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 2016

Ufficio dell'aria, del clima e delle energie rinnovabili
Sandra Steingruber
Telefono: 091 814 29 30
e-mail: sandra.steingruber@ti.ch
Bellinzona, 16.5.2017

Chemical analysis:	Laboratorio SPAAS, DT Canton Ticino
Chemical sampling: Claudia Sartori, Manuela Simoni Vassalli	Pietro Bomio-Pacciorini, David Fontana, Pasquale Caterino, Attilio Pirolini, Laboratorio SPAAS, DT Canton Ticino Sergio Kraschitz, Sandra Steingruber SPAAS, DT Canton Ticino Switzerland Adriano Bolgé, Anna Bonetti, Dorina Genucchi, Rinaldo Gnesa, Armando Tison, Centrale Elettrica del Ritom (FFS), Funicolare Cassarate-Monte Brè, MeteoSwiss Locarno Monti, Ofima
Sampling and determination of macroinvertebrates	Fürst & Associati SA, Corrado Cara

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Executive Summary

The Convention on Long-Range Transboundary Air Pollution (CLRTAP) of the UN Economic Commission for Europe (UNECE) was concluded in Geneva in 1979 and entered into force in 1983. It comprises eight protocols on the reduction of specific air pollutants. Switzerland has ratified all the protocols, and is actively involved in a variety of CLRTAP bodies. In addition to its Executive Body, the CLRTAP operates in three main working groups and programmes in which Switzerland is actively involved: Working Group on Strategies & Review, European Monitoring & Evaluation Programme (EMEP), Working Group on Effects (WGE). The WGE promotes international cooperation on research into, and the monitoring of, the impacts of air pollutants on human health and the environment. This scientific activities are carried out by six international cooperation programmes (ICPs) plus a working group focusing on health-related impacts of air pollution (Task Force on Health). The effects of cross-border air pollution on aquatic ecosystems are studied by The International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes (ICP Waters). In Switzerland, because of the abundance of crystalline bedrock many surface waters in northern Canton Ticino are sensitive to acidification. Since the same region is highly affected by long-range transport of atmospheric pollutants originating from the plain of the River Po, in Italy, one of the most urbanized and industrialized areas of Europe, mainly chemical but also biological parameters of mountain lakes and high-altitude stretches of rivers and streams in this area are examined by the Office for Air, Climate and Renewable Energies of the Canton of Ticino on behalf of the Federal Office for the Environment (FOEN) under the ICP Waters. Results of this investigations are regularly published in yearly reports.

During 2016 precipitations in southern Switzerland were close to norm values of (average 1981-2010) during the first half of the year but significantly lower between June and October in northern Ticino (Sopraceneri).

Compared to mean values during 2005-2015, rainwater concentrations of sulphate, nitrate, ammonium and base cations during 2016 were lower during summer months. Alkaline rain events in April and October caused positive base cations and pH peaks and negative acidity peaks during the same months. Depositions of sulphate, nitrate, ammonium, base cations were highest in April and summer values were smaller than 2005-2015 averages. Monthly mean depositions of acidity were mostly negative and reached lowest values in April and October because of the occurrence of alkaline rain events.

Significant time trends were observed for rainwater concentrations and depositions. As a consequence of reduced SO_2 emissions, sulphate concentrations and depositions decreased significantly at all sites particularly before 2000. Since 1990, annual mean concentrations decreased from around 75 meq m^{-3} (Locarno Monti and Lugano) to below 25 meq m^{-3} at all sites and depositions from 110 meq m^{-2} to below 40 meq m^{-2}. Because of the reduction of the emissions of NO_x, after 2000 concentrations and depositions of nitrate also decreased significantly at most sites (7 out of 9 for concentrations and 5 out of 9 for depositions). During the last 5 years (2012-2016) annual mean concentrations ranged from a minimum of 22 to a maximum of 66 meq m^{-2} and annual mean depositions from a minimum of 12 to a maximum of 36 meq m^{-2}. Concentrations and depositions of

ammonium also slightly decreased at some sites after 2000 (5 out 9 for concentrations and 1 out of 9 for depositions). Consequently, concentrations and depositions of rainwater acidity decreased significantly at all sites from annual mean values of 30-60 meq m^{-3} and 60 meq m^{-2}, respectively to -12 and -36 meq m^{-3} and – 22 and -66 meq m^{-2} during the last 5 years. pH also decreased significantly at all sites. At Locarno Monti and Lugano values decreased from around 4.3 to 5.2-5.8.

Because of the low precipitation volume in early autumn, lakes concentrations of sulphate, base cations, silica, alkalinity and pH were slightly higher and concentrations of nitrate slightly lower compared to the most recent years values.

In agreement with trends in rainwater concentrations and depositions, 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 2000-2016), concentration trend rates of nitrate were higher after 2000, indicating a more pronounced decrease more recently. Concentrations of aluminum also decreased, 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 and after 2012 in Laghetto Gardiscio from around 60 to 20 $\mu g\ l^{-1}$.

Similar to lake chemistry, because of less precipitations than usual, early autumn river water chemistry was also characterized by slightly higher concentrations of sulphate, base cations, silica, alkalinity and pH values and lower concentrations of nitrate compared to the most recent years values. Apart from that, concentrations of sulphate, base cations, alkalinity and silica were as usual lower during the snow melt period from March to June and higher during the other months, while concentrations of nitrate behaved opposite to this trend.

River chemistry also responded to emission reductions of sulphur and nitrogen. The time trend analysis revealed that from 2000 to 2016 concentrations of sulphate and nitrate decreased significantly in all 3 rivers and alkalinity in the 2 less alkaline rivers Vedeggio and Verzasca.

Since 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, macroinvertebrates as bioindicators have also been studied in 4 lakes and 1 river.

Among the monitored 4 lakes, the macroinvertebrate population changed with lake pH and aluminum concentrations. Numbers of total, EPT (Ephemeroptera, Plecoptera, Trichoptera), acid sensitive and chironomid taxa decreased with increasing aluminum concentrations. The same rank order was observed for the relative abundance of acid sensitive taxa. As regards temporal changes, almost no trend can be observed. The only early sign of recovery seems to be the reappearance of *Crenobia alpina* in Lago di Tomè after 2006.

As regards macroinvertebrates in rivers, a Braukmann and Biss (2004) class of on average 2 could be calculated for river Verzasca, that corresponds to predominantly neutral to episodically weakly acidic waters with pH's normally around 6.5-7.0, reflecting well the measured water chemistry. However, since the beginning of monitoring in 2000, no time trend could be observed.

Overall, despite significant decrease in deposition of acidifying pollutants and significant increase of alkalinity in most lakes and rivers, the most sensitive surface waters did still not completely recover. Further decrease in emissions, especially nitrogen oxides and ammonia is needed.

Riassunto

La Convenzione sull'inquinamento atmosferico a lunga distanza (CLRTAP) della Commissione economica per l'Europa delle Nazioni Unite (UNECE) è stata stipulata a Ginevra nel 1979 ed è entrata in vigore nel 1983. Comprende otto protocolli concernenti la riduzione di specifici inquinanti atmosferici. La Svizzera ha ratificato tutti i protocolli e partecipa in modo attivo in diversi gremi della CLRTAP. Oltre all'organo esecutivo la CLRTAP opera in 3 principali gremi: Working Group on Strategies & Review, European Monitoring & Evaluation Programme (EMEP), Working Group on Effects (WGE). Il gruppo di lavoro WGE promuove la collaborazione internazionale nell'ambito della ricerca e della sorveglianza degli effetti degli inquinanti atmosferici sulla salute umana e sull'ambiente. Questi lavori scientifici sono svolti attraverso sei Programmi cooperativi internazionali (ICP) nonché un gruppo di lavoro che indaga segli effetti degli inquinanti sulla salute (Task Force on Health). Gli effetti dell'inquinamento atmosferico transfrontaliero sugli ecosistemi acquatici sono studiati dal Programma di valutazione e osservazione degli effetti dell' inquinamento atmosferico su fiumi e laghi (ICP Waters). In Svizzera, a causa della geologia prevalentemente cristallina, molte acque superficiali nel nord del Canton Ticino sono sensibili all'acidificazione. Siccome la stessa zona è influenzata fortemente dal trasporto a lunga distanza di inquinanti atmosferici provenienti dalla Pianura Padana, una delle zone maggiormente urbanizzate in Europa, l'Ufficio dell'Aria, del Clima e delle Energie Rinnovabili del Canton Ticino monitora regolarmente la chimica, ma anche parametri biologici di laghi alpini e tratti di fiumi ad alta quota su incarico dell'Ufficio Federale per l'Ambiente (UFAm) nell'ambito dell'ICP Waters. I risultati di questo monitoraggio sono regolarmente pubblicati in rapporti annuali.

Nel 2016 le precipitazioni in Ticino sono state simili ai valori norma (media 1981-2010) nella prima metà dell'anno, ma significativamente minori nel periodo da giugno a ottobre nella parte nord del Cantone.

Rispetto ai valori medi del periodo 2005-2015, le concentrazioni di solfato, nitrato, ammonio e cationi basici sono state inferiori durante i mesi estivi. Eventi di pioggia alcalina in aprile e ottobre hanno causato dei picchi positivi di concentrazioni di cationi basici e pH e picchi negativi di acidità. Le più alte deposizioni di solfato, nitrato, ammonio e cationi basici sono state osservate in aprile, mentre le deposizioni estive sono state inferiori alle medie del periodo 2005-2015. Le concentrazioni medie mensili di acidity sono state prevalentemente negative con valori minimi in aprile e ottobre a causa degli eventi di pioggia alcalina.

Trend temporali significativi sono stati osservati per le concentrazioni di ioni e cationi nelle precipitazioni e per le deposizioni. Grazie alla riduzione delle emissioni di SO_2, le concentrazioni e le deposizioni di solfato sono diminuite in modo significativo in tutti i punti di prelievo in particolare prima del 2000. Dal 1990, le concentrazioni medie annue sono diminuite da circa 75 meq m^{-3} (Locarno Monti and Lugano) a valori inferiori a 25 meq m^{-3} in tutte le stazioni di campionamento e le deposizioni da 110 meq m^{-2} a valori inferiori a 40 meq m^{-2}. A causa della diminuzione delle emissioni di NO_x, dopo il 2000 le concentrazioni e le deposizioni di nitrato sono diminuite significativamente quasi ovunque (7 stazioni su 9 per le concentrazioni e 5 stazioni su 9 per le deposizioni). Durante gli ultimi 5 anni (2012-

2016) le concentrazioni medie annue variavano da un minimo di 22 a un massimo di 66 meq m^{-3} e le deposizioni da un minimo di 12 a un massimo di 36 meq m^{-2}. Le concentrazioni e le deposizioni di ammonio sono anche diminuite leggermente in alcuni punti dopo il 2000 (5 stazioni su 9 per le concentrazioni e 1 stazione su 9 per le deposizioni). Conseguentemente, le concentrazioni e le deposizioni di acidità sono diminuite in modo significativo in tutti i punti di monitoraggio da valori medi annui di 30-60 meq m^{-3} rispettivamente 60 meq m^{-2}, a valori che variano da -12 a -36 meq m^{-3} rispettivamente da – 22 a -66 meq m^{-2} durante gli ultimi 5 anni. Anche il pH è diminuito significativamente ovunque. A Locarno Monti e a Lugano il pH medio annuo è diminuito da circa 4.3 a 5.2-5.8 circa.

Per quanto riguarda i laghi alpini, nel 2016 a causa delle esigue precipitazioni durante il periodo di inizio autunno, le concentrazioni di solfato, cationi basici, silice, alcalinità e pH sono stati leggermente superiori e le concentrazioni di nitrato leggermente inferiori rispetto agli anni precedenti.

Similmente ai trend delle concentrazioni nelle precipitazioni e delle deposizioni atmosferiche, dagli anni 1980's ad oggi, le concentrazioni di solfato e nitrato sono diminuite in quasi tutti i laghi, causando un aumento dell'alcalinità e del pH. A differenza delle concentrazioni di solfato, che sono diminuite in pressoché ugual misura durante i 2 periodo temporali analizzati (1980's-2015 and 2000-2016), le concentrazioni di nitrato sono diminuite soprattutto dopo il 2000. Anche le concentrazioni di alluminio disciolto sono diminuite in modo significativo nei laghi maggiormente acidi (pH < 6): dopo il 2005 nel Lago di Tomé da valori medi annui di 40 a 20 $\mu g\ l^{-1}$ e nel Starlaresc da Sgiof da 80-100 $\mu g\ l^{-1}$ a 40-60 $\mu g\ l^{-1}$ e dopo il 2012 nel Laghetto Gardiscio da circa 60 a 20 $\mu g\ l^{-1}$.

Analogamente a quanto osservato per la chimica dei laghi, a causa delle precipitazioni di inizio autunno inferiori alla norma, in questi mesi nei fiumi Maggia, Vedeggio e Verzasca le concentrazioni di solfato, cationi basici alcalinità e pH sono anche stati leggermente superiori e le concentrazioni di nitrato leggermente inferiori rispetto agli anni più recenti. Altrimenti le concentrazioni di solfato, cationi basici, alcalinità, silice e il pH sono stati come sempre più bassi e le concentrazioni di nitrato più alte durante il periodo dello scioglimento delle nevi da marzo a giugno.

La riduzione delle emissioni di zolfo e azoto si riflette anche nella chimica dei fiumi. L'analisi delle tendente temporali ha mostrato una diminuzione delle concentrazioni di solfato e nitrato in tutti e 3 i fiumi monitorati ed è aumentata l'alcalinità nei 2 fiumi con minore alcalinità (Vedeggio, Verzasca).

Siccome il fine ultimo delle misure per ridurre le emissioni è la ripresa della biologia, per esempio il ritorno di specie sensibili all'acidificazione precedentemente scomparsi e il ripristino delle funzioni biologiche che sono state alterate durante il processo di acidificazione, si è deciso di studiare anche i macroinvertebrati come bioindicatori in 3 laghi e 1 fiume.

Nei 4 laghi monitorati la popolazione di macroinvertebrati varia con il pH e le concentrazioni di alluminio. I numeri di taxa totale, taxa EPT (Efemerotteri, Plecotteri, Tricotteri) e taxa sensibili all’acidificazione e di chironomidi diminuiscono con l’aumentare delle concentrazioni di alluminio e con il diminuire del pH. L’abbondanza relativa di taxa sensibili all’acidificazione segue la stessa graduatoria. Per quanto riguarda l’evoluzione temporale, non si è osservato praticamente alcuna tendenza. L’unico primo segno di recupero sembra essere il ritorno di *Crenobia alpina* nel Lago di Tomè dopo il 2006.

Il monitoraggio dei macroinvertebrati nel fiume Verzasca ha permesso di assegnare quest’ultimo alla classe 2 secondo il sistema di classificazione di Braukmann and Biss (2004). Questa classe caratterizza acque prevalentemente neutre o leggermente acide con pH normalmente attorno i 6.5-7.0, riflettendo in questo modo bene la chimica normalmente misurata nel fiume Verzasca. Dall’inizio del suo monitoraggio nel 2000, non è stato possibile però osservare una tendenza temporale nella popolazione di macroinvertebrati.

Riassumendo, nonostante le concentrazioni di acidità e delle sue deposizioni sono diminuite in modo significativo nella maggior parte dei laghi e dei fiumi, le acque maggiormente sensibili all’acidificazione non si sono ancora riprese completamente. È necessario quindi diminuire ulteriormente le emissioni atmosferiche, in particolare di NO_x e NH_3.

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 (CLRTAP) 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, as well as water chemistry in 21 high altitude lakes and 3 rivers. Macroinvertebrates as indicators are sampled in 4 lakes and 1 river.

1.1 Climatic parameters during 2016

2016 was characterized by warm temperatures and belongs to the 10 warmest years since the beginning of measurements in 1864. Annual mean temperature over all Switzerland was 0.7°C higher than the norm value (mean 1981-2010). Compared to norm values, monthly precipitation volumes in northern Ticino (Sopraceneri) were average until June with low vales in January and increasing volumes in spring, but, with exception of November, lower in the second half of the year. In southern Ticino monthly precipitation volumes differed less from norm values.

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)

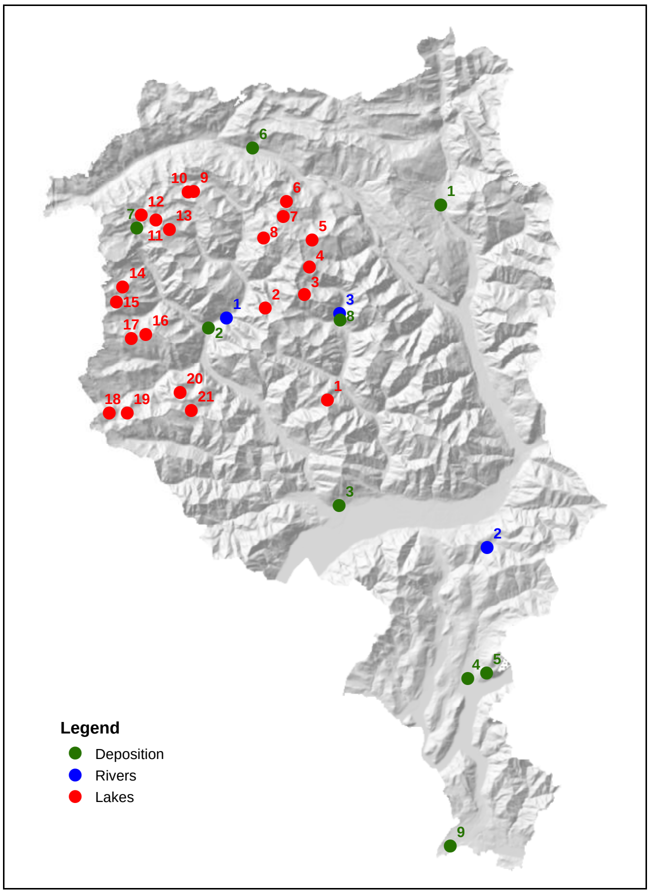


Table 2.1 Geographic and morphometric parameters of the wet deposition sampling sites

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 aluminum 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 at 9 sites, 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	20 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	1.6 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	7.5 μg P l^{-1}
soluble reactive Si	CA filter	PP bottle, 4°C	ICP-OES with ultrasonic nebulizer	0.1 mg SiO_2 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)	1.0 μg l^{-1}
total Al	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	1.0 μg l^{-1}
soluble Pb	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
total Pb	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
soluble Cd	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
total Cd	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
soluble Cu	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
total Cu	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 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 Cr	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
total Cr	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
soluble Ni	PC filter	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 μg l^{-1}
total Ni	No	acid washed PP bottle, +HNO_3, 4°C	Adsorptive Stripping Voltammetry (AdSV)	0.1 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 the 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.

For the data analysis concentrations of calcium, magnesium, sodium and potassium were summed up and presented and discussed as base cations.

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 1.4” (Marchetto, 2015).

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 2016 are shown in Tab. 3.2.

Table 3.2 Yearly mean rain water concentrations and deposition rates during 2016

Sampling site	Precipitation (mm)	Analysed precipitation (mm)	Cond 25°C (µS cm^{-1})	pH	Ca^{2+}		Mg^{2+}		Na^{+}		K^{+}		NH_4^{+}		HCO_3^{-}		SO_4^{2-}		NO_3^{-}		Cl^{-}		Acidity = $H^{+}– HCO_3^{-}$	
					Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})	Concentration (meq m^{-3})	Deposition (meq m^{-2})
Acquarossa	1124	1023	10	5.4	23	26	4	5	6	6	2	2	36	40	25	28	15	16	29	33	5	6	-21	-24
Bignasco	1470	1519	10	5.4	17	26	3	5	5	8	2	3	30	44	19	28	13	19	25	36	5	8	-15	-22
Locarno Monti	1620	1469	12	5.5	23	37	4	7	9	14	2	3	43	69	26	42	19	30	33	53	8	13	-22	-36
Lugano	1681	1302	10	5.6	13	22	2	4	5	8	2	3	38	64	18	31	15	25	27	45	6	9	-15	-26
Monte Brè	1681	1438	10	5.6	20	33	3	5	7	11	3	4	34	57	21	35	14	24	26	43	9	15	-19	-31
Piotta	1234	1096	8	5.5	16	19	2	3	6	7	1	2	25	31	16	20	11	14	20	25	6	8	-13	-16
Robiei	2341	1786	9	5.6	15	35	2	5	4	9	1	3	25	57	13	31	11	27	23	53	3	8	-11	-25
Sonogno	1850	1760	10	5.8	19	36	3	6	6	12	2	4	36	67	27	51	13	25	25	46	7	12	-26	-48
Stabio	1763	1570	12	5.7	16	28	3	5	7	12	2	4	50	89	26	46	18	32	32	57	7	12	-24	-43

In general, ion concentrations of anthropogenic origin (sulphate, nitrate, ammonia) still decrease from sites with low to high latitude and from low to high altitude, even though the gradients are not as pronounced as they were at the beginning of measurements. During 2016 highest concentrations of the sum of sulphate, nitrate, ammonia were measured at Stabio and Locarno Monti and lowest at Piotta and Robiei. 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 2016, highest deposition rates of the sum of ammonia, nitrate and sulphate occurred at Stabio 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 2016 and their average values during the period 2005-2015 are reported in Fig. 3.1. Similarly, seasonal variations of monthly mean rainwater concentrations of the main chemical parameters during 2016 and their mean values during the period 2005-2015 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 2016 was higher in February, and lower in August, September, December.

During 2005-2015 average sulphate concentrations were higher in summer and lower in winter at sampling stations with low concentrations (Bignasco, Piotta, Robiei). At sites with higher concentrations, the period with high sulphate concentrations started already in late winter. This seasonality is the result of the combination of the seasonality of SO_2 concentration in the air (highest in winter and lowest in summer), the oxidation rate from SO_2 to SO_4^{2-} (highest in summer and lowest in winter) and at high altitudes also the seasonality of thermal convection (occasionally absence of vertical transport in winter).

Monthly mean concentrations of nitrate during 2005-2015 were highest in February-March and lowest in November-January. The nitrate peak at the end of the winter is most probably the result of the high concentrations of NO_2 in winter, the already increasing oxidation rates of NO_x to NO_3^- in spring (lowest in winter and highest in summer) and at high altitudes the absence of vertical transport of pollutants induced by thermal convection.

The seasonality of monthly mean concentrations of ammonium during 2005-2015 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 2005-2015 were highest in May-June. Opposite to base cations behaved acidity, whose monthly mean concentrations were highest during winter and lowest during spring and autumn, indicating that concentrations of base cations heavily influence the seasonality of acidity. As a consequence of decreased acidity during summer, pH values were usually highest in summer.

Compared to the last decades values concentrations of sulphate, nitrate and base cations were in general lower than average values of 2005-2015, especially at the usually more polluted sites (low latitude and low altitude) and from May to August. Consequently, differences in concentrations among sampling stations became less significant. Compared to 2005-2015 average values, concentrations of acidity were slightly lower. The negative peaks in April and October correspond to the two peaks in concentrations of base cations. The particularly high base cations and alkalinity peaks in April and October were caused by alkaline rain events that occurred during weeks 13th and 14th week (28.3.16-10.4.16) and 43th (23-30.10.16). Monthly pH's of 2016 were higher compared to 2000-2015 averages. Only 11% of the monthly mean values were below pH 5 during 2016, while they were 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.

Trends of wet depositions behave in general similar to trends of concentrations, with the difference that rainwater volume gain further importance (Fig. 3.3). During 2005-2015 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. Average monthly deposition of acidity behaved opposite to base cations.

During 2016, depositions of sulphate, nitrate and ammonium were in general similar or slightly lower than 2005-2015 average values, with exception of April when precipitations were higher and depositions therefore also. For base cations and acidity highest respectively lowest values were observed during the already mentioned alkaline rain event in April and October 2016. This events contributed with a minimum of 15% (Stabio) and a maximum of 47% (Piotta) to the total yearly alkalinity.

Figure 3.1 Monthly precipitations

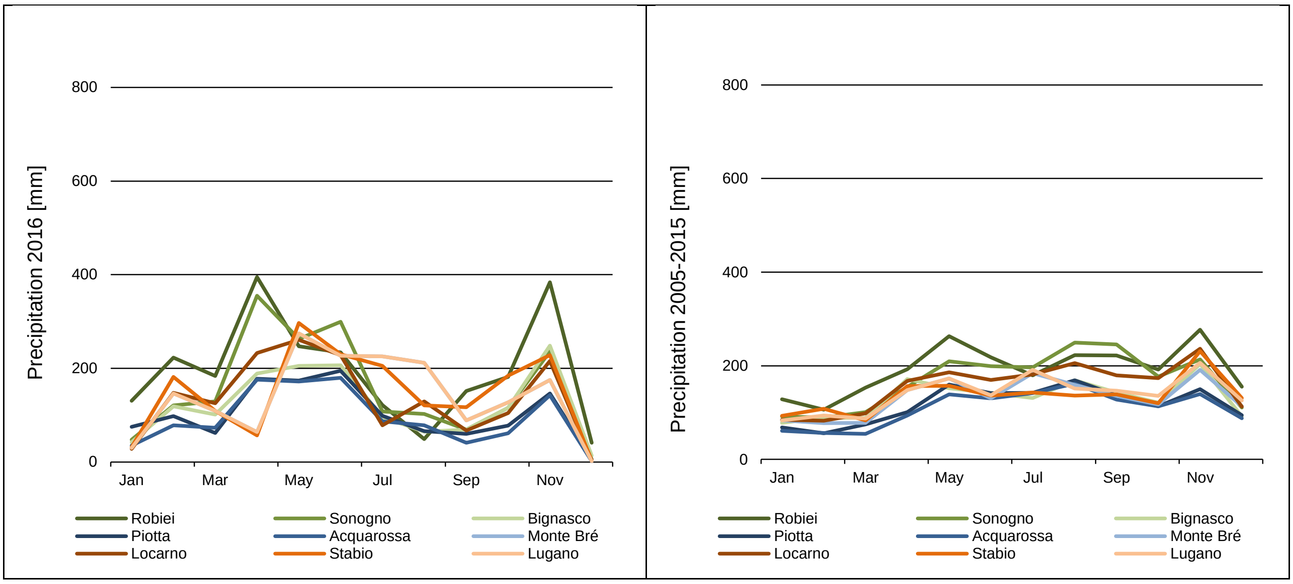
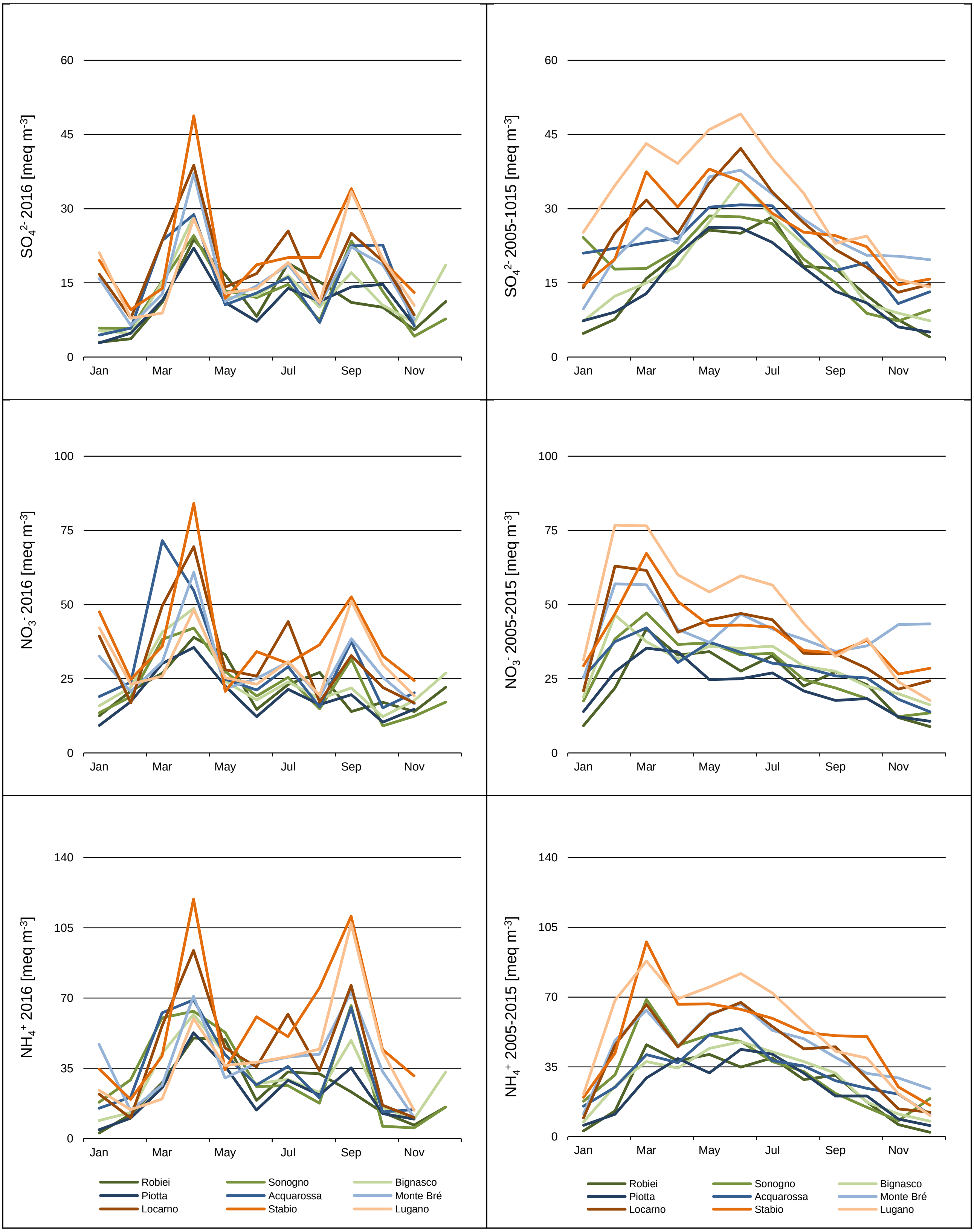


Figure 3.2 Seasonal variations of monthly average rain water concentrations



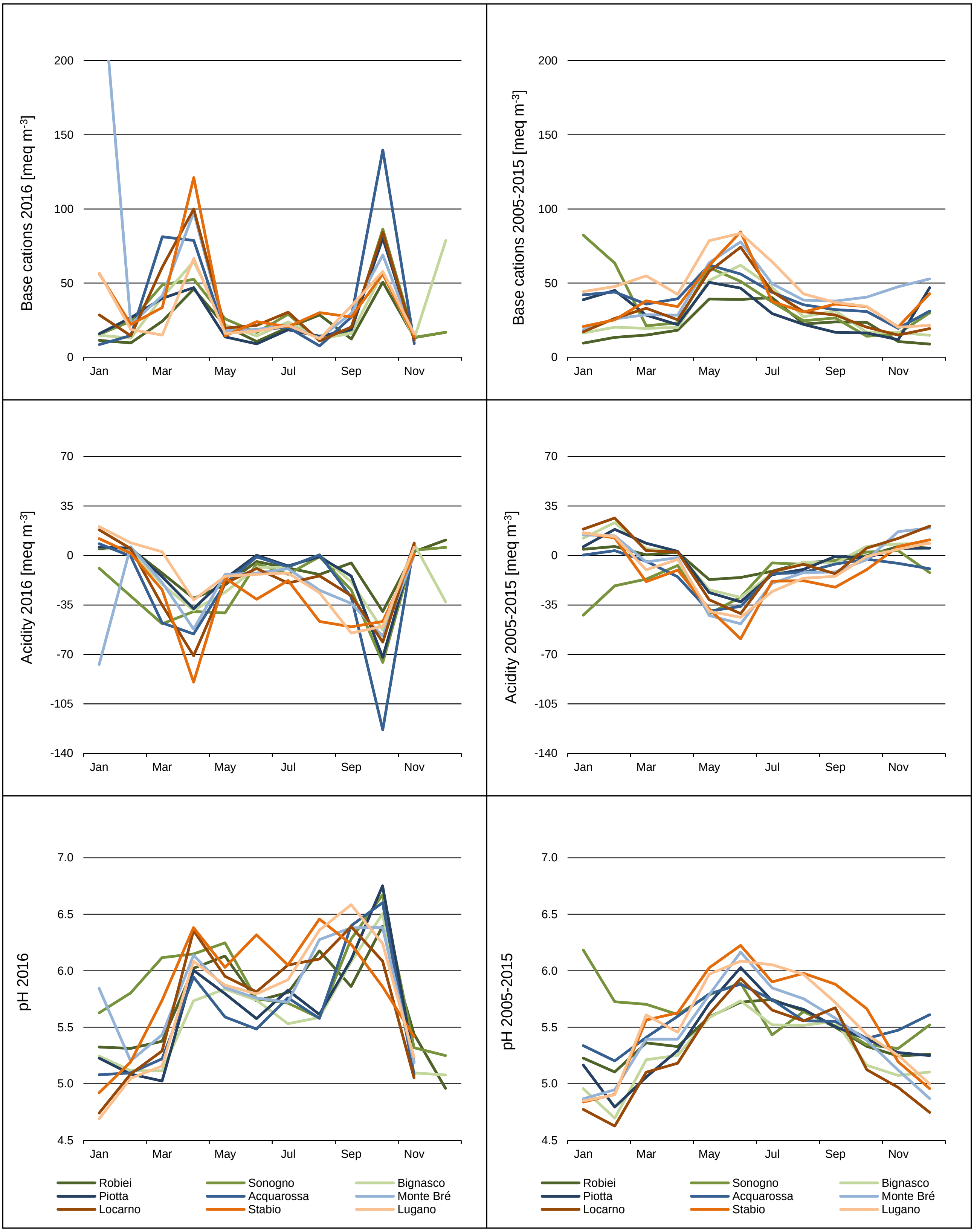
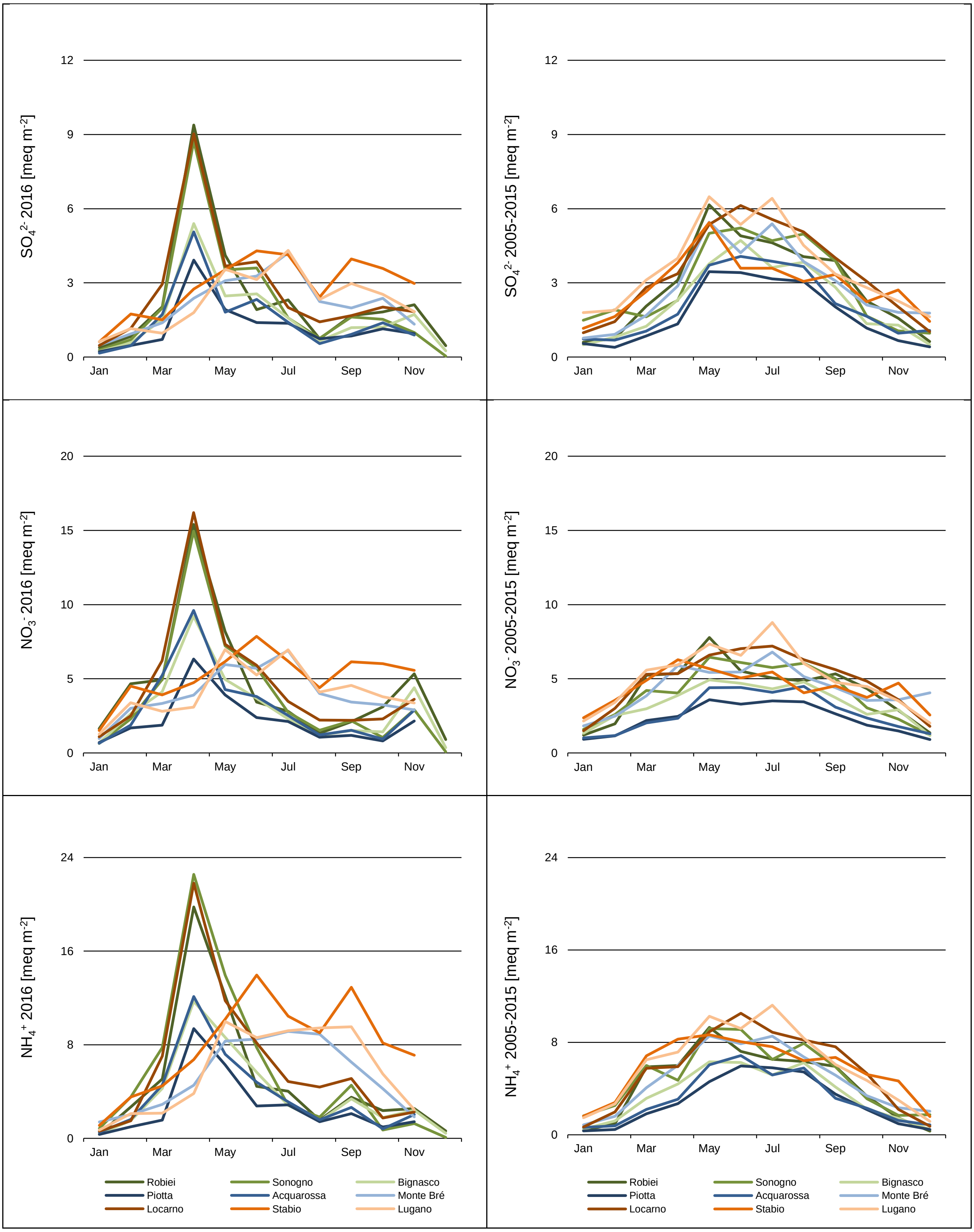
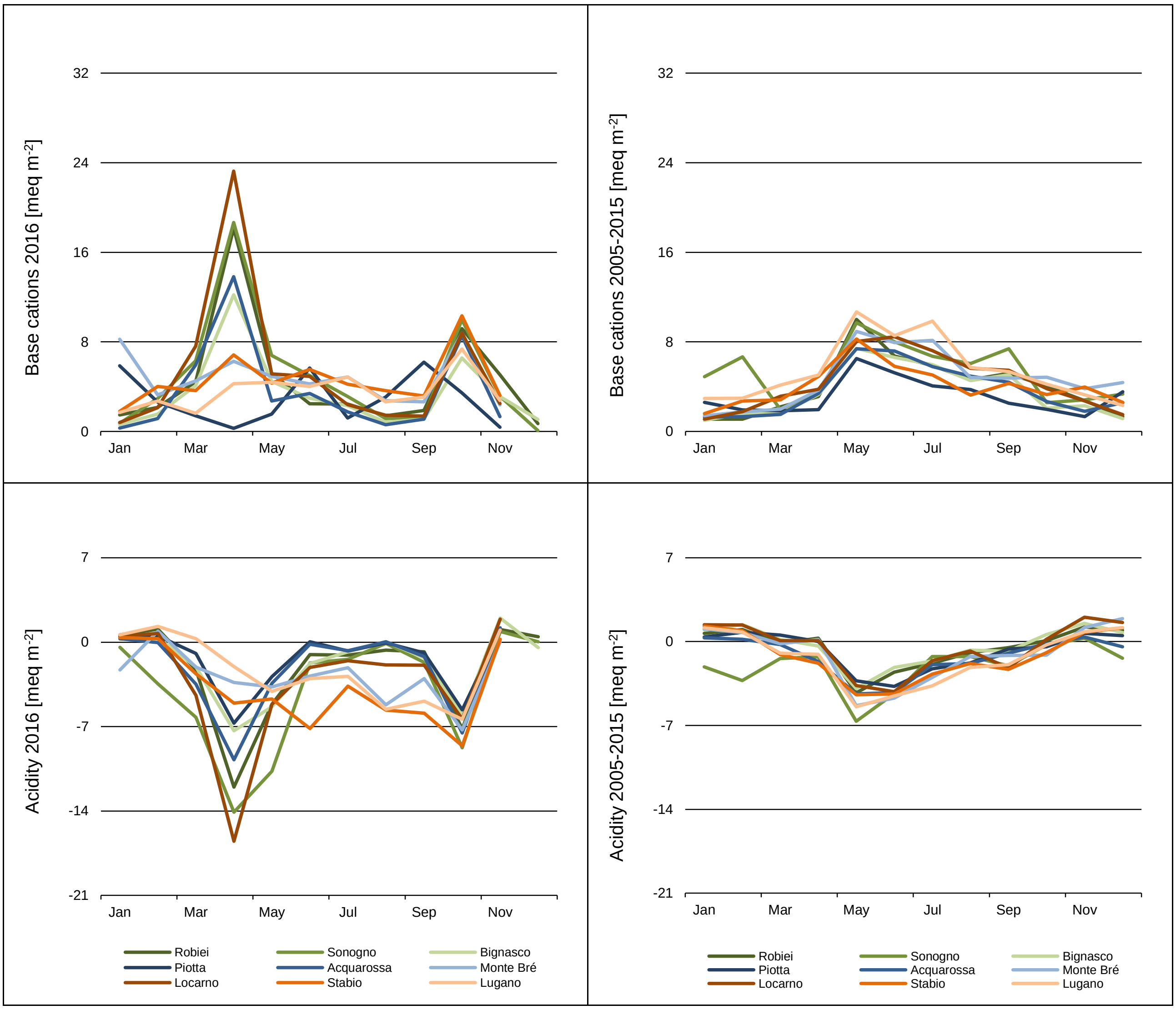

Base cations 2016 [meq m-3]
Base cations 2005-2015 [meq m-3]
200
150
100
50
0
Acidity 2016 [meq m-3]
Acidity 2005-2015 [meq m-3]
70
35
0
-35
-70
-105
-140
pH 2016
pH 2005-2015
7.0
6.5
6.0
5.5
5.0
4.5
Jan
Mar
May
Jul
Sep
Nov
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano

Figure 3.3 Seasonal variations of monthly wet deposition

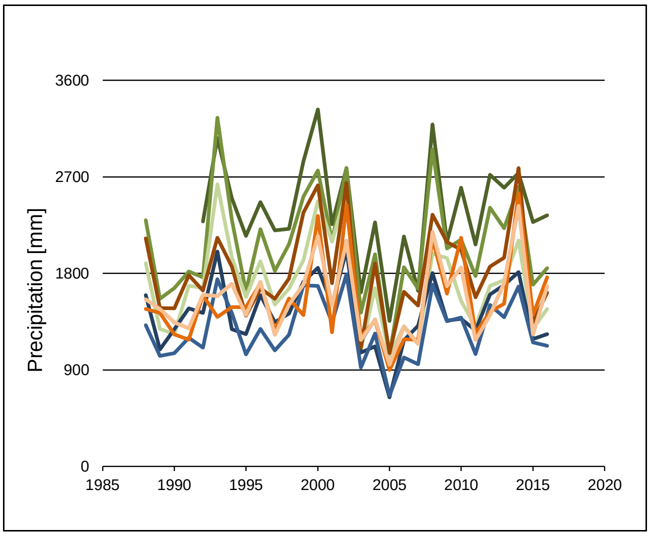



Base cations 2016 [meq m-2]
32
24
16
8
0
Jan
Mar
May
Jul
Sep
Nov
Base cations 2005-2015 [meq m-2]
32
24
16
8
0
Jan
Mar
May
Jul
Sep
Nov
Acidity 2016 [meq m-2]
7
0
-7
-14
-21
Jan
Mar
May
Jul
Sep
Nov
Robiei
Sonogno
Bignasco
Piotta
Acquarossa
Monte Bré
Locarno
Stabio
Lugano
Acidity 2005-2015 [meq m-2]
7
0
-7
-14
-21
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 2016 varied between 85-116%.

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.

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.

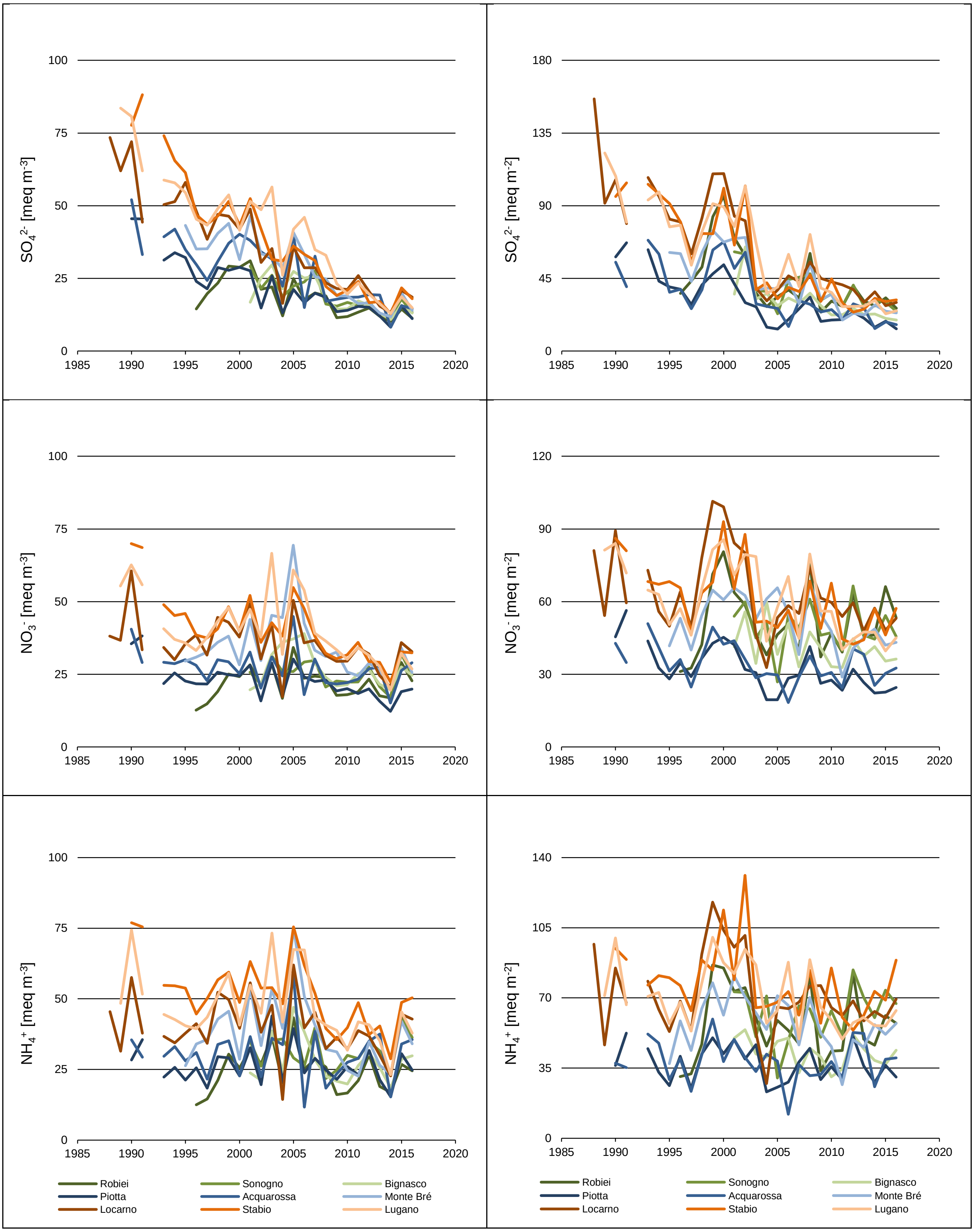
Concentrations and depositions of acidity, that can be calculated as the difference between acid anions and base cations and ammonia, decreased significantly at most sites. In general, concentrations and depositions of acidity decreased from values around 30-40 meq/m^3 and 60 meq/m^2, respectively to values around -15 meq/m^3 and -25 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 5.3 and 5.7 today.

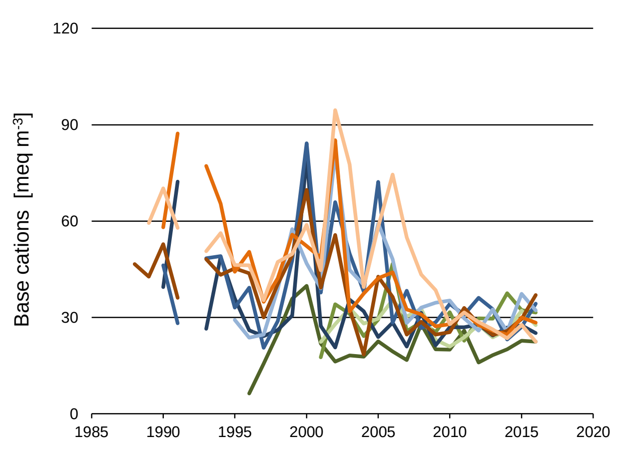
Trends of rainwater concentrations were analyzed for two different time periods: from 1988-1991 until 2000 and from 2000 until 2016. Since trends of depositions are “disturbed” by the precipitation volumes that vary irregularly through time, trends in depositions were calculated only for the entire monitoring 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.

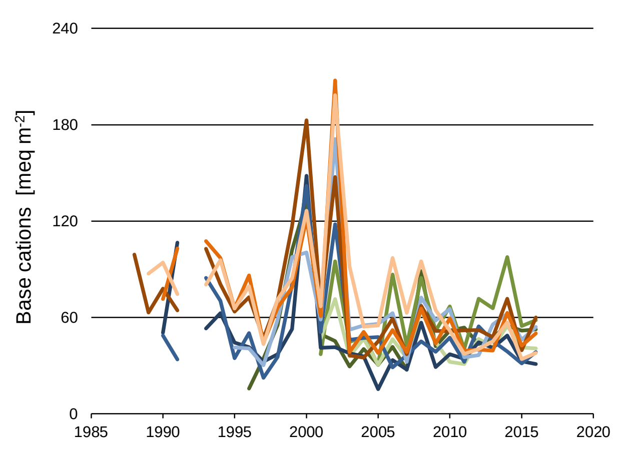
Sulphate concentrations decreased at all sites and, with exceptions of Acquarossa, rates were higher before 2000. Nitrate and ammonium started to decrease significantly only after 2000 (7 out of 9 for nitrate and 5 out of 9 for ammonium). Before 2000 a significant decrease could only be observed at Stabio. Because of the decrease in sulphate but also in nitrate concentrations, concentrations of hydrogen ions and total acidity decreased significantly at all sites, although the decreasing rates were higher before 2000.

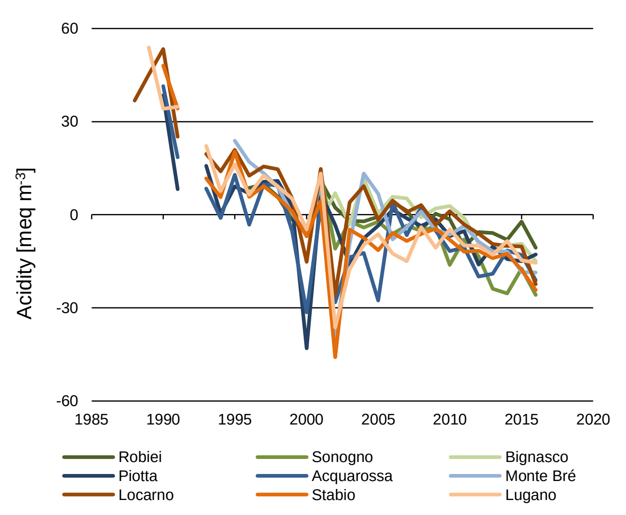
Trends in deposition are similar but less pronounced. The decrease in depositions of sulphate was significant at all sites. Depositions of nitrate decreased significantly at Acquarossa, Monte Brè, Locarno Monti, Piotta, Stabio. Less significant were trends for ammonium. Depositions of ammonium decreased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

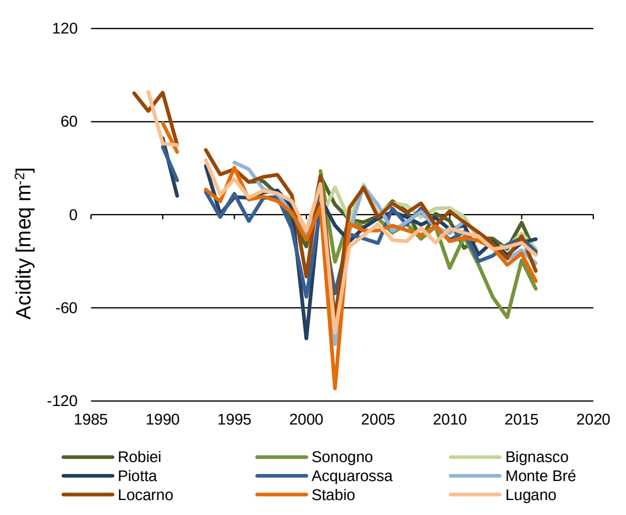
Figure 3.5 Temporal variations of annual mean rainwater concentrations, deposition rates and pH




Base cations [meq m-3]
0
30
60
90
120
1985
1990
1995
2000
2005
2010
2015
2020


Base cations [meq m-2]
0
60
120
180
240
1985
1990
1995
2000
2005
2010
2015
2020


Acidity [meq m-3]
-60
-30
0
30
60
1985
1990
1995
2000
2005
2010
2015
2020
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano


Acidity [meq m-2]
-120
-60
0
60
120
1985
1990
1995
2000
2005
2010
2015
2020
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano

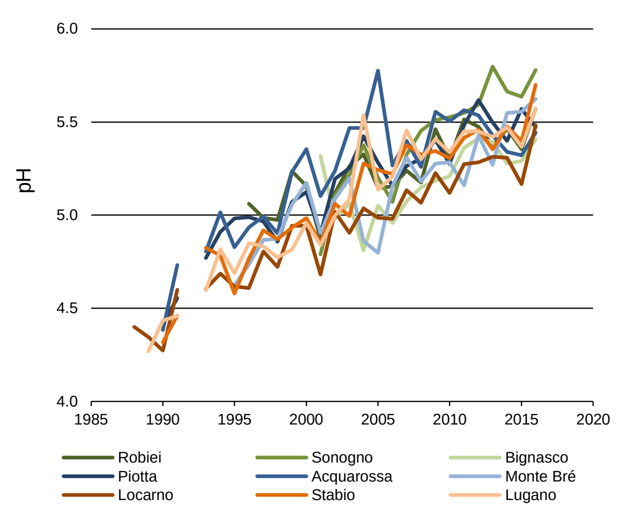

pH
4.0
4.5
5.0
5.5
6.0
1985
1990
1995
2000
2005
2010
2015
2020
Robiei
Piotta
Locarno
Sonogno
Acquarossa
Stabio
Bignasco
Monte Bré
Lugano

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^+**		**Cl^-**		**Base cations**		**H^+**		**Total acidity**	
(meq m^{-3} yr^{-1})	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate	rate
	'80/'90-00	'00-16	'90-00	'00-16	'90-00	'00-16	'90-00	'00-16	'90-00	'00-16	'90-00	'00-16	'90-00	'00-16
Acquarossa	-1.41	-1.54	-1.04	-0.44	-1.04	-0.30	-0.83	-0.06	-0.03	-2.04	-2.29	-0.02	-4.53	-0.10
Bignasco		-0.87		-0.62		-0.28		-0.04		-0.43		-0.53		-1.39
Monte Brè		-1.29		-0.74		-0.50		-0.02		-0.50		-0.45		-1.67
Locarno Monti	-3.20	-1.53	-0.78	-1.13	-0.54	-0.84	-0.61	-0.09	-0.70	-0.80	-3.48	-0.60	-4.38	-1.43
Lugano	-2.79	-2.52	-1.22	-1.60	-0.10	-1.33	-0.70	-0.30	-0.63	-2.39	-2.85	-0.24	-4.28	-0.98
Piotta	-1.43	-0.73	-0.62	-0.60	-0.11	-0.40	-0.43	-0.05	-1.10	-0.43	-1.63	-0.28	-2.14	-0.61
Robiei		-0.78		-0.15		-0.34		0.00		-0.16		-0.30		-0.63
Sonogno		-0.58		-0.34		-0.04		0.07		-0.01		-0.29		-1.40
Stabio	-3.44	-1.80	-2.08	-1.13	-0.85	-1.03	-0.98	-0.10	-2.93	-0.97	-2.65	-0.26	-3.83	-1.41

DEPOSITIONS	**SO_4^{2-}**	**NO_3^-**	**NH_4^+**	**Cl^-**	**Base cations**	**H^+**	**Total acidity**
(meq m^{-2} yr^{-1})	rate	rate	rate	rate	rate	rate	rate
	beginning-16	beginning-16	beginning-16	beginning-16	beginning-16	beginning-16	beginning-16
Acquarossa	-1.22	-0.51	-0.18	-0.12	-0.53	-0.49	-1.16
Bignasco	-0.75	-0.36	0.03	0.05	0.02	-0.46	-1.41
Monte Brè	-1.58	-0.63	-0.30	0.09	0.02	-0.82	-2.03
Locarno Monti	-2.57	-0.85	-0.46	-0.31	-0.69	-1.72	-2.75
Lugano	-2.47	-0.51	-0.12	-0.17	-0.77	-1.18	-2.51
Piotta	-0.77	-0.44	-0.13	-0.10	-0.40	-0.56	-1.04
Robiei	-1.22	-0.15	-0.26	-0.01	-0.08	-0.59	-1.30
Sonogno	-0.78	-0.22	0.17	0.14	0.56	-0.46	-2.34
Stabio	-2.57	-0.91	-0.34	-0.18	-1.04	-0.88	-2.33

3.6.2 Alpine lakes

Spatial variations

During 2016 sampling of Alpine lakes occurred at the following days: 7.7, 7.9, 10.10. 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 31 µS cm^{-1}, total alkalinity between -2 and 94 meq m^{-3}, pH between 5.5 and 7.3, sulphate between 12 and 185 meq m^{-3}, nitrate between 2 and 27 meq m^{-3}, dissolved organic carbon between 0.4 and 1.2 mg C l^{-1}, reactive dissolved silica between 0.8 and 3.1 mg SiO_2 l^{-1} and dissolved aluminum between 2 and 31 µg l^{-1}.

Table 3.4 Average lake surface water concentrations during autumn 2016 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})	7.0	8.4	27.0	9.0	7.8	30.9	14.8	21.5	9.2	8.7	18.3	113.2	14.9	14.3	7.2	10.2	13.9	8.9	10.2	9.0	15.4
pH	6.1	5.9	6.9	6.3	5.5	6.5	6.7	7.2	6.9	7.0	7.0	7.8	6.9	7.3	6.5	6.7	6.9	6.7	6.8	6.4	7.0
Alkalinity (meq m^{-3})	13	7	85	18	-2	33	49	84	42	43	86	636	70	94	30	46	65	52	49	30	84
Ca^{2+} (meq m^{-3})	20	34	154	44	23	141	69	100	44	42	101	861	91	84	35	54	79	42	51	35	76
Mg^{2+} (meq m^{-3})	9	6	15	6	9	54	17	24	7	6	14	113	8	6	5	7	9	8	8	10	15
Na^{+} (meq m^{-3})	12	13	23	11	7	22	15	28	13	11	17	20	13	19	11	14	15	16	17	14	20
K^{+} (meq m^{-3})	3	4	14	4	6	15	12	13	9	7	11	24	7	7	4	5	7	5	4	8	12
NH_4^{+} (meq m^{-3})	4.3	1.9	<1.4	<1.8	3.5	2.3	<2.1	<2.7	<2.0	<1.4	<1.9	<1.8	<1.7	<1.9	<2.1	2.1	<1.7	2.1	2.0	2.4	2.4
SO_4^{2-} (meq m^{-3})	20	21	112	32	32	185	62	74	22	20	61	416	42	17	12	15	26	18	24	22	31
NO_3^{-} (meq m^{-3})	14	27	19	15	12	11	11	12	12	9	8	10	12	16	15	23	22	2	11	17	16
Cl^{-} (meq m^{-3})	5	4	3	3	3	4	2	3	3	2	2	5	2	3	3	3	3	3	4	4	4
SRP (µg P l^{-1})	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5
DOC (mg C l^{-1})	1.0	0.5	0.5	0.5	0.4	0.5	0.5	0.7	1.0	1.1	0.5	0.5	0.6	0.7	0.5	0.6	0.5	1.2	1.0	1.0	0.8
SiO_2 (mg l^{-1})	1.7	1.6	3.0	1.4	0.8	2.1	1.9	3.1	1.3	1.3	1.8	1.9	1.4	2.6	1.5	1.7	2.1	2.1	2.1	1.6	2.7
$Al_{dissolved}$ (µg l^{-1})	31	15	3	3	23	4	4	8	6	9	2	7	6	8	2	5	10	17	11	8	7
Al_{tot} (µg l^{-1})	62	21	5	6	27	8	15	12	16	20	4	12	9	11	5	11	15	34	19	28	9
$Pb_{dissolved}$ (µg l^{-1})	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pb_{total} (µg l^{-1})	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
$Cd_{dissolved}$ (µg l^{-1})	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd_{total} (µg l^{-1})	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
$Cu_{dissolved}$ (µg l^{-1})	0.2	0.1	0.2	<0.1	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.1	0.2	<0.1
Cu_{tot} (µg l^{-1})	0.3	0.1	0.2	0.1	0.3	0.3	0.4	0.4	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.1	0.2	0.1
$Zn_{dissolved}$ (µg l^{-1})	1.9	1.2	0.6	0.7	1.5	1.1	0.7	0.2	0.8	0.3	0.4	0.2	0.6	0.4	0.5	0.5	0.4	1.2	0.8	1.1	0.5
Zn_{total} (µg l^{-1})	*2.0*	1.2	0.6	0.7	1.5	1.2	0.7	0.6	1.0	0.6	0.4	0.4	0.6	0.4	0.5	0.5	0.4	1.2	0.9	1.2	0.5
$Cr_{dissolved}$ (µg l^{-1})	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr_{total} (µg l^{-1})	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
$Ni_{dissolved}$ (µg l^{-1})	*0.1*	0.1	0.1	0.1	1.4	6.1	0.5	0.3	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Ni_{total} (µg l^{-1})	*0.1*	0.1	0.1	0.1	1.4	6.1	0.5	0.4	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1

In order to better compare chemistry of lakes with low alkalinities, values of the main parameters measured during 2016 and their mean values from 2005 to 2015 are shown graphically in Fig. 3.6.

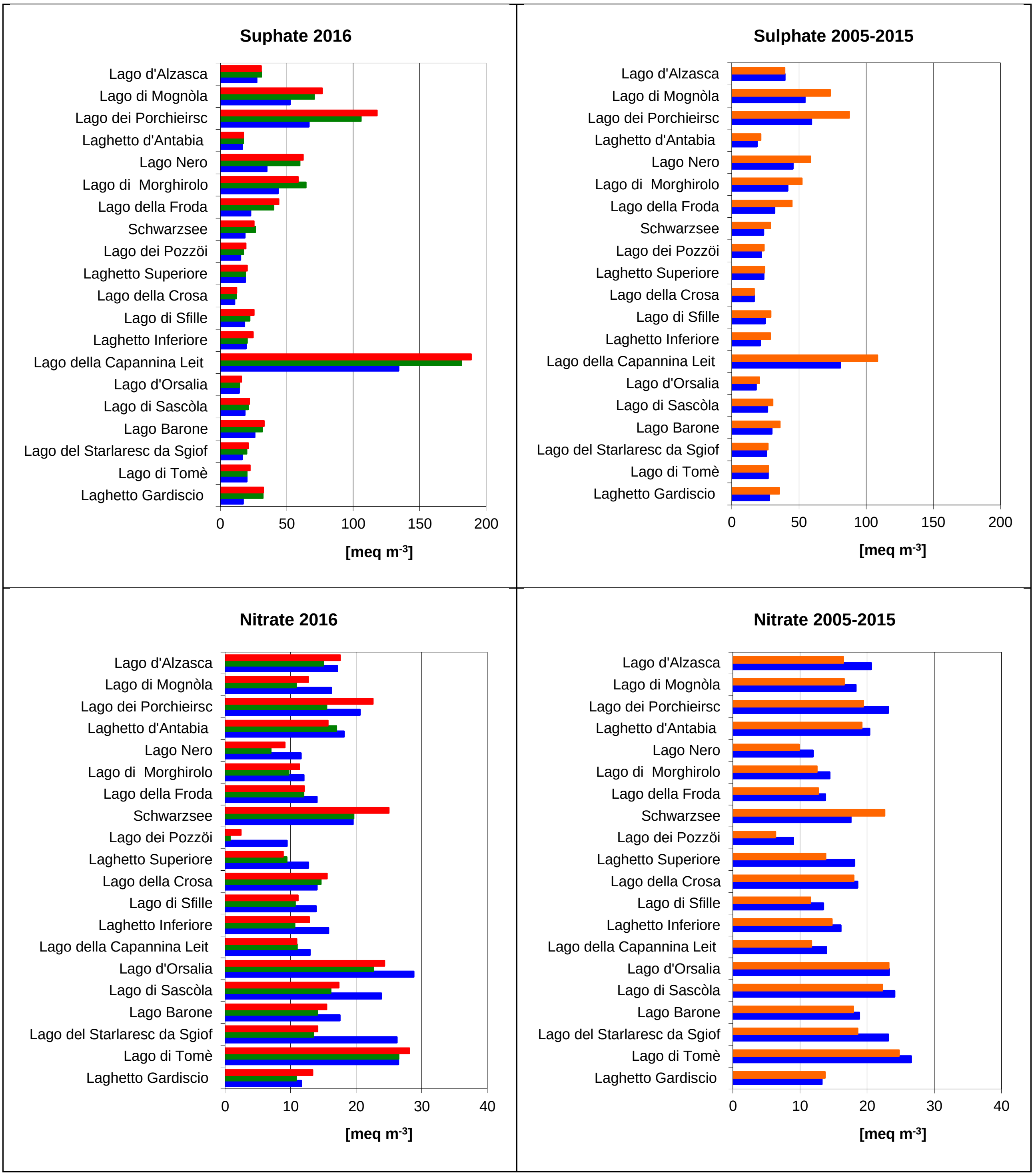
In general, values from 2016 were not much different from average values of the period 2005-2015. Concentrations of sulphate were significantly higher in lakes Leit and Porchieirsc, but in all other lakes concentrations were slightly lower than 2005-2015 averages. Highest concentrations of sulphate were measured in lakes with probably sulphur sources in their catchments (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.

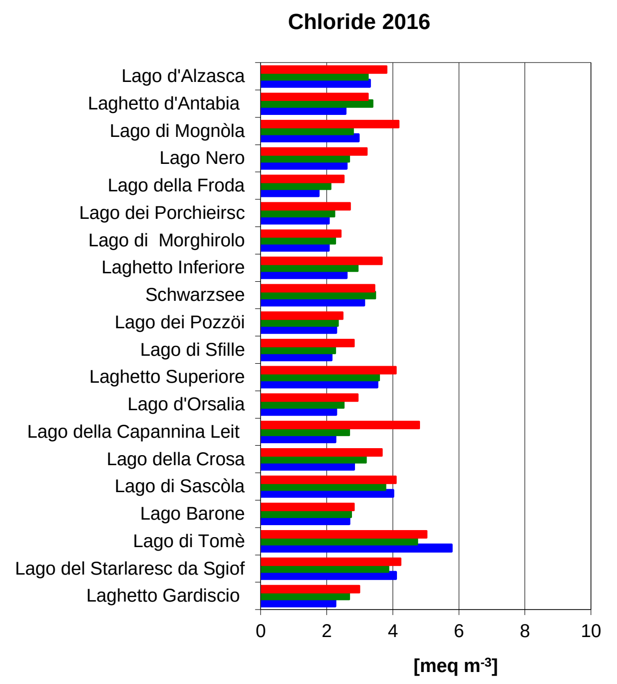
Concentrations of nitrate were also for most lakes only slightly lower than during the previous decade. Surprisingly low were autumn concentrations of nitrate in lake Pozzöi. Uptake by phytoplankton (algal bloom) might be the reason. Although concentrations of total nitrogen were not measured, the, compared to the other lakes, slightly higher concentrations of DOC might confirm the hypothesis. Similar than observed for sulphate, concentrations of nitrate in rainwater do not vary enough among lakes to explain differences in lake concentrations. These are determined by the retention capacity of the lakes catchments. As observed for sulphate, concentrations of base cations during 2016 were higher than average values of 2005-2015 in lakes Leit and Porchieirsc, while in the other lakes concentrations were similar or slightly lower. Highest concentrations of base cations normally characterize lakes with highest alkalinities and pH's. Lago Leit again differs from this tendency and has very high concentrations of base cations compared to its alkalinity and pH. Alkalinities below 0 meq m^{-3} were detected only in Laghetto Gardiscio, while alkalinities constantly above 50 meq m^{-3} were measured only in Lago dei Porchieirsc, Laghetto d'Antabia and Lago d'Alzasca. All other 16 lakes were at least temporary sensitive to acidification ($0 <$ alkalinity < 50 meq m^{-3}). Compared to mean values from 2005-2015, alkalinities and pH's were slightly higher during 2016. In general, lakes with low pH's are characterized by relatively high concentrations of aluminum (Lago del Starlaresc da Sgiof: 34-48 µg l^{-1}; Laghetto Gardiscio: 23-27 µg $l^{-1}$and Lago di Tomè: 15-21 µg l^{-1}). In these lakes, coherently with the higher pH values, concentrations of aluminum measured during 2016 were slightly lower compared to 2005-2016 mean values.

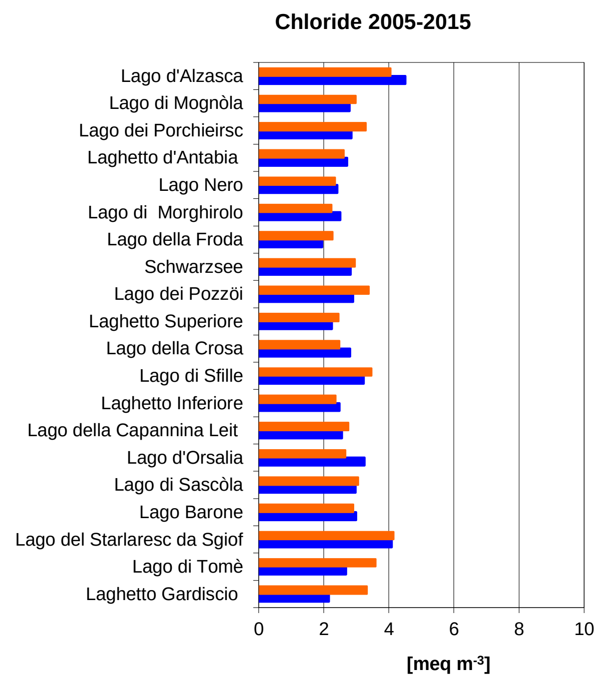
Seasonal variations

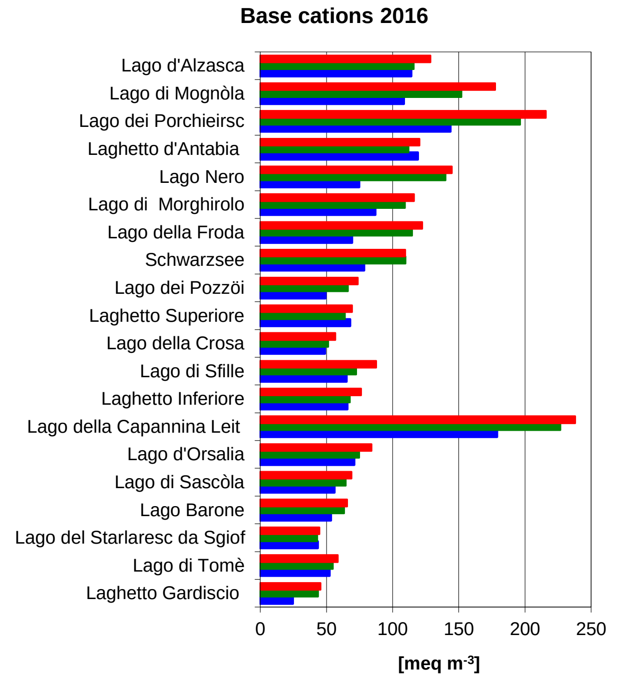
Fig. 3.6 also shows some seasonal differences. In most lakes alkalinity and pH and concentrations of sulphate and base cations tend to be lower in July than in September and October. The reason is the elevated discharge (precipitation and snow melt) in spring that causes a dilution of sulphate, base 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.

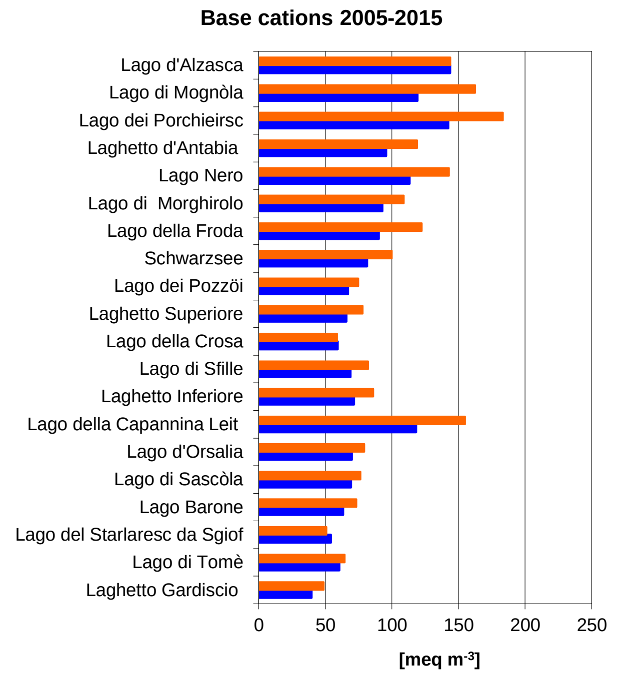
Figure 3.6 Concentrations of the main chemical parameters in 20 Alpine lakes during 2016 and their average values from 2005 to 2015. Blue columns represent summer, green early autumn, red late autumn and orange mean autumn values.

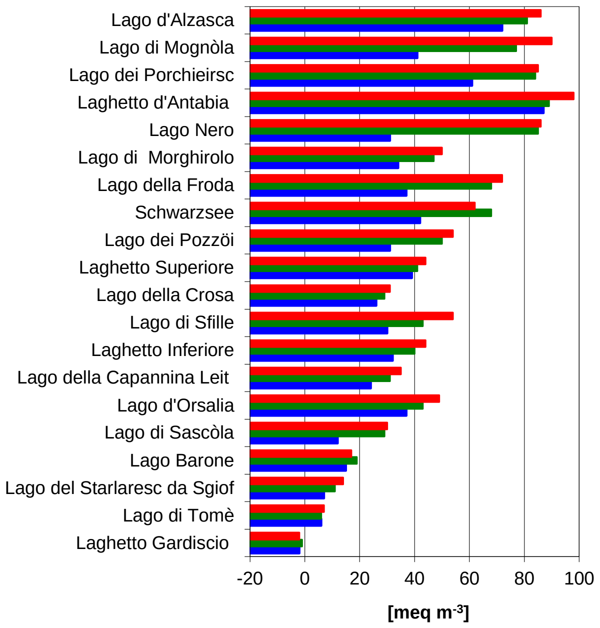



Chloride 2016

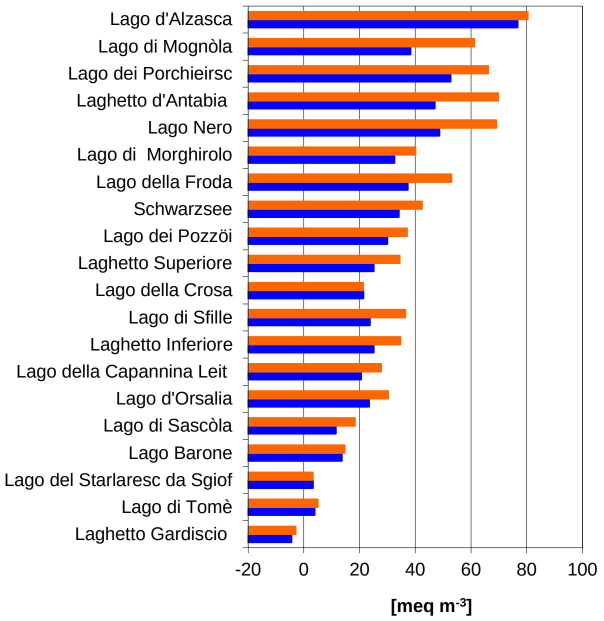

Chloride 2005-2015


Base cations 2016

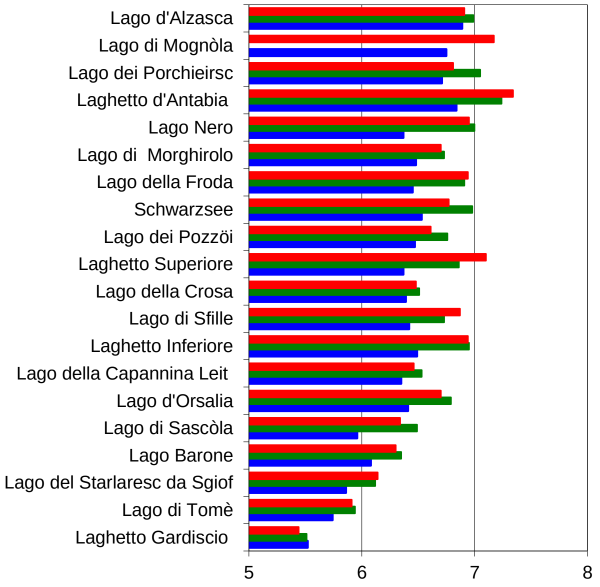

Base cations 2005-2015



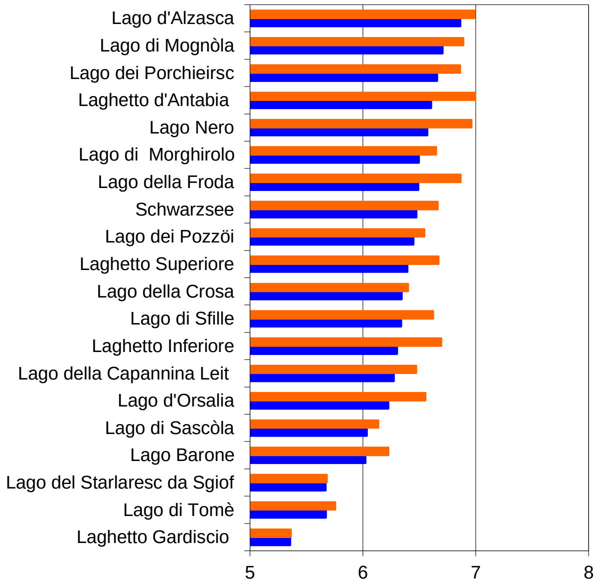
Alkalinity 2016



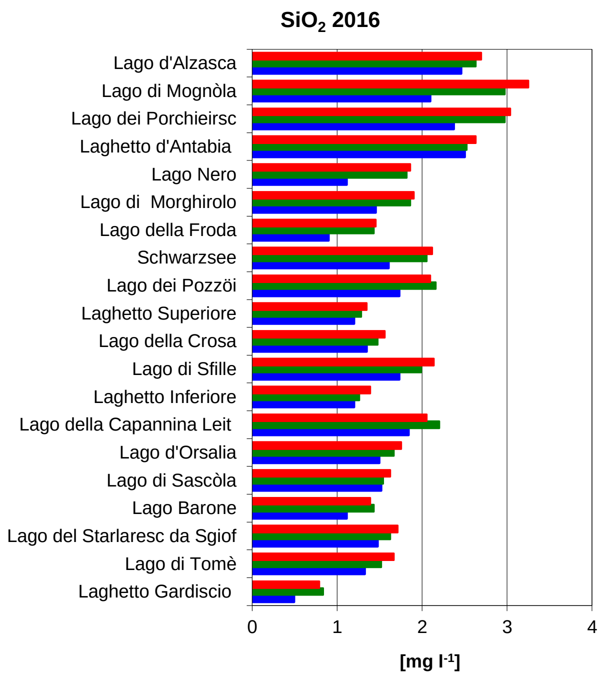
Alkalinity 2005-2015

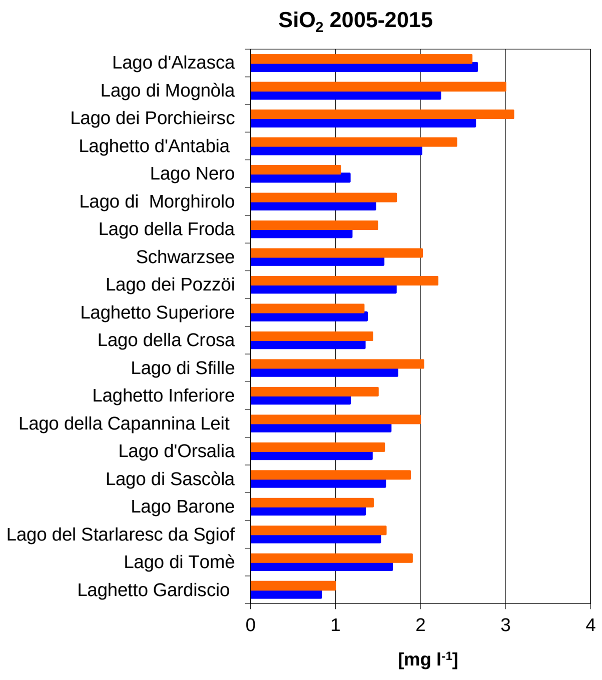


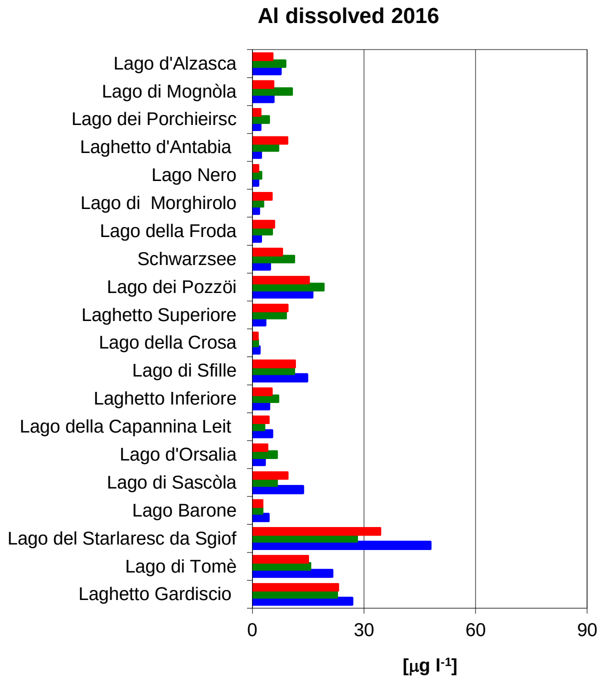
pH 2016

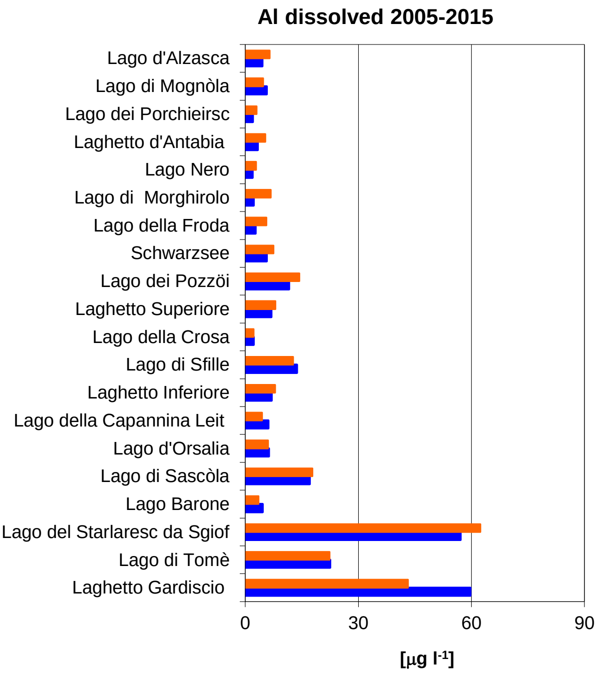


pH 2005-2015


SiO2 2016
Lago d'Alzasca
Lago di Mognòla
Lago dei Porchieirsc
Laghetto d'Antabia
Lago Nero
Lago di Morghirolo
Lago della Froda
Schwarzsee
Lago dei Pozzöi
Laghetto Superiore
Lago della Crosa
Lago di Sfille
Laghetto Inferiore
Lago della Capannina Leit
Lago d'Orsalia
Lago di Sascòla
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Tomè
Laghetto Gardiscio
0
1
2
3
4
[mg l-1]


SiO2 2005-2015
Lago d'Alzasca
Lago di Mognòla
Lago dei Porchieirsc
Laghetto d'Antabia
Lago Nero
Lago di Morghirolo
Lago della Froda
Schwarzsee
Lago dei Pozzöi
Laghetto Superiore
Lago della Crosa
Lago di Sfille
Laghetto Inferiore
Lago della Capannina Leit
Lago d'Orsalia
Lago di Sascòla
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Tomè
Laghetto Gardiscio
0
1
2
3
4
[mg l-1]


Al dissolved 2016
Lago d'Alzasca
Lago di Mognòla
Lago dei Porchieirsc
Laghetto d'Antabia
Lago Nero
Lago di Morghirolo
Lago della Froda
Schwarzsee
Lago dei Pozzöi
Laghetto Superiore
Lago della Crosa
Lago di Sfille
Laghetto Inferiore
Lago della Capannina Leit
Lago d'Orsalia
Lago di Sascòla
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Tomè
Laghetto Gardiscio
0
30
60
90
[µg l-1]


Al dissolved 2005-2015
Lago d'Alzasca
Lago di Mognòla
Lago dei Porchieirsc
Laghetto d'Antabia
Lago Nero
Lago di Morghirolo
Lago della Froda
Schwarzsee
Lago dei Pozzöi
Laghetto Superiore
Lago della Crosa
Lago di Sfille
Laghetto Inferiore
Lago della Capannina Leit
Lago d'Orsalia
Lago di Sascòla
Lago Barone
Lago del Starlaresc da Sgiof
Lago di Tomè
Laghetto Gardiscio
0
30
60
90
[µg l-1]

Temporal variations

In order to show temporal variations of lake water 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 in most lakes, because of reduced SO_x emissions and therefore also sulphate depositions. Concentrations of nitrate also slightly decreased as a consequence of reduced emissions of NO_x. As a consequence of decreasing sulphate and nitrate concentrations, concentrations of base cations decreased as well and alkalinity and pH increased. However, contrary to this general trend, in some lakes concentrations of sulphate and base cations are not decreasing (Porchieirsc, Nero), in others they are even increasing (Leit, Morghirolo, Mognola), that's why 90^{th} percentiles are not decreasing like median values (Fig. 3.7).

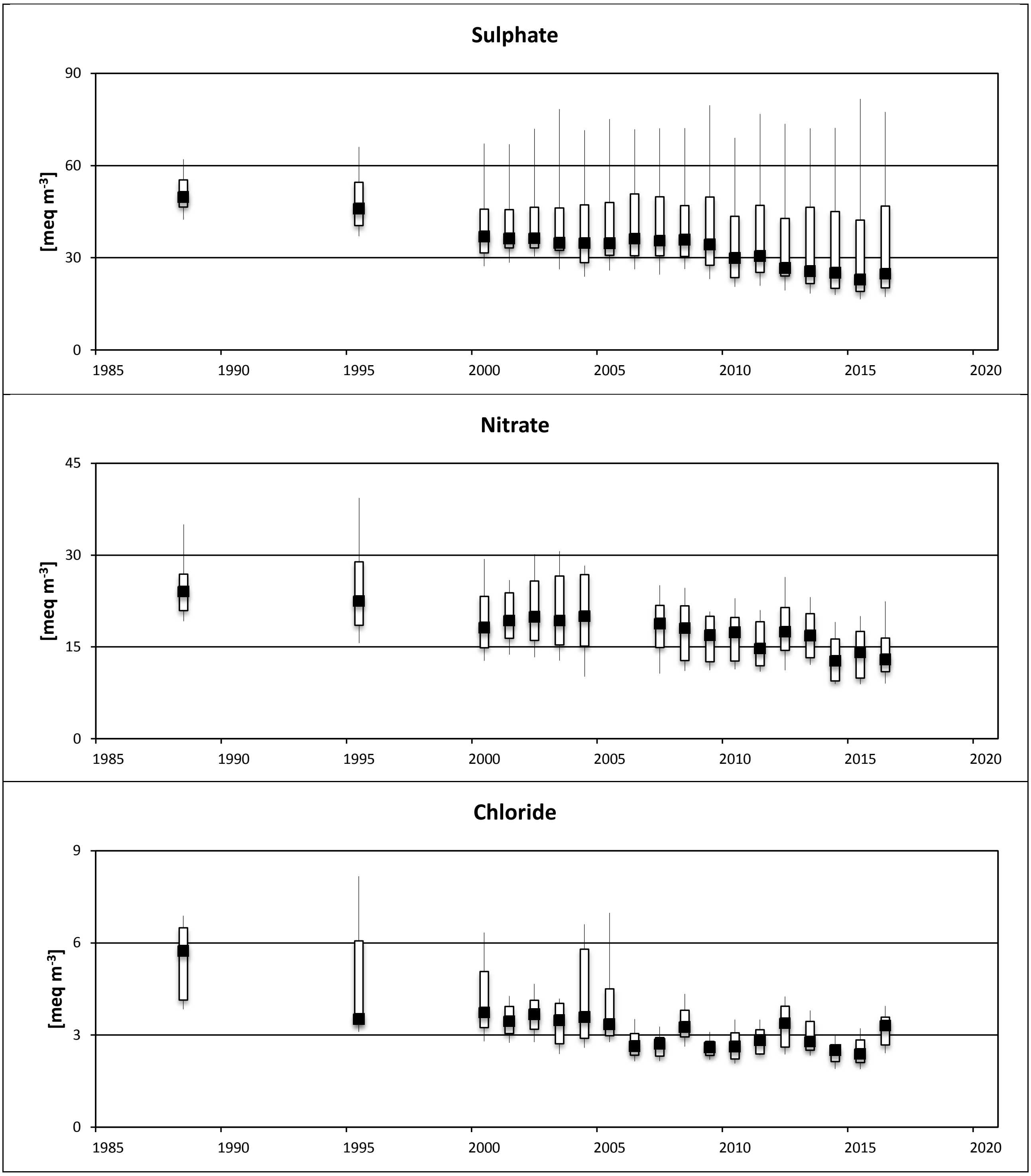
The significantly higher concentrations of chloride, base cations, alkalinity and pH and lower concentrations of nitrate in autumn 2016 compared to the most recent years, are most probably due to the long precipitation poor period lasting from June to October.

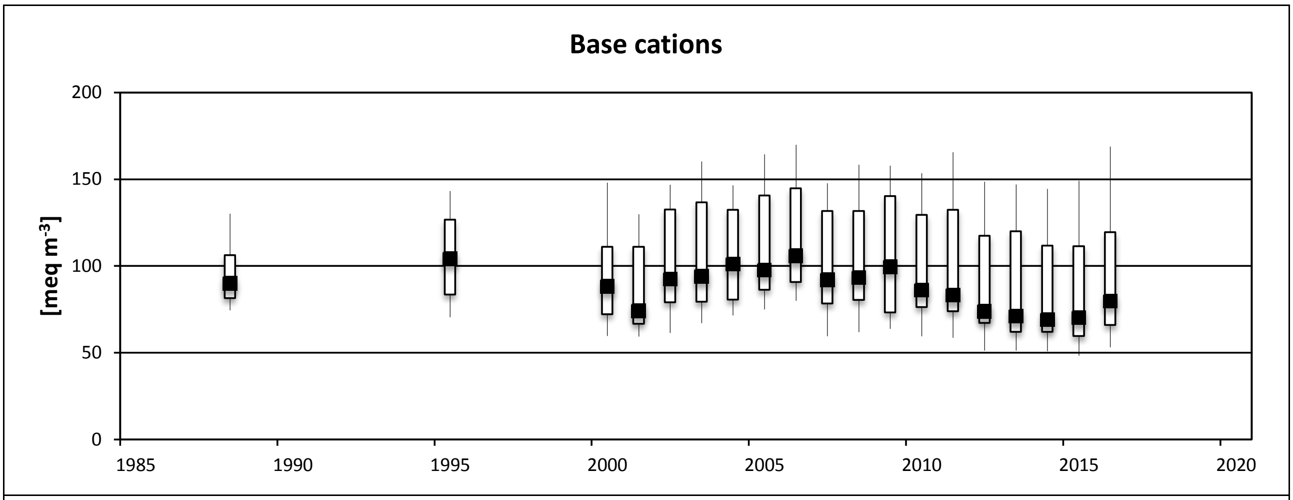
Aluminum concentrations of the 3 most acidic lakes are presented in Fig. 3.8 (see also trends in Tab. 3.5). The most evident decrease in concentrations occurred in Lago del Starlaresc da Sgiof from 80-100 to 30-60 µg l^{-1}. In Lago di Tomè concentrations decreased from about 40 to 20 µg l^{-1} and in Laghetto Gardiscio from 30-60 µg l^{-1} to 20-35 µg l^{-1}.

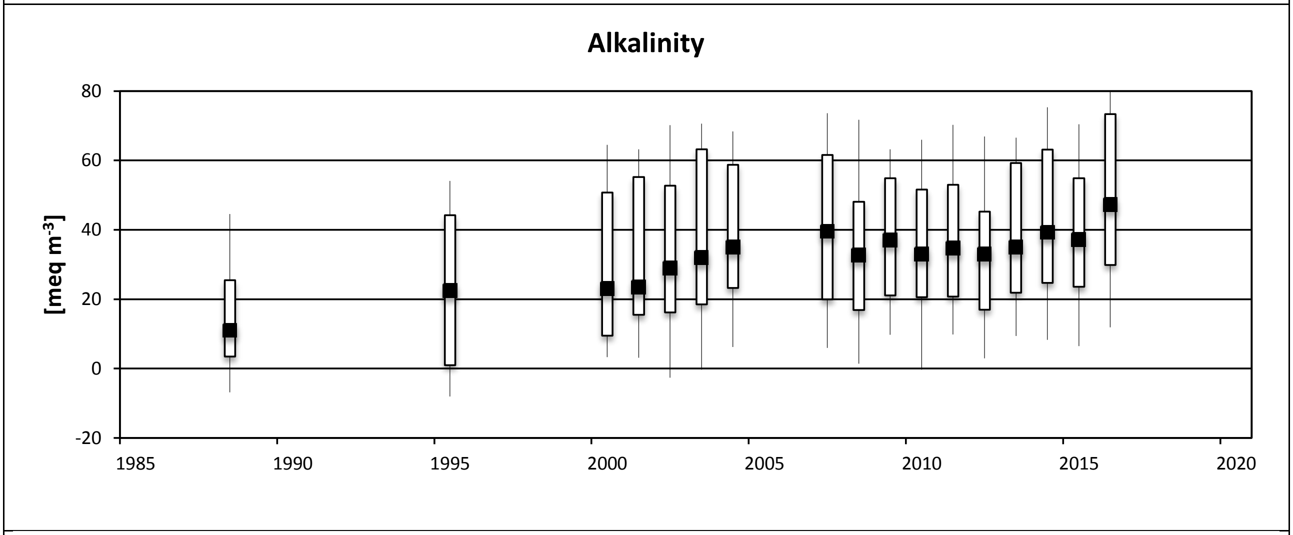
Results of a detailed trend analysis of the main parameters are presented in Tab. 3.5. Trends were calculated for the entire monitoring period and after 2000, when sampling occurred more regularly and frequently. Thanks to decreasing sulphate and nitrate depositions, since the 1980s concentrations of sulphate and nitrate decreased significantly in 15 and 16 lakes, respectively. While for sulphate the calculated decreasing 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 15 lakes and increasing concentrations of total alkalinity (significant in 17 lakes). For the first time the decrease in aluminum concentrations was significant not only in Lago del Starlaresc da Sgiof and Lago di Tomè but also in Lago Gardiscio.

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). A sulphur budget analysis of the catchments (data not shown) showed that in the other lakes, whereas neither a sulphate decrease nor increase could be observed (Porchieirsc, Nero), sulphur release from the catchments is also significantly increasing. Climate change leading to melting of permafrost and rock glaciers (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 2016 (calculated from autumn mean values).




Base cations
[meq m^{-3}]
200
150
100
50
0
1985
1990
1995
2000
2005
2010
2015
2020


Alkalinity
[meq m^{-3}]
80
60
40
20
0
-20
1985
1990
1995
2000
2005
2010
2015
2020

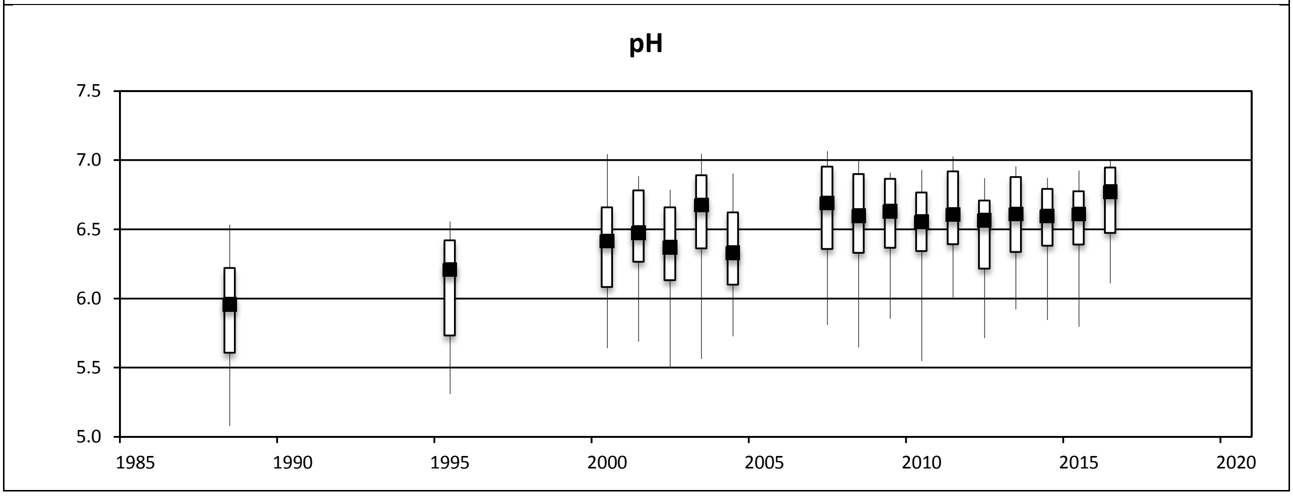

pH
7.5
7.0
6.5
6.0
5.5
5.0
1985
1990
1995
2000
2005
2010
2015
2020

Figure 3.8 Temporal variations of dissolved aluminum in the 3 most acidic lakes from 1988 to 2016 (mean autumn values).

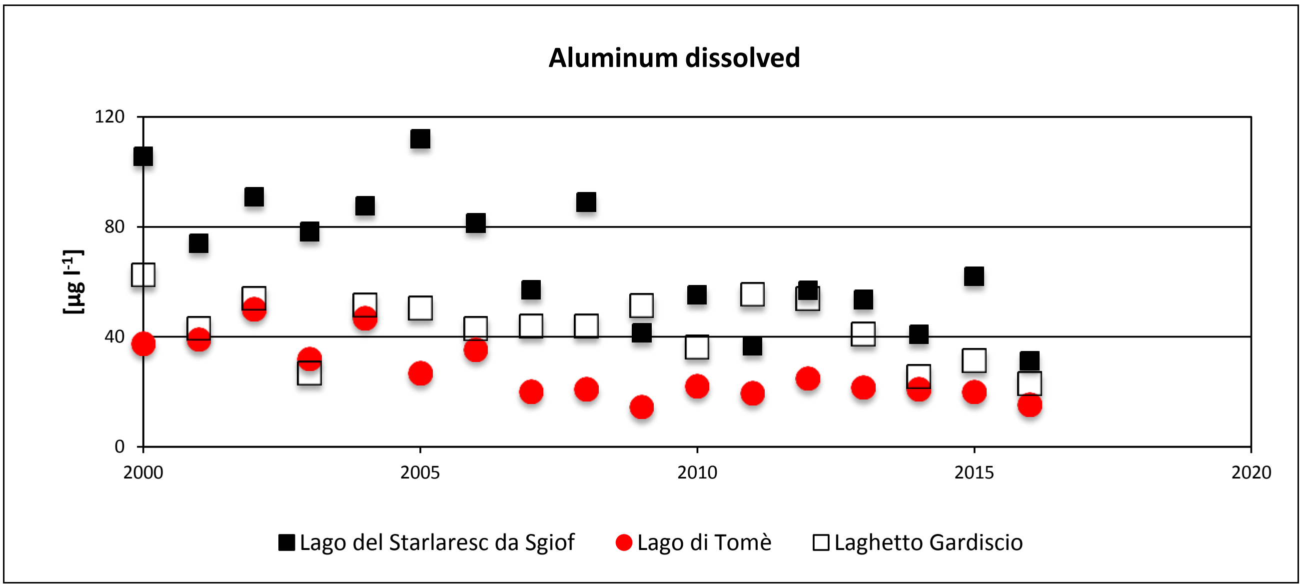


Table 3.5 Results from trend analyses during the indicated time periods. Red values of concentration rates indicate significant trends.

Lake	SO_4^{2-}		NO_3^-		Cl^-		Base cations		H^+		Total alkalinity		Al_{dis}
	rate '80-16	rate 00-16	rate '80-16	rate 00-16	rate '80-16	rate 00-16	rate '80-16	rate 00-16	rate '80-16	rate 00-16	rate '80-16	rate 00-16	rate 00-16
Lago del Starlaresc da Sgiof	-1.29	-1.21	-0.56	-0.83	-0.10	-0.11	-1.06	-1.32	-4.7E-1	-3.6E-1	0.95	1.25	-3.83
Lago di Tomè	-0.92	-0.82	-0.33	-0.85	-0.05	-0.05	-1.20	-1.78	-6.9E-2	-2.8E-2	0.38	0.16	-1.39
Lago dei Porchieirsc	0.61	0.44	-0.41	-0.54	-0.04	-0.06	0.05	-0.65	-4.2E-3	-6.9E-4	0.75	0.47	
Lago Barone	-0.44	-0.40	-0.27	-0.50	-0.07	-0.08	-0.50	-0.74	-3.7E-2	-1.8E-2	0.56	0.56	
Laghetto Gardiscio	-0.25	-0.21	-0.23	-0.29	-0.06	-0.05	-0.43	-0.48	-1.0E-1	-6.6E-2	0.27	0.20	-1.34
Lago Leit	2.85	5.21	-0.25	-0.29	-0.04	0.02	2.72	4.48	-8.3E-3	2.3E-2	0.50	0.35	
Lago di Morghirolo	0.34	0.82	-0.17	-0.28	-0.05	-0.05	0.63	0.38	-3.9E-3	-8.3E-4	0.77	0.70	
Lago di Mognòla	0.36	0.27	-0.19	-0.40	-0.04	-0.03	0.31	-1.04	-7.7E-4	2.3E-3	0.00	-0.38	
Laghetto Inferiore	-0.95	-0.91	-0.44	-0.63	-0.09	-0.07	-1.09	-1.79	-8.9E-3	-9.3E-3	0.56	0.67	
Laghetto Superiore	-0.84	-0.80	-0.41	-0.75	-0.06	-0.05	-0.45	-1.07	-1.5E-2	-1.2E-2	0.93	1.07	
Lago Nero	0.05	0.27	-0.12	-0.20	-0.06	-0.03	0.28	0.19	-2.8E-3	--1.8E-4	0.71	0.65	
Lago della Froda	-0.32	-0.31	-0.26	-0.34	-0.04	-0.03	0.13	-0.10	-5.7E-3	-2.0E-3	0.75	0.52	
Lago d'Antabia	-0.74	-0.77	-0.35	-0.55	-0.08	-0.08	-0.28	-1.42	-3.7E-3	-1.2E-3	0.72	0.60	
Lago della Crosa	-0.84	-0.78	-0.17	-0.33	-0.07	-0.08	-0.62	-1.06	-2.4E-2	-8.8E-3	0.71	0.69	
Lago d'Orsalìa	-0.95	-0.91	-0.27	-0.61	-0.09	-0.09	-0.36	-1.08	-3.8E-2	-1.4E-2	1.03	1.00	
Schwarzsee	-1.08	-1.10	-0.25	-0.27	-0.06	-0.09	-1.19	-1.73	-7.9E-3	-5.6E-3	0.57	0.40	
Laghi dei Pozzöi	-1.09	-1.03	-0.19	-0.27	-0.09	-0.04	-0.86	-1.66	-4.7E-3	-4.0E-3	0.44	0.48	-0.64
Lago di Sfille	-0.94	-0.88	-0.22	-0.26	-0.07	-0.07	-0.74	-1.01	-1.0E-2	-7.5E-3	0.77	0.83	-0.86
Lago di Sascòla	-1.03	-1.02	-0.29	-0.81	-0.11	-0.10	-1.25	-2.20	-1.8E-2	-7.9E-3	0.42	0.38	-0.21
Lago d'Alzasca	-1.00	-1.03	-0.06	-0.12	-0.09	-0.11	-0.45	-1.83	-3.0E-3	-7.7E-4	0.89	0.83	

3.6.3 Alpine rivers

Spatial variations

During 2016 river water was sampled at the following days: 18.1, 15.2, 14.3, 11.4, 2.5, 13.6, 11.7, 8.8, 12.9, 24.10, 11.11, 12.12. Annual mean concentrations of the chemical parameters measured in river Maggia, Vedeggio and Verzasca during 2016 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 2016 average alkalinity was 354 meq m^{-3} in river Maggia, 185 meq m^{-3} in river Vedeggio and 75 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 7.5 in river Maggia, 7.1 in river Vedeggio and 6.9 in river Verzasca. Their minimum pH's were not much lower (Maggia: 7.4, Vedeggio: 7.1, Verzasca: 6.8).

Table 3.6 Average concentrations in river water during 2016. 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})	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})	$Pb_{dissolved}$ (µg l^{-1})	Pb_{tot} (µg l^{-1})	$Cd_{dissolved}$ (µg l^{-1})	Cd_{total} (µg l^{-1})	$Cu_{dissolved}$ (µg l^{-1})	Cu_{tot} (µg l^{-1})	$Zn_{dissolved}$ (µg l^{-1})	Zn_{total} (µg l^{-1})	$Cr_{dissolved}$ (µg l^{-1})	Cr_{total} (µg l^{-1})	$Ni_{dissolved}$ (µg l^{-1})	Ni_{total} (µg l^{-1})
Maggia	7.5	67	354	408	53	80	40	200	32	33	<7.5	0.7	5.5	7.9	8.6	<0.1	<0.1	<0.1	<0.1	0.4	0.4	1.8	1.9	<0.1	<0.1	0.2	0.2
Vedeggio	7.1	45	185	223	70	71	14	125	60	25	<7.5	0.8	7.6	6.5	9.0	<0.1	<0.1	<0.1	<0.1	0.4	0.5	1.2	1.3	<0.1	<0.1	0.8	0.9
Verzasca	6.9	24	75	117	18	37	15	70	43	12	<7.5	0.6	4.5	10.4	11.1	<0.1	<0.1	<0.1	<0.1	0.3	0.3	1.0	1.1	<0.1	<0.1	0.2	0.2

Seasonal variations

Fig. 3.9 shows the daily mean discharges during 2016 and average values during 2005-2015. Discharges are usually low during winter, high in spring because of frequent precipitation and snow melt, average during summer and higher again in autumn. 2016 was characterized by typical low discharges during winter and high values during spring but low values afterwards.

Concentrations of the main chemical parameters in river water during sampling days in 2016 and their average values during 2005-2015 are shown in Fig. 3.10.

During 2005-2015 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 lower retention (uptake by vegetation and algae, denitrification) and occasionally higher values during precipitation events or snow melt because of leakage from soils. Concentrations of aluminum seem to reach their highest concentrations during high flow events. In fact, their average concentrations during 2005-2015 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.

Concentrations during 2016 were in general in the same range as average values measured during 2005-2015. However, because of the dry autumn, concentrations of sulphate, base cations, silica, alkalinity and pH were less diluted and therefore slightly higher than usual. Differently, concentrations of nitrate and aluminum that are normally higher during increased discharge, were slightly lower than average after August.

Figure 3.9 Daily mean discharge during 2016 and average daily mean discharge during 2005-2015. Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2017), discharge of river Verzasca at Sonogno was estimated by discharge values measured at Lavertezzo by BWG (2001-2004) and BAFU (2005-2017), discharge of river Maggia at Brontallo was estimated from values measured at Brontallo by Ofima and at Bignasco by BWG (2001-2004) and BAFU (2005-2017).

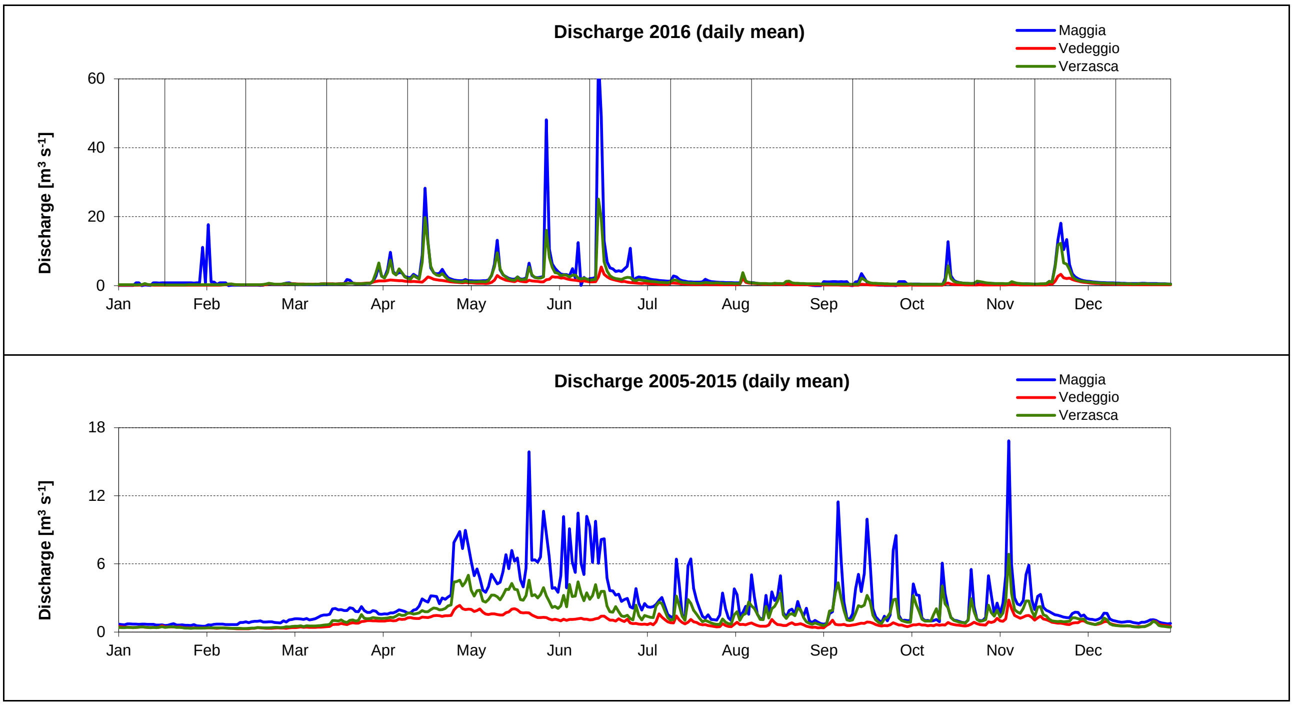
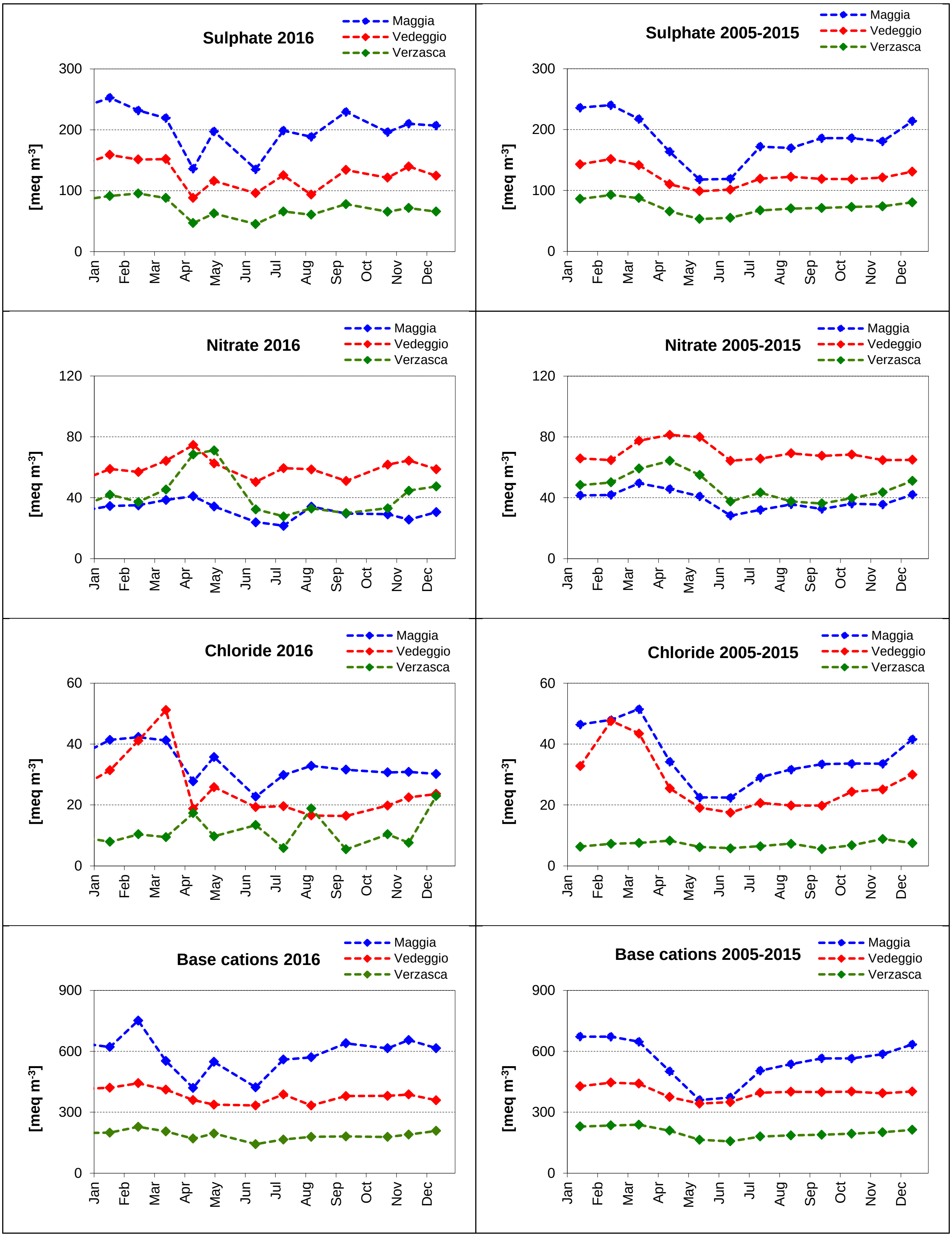
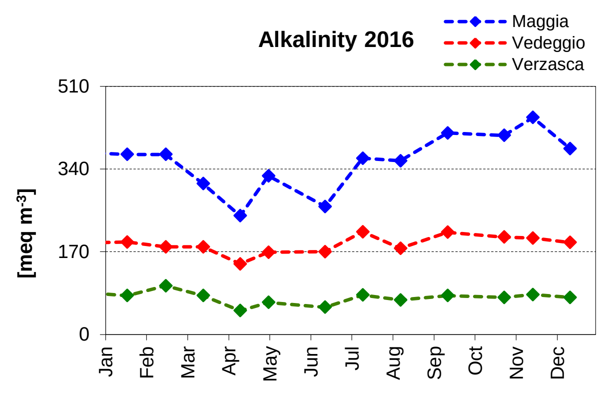
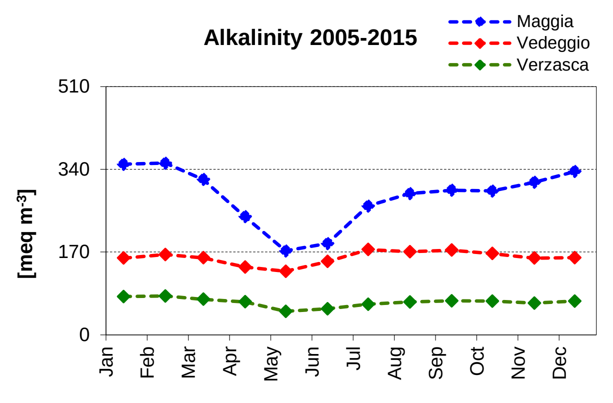
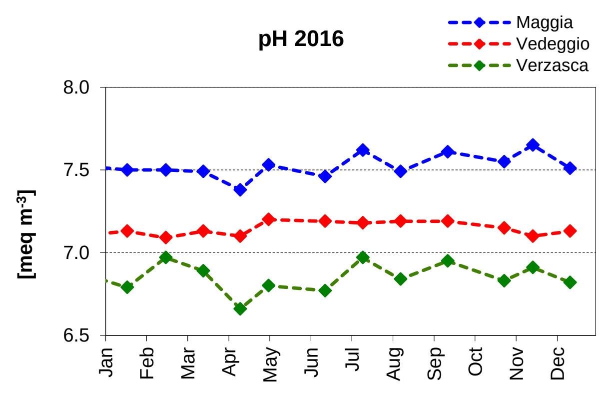


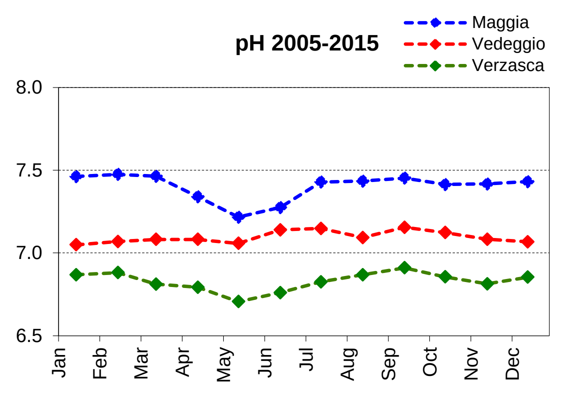
Figure 3.10 Concentrations of the main chemical parameters in river water during sampling days in 2016 and their average values from 2005 to 2015.

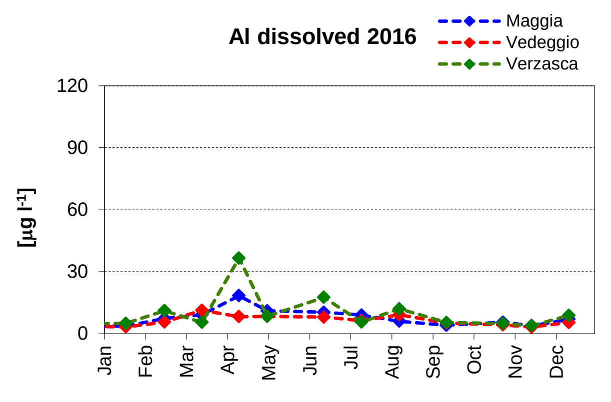


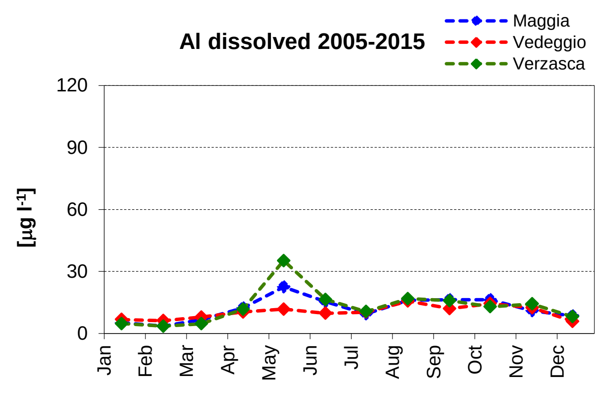

Alkalinity 2016
Maggia
Vedeggio
Verzasca
510
340
170
0
[meq m-3]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

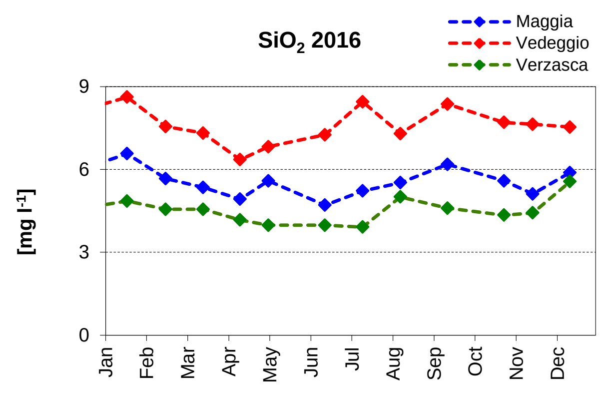

Alkalinity 2005-2015
Maggia
Vedeggio
Verzasca
510
340
170
0
[meq m-3]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

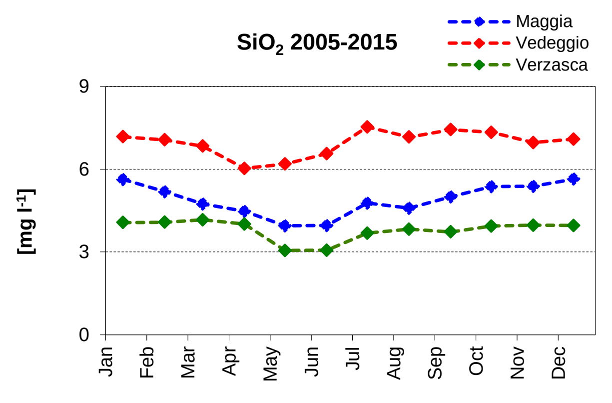

pH 2016
Maggia
Vedeggio
Verzasca
8.0
7.5
7.0
6.5
[meq m-3]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


pH 2005-2015
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 2016
Maggia
Vedeggio
Verzasca
120
90
60
30
0
[µg l-1]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Al dissolved 2005-2015
Maggia
Vedeggio
Verzasca
120
90
60
30
0
[µg l-1]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SiO2 2016
Maggia
Vedeggio
Verzasca
9
6
3
0
[mg l-1]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SiO2 2005-2015
Maggia
Vedeggio
Verzasca
9
6
3
0
[mg l-1]
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 2016 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 2000-2016. Results of the trend analysis are shown in Tab. 3.7. Concentrations of sulphate and nitrate decreased significantly in all 3 rivers. No significant trend can be observed for base cations and pH, while for alkalinity significant increasing trends were detected in river Vedeggio and Verzasca.

Figure 3.11 Monthly mean discharge in river water from 2000 to 2016. Discharge of river Vedeggio at Isone was measured by the Canton of Ticino (UCA, 2001-2017), discharge of river Verzasca at Sonogno was estimated by discharge values measured at Lavertezzo by BWG (2001-2004) and BAFU (2005-2017), discharge of river Maggia at Brontallo was estimated from values measured at Brontallo by Ofima and at Bignasco by BWG (2001-2004) and BAFU (2005-2017).

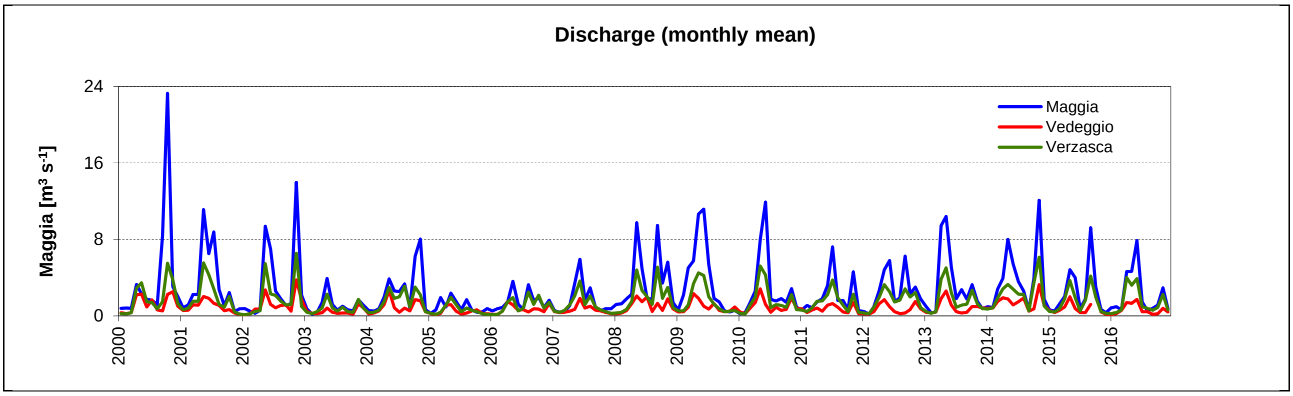
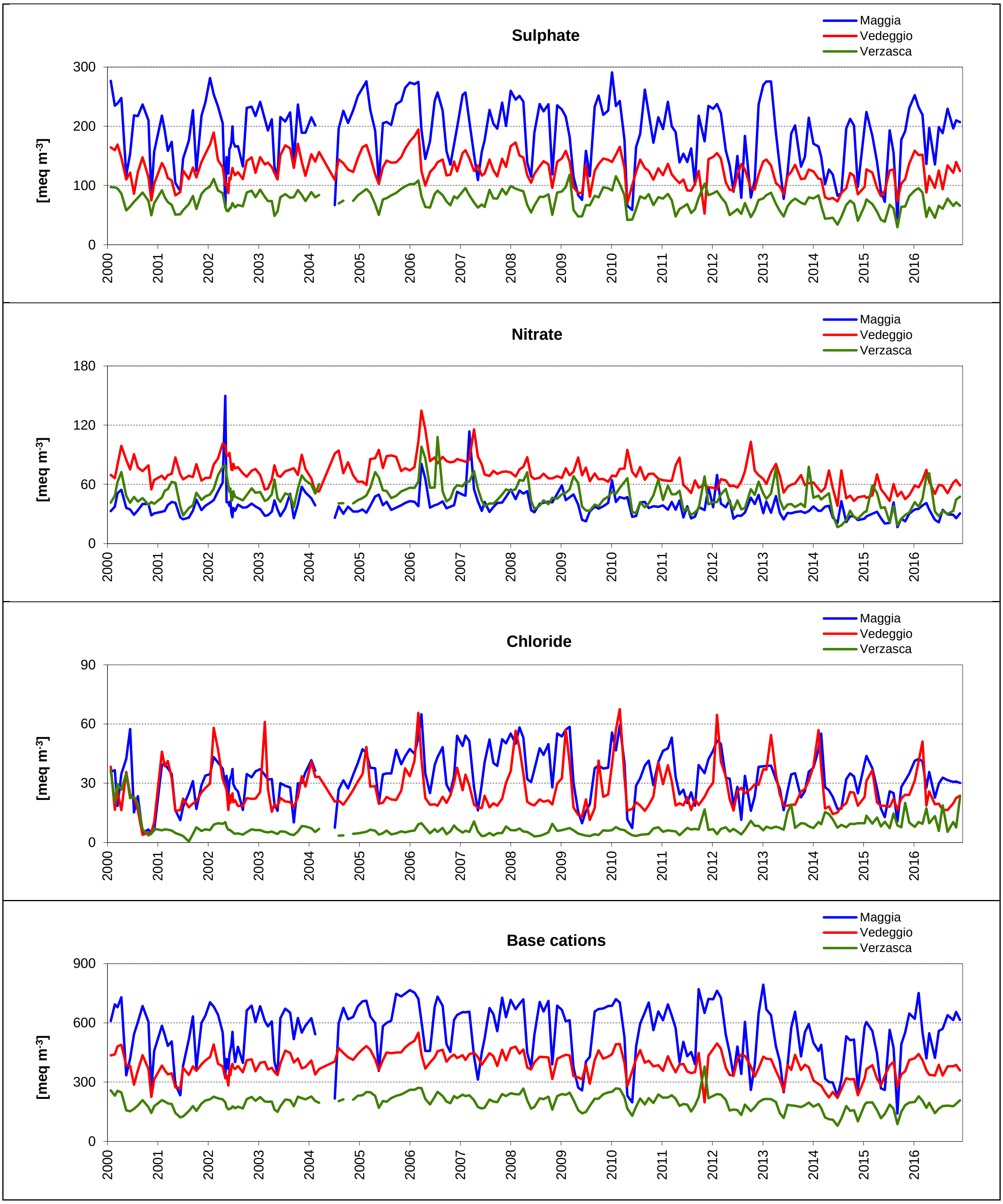
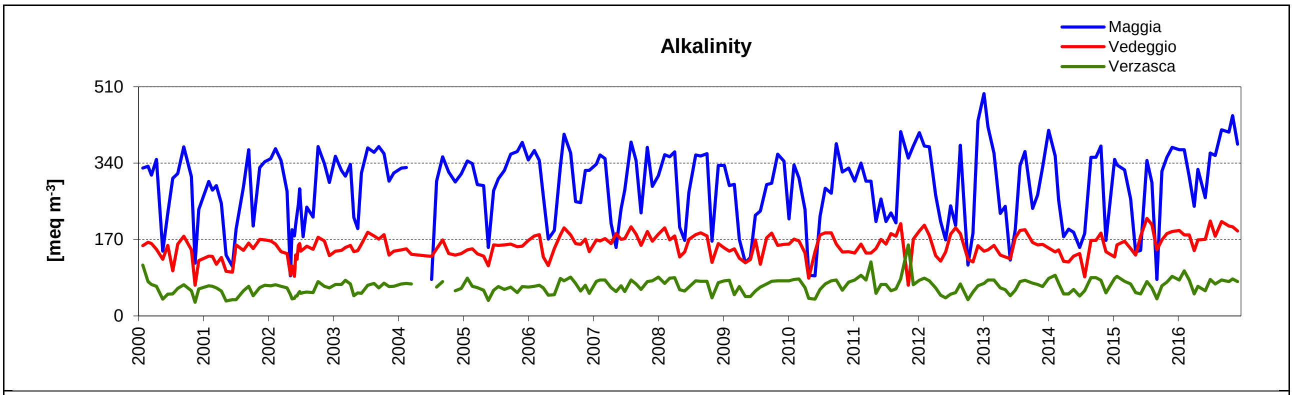
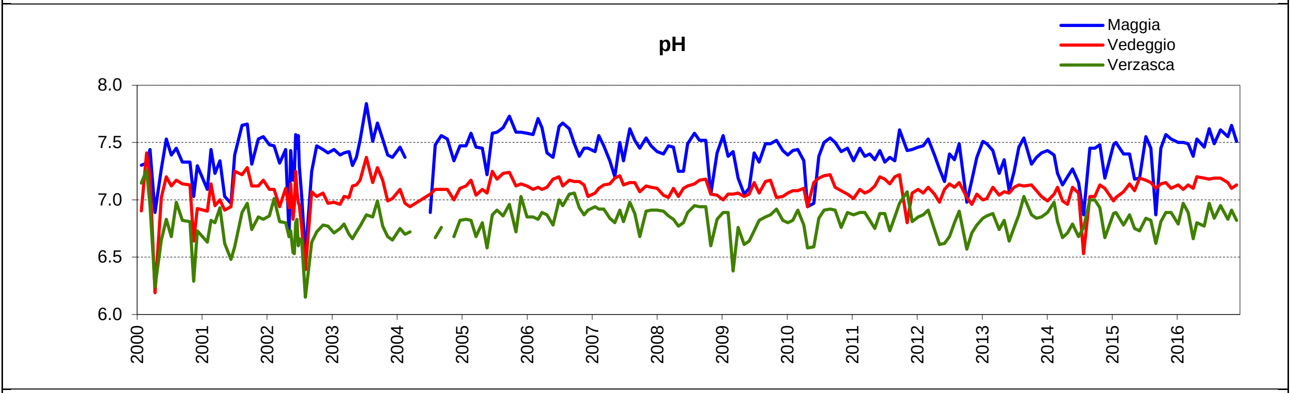
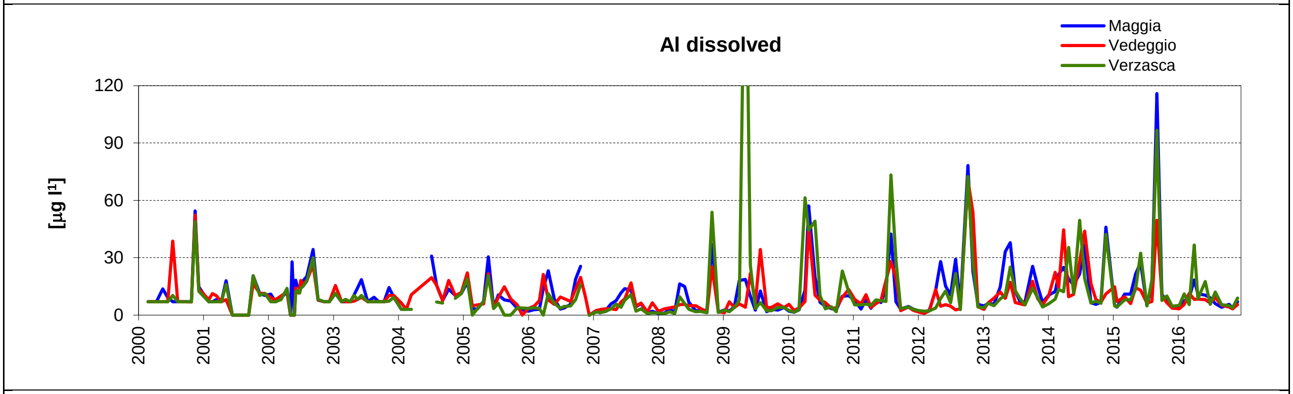


Figure 3.12 Concentrations of the main chemical parameters in river water from 2000 to 2016




Alkalinity
Maggia
Vedeggio
Verzasca
[meq m⁻³]
510
340
170
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016


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
2015
2016


Al dissolved
Maggia
Vedeggio
Verzasca
[µg l⁻¹]
120
90
60
30
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

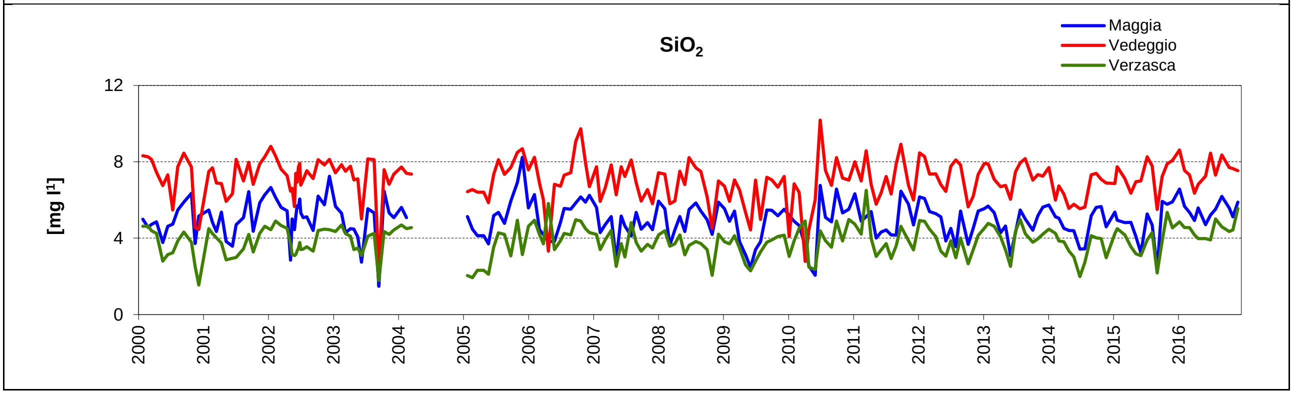

SiO₂
Maggia
Vedeggio
Verzasca
[mg l⁻¹]
12
8
4
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Table 3.7 Results from trend analyses (significant trends in red) during the period 2000-2016. 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^-		Cl^-		Base cations		H^+		Alkalinity	
	P	rate	p	rate	p	rate	p	rate	p	rate	p	rate
Maggia	0.009	-4.09	0.019	-0.82	0.696	0.07	0.381	-2.17	0.806	0.00	0.269	1.33
Vedeggio	0.016	-1.44	0.002	-1.36	0.934	0.01	0.220	-2.08	0.502	0.00	0.016	1.50
Verzasca	0.011	-0.94	0.005	-0.90	0.014	0.20	0.253	-1.18	0.308	0.00	0.003	0.89

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 aluminum increase with decreasing pH below 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 2016 spring and autumn lake pH's were 6.5/6.9 in Laghetto Inferiore, 6.4/7.0 in Laghetto Superiore, 5.9/6.1 in Lago del Starlaresc da Sgiof and 5.7/5.9 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 2016 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 Laghetto Inferiore, Laghetto Superiore and Lago del Starlaresc da Sgiof. In Laghetto Inferiore pH and alkalinity increased from about 6.5 and 28 µeq l^{-1} (average 2000-2003) to 6.7 and 36 µeq l^{-1} (average 2013-2016), in Laghetto Superiore from 6.4 and 24 µeq l^{-1} to 6.7 and 38 µeq l^{-1}, in Lago del Starlaresc da Sgiof from 5.2 and -9 µeq l^{-1} to 5.9 and 8 µeq l^{-1} and in Lago di Tomè from 5.7 and 2 µeq l^{-1} to 5.8 and 6 µeq l^{-1}. Concentrations of dissolved aluminum 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 19 µeq l^{-1} in the second. In Laghetto Inferiore and Superiore concentrations of aluminum are at present around 7-8 µeq l^{-1}. In river Verzasca only alkalinity showed a significant improvement increasing from about 59 to 70 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 potential regressions were calculated between the yearly number of taxa (total, EPT, AS) and the number of sampled individuals per taxa group (total, EPT, AS). If statistically significant, this relations were used to standardize the yearly number of taxa (total, EPT, AS) to a sample size of 1000 individuals for total taxa and a percentage of this for EPT and AS corresponding to the average proportion of this taxa groups during the entire monitoring period. For rivers the acidification class described in Braukmann and Biss (2004) was also calculated.

Moreover, for lakes only, since they are generally poor in species and in terms of relative abundances chironomids are often the most important taxonomic group, in order to gain more informations regarding the taxonomic composition of invertebrates, determination of chironomids from past samples to the species level was started. Since their identification requires supplementary expertizes and therefore additional financial resources, this work is done irregularly when financing is available. Until now chironomids were determined for the years 2003, 2004, 2007, 2009 and for some lakes for 2012 as well. This report presents results of the first 4 analysed years.

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 2016 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 Lago di Tomè 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 (*Nemoura sp.* in all lakes, *Leuctra sp.* in Laghetto Inferiore, Laghetto Superiore and Lago di Tomè, *Protonemoura sp.* in Laghetto Inferiore and Superiore) and Trichoptera (*Rhyacophila sp.* in Laghetto Inferiore, Laghetto Superiore and Lago di Tomè). 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, Laghetto Superiore and a small percentage in Lago di Tomè. In general, relative abundances of invertebrates sampled on fine and coarse substrates do no differ greatly. Only chironomids are often slightly more abundant on fine substrate.

Highest total taxa numbers were found in Laghetto Inferiore (15), followed by Laghetto Superiore and Lago di Tomè (12), Laghetto Inferiore (11) and Lago del Starlaresc da Sgiof (9). Regarding EPT, the highest number of taxa was identified in Laghetto Inferiore (11), then in Laghetto Superiore (8), Lago di Tomè (7) and at last in Lago del Starlaresc da Sgiof (1). The same rank order was observed for the relative abundance of AS taxa (Laghetto Inferiore: 25.1%, Laghetto Superiore: 17.0%, Lago di Tomè: 1.6%, Lago del Starlaresc da Sgiof: 0.0%). These abundances were mainly determined by the presence of Planariidae (probably *Crenobia alpina*). Relative abundances of other AS species were low (Laghetto Inferiore: 2.0% *Ecdyonurus sp., 0.1% Protonemoura nimborum*; Laghetto Superiore: 1.5% *Ecdyonurus sp., 0.1% Protonemoura nimborum,* 0.2% *Perlodes intricatus;* Lago di Tomè: 0.1% *Atherix ibis*). In Lago del Starlaresc da Sgiof acid sensitive taxa were absent. Decreasing total, EPT and AS taxa and relative abundance of AS taxa in the following lake order Laghetto Inferiore and Superiore, Lago di Tomè and Lago del Starlaresc da Sgiof reflect well increasing aluminum concentrations (see par. 4.1). In fact, pH's of both Lago di Tomè and Lago del Starlaresc da Sgiof are still at least occasionally below 6.

Regarding the speciation of chironomids (Tab. 4.3), during the first 4 analyzed years (2003, 2004, 2007, 2009) totally 62 taxa were determined: 27 were restricted to the outlet, 11 to the littoral and 24 were found in both. The number of taxa in the outlets was often higher than in the littorals, which is not surprising since in the firsts species typical for both running and standing waters can be found. Among lakes the number of chironomid taxa followed the same rank order than observed for not chironomids. Highest total taxa numbers (littoral+outlets) were found in Laghetto Inferiore (39) and Laghetto Superiore (40) and lower numbers in Lago di Tomè (26) followed by Lago del Starlaresc da Sgiof

(23), indicating that the number of chironomid taxa may also decrease with increasing acidity. In terms of taxa numbers (Table 4.3) the richest subfamily was Orthocladiinae followed by similar numbers of Chironominae and Tanypodinae. In terms of relative abundances, as expected from Alpine lakes (Füreder et al. 2012), Orthocladiinae was the dominant subfamily in outlets of Laghetto Inferiore (50% *Tvetenia bavarica/calvescens, 30% Corynoneura lobata, 5% Rheocricotopus effusus)* and Laghetto Superiore (42% *Tvetenia bavarica/calvescens, 21% Corynoneura lobata, 8% Rheocricotopus effusus*). For littorals, next to Orthocladiinae (14% *Corynoneura scutellata*, 11% *Psectrocladius sordidellus-Gr.*, 6% *Corynoneura lobata*, 5% *Corynoneura lacustris* in Laghetto Inferiore and 32% *Corynoneura scutellata*, 6% *Psectrocladius sordidellus-Gr.*, 5% *Heterotrissocladius marcidus*, 5% *Corynoneura lacustris* in Laghetto Inferiore), Tanypodinae (23% and 10% *Zavrelimyia melanura* in Laghetto Inferiore and Laghetto Superiore respectively and 8% Z. barbatipes in both lakes) and Tanytarsini (16% and 11% *Micropsectra atrofasciata* in Laghetto Inferiore and Laghetto Superiore, respectively and 7% *Paratanytarsus austriacus* in Laghetto Superiore). Tanytarsini dominated in outlet and littoral of Lago del Starlaresc da Sgiof (24% *Paratanytarsus austriacus*, 18% *Micropsectra sp.*, 8% *Zavrelimyia melanura* in the outlet and 25% *Paratanytarsus austriacus*, 19% *Tanytarsus sp.,* 15% *Cladotanytarsus sp.*, 5% *Micropsectra* in the littoral). Similar fauna composition was found in warm Alpine lakes by Boggero and Lencioni (2006). Other publications (http://www.landcareresearch.co.nz/resources/identification/animals/freshwater-invertebrates/guide/no-jointed-legs2/true-fly-larvae/midges/chironomid-midge13) indicate abundance of Tanytarsini together with the presence of abundant algae or aquatic plant. Indeed, because of its low depth (max. depth: 6 m) and its relatively low altitude (1865 m a.s.l.) Lago del Starlaresc da Sgiof is characterized by high summer surface temperatures (up to 21°C, July 2015) and aquatic vegetation. In the littoral of Lago di Tomè, Tanypodinae were most abundant (46% *Zavrelimyia melanura*) followed by Orthocladiinae (17% *Heterotrissocladius marcidus*) and Tanytarsini (8% Micropsectra sp., 7% *Paratanytarsus austriacus*); in the outlet the relative abundance of Tanypodinae (18% *Zavrelimyia melanura)* decreased on account of Chironomini (23% *Polypedilum nubeculosum-Gr.,* 7% *P. laetum*), while Orthocladiinae remained relatively unchanged (26% *Corynoneura lobata*). High abundances of Tanypodinae and Chironomini are reported to occur at warmer temperatures, while Orthocladiinae and Diamesinae seem to be more common in cold waters (Eggermint and Heiri, 2012). High abundance of Tanypodinae were also related to low altitude and high nitrate concentrations (Boggero and Lencioni, 2006). In fact, deep lake Lago di Tomè (max. depth 38 m) is situated at low altitude (1692 m a.s.l.), has, compared to the other lakes, high nitrate concentrations (average autumn 2016: 27 meq m^{-3}) and relatively high summer surface temperatures (up to 18°C, August 2003).

Table 4.1 Lake sample sizes during 2016

LAKE OUTLETS	MONTH	Fine substrate	Coarse substrate
INF	**July (4.7.2016)**	596	679
	October (5.10.2016)	255	139
SUP	**July (4.7.2016)**	218	309
	October (5.10.2016)	252	398
TOM	**July (7.7.2016)**	480	241
	October (10.10.2016)	191	69
STA	**July (7.7.2016)**	70	72
	October (10.10.2016)	498	336

Table 4.2 Relative abundance and number of taxa in lake outlets on different substrates during 2016. ***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	**11.4%**	**23.3%**	**21.3%**	**13.8%**				**7.5%**	**23.0%**	**17.6%**	**1.5%**	
Naididae	11.4%	23.3%	21.3%	13.8%					17.3%	17.6%		
COLEOPTERA						**0.7%**					**0.4%**	
Agabus sp.						0.7%					0.4%	
DIPTERA	**55.7%**	**38.4%**	**36.7%**	**53.4%**	**87.1%**	**64.8%**	**97.9%**	**67.9%**	**47.0%**	**45.1%**	**75.9%**	**82.9%**
Atheriix ibis						0.2%					0.1%	
Ceratopogonidae							29.6%	29.9%				29.8%
Chironomidae	52.6%	36.5%	31.9%	50.9%	59.0%	32.3%	68.2%	38.0%	44.6%	41.4%	45.7%	53.1%
Simuliidae	3.0%	1.9%	4.8%	2.5%	28.1%	32.2%			2.5%	3.7%	30.2%	
EPHEMEROPTERA	**1.5%**	**2.6%**	**2.6%**	**0.5%**					**2.0%**	**1.5%**		
Ecdyonurus sp.	1.5%	2.6%	2.6%	0.5%					2.0%	1.5%		
ODONATA							**2.0%**	**0.7%**				
Aeshna affinis								0.1%				0.1%
Aeshna sp.							0.7%	0.4%				0.6%
Libellula sp.							0.7%					0.4%
Orthetrum sp.								0.1%				0.1%
Libellulidae							0.6%					0.3%
PLECOPTERA	**9.7%**	**8.3%**	**22.2%**	**15.7%**	**10.7%**	**26.1%**	**0.1%**	**23.8%**	**9.0%**	**18.9%**	**18.4%**	**12.0%**
Leuctra sp.	0.1%		3.0%	2.4%	7.4%	23.9%			0.0%	2.7%	15.7%	
Nemoura avicularis												
Nemoura minima		0.7%							0.4%			
Nemoura mortoni		0.1%			0.5%				0.0%		0.3%	
Nemoura sp.	8.5%	4.8%	6.6%	10.1%	2.8%	2.2%	0.1%	23.8%	6.6%	8.3%	2.5%	12.0%
Protonemoura nimborum.	0.2%			0.2%					0.1%	0.1%		
Protonemoura sp.	0.9%	2.7%	12.6%	2.6%					1.8%	7.6%		
Isoperla grammatica												
Perlodes intricatus				0.4%						0.2%		
TRICHOPTERA	**0.7%**	**2.5%**	**3.0%**	**0.4%**	**2.2%**	**5.5%**			**1.6%**	**1.7%**	**3.8%**	
Limnephilus sp.						0.9%					0.5%	
Plectrocnemia sp.				0.1%						0.1%		
Policentropodidae		1.8%							0.9%			
Rhyacophila (Rhyacophila) sp.			3.0%	0.3%	0.1%	1.4%				1.7%	0.8%	
Rhyacophila praemorsa	0.3%				0.5%				0.1%		0.3%	
Rhyacophlidae sp.	0.4%				1.6%	3.1%			0.2%		2.3%	
Rhyacophlidae		0.7%							0.4%			
TURBELLARIA	**21.2%**	**24.9%**	**14.2%**	**16.2%**		**2.9%**			**23.0%**	**15.2%**	**1.5%**	
Planariidae	21.2%	24.9%	14.2%	16.2%		2.9%			23.0%	15.2%	1.5%	
Rel. abundance EPT taxa	11.8%	13.4%	27.8%	16.6%	12.9%	31.6%	0.1%	23.8%	12.6%	22.2%	22.3%	12.0%
Rel. abundance AS taxa	22.8%	27.5%	16.8%	17.2%		3.1%			25.1%	17.0%	1.6%	
Number total taxa	11	11	9	12	8	10	6	7	15	12	12	9
Number EPT taxa	7	7	5	8	6	5	1	1	11	8	7	1
Number AS taxa	3	2	2	4	0	2	0	0	3	4	2	0

Table 4.3 Chironomid subfamilies and tribes relative abundances averaged over the years 2003, 2004, 2007, 2009 and their number of identified taxa in lake outlets and littorals. *0.0% indicate values >0.0% but < 0.05%.* LIT and OUT stay for littoral and outlet, respectively.

	Relative abundances %								Number of taxa							
TAXA	INF		SUP		TOM		STA		INF		SUP		TOM		STA	
	LIT	OUT	LIT	OUT	LIT	OUT	LIT	OUT	LIT	OUT	LIT	OUT	LIT	OUT	LIT	OUT
CHIRONOMINAE	**22.7**	**2.2**	**19.1**	**4.3**	**14.6**	**33.8**	**71.6**	**54.7**	**4**	**2**	**4**	**2**	**4**	**4**	**7**	**6**
Chironomini	1.9		0.2		0.2	30.3	6.9	10.6	2	0	1	0	1	2	2	2
Tanytarsini	20.8	2.2	18.9	4.3	14.4	3.5	64.8	44.0	2	2	3	2	3	2	5	4
DIAMESINAE	**0.0**	**1.1**		**2.1**		**1.1**		**0.3**	**1**	**3**	**0**	**2**	**0**	**2**	**0**	**1**
Diamesini	0.0	1.1		2.1		1.1		0.3	1	3	0	2	0	2	0	1
ORTHOCLADIINAE	**41.0**	**95.3**	**54.5**	**85.5**	**28.5**	**40.0**	**16.5**	**34.3**	**12**	**20**	**16**	**22**	**6**	**13**	**4**	**9**
PRODIAMESINAE	**1.4**		**1.1**		**0.5**				**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
TANYPODINAE	**33.5**	**0.6**	**23.8**	**6.1**	**52.6**	**23.9**	**10.5**	**9.4**	**5**	**3**	**5**	**3**	**4**	**3**	**4**	**5**
Macropelopiini	2.4	0.0	2.5		0.9		3.1	0.2	2	1	2	0	1	0	1	2
Pentaneurini	31.1	0.6	21.3	6.1	51.6	23.9	2.5	9.0	3	2	3	3	3	3	2	2
Procladiini							4.9	0.2							1	1
NOT DETERMINED	**1.3**	**0.7**	**1.4**	**2.0**	**3.8**	**1.1**	**1.4**	**1.3**								
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**23**	**28**	**25**	**25**	**15**	**22**	**15**	**20**

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. 4.4. In Laghetto Inferiore, Laghetto Superiore and Lago del Starlaresc da Sgiof trends in the invertebrate population cannot be observed. In the first two, acid sensitive indicators like the relative abundance of AS taxa and the number of AS indicate the presence of acid sensitive species, however their abundance and numbers did not change since the beginning of sampling, in the latter AS species are still absent. The only early sign of recovery seems to be the reappearance of *Crenobia alpina* in Lago di Tomè after 2006.

Table 4.4 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	2016
INF	Sampling times	1	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
	Individuals	64	80	293	1215	2003	8336		7712	10507	5250	958	4587	4587	3515	1206	1669
	Rel. abundance OLIGOCHAETA	22%	6%	11%	25%	36%	30%		30%	23%	23%		18%	1%	9%	10%	17%
	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%	47%
	Rel. abundance CHIRONOMIDAE	38%	13%	17%	29%	23%	18%		39%	46%	51%	86%	50%	70%	54%	55%	45%
	Rel. abundance SIMULIDAE (%)		5%	26%	8%	5%	25%		18%	6%	8%	2%	22%	22%	23%	9%	2%
	Rel. abundance EPHEMEROPTERA				2%	2%	1%		1%	1%	0%	0%	0%	0%	0%	1%	2%
	Rel. abundance HETEROPTERA														0%		
	Rel. abundance PLECOPTERA	27%	56%	33%	23%	16%	12%		5%	5%	6%	6%	2%	1%	9%	10%	9%
	Rel. abundance TRICHOPTERA		8%	1%	3%	3%	3%		0%	1%	1%	1%	0%	0%	1%	2%	2%
	R Rel. abundance BIVALVIA											0%					
	Rel. abundance TURBELLARIA	5%	5%	11%	2%	10%	8%		5%	18%	9%	1%	6%	4%	4%	14%	23%
	Rel. abundance EPT taxa	27%	64%	34%	28%	21%	16%		7%	6%	8%	6%	2%	2%	10%	13%	13%
	Rel. abundance AS taxa	5%	5%	11%	5%	14%	11%		6%	18%	9%	1%	6%	5%	4%	15%	25%
	Standardized number total taxa	12	12	13	20	16	16	12	15	14	13	13	9	9	10	11	10
	Standardized number EPT taxa	7	4	5	8	6	6	3	8	6	7	6	5	5	5	6	6
	Standardized number AS taxa	2	2	1	5	4	4	4	4	2	2	6	2	2	2	2	2
SUP	Sampling times	1	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
	Individuals	49	34	150	1523	1744	6624	5736	5347	4977	5469	963	6723	1711	1249	1137	1177
	Rel. abundance OLIGOCHAETA	6%	3%	6%	21%	20%	38%	50%	64%	43%	29%	1%	24%	7%	26%	17%	18%
	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%	45%
	Rel. abundance CHIRONOMIDAE	59%	6%	42%	30%	36%	31%	27%	19%	44%	43%	65%	63%	83%	38%	30%	41%
	Rel. abundance SIMULIDAE	4%		5%	5%	13%	16%	11%	11%	5%	6%	16%	3%	4%	18%	12%	4%
	Rel. abundance EPHEMEROPTERA				9%	7%	1%	0%	0%	0%	0%	1%		1%	0%	0%	2%
	Rel. abundance HETEROPTERA					0%									0%		
	Rel. abundance PLECOPTERA	18%	68%	38%	30%	17%	11%	10%	3%	6%	21%	13%	7%	2%	12%	19%	19%
	Rel. abundance TRICHOPTERA		24%	1%	4%	3%	1%	1%	1%	1%	1%	2%	1%	0%	0%	3%	2%
	Rel. abundance TURBELLARIA	12%		5%	1%	4%	1%	1%	2%	1%	1%	3%	2%	1%	5%	19%	15%
	Rel. abundance EPT taxa	18%	91%	39%	43%	27%	13%	11%	4%	7%	21%	15%	8%	3%	13%	20%	22%
	Rel. abundance AS taxa	12%	3%	5%	11%	12%	2%	1%	3%	1%	1%	4%	2%	2%	5%	20%	17%
	Standardized number total taxa	9	18	13	18	20	15	14	15	19	13	14	7	10	9	13	11
	Standardized number EPT taxa	4	13	6	8	9	7	7	13	9	5	8	6	9	5	7	6
	Standardized number AS taxa	2	3	2	3	4	3	4	2	2	2	3	1	2	2	2	2

LAKE	PARAMETER	2000	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014	2015	2016
TOM	Sampling times	1	2	2	1	1	2	2	2	2	2	2	2	2	2	2
	Individuals	11	156	331	337	2128	2983	3975	4407	3726	230	858	319	4129	365	981
	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%	0%
	Rel. abundance DIPTERA	36%	28%	34%	40%	84%	58%	64%	90%	87%	53%	77%	72%	70%	66%	76%
	Rel. abundance Athericidae															0%
	Rel. abundance CHIRONOMIDAE	36%	14%	33%	37%	75%	38%	57%	61%	65%	26%	40%	68%	19%	49%	46%
	Rel. abundance SIMULIDAE		14%	1%	3%	9%	20%	6%	29%	22%	26%	36%	5%	51%	16%	30%
	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%	18%
	Rel. abundance TRICHOPTERA	9%	2%	4%	1%	2%	2%	1%	1%	1%	1%	1%	1%	3%	6%	4%
	Rel. abundance TURBELLARIA						1%	0%	0%	0%		3%		0%		1%
	Rel. abundance EPT taxa	45%	62%	61%	59%	15%	39%	35%	9%	12%	4%	15%	27%	13%	34%	22%
	Rel. abundance AS taxa					0%	1%	0%	0%	0%		3%		0%		1%
	Standardized number total taxa	12	16	20	10	14	14	12	15	14	10	10	9	8	10	8
	Standardized number EPT taxa	2	5	6	3	9	9	8	12	11	2	4	4	5	4	4
	Number AS taxa	0	0	0	0	1	2	2	3	1	0	1	0	2	0	1
STA	Sampling times	1	2	2	1	2	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	976
	Rel. abundance OLIGOCHAETA			1%	3%	3%	1%	0%	2%	10%		6%	6%		4%	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%	83%
	Rel. abundance CERATOPOGONIDAE		16%	5%	10%	14%	3%	5%	14%	13%	7%	20%	15%	8%	12%	30%
	Rel. abundance CHIRONOMIDAE	29%	69%	85%	56%	75%	93%	79%	71%	56%	63%	34%	59%	16%	73%	53%
	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%	1%
	Rel. abundance PLECOPTERA	24%	2%	2%	5%	1%	1%	9%	8%	12%	1%	16%		26%	8%	12%
	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%	12%
	Rel. abundance AS taxa								0%							
	Standardized number total taxa	12	9	14	14	12	9	13	16	13	14	11	7	8	11	8
	Number EPT taxa	2	3	3	1	4	6	6	8	6	1	1	0	2	2	1
	Number AS taxa	0	0	0	0	0	0	0	1	0	0	0	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 2016 are shown in Tab. 4.5 and 4.6, 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. 4.7 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 4.5 River Verzasca sample sizes during 2016.

RIVER	SITE	SUBSTRATE	March (4.3.16)	July (5.7.16)	November (4.11.16)
VER	Pool	fine	361	527	757
		coarse	974	601	274
	Run	fine	1190	136	546
		coarse	820	518	506

Table 4.6 Relative abundance and number of taxa in river Verzasca during 2016. ***0.0% indicate values >0.0% but < 0.05%.***

TAXA	Pool		Run		Yearly average
	Fine	Coarse	Fine	Coarse	
OLIGOCHAETA	0.1%	0.1%	0.0%	0.2%	0.1%
Naididae	0.1%	0.1%		0.1%	0.0%
HYDRACARINA		0.2%	0.1%	0.3%	0.1%
COLEOPTERA	4.9%	16.3%	14.3%	12.8%	12.1%
Esolus sp.	4.3%	14.9%	13.7%	12.1%	11.3%
Hydraena sp.	0.5%	1.4%	0.6%	0.7%	0.8%
DIPTERA	26.2%	10.0%	26.1%	12.0%	18.6%
Atherix ibis	0.9%	1.1%	0.0%	0.2%	0.6%
Blephariceridae	0.1%			0.1%	0.1%
Chironomidae	22.9%	8.6%	24.8%	10.7%	16.7%
Hexatoma sp.	0.1%		0.0%		0.0%
Limoniidae	0.5%	0.2%	0.5%	0.9%	0.5%
Pediciidae	1.8%	0.1%			0.5%
Simuliidae		0.1%	0.8%	0.1%	0.3%
EPHEMEROPTERA	37.8%	49.9%	33.8%	43.1%	41.2%
Baetis sp.	17.4%	33.0%	16.4%	27.9%	23.7%
Ecdyonurus helveticus		0.1%	4.0%	0.1%	1.1%
Ecdyonurus sp.	7.3%	5.2%		5.0%	4.4%
Epeorus alpinus			0.5%		0.1%
Epeorus sp.	0.6%	1.0%	1.4%	0.2%	0.8%
Rhithrogena sp.	12.5%	10.6%	11.6%	10.0%	11.2%
PLECOPTERA	26.7%	20.1%	17.2%	25.7%	22.4%
Leuctra sp.	5.3%	5.0%			
Amphinemoura sulcicollis		0.0%	0.1%	0.0%	0.0%
Amphinemoura standfussi	0.0%	0.3%			0.1%
Amphinemoura sp.	1.0%	0.2%	0.6%	1.4%	0.8%
Nemoura mortoni	0.2%	0.2%	0.2%	0.4%	0.3%
Nemoura sp.	8.0%	8.8%	3.8%	6.2%	6.7%
Protonemura brevistyla		0.0%			0.0%
Protonemura nimborum			0.0%	0.0%	0.0%
Protonemura sp.	10.9%	4.8%	6.8%	13.3%	9.0%
Perla grandis	0.4%	0.3%	0.9%	0.0%	0.4%
Perla sp.	0.5%	0.2%	0.2%	0.3%	0.3%
Isoperla sp.	0.1%	0.0%	0.1%		0.1%
Rhabdiopteryx neglecta			0.0%		0.0%
Rhabdiopteryx sp.	0.4%	0.0%		0.3%	0.2%

TAXA	Pool		Run		Yearly average
	Fine	Coarse	Fine	Coarse	
TRICHOPTERA	2.3%	2.2%	1.4%	2.0%	2.0%
Hydropsyche modesta			0.1%		0.0%
Hydropsyche sp.	0.0%	0.1%			0.0%
Drusus discolor		0.1%		0.0%	0.0%
Drusus muelleri			0.0%	0.1%	0.0%
Drusus sp.		0.1%	0.3%	0.1%	0.1%
Philopotamus montanus	0.1%	0.2%	0.2%	0.4%	0.2%
Philopotamus sp.	0.8%	0.5%		0.1%	0.3%
Wormaldia copiosa	0.1%	0.4%	0.1%	0.1%	0.2%
Wormaldia sp.	0.6%		0.1%	0.3%	0.3%
Rhyacophila sp.	0.4%	0.2%			0.1%
Rhyacophila torrentium	0.2%	0.2%		0.3%	0.2%
Rhyacophila (Hyperrhyacophila) sp.	0.1%				0.0%
Rhyacophila (Hyporhyacophila) sp.		0.1%	0.4%		0.1%
Rhyacophila dorsalis-Gr.	0.1%				0.0%
Rhyacophila (Rhyacophila) sp.		0.1%	0.2%	0.6%	0.2%
TURBELLARIA	2.0%	1.3%	7.0%	3.9%	3.6%
Polycelis tenuis/nigra				2.7%	0.7%
Planariidae	2.0%	1.3%	7.0%	1.2%	2.9%
Rel. abundance EPT taxa	66.9%	72.2%	52.4%	70.8%	65.6%
Rel. abundance AS taxa	43.8%	55.5%	43.2%	49.2%	47.9%
Number total taxa	33	37	34	36	49
Number EPT taxa	23	27	24	24	35
Number AS taxa	14	14	16	16	19
Acidification class (Braukmann & Biss)	2	2	2	2	2

Table 4.7 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	2016
Sampling times	8	6	6	6	5	4	4	4	4	4	4	3	3	3	3	3
Individuals	1574	2258	2569	3759	4267	12894	15012	21046	20233	11684	4510	8570	8404	5885	6813	7210
Rel. abundance OLIGOCHAETA	0%	1%	0%		0%	1%	0%	3%	1%	5%	0%	1%	0%	0%	3%	0%
Rel. abundance HYDRACARINA	2%	1%	1%	2%	0%	1%	1%	1%	2%	1%	1%	1%	1%	0%	0%	0%
Rel. abundance COLEOPTERA	18%	22%	23%	14%	18%	16%	24%	19%	17%	8%	22%	11%	12%	5%	13%	12%
Rel. abundance DIPTERA	12%	8%	10%	19%	12%	19%	20%	22%	23%	21%	30%	36%	38%	5%	12%	19%
Rel. abundance ATHERICIDAE	3%	2%	2%	1%	1%	1%	1%	0%	1%	0%	1%	0%	0%	0%	2%	1%
Rel. abundance BLEPHARICIDAE	0%		0%	0%		0%	0%	0%	0%		1%	0%	0%	0%	0%	0%
Rel. abundance CHIRONOMIDAE	6%	4%	4%	16%	9%	17%	17%	20%	21%	19%	26%	32%	35%	3%	7%	17%
Rel. abundance EMPIDIDAE	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%			
Rel. abundance LIMONIIDAE	3%	2%	4%	2%	2%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%
Rel. abundance PEDICIIDAE								0%							1%	1%
Rel. abundance SIMULIIDAE	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	2%	1%	1%	0%
Rel. abundance THAUMALEIDAE								0%								
Rel. abundance TIPULIDAE							0%									
Rel. abundance EPHEMEROPTERA	46%	45%	36%	41%	55%	45%	36%	41%	38%	34%	35%	37%	33%	59%	45%	41%
Rel. abundance PLECOPTERA	18%	18%	25%	18%	11%	14%	16%	12%	17%	29%	8%	13%	14%	28%	16%	22%
Rel. abundance TRICHOPTERA	3%	4%	3%	4%	2%	2%	2%	1%	1%	2%	2%	1%	1%	2%	3%	2%
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%	7%	4%
Rel. abundance EPT taxa	67%	67%	64%	64%	69%	61%	53%	54%	56%	64%	45%	51%	47%	89%	64%	66%
Rel. abundance AS taxa	49%	51%	43%	46%	61%	51%	40%	43%	40%	36%	39%	39%	34%	62%	56%	47%
Standardized number total taxa	29	26	27	27	22	23	25	26	33	29	24	26	22	26	23	21
Standardized number EPT taxa	18	16	15	17	12	13	15	15	19	17	14	14	12	15	13	11
Standardized number AS taxa	9	8	9	10	8	8	9	9	12	9	10	9	9	9	8	8
Acidification class (Braukmann & Biss)	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2

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Acknowledgments

The study was requested and financially supported by the Federal Office for the Environment (FOEN). We would like to thank Beat Achermann and Gaston Theis (FOEN) for their support.