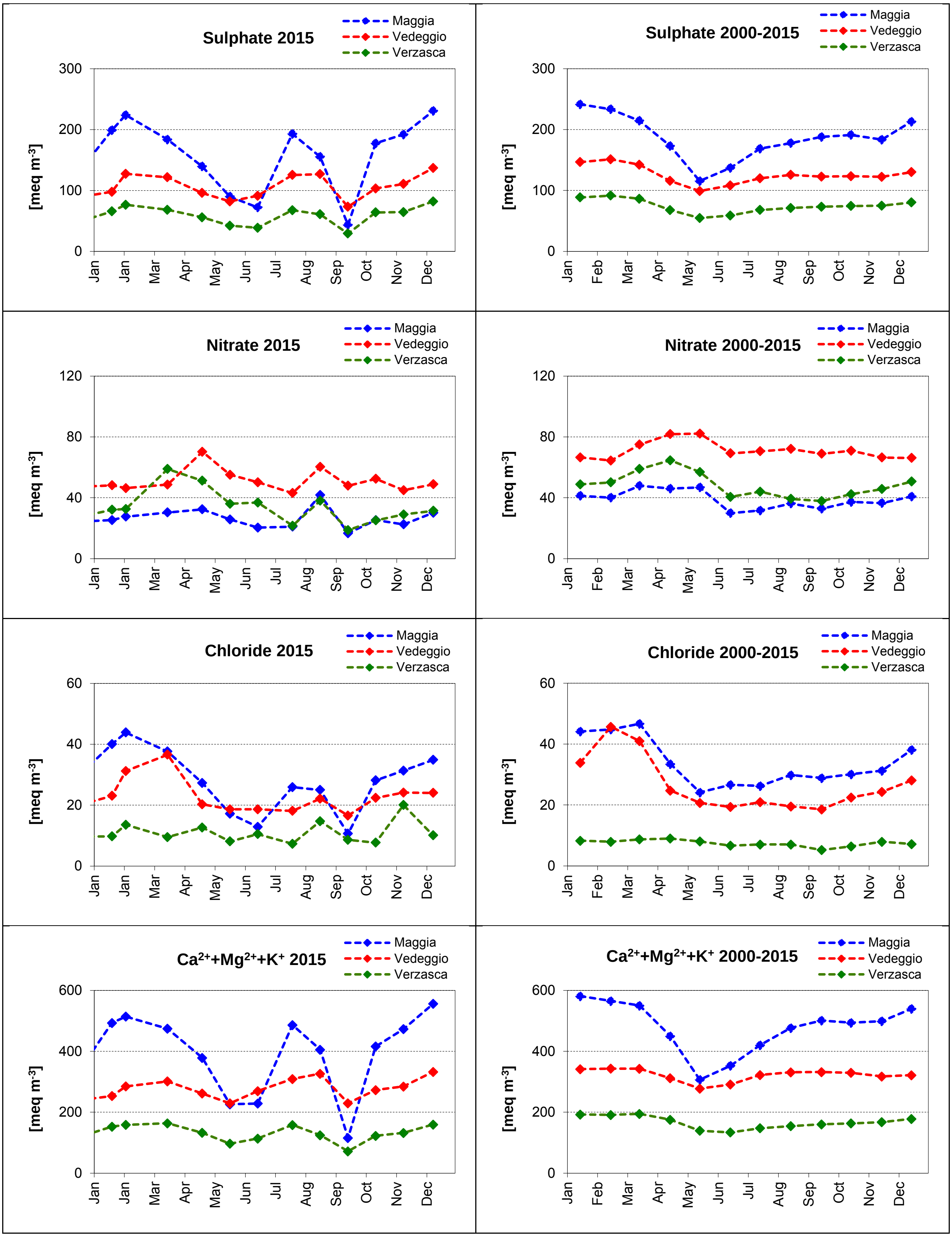
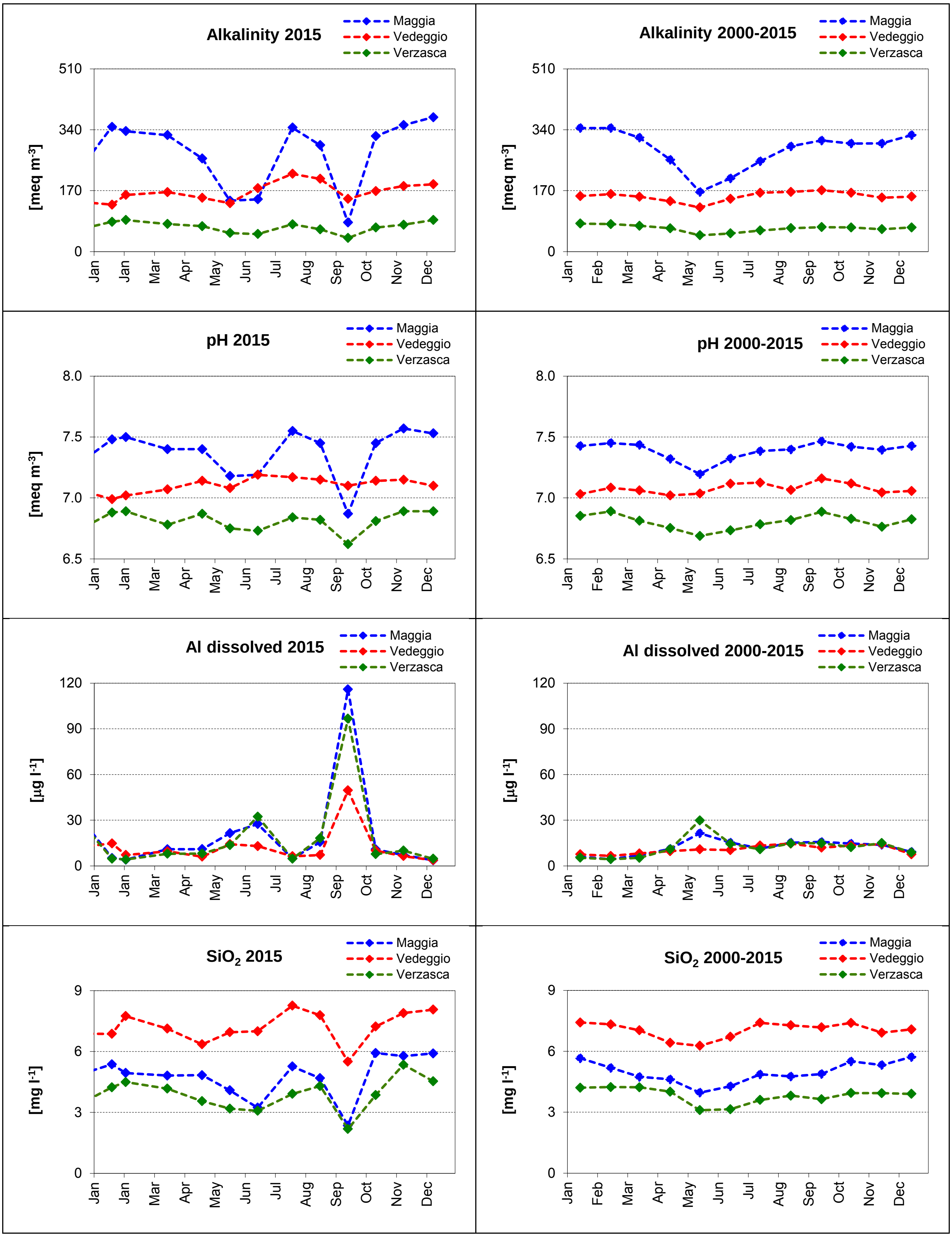


Figure 3.10 Concentrations of the main chemical parameters in river water during sampling days in 2015 and their average values from 2000 to 2010.




Alkalinity 2015
Maggia
Vedeggio
Verzasca
[meq m-3]
510
340
170
0
Jan
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Alkalinity 2000-2015
Maggia
Vedeggio
Verzasca
[meq m-3]
510
340
170
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
pH 2015
Maggia
Vedeggio
Verzasca
[meq m-3]
8.0
7.5
7.0
6.5
Jan
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
pH 2000-2015
Maggia
Vedeggio
Verzasca
8.0
7.5
7.0
6.5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Al dissolved 2015
Maggia
Vedeggio
Verzasca
[µg l-1]
120
90
60
30
0
Jan
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Al dissolved 2000-2015
Maggia
Vedeggio
Verzasca
[µg l-1]
120
90
60
30
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
SiO2 2015
Maggia
Vedeggio
Verzasca
[mg l-1]
9
6
3
0
Jan
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
SiO2 2000-2015
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 2015 are presented graphically in Fig. 3.11 and 3.12, respectively.

Similar to what observed for lake chemistry, also in rivers, concentrations of sulphate and during the last few years also of nitrate seem to have decreased. However, 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 Mann-Kendall test for the period 2000-2015. Results of the trend analysis are shown in Tab. 3.7. Concentrations of sulphate decreased significantly in all 3 rivers. Concentrations of nitrate decreased significantly in rivers Vedeggio and Verzasca and almost significantly in river Maggia. No significant trend can be observed for base cations, while for alkalinity significant increasing trends were detected only in river Verzasca and almost in river Vedeggio.

Figure 3.11 Monthly mean discharge in river water from 2000 to 2015. Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2016). Discharge of river Verzasca at Sonogno was estimated by discharge values of Verzasca at Lavertezzo by BWG (2001-2004) and BAFU (2005-2016) and discharge of river Maggia at Brontallo was measured by OFIMA.

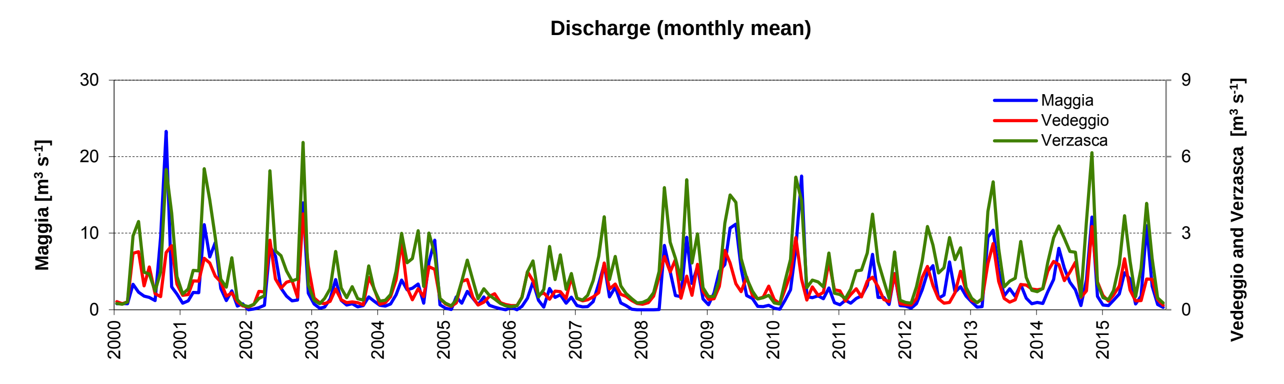
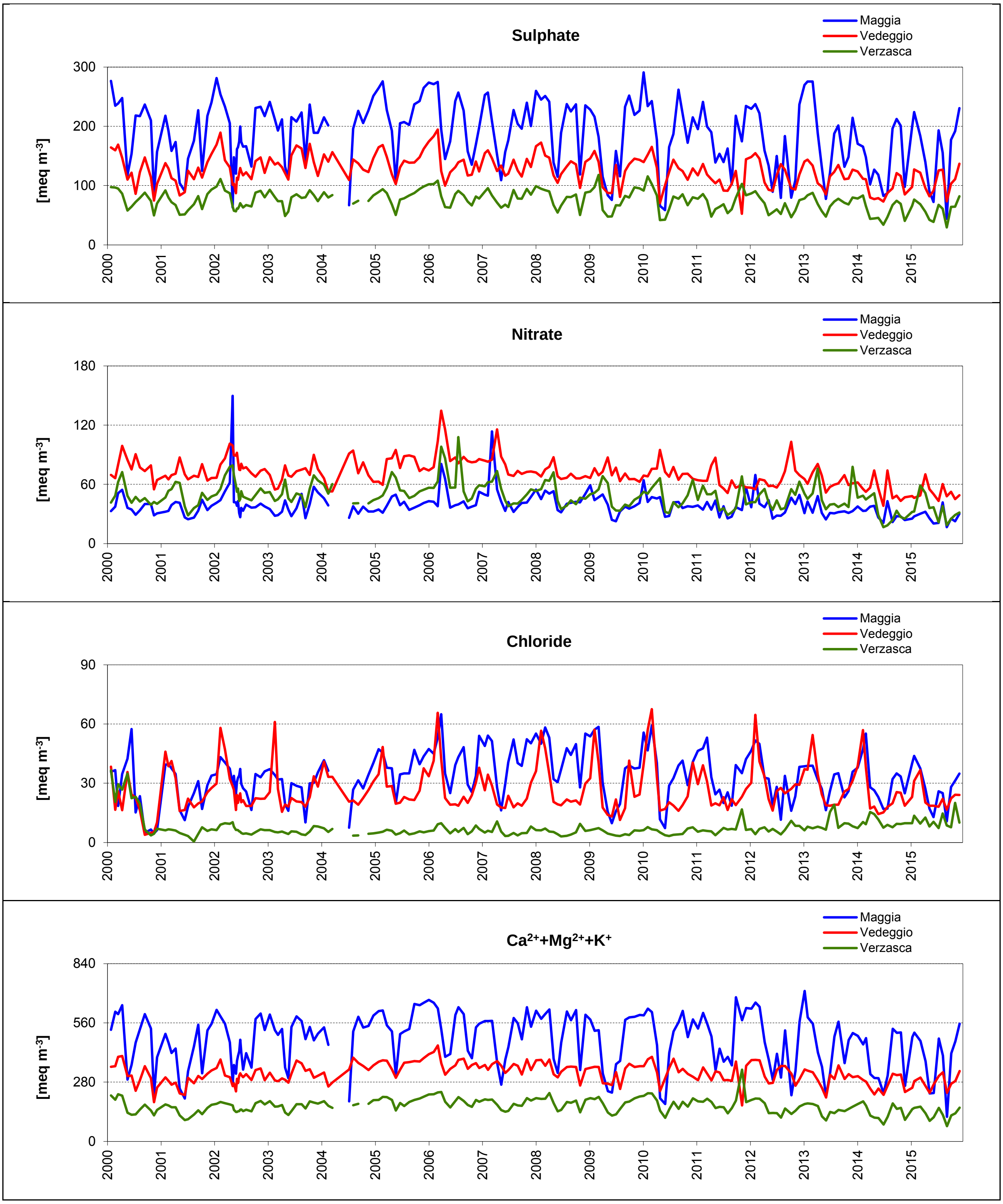


Figure 3.12 Concentrations of the main chemical parameters in river water from 2000 to 2015



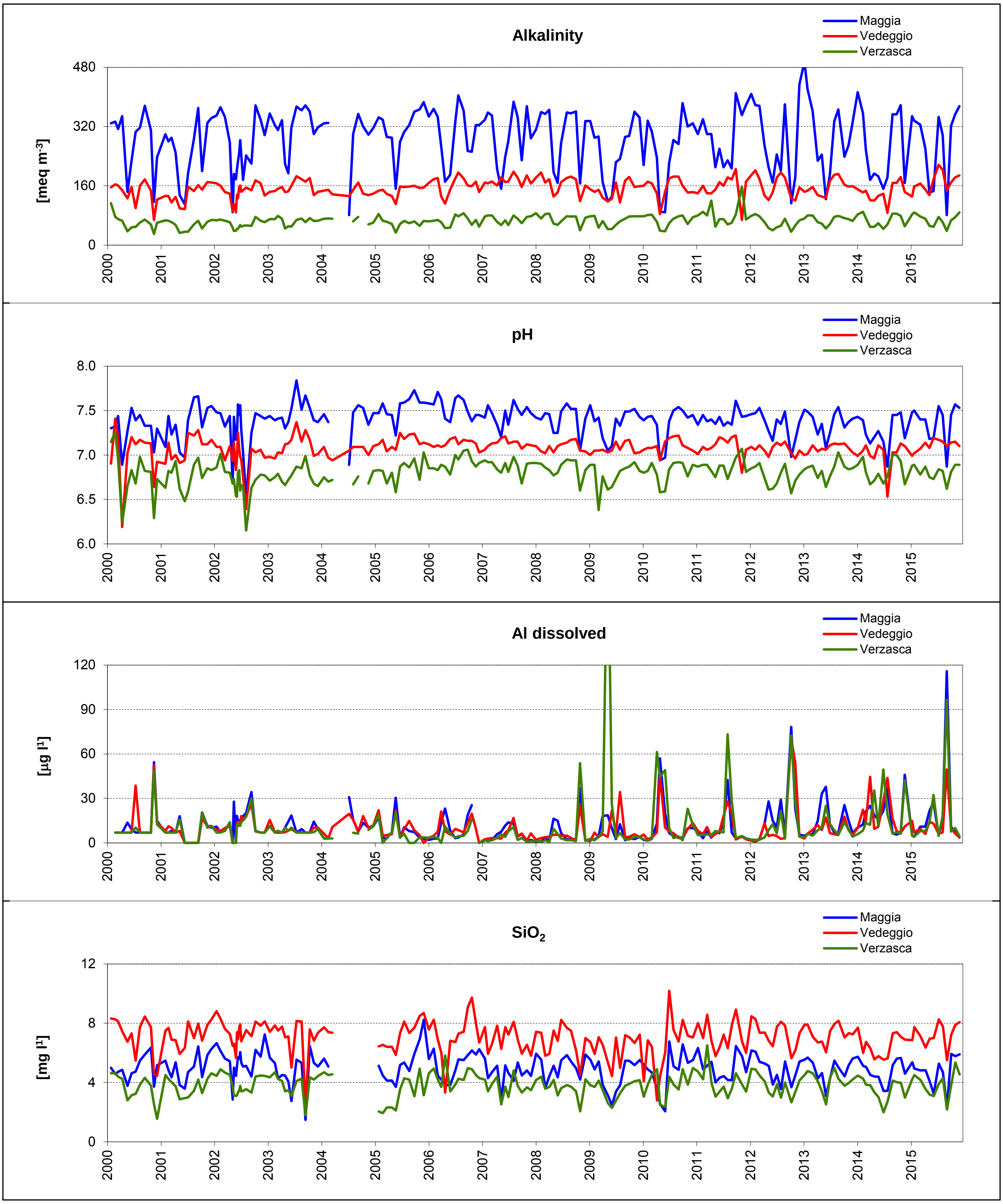

Alkalinity
Maggia
Vedeggio
Verzasca
[meq m-3]
480
320
160
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
pH
8.0
7.5
7.0
6.5
6.0
Al dissolved
[µg l-1]
120
90
60
30
SiO_2
[mg l-1]
12
8
4

Table 3.7 Results from trend analyses (significant trends in red) during the period 2000-2015. p corresponds to the probability level obtained with the seasonal Mann-Kendall test and the rate (meq m^{-3} yr^{-1}) was calculated 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	0.039	-2.17	0.084	-0.50	0.278	-3.00	0.529	0.00	0.834	0.28
Vedeggio	0.007	-1.88	0.003	-1.43	0.273	-2.00	0.987	0.00	0.061	1.13
Verzasca	0.012	-1.00	0.009	-0.92	0.333	-1.13	0.416	0.00	0.009	0.83

4 Macroinvertebrates as bioindicators

4.1 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 2015 spring and autumn lake pH's were 6.6/6.7 in Laghetto Inferiore, 6.5/6.6 in Laghetto Superiore, 6.2/5.7 in Lago del Starlaresc da Sgiof and 5.9/5.8 in Lago di Tomè. 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 2015 values ranged between 6.6 and 6.9.

During the macroinvertebrate monitoring period (from 2000 to present) autumn pH and alkalinity increased significantly only in lakes Superiore and Starlaresc da Sgiof. In Laghetto Inferiore pH and alkalinity increased from about 6.5 and 28 µeq l^{-1} (average 2000-2003) to 6.6 and 33 µeq l^{-1} (average 2012-2015), in Laghetto Superiore from 6.4 and 24 µeq l^{-1} to 6.6 and 35 µeq l^{-1}, in Lago del Starlaresc da Sgiof from 5.2 and -9 µeq l^{-1} to 5.8 and 5 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 53 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 66 µg l^{-1}.

4.2 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. 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.

4.3 Results and discussion

4.3.1 Lakes

Sample size and the relative abundance of identified taxa and taxa groups (EPT, AS) with the most important taxa numbers (total, EPT, AS) in lakes during 2015 are shown in Tab. 4.1 and 4.2, respectively. At all sites Diptera was the most abundant order, 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 were Oligochaeta (Naididae in Laghetto Inferiore and Superiore), Plecoptera (*Leuctra sp.*, *Nemoura sp.*, *Protonemoura sp.*) and Trichoptera (*Rhyacophila sp.*). The more acid sensitive Ephemeroptera were found only in Laghetto Inferiore and Laghetto Superiore (*Ecdyonurus sp.*), Odonata (*Aeshna sp., Libellula sp., Orthetrum 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 and Laghetto Superiore. In general, relative abundances of invertebrates sampled on fine and coarse substrates do no differ greatly. Only chironomids seem to be slightly more abundant on fine substrate.

Highest total taxa numbers were found in Laghetto Superiore (16), followed by Lago di Tomè (14), Laghetto Inferiore (11) and Lago del Starlaresc da Sgiof (9). Regarding EPT, the highest number of taxa was identified in Laghetto Superiore (11), then in Laghetto Inferiore (7), Lago di Tomè (5) and at last in Lago del Starlaresc da Sgiof (3).

Only few acid sensitive taxa were determined: *Isoperla grammatica* and *Perlodes intricatus in Laghetto Superiore, Ecdyonurus sp.* and probably *Crenobia alpina* in Laghetto Inferiore and Laghetto Superiore. These results are not surprising since pH's of both Lago di Tomè and Lago del Starlaresc da Sgiof are still at least occasionally below 6.

Table 4.1 Lake sample sizes during 2015

LAKE OUTLETS	MONTH	Fine substrate	Coarse substrate
INF	July (13.7.2015)	173	532
	October (30.09.2015)	248	259
SUP	July (13.7.2015)	203	471
	October (30.09.2015)	221	192
TOM	July (13.7.2015)	68	64
	October (05.10.2015)	191	42
STA	July (13.7.2015)	115	399
	October (05.10.2015)	376	576

Table 4.2 Relative abundance and number of taxa in lake outlets on different substrates during 2015.
0.0% indicate values >0.0% but < 0.05%.

TAXA	INF		SUP		TOM		STA		INF	SUP	TOM	STA
	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse				
OLIGOCHAETA	**8.9%**	**10.8%**	**25.2%**	**8.6%**				**8.4%**	**9.8%**	**16.9%**		**4.2%**
Naididae	8.9%	10.8%	25.2%	8.6%					9.8%	16.9%		
COLEOPTERA						**1.2%**		**0.3%**		**0.1%**	**0.6%**	**0.1%**
Agabus sp.				0.3%		1.2%		0.1%		0.1%	0.6%	0.1%
Potamophilus sp.								0.1%				0.1%
DIPTERA	**65.3%**	**61.3%**	**37.9%**	**46.6%**	**75.6%**	**55.6%**	**98.1%**	**73.5%**	**63.3%**	**42.2%**	**65.6%**	**85.8%**
Ceratopogonidae					0.5%	1.2%	16.4%	8.0%			0.9%	12.2%
Chironomidae	59.0%	50.0%	29.8%	29.9%	57.8%	39.8%	81.3%	64.3%	54.5%	29.8%	48.8%	72.8%
Simuliidae	6.3%	11.3%	8.1%	16.7%	17.2%	14.7%	0.4%	1.2%	8.8%	12.4%	15.9%	0.8%
EPHEMEROPTERA	**0.3%**	**0.9%**	**0.2%**						**0.6%**	**0.1%**		
Ecdyonurus sp.	0.3%	0.9%	0.2%						0.6%	0.1%		
ODONATA							**1.4%**	**0.3%**				**0.9%**
Aeshna affinis								0.3%				0.1%
Aeshna sp.							0.8%					0.4%
Libellula sp.							0.4%					0.2%
Orthetrum sp.								0.1%				0.0%
Libellulidae							0.1%					0.1%
PLECOPTERA	**12.4%**	**7.9%**	**14.8%**	**22.3%**	**20.6%**	**34.9%**	**0.5%**	**15.8%**	**10.2%**	**18.5%**	**27.7%**	**8.2%**
Leuctra sp.	0.3%		3.2%	3.6%	16.9%	31.3%		15.8%	0.1%	3.4%	24.1%	
Nemoura minima.				0.3%						0.1%		
Nemoura sp.	10.1%	6.1%	7.4%	11.5%	3.7%	3.6%	0.5%		8.1%	9.5%	3.6%	8.2%
Protonemoura nimborum.				0.1%						0.1%		
Protonemoura sp.	2.0%	1.8%	4.2%	6.1%					1.9%	5.1%		
Isoperla grammatica				0.2%						0.1%		
Perlodes intricatus				0.5%						0.3%		
TRICHOPTERA	**1.8%**	**1.8%**	**3.2%**	**2.6%**	**3.8%**	**8.3%**		**1.7%**	**1.8%**	**2.9%**	**6.1%**	**0.9%**
Limnephilus sp.					0.3%	0.8%					0.5%	
Plectrocnemia geniculata				0.3%				0.1%		0.1%		0.0%
Policentropodidae		1.0%							0.5%			
Rhyacophila (Rhyacophila) sp.			3.2%	0.2%	3.0%	7.5%				1.7%	5.3%	
Rhyacophila praemorsa		0.1%		2.1%	0.5%				0.0%	1.0%	0.3%	
Rhyacophlidae	1.8%	0.8%							1.3%			
TURBELLARIA	**11.3%**	**17.3%**	**18.7%**	**19.7%**					**14.3%**	**19.2%**		
Planariidae	11.3%	17.3%	18.7%	19.7%					14.3%	19.2%		
Rel. abundance EPT taxa	14.5%	10.6%	18.2%	24.9%	24.4%	43.2%	0.5%	17.5%	12.6%	21.5%	33.8%	9.0%
Rel. abundance AS taxa	11.6%	18.2%	19.0%	20.6%	0.0%	0.0%	0.0%	0.0%	14.9%	19.8%	0.0%	0.0%
Number total taxa	9	10	9	15	8	8	7	11	11	16	9	14
Number EPT taxa	5	6	5	10	5	4	1	3	7	11	5	3
Number AS taxa	2	2	2	4	0	0	0	0	2	5	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. 4.3. Trends in the invertebrate population cannot be observed. In particular, almost no positive trend can be detected for acid sensitive indicators like the relative abundance of AS taxa and the standardized number of AS. The only early sign of recovery seems to be the reappearance of *Crenobia alpina* in Lago di Tomè after 2006.

Table 4.3 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	2015
	Sampling times	1	3	3	3	3	3	3	2	2	2	2	2	2	2	2
	Individuals	64	80	293	1215	2003	8336		7712	10507	5250	958	4587	4587	3515	1206
	Rel. abundance OLIGOCHAETA	22%	6%	11%	25%	36%	30%		30%	23%	23%		18%	1%	9%	10%
	Rel. abundance HYDRACARINA			1%	0%	0%	0%		0%	0%	0%	1%	0%	0%		
	Rel. abundance COLEOPTERA				0%	0%	0%					0%				
	Rel. abundance DIPTERA	47%	25%	44%	44%	33%	45%		58%	52%	60%	92%	73%	92%	77%	63%
	Rel. abundance CHIRONOMIDAE	38%	13%	17%	29%	23%	18%		39%	46%	51%	86%	50%	70%	54%	55%
	Rel. abundance SIMULIDAE (%)		5%	26%	8%	5%	25%		18%	6%	8%	2%	22%	22%	23%	9%
	Rel. abundance EPHEMEROPTERA				2%	2%	1%		1%	1%	0%	0%	0%	0%	0%	1%
INF	Rel. abundance HETEROPTERA														0%	
	Rel. abundance PLECOPTERA	27%	56%	33%	23%	16%	12%		5%	5%	6%	6%	2%	1%	9%	10%
	Rel. abundance TRICHOPTERA		8%	1%	3%	3%	3%		0%	1%	1%	1%	0%	0%	1%	2%
	R Rel. abundance BIVALVIA											0%				
	Rel. abundance TURBELLARIA	5%	5%	11%	2%	10%	8%		5%	18%	9%	1%	6%	4%	4%	14%
	Rel. abundance EPT taxa	27%	64%	34%	28%	21%	16%		7%	6%	8%	6%	2%	2%	10%	13%
	Rel. abundance AS taxa	5%	13%	11%	12%	18%	13%		7%	20%	11%	4%	6%	5%	4%	15%
	Standardized number total taxa	14	13	14	20	16	15	12	14	12	12	13	8	8	9	11
	Standardized number EPT taxa	7	5	6	12	9	10	5	9	7	8	5	4	4	5	7
	Standardized number AS taxa	2	3	1	6	5	5	4	5	3	3	4	1	1	2	2
	Sampling times	1	3	3	3	3	3	3	2	2	2	2	2	2	2	2
	Individuals	49	34	150	1523	1744	6624	5736	5347	4977	5469	963	6723	1711	1249	1137
	Rel. abundance OLIGOCHAETA	6%	3%	6%	21%	20%	38%	50%	64%	43%	29%	1%	24%	7%	26%	17%
	Rel. abundance HYDRACARINA					0%	0%	0%	0%	0%	0%					
	Rel. abundance COLEOPTERA				0%		0%			0%	0%	0%				0%
	Rel. abundance DIPTERA	63%	6%	50%	35%	49%	47%	38%	30%	49%	49%	81%	65%	88%	56%	42%
	Rel. abundance CHIRONOMIDAE	59%	6%	42%	30%	36%	31%	27%	19%	44%	43%	65%	63%	83%	38%	30%
	Rel. abundance SIMULIDAE	4%		5%	5%	13%	16%	11%	11%	5%	6%	16%	3%	4%	18%	12%
SUP	Rel. abundance EPHEMEROPTERA				9%	7%	1%	0%	0%	0%	0%	1%		1%	0%	0%
	Rel. abundance HETEROPTERA					0%									0%	
	Rel. abundance PLECOPTERA	18%	68%	38%	30%	17%	11%	10%	3%	6%	21%	13%	7%	2%	12%	19%
	Rel. abundance TRICHOPTERA		24%	1%	4%	3%	1%	1%	1%	1%	1%	2%	1%	0%	0%	3%
	Rel. abundance TURBELLARIA	12%		5%	1%	4%	1%	1%	2%	1%	1%	3%	2%	1%	5%	19%
	Rel. abundance EPT taxa	18%	91%	39%	43%	27%	13%	11%	4%	7%	21%	15%	8%	3%	13%	20%
	Rel. abundance AS taxa	12%	3%	5%	11%	12%	2%	1%	3%	1%	1%	4%	2%	2%	5%	20%
	Standardized number total taxa	14	28	17	17	19	12	11	13	15	11	14	6	9	8	13
	Standardized number EPT taxa	5	23	9	12	12	6	7	9	8	6	8	4	6	5	8
	Standardized number AS taxa	2	3	2	5	7	3	3	2	2	1	3	1	2	2	4

LAKE	PARAMETER	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014	2015
TOM	Sampling times	1	2	2	1	1	2	2	2	2	2	2	2	2	2
	Individuals	11	156	331	337	2128	2983	3975	4407	3726	230	858	319	4129	365
	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%	1%
	Rel. abundance DIPTERA	36%	28%	34%	40%	84%	58%	64%	90%	87%	53%	77%	72%	70%	66%
	Rel. abundance CHIRONOMIDAE	36%	14%	33%	37%	75%	38%	57%	61%	65%	26%	40%	68%	19%	49%
	Rel. abundance SIMULIDAE		14%	1%	3%	9%	20%	6%	29%	22%	26%	36%	5%	51%	16%
	Rel. abundance HETEROPTERA			0%		0%	0%							1%	
	Rel. abundance MEGALOPTERA	18%	2%	1%	1%	0%		0%	0%	0%					
	Rel. abundance PLECOPTERA	36%	60%	57%	58%	13%	37%	34%	8%	10%	3%	14%	27%	10%	28%
	Rel. abundance TRICHOPTERA	9%	2%	4%	1%	2%	2%	1%	1%	1%	1%	1%	1%	3%	6%
	Rel. abundance TURBELLARIA						1%	0%	0%	0%		3%		0%	
	Rel. abundance EPT taxa	45%	62%	61%	59%	15%	39%	35%	9%	12%	4%	15%	27%	13%	34%
	Rel. abundance AS taxa					0%	1%	0%	0%	0%		3%		0%	
	Standardized number total taxa	13	16	20	11	14	14	12	15	14	10	10	9	8	10
	Standardized number EPT taxa	6	8	8	4	7	7	6	8	8	3	4	5	3	5
	Standardized number AS taxa	0	0	0	0	1	2	1	2	1	0	1	0	1	0
STA	Sampling times	1	2	2	1	2	2	2	2	2	2	2	2	2	2
	Individuals	21	706	808	478	2634	6223	3451	3935	2846	604	766	929	1512	1436
	Rel. abundance OLIGOCHAETA			1%	3%	3%	1%	0%	2%	10%		6%	6%		4%
	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%	0%
	Rel. abundance DIPTERA	29%	85%	91%	66%	89%	96%	85%	87%	74%	95%	69%	87%	73%	86%
	Rel. abundance CERATOPOGONIDAE		16%	5%	10%	14%	3%	5%	14%	13%	7%	20%	15%	8%	12%
	Rel. abundance CHIRONOMIDAE	29%	69%	85%	56%	75%	93%	79%	71%	56%	63%	34%	59%	16%	73%
	Rel. abundance SIMULIDAE				0%	0%	0%	1%	2%	4%	0%	15%	13%	49%	1%
	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%	1%
	Rel. abundance PLECOPTERA	24%	2%	2%	5%	1%	1%	9%	8%	12%	1%	16%		26%	8%
	Rel. abundance TRICHOPTERA	33%	5%	4%		0%	0%	1%	1%	1%				0%	1%
	Rel. abundance EPT taxa	57%	7%	6%	5%	2%	1%	10%	9%	13%	1%	16%		26%	9%
	Rel. abundance AS taxa					0%			0%		25%				
	Standardized number total taxa	12	9	14	14	12	9	13	16	13	14	11	7	8	11
	Standardized number EPT taxa	6	3	3	1	3	4	4	5	4	1	1	0	2	2
	Standardized number AS taxa	0	0	0	0	1	0	0	1	0	1	0	0	0	0

4.3.2 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 2015 are shown in Tab. 4.4 and 4.5, respectively. The most abundant taxonomic groups were Ephemeroptera and Plecoptera. 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. 4.6 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 4.4 River Verzasca sample sizes during 2015.

RIVER	SITE	SUBSTRATE	March (16.3.15)	July (15.7.15)	November (4.11.15)
VER	Pool	fine	179	929	525
		coarse	1014	686	382
	Run	fine	659	536	521
		coarse	667	696	460

Table 4.5 Relative abundance and number of taxa in river Verzasca during 2015. ***0.0% indicate values >0.0% but < 0.05%.***

TAXA	Pool		Run		Yearly average
	Fine	Coarse	Fine	Coarse	
OLIGOCHAETA	2.1%	0.6%	4.9%	2.3%	2.5%
Naididae	2.1%	0.6%	1.8%	2.1%	1.7%
HYDRACARINA		0.1%	0.1%	0.1%	0.1%
COLEOPTERA	10.7%	13.1%	10.1%	21.4%	13.8%
Esolus sp.	9.8%	12.7%	9.9%	20.7%	13.3%
Hydraena sp.	0.8%	0.4%	0.2%	0.7%	0.5%
DIPTERA	14.8%	11.2%	12.3%	10.4%	12.0%
Atherix ibis	1.8%	1.6%	1.7%	3.9%	2.2%
Athericidae	0.4%				0.1%
Blephariceridae	0.1%	0.2%	0.2%	0.1%	0.2%
Chironomidae	9.5%	7.7%	7.6%	4.8%	7.4%
Hexatoma sp.	0.7%	0.3%	0.1%	0.2%	0.3%
Limoniidae	0.3%	0.1%	0.3%	0.4%	0.3%
Pediciidae	0.2%	0.3%	0.5%		0.2%
Simuliidae	1.7%	1.0%	2.0%	0.2%	1.2%
EPHEMEROPTERA	33.5%	55.6%	56.9%	44.1%	47.5%
Baetis alpinus.				0.1%	0.0%
Baetis sp.	16.1%	23.9%	33.6%	23.3%	24.2%
Ecdyonurus helveticus.		2.6%		0.0%	0.7%
Ecdyonurus sp.	9.0%	2.9%	0.8%	3.1%	3.9%
Epeorus alpinus.			0.4%	0.2%	0.2%
Epeorus sp.	0.8%	0.5%	0.3%	0.0%	0.4%
Rhithrogena sp.	7.5%	25.8%	21.8%	17.3%	18.1%
PLECOPTERA	26.0%	14.9%	8.7%	16.3%	16.5%
Leuctra sp.	7.8%	4.7%	3.0%	2.5%	4.5%
Amphinemoura sulcicollis		0.0%	0.1%	0.1%	0.0%
Amphinemoura standfussi		0.0%	0.1%		0.0%
Amphinemoura sp.	0.7%	0.2%	0.7%	0.8%	0.6%
Nemoura mortoni	0.2%	0.1%	0.1%	0.0%	0.1%
Nemoura sp.	8.9%	4.4%	2.1%	4.5%	4.9%
Protonemura brevistyla		0.0%			0.0%
Protonemura nimborum			0.1%	0.0%	0.0%
Protonemura sp.	6.1%	3.7%	1.7%	7.7%	4.8%
Perla grandis	0.9%	0.3%	0.3%	0.1%	0.4%
Perla sp.	0.6%	1.4%	0.4%	0.4%	0.7%
Isoperla sp.	0.4%	0.0%	0.2%		0.2%
Rhabdiopteryx neglecta			0.1%	0.1%	0.0%
Rhabdiopteryx sp.	0.4%	0.0%			0.1%

TAXA	Pool		Run		Yearly average
	Fine	Coarse	Fine	Coarse	
TRICHOPTERA	3.8%	2.5%	1.0%	4.6%	3.0%
Hydropsyche sp.	0.1%	0.1%	0.1%		0.1%
Drusus alpinus		0.0%			0.0%
Drusus annulatus				0.0%	0.0%
Drusus discolor		0.1%		0.1%	0.1%
Drusus muelleri		0.1%		0.0%	0.0%
Melampophylax mucoreus		0.0%			0.0%
Philopotamus montanus	0.2%	0.7%	0.4%	2.2%	0.8%
Philopotamus sp.	0.9%				0.2%
Wormaldia copiosa.	0.1%	0.3%	0.1%	0.3%	0.2%
Wormaldia sp.	0.6%				0.2%
Philopotamidae	0.4%				0.1%
Rhyacophila sp.	0.9%	0.5%			0.4%
Rhyacophila torrentium	0.0%	0.2%		1.6%	0.5%
Rhyacophila (Hyperrhyacophila) sp.	0.1%				0.0%
Rhyacophila (Hyporhyacophila) sp.		0.2%	0.3%		0.1%
Rhyacophila dorsalis-Gr.	0.2%	0.2%			0.1%
Rhyacophila (Rhyacophila) sp.			0.1%	0.4%	0.1%
Rhyacophilidae	0.4%				0.1%
TURBELLARIA	9.0%	1.9%	6.0%	1.6%	4.6%
Polycelis tenuis/nigra				0.0%	0.0%
Planariidae	9.0%	1.9%	6.0%	1.5%	4.6%
Rel. abundance EPT taxa	63.4%	73.1%	66.6%	65.0%	67.0%
Rel. abundance AS taxa	40.3%	60.5%	60.5%	51.67%	53.2%
Number total taxa	36	40	34	37	51
Number EPT taxa	24	28	21	24	37
Number AS taxa	15	13	14	15	18
Acidification class (Braukmann & Biss)	2	2	2	2	2

Table 4.6 Temporal variations of the relative abundances and the number of taxa in river Verzasca.
0% indicate values >0% but < 0.5%.

PARAMETER	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014	2015
Sampling times	8	6	6	6	5	4	4	4	4	4	4	3	3	3	3
Individuals	1574	2258	2569	3759	4267	12894	15012	21046	20233	11684	4510	8570	8404	5885	6813
Rel. abundance OLIGOCHAETA	0%	1%	0%		0%	1%	0%	3%	1%	5%	0%	1%	0%	0%	0%
Rel. abundance HYDRACARINA	2%	1%	1%	2%	0%	1%	1%	1%	2%	1%	1%	1%	1%	0%	0%
Rel. abundance COLEOPTERA	18%	22%	23%	14%	18%	16%	24%	19%	17%	8%	22%	11%	12%	5%	15%
Rel. abundance DIPTERA	12%	8%	10%	19%	12%	19%	20%	22%	23%	21%	30%	36%	38%	5%	13%
Rel. abundance CHIRONOMIDAE	6%	4%	4%	16%	9%	17%	17%	20%	21%	19%	26%	32%	35%	3%	8%
Rel. abundance EPHEMEROPTERA	46%	45%	36%	41%	55%	45%	36%	41%	38%	34%	35%	37%	33%	59%	51%
Rel. abundance HETEROPTERA	18%	18%	25%	18%	11%	14%	16%	12%	17%	29%	8%	13%	14%	28%	18%
Rel. abundance PLECOPTERA	3%	4%	3%	4%	2%	2%	2%	1%	1%	2%	2%	1%	1%	2%	3%
Rel. abundance TRICHOPTERA	3%	4%	3%	4%	2%	2%	2%	1%	1%	2%	2%	1%	1%	2%	3%
Rel. abundance BIVALVIA												0%			
Rel. abundance GASTROPODA									0%						
Rel. abundance TURBELLARIA	1%	0%	1%	0%	0%	3%	1%	0%	1%	0%	2%	1%	1%	1%	0%
Rel. abundance EPT taxa67	67%	67%	64%	64%	69%	61%	53%	54%	56%	64%	45%	51%	47%	89%	72%
Rel. abundance AS taxa	52%	54%	45%	46%	62%	51%	40%	43%	41%	36%	40%	39%	35%	62%	56%
Standardized number total taxa	31	29	31	32	27	32	36	38	48	40	29	34	29	32	30
Standardized number EPT taxa	19	18	18	21	16	21	24	25	32	27	18	20	17	21	19
Standardized number AS taxa	11	10	11	13	11	12	14	14	19	14	13	13	13	12	11
Acidification class (Braukmann & Biss)	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2

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