Photo: S. Rioggi

Lago Nero observatory
Report of the five-years activities as a contribution to ICP-IM

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13 May 2020

TF-ICP-IM

University of Applied Sciences and Arts of Southern Switzerland

SUPSI

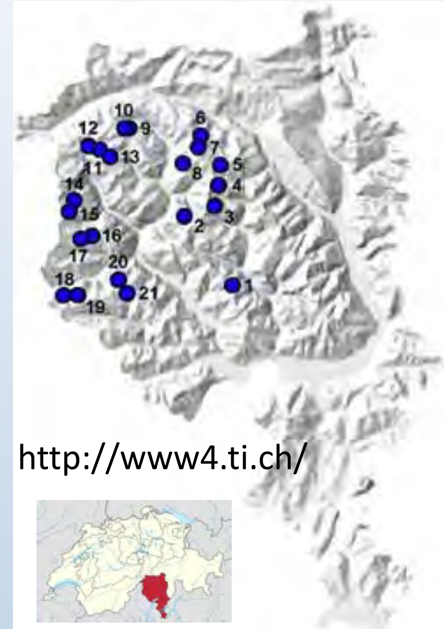
Summary

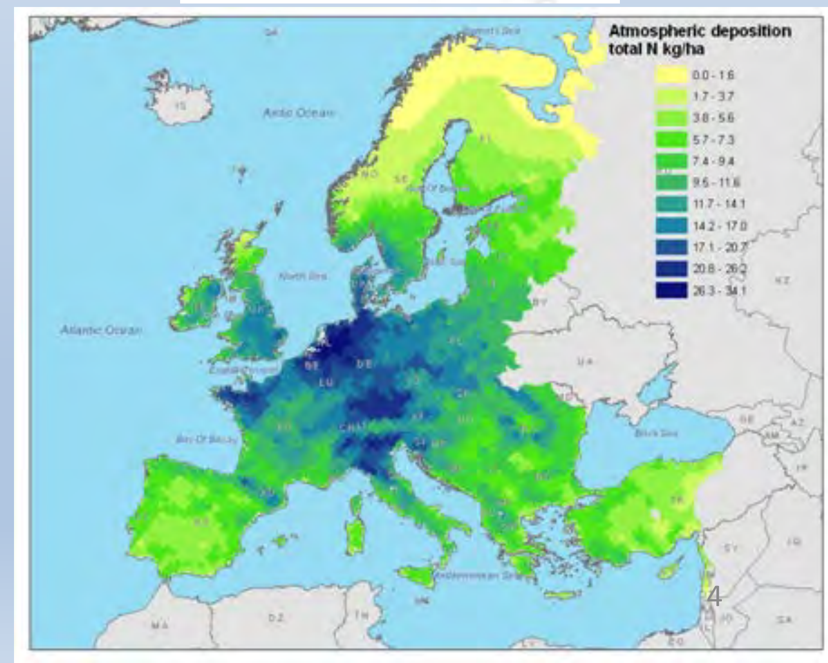
- Introduction
- Overview of tasks
- Mandatory and additional parameters measured
- Main results
  - Runoff and water chemistry
  - Input-output budgets
  - Soil survey
  - Vegetation survey
  - Additional monitoring of non-mandatory environmental parameters
    - Lake temperature profiles
    - Cryosphere monitoring
- Conclusions
- Perspectives and future activities

Introduction

Introduction and motivation of the project

- Mountain catchments are ideal indicators of large-scale pressures.
- Therefore, catchments in Europe and North America have been instrumented to monitor long-term effects of air pollution and climate change.
- In Switzerland, 20 mountain lakes on the southern slope of the Alps are included in ICP-W and monitored extensively.
- Worldwide, extensive monitoring programmes are increasingly complemented with intensive, integrated programmes (e.g. ICP-IM).
- Aim of the Lago Nero project: integrate ICPW extensive monitoring with an intensive monitoring on the southern slope of the swiss Alps part of ICP-IM





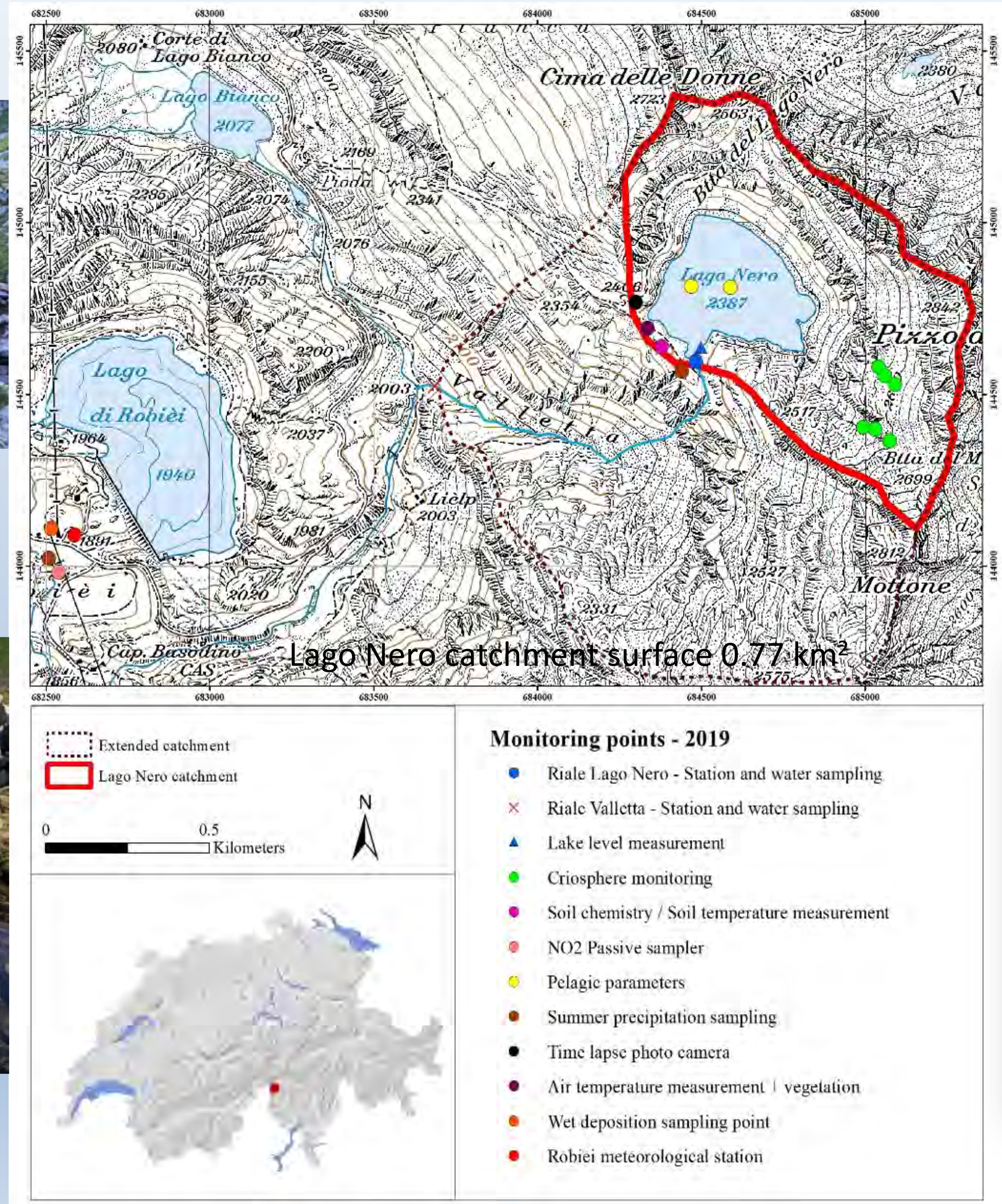
The Lago Nero

Lago Nero team (2015-2020)

Collaborators	Role	affiliation
Luca Colombo	Project leader	LMA-SUPSI[1]
Fabio Lepori	Researcher, project coordinator	IST-SUPSI[2]
Andreas Bruder	Researcher	LMA-SUPSI[1]
Maurizio Pozzoni	Researcher	IST-SUPSI
Sebastian Pera	Researcher	IST SUPSI
Cristian Scapozza	Researcher	IST-SUPSI
Monica Bulgheroni	Research assistant	IST-SUPSI
Stefano Beatrizotti	Technical assistant	IST-SUPSI
Mattia Domenici	Technical assistant	IST-SUPSI
Arturo Di Giacinto	Technical assistant	IST-SUPSI
Stefano Rioggi	Technical assistant	IST-SUPSI

[1]Laboratory of applied microbiology; [2]Institute of Earth Sciences

The Lago Nero observatory



Overview of tasks -1-: Mandatory sub-programme status

	Sub-programme	Sampling frequency	Data source	status
1	Meteorology	▪ 10 min ▪ 2 h for temperature	MeteoSwiss SUPSI	✓
2	Air chemistry	▪ monthly for NO_2-N ▪ yearly for AOT40 ▪ 5-10 year for SO_2, NO_3^-, HNO_3, NH_3, NH_4^+	UACER, ICPW MeteoTest MeteoTest (modelled)	✓ ✓
3	Precipitation chemistry	▪ weekly	UACER, ICPW	✓
4	Runoff water chemistry	▪ *c.* monthly for chemical parameters ▪ 10 min for temperature and discharge	SUPSI	✓
5	Soil water chemistry	▪ *c.* monthly	SUPSI	✓
6	Vegetation survey	▪ 5-year intervals	SUPSI	✓
7	Soil chemistry and structure	▪ 5-year intervals	SUPSI	✓

Monitoring Site above treeline (~2500m a.s.l.) No Throughfall, Foliage- and Litterfall Chemistry and trunk epiphytes

Overview of tasks -2-: Optional sub-programmes and additional monitoring

Optional sub-programmes

	Sub-programme	Sampling frequency	Data source	status
1	Lake Water chemistry	▪ 2x/year	UACER, ICPW	✓

Additional monitoring

	Environmental component	Sampling frequency	Data source	status
1	Lake temperature profiles	▪ 1 hour	SUPSI	✓
2	Physico-chemical characterisation of extended catchment	▪ Monthly during summer	SUPSI	Discontinued end 2018
3	Cryosphere (rock glacier and permafrost)	▪ 2x/year outflow RG	SUPSI	✓
4	Snowpack and lake ice (including time lapse camera)	▪ Daily	MeteoSwiss and SUPSI	✓
5	3D-model of the catchment (360° laser scan	▪ 1x	SUPSI	✓

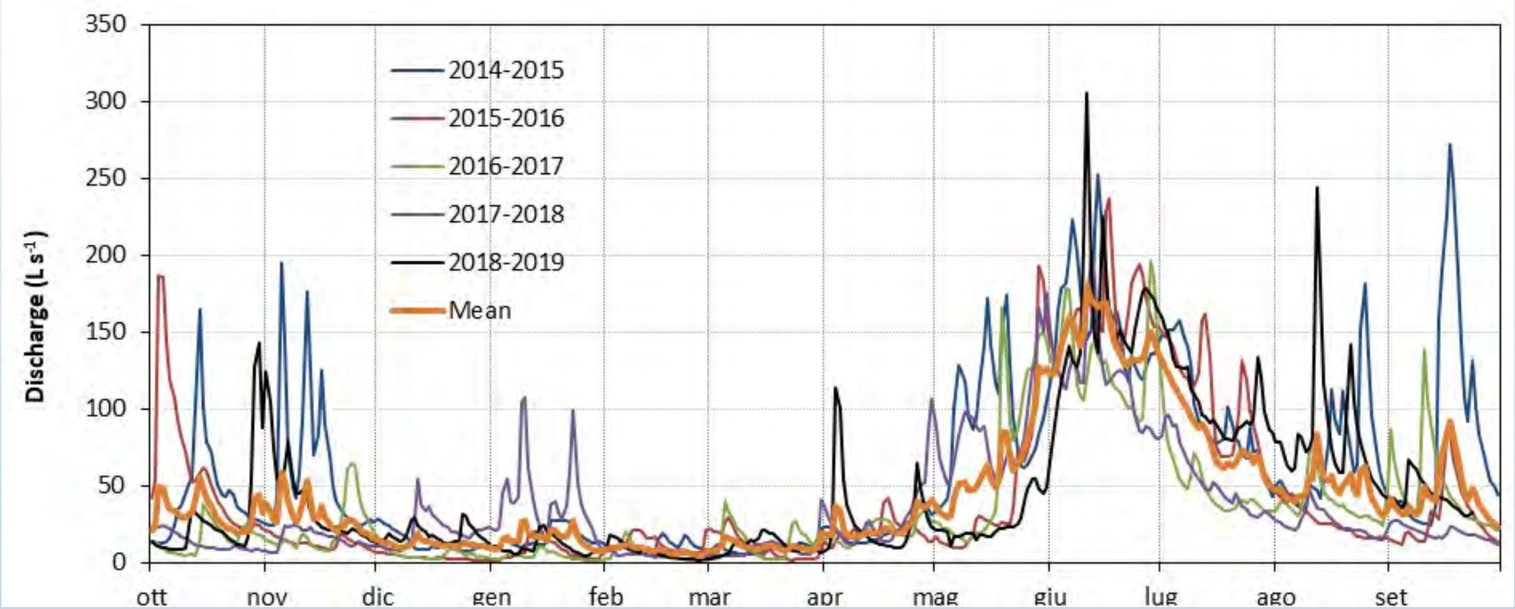
Main results

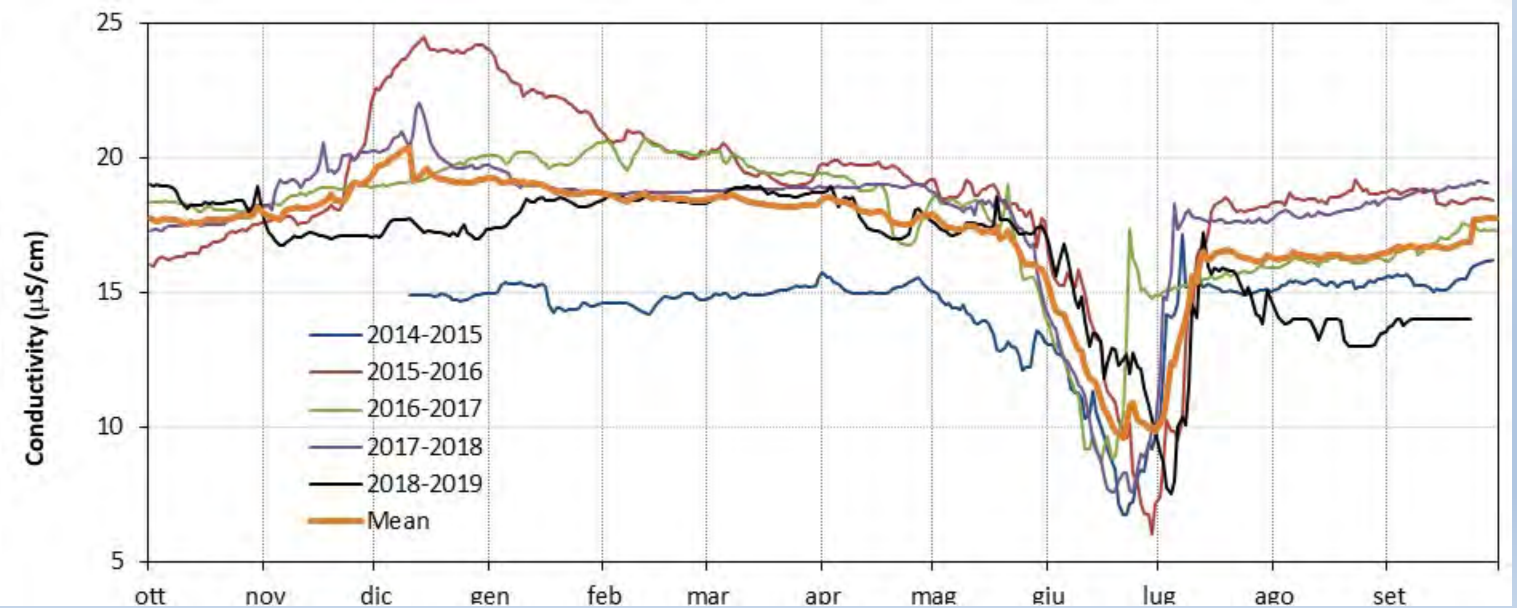
- Deposition and runoff water chemistry
- Input-output budgets
- Soil water chemistry
- Vegetation survey
- Soil survey
- Additional monitoring of non-mandatory environmental parameters
  - Lake temperature profiles
  - Cryosphere monitoring

Lago Nero part of the I£CPW monitoring of 20 swiss alpine lakes

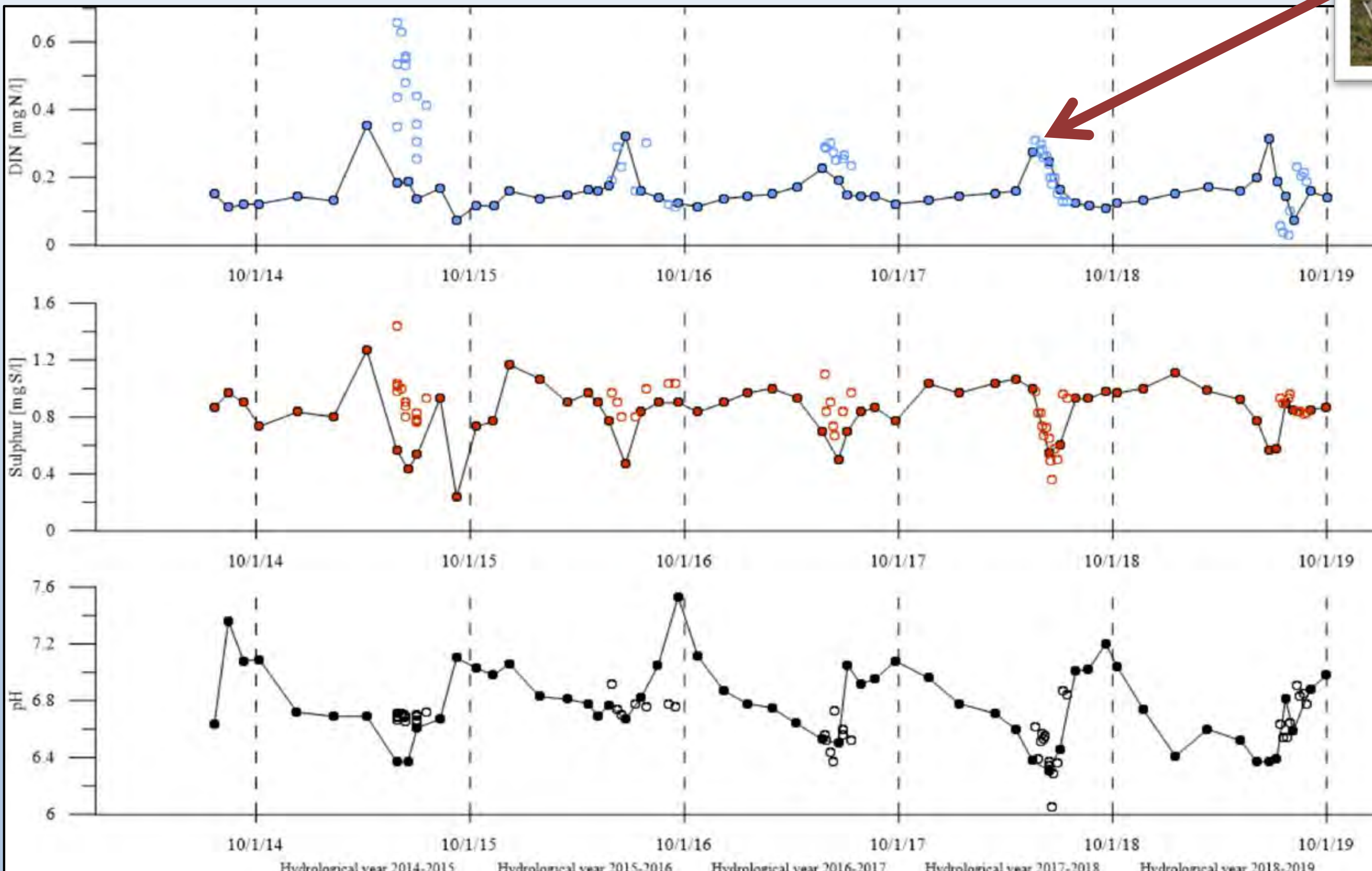
Runoff Chemistry

Runoff chemistry -1-





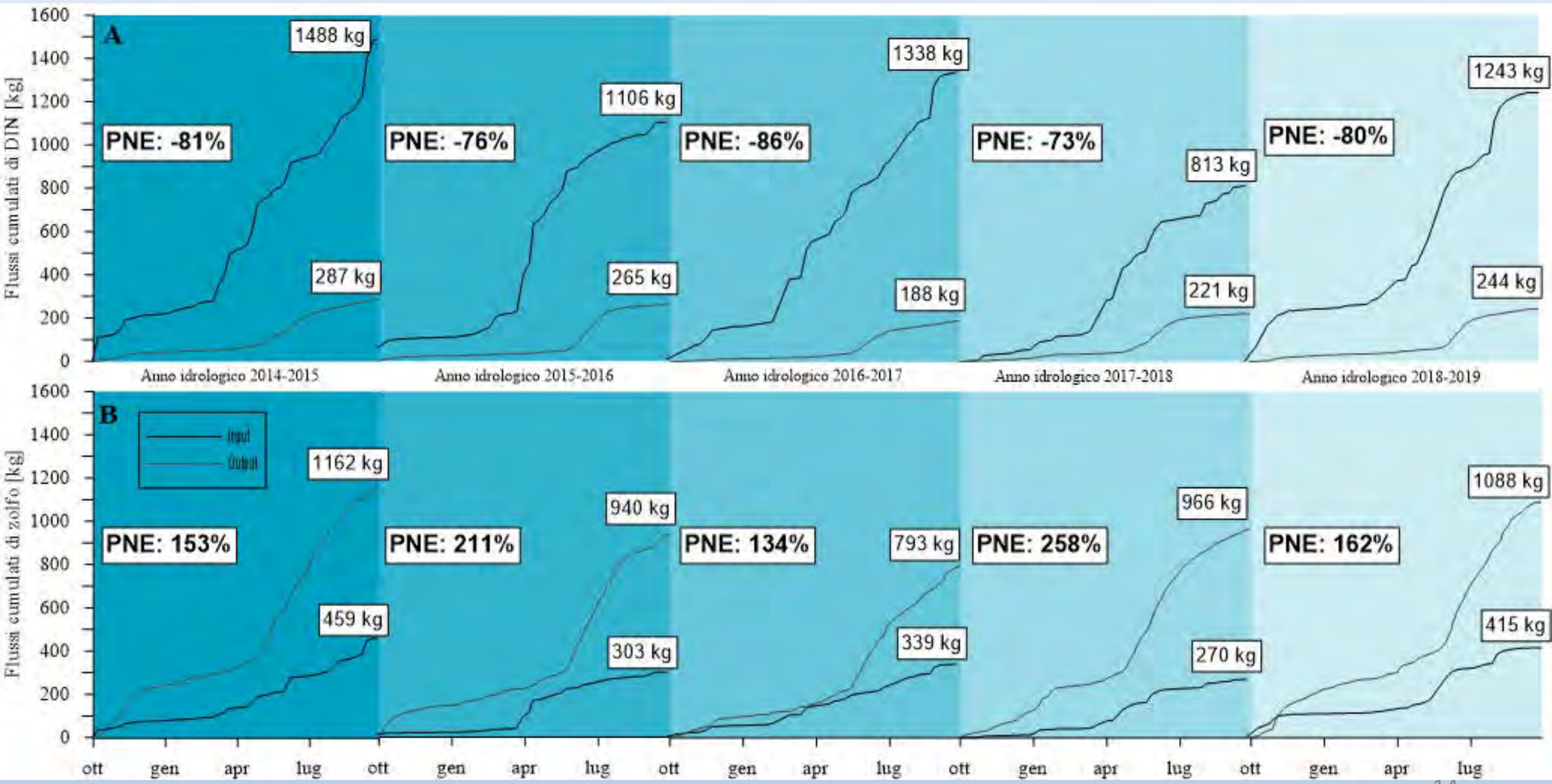
Runoff chemistry -2-



Multi-year comparison of N e S fluxes

Yearly precipitation (Mean 2420 mm)

3082 mm | 2031 mm | 2313 mm | 1927 mm | 2696 mm

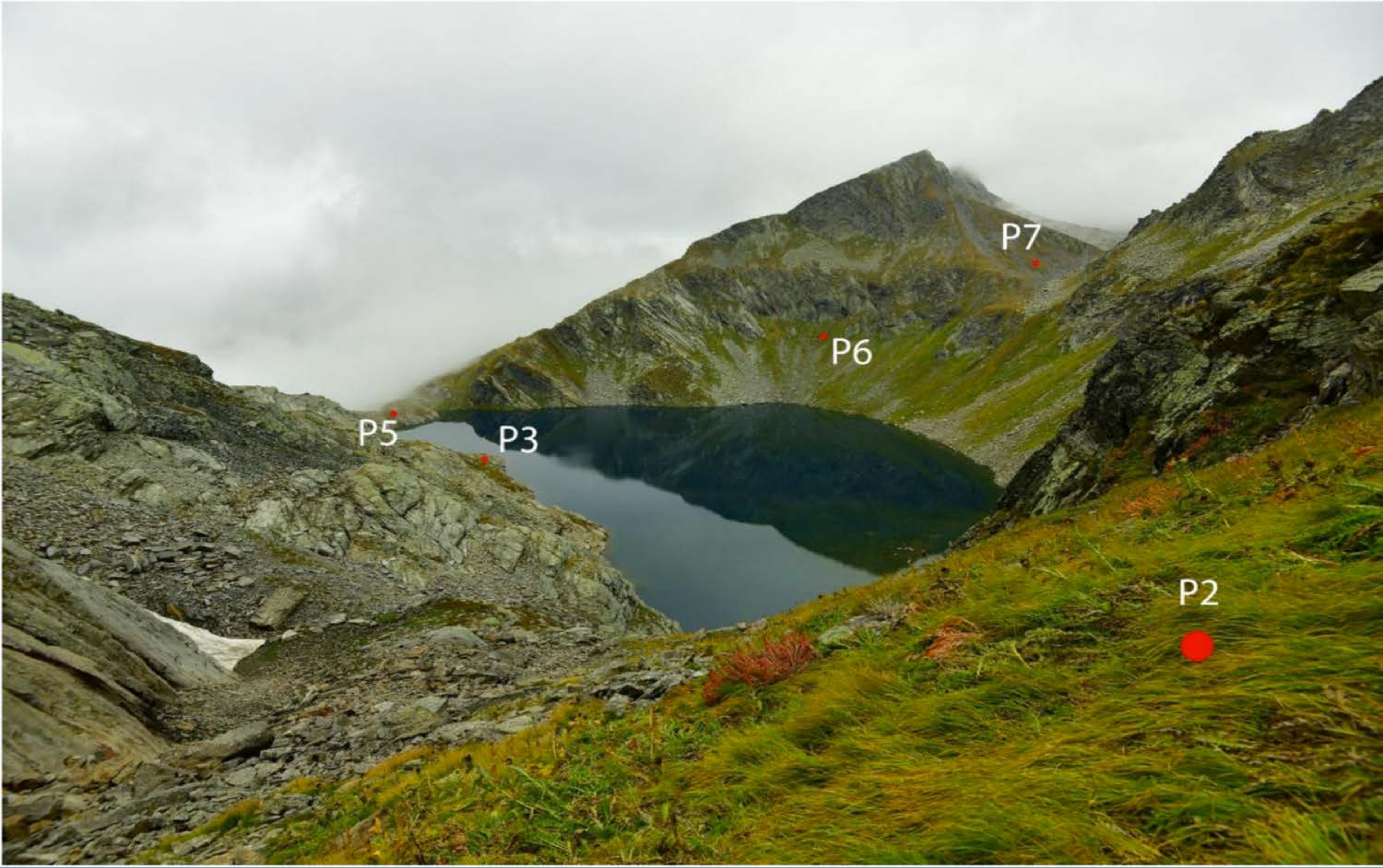


Input-output budgets

		2014-2015	2015-2016	2016-2017	2017-2018	2018-2019
yearly precipitation	mm	3082	2031	2313	1927	2696
Nitrogen (DIN)	N, Input (kg)	1488	1106	1338	813	1243
	N, Output (kg)	287	265	188	221	244
	N, pne[1] (%)	-81	-76	-86	-73	-80
	N Load[2], N $kg_* ha^{-1} {}_* y^{-1}$	19.3	14.4	17.4	10.6	16.1
	Critical Load exceedance, CLexc , N $kg_* ha^{-1} {}_* y^{-1}$	16.3	11.4	14.4	7.6	13.1
Sulfur	S, Input (kg)	459	303	339	270	415
	S, Output (kg)	1162	940	973	966	1088
	S, pne[1] (%)	**153**	**211**	**134**	**258**	**162**
	S-Load, S, $kg_* ha^{-1} {}_* y^{-1}$	6.0	3.9	4.4	3.5	5.4

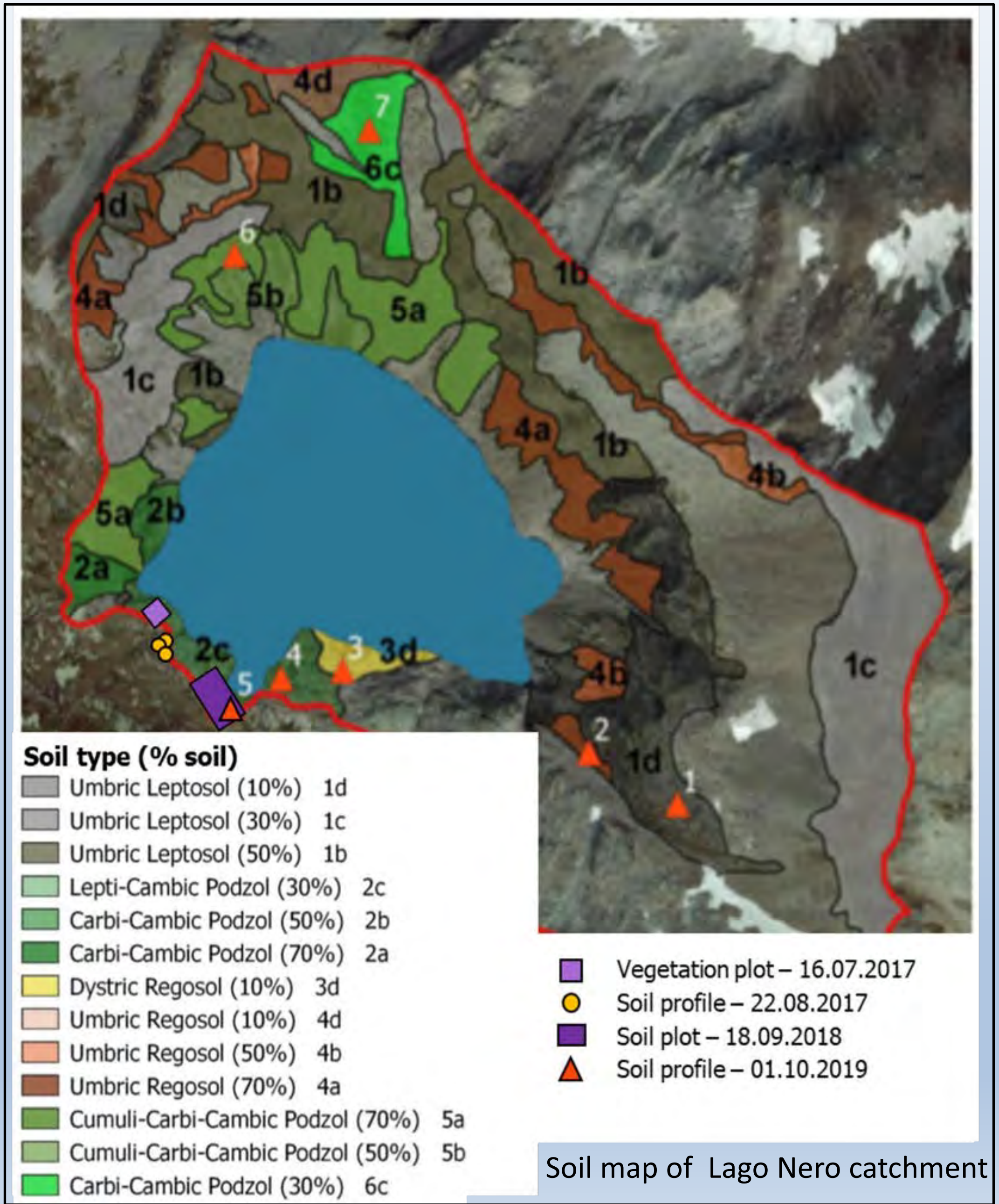
[1] pne, percent net export, %

[2] Lago Nero catchment surface 0.77 km^2; Empirical Critical Load for N-nutrient for alpine Lakes: ~3 $kg/ha^{-1}y^{-1}$, (Baron e.a. 2011)



Soil survey

Soil survey

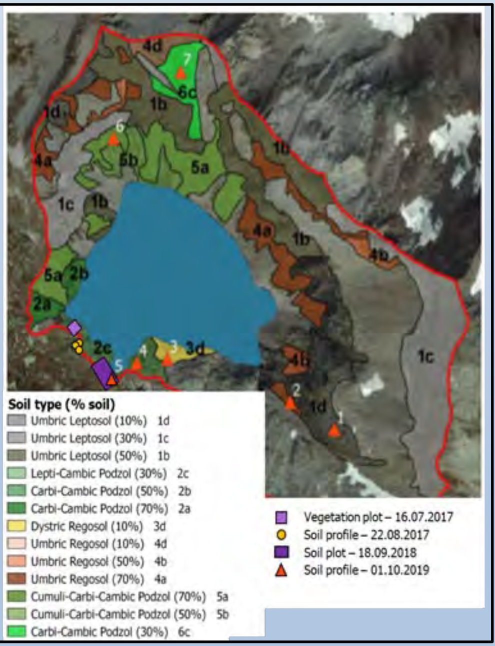


Soil map of Lago Nero catchment

Soil survey and soil chemistry

All the analyzed profile, 1-7, showed common characteristics:

- extremely low pH-value,
- high content of organic carbon
- strong mineral alteration, mostly due to the high level of rainfall.



Sample point	Horizon profile	Texture profile	pH, H_2O	pH, KCl	TOC, g/kg	Fe_{ox} g/kg	Al_{ox} g/kg	Ca^{2+} Cmol/kg	Mg^{+} Cmol/kg	Na^{+} Cmol/kg	K^{+} Cmol/kg
1	A	FS	4.7	3.9	32	5.8	4.7	4.16	0.59	0.08	0.12
2	A1+A2	SL	4.4	3.1	39	6.3	3.4	4.54	0.5	0.03	0.18
3	A1+CA	SL	4.8	4.1	13	2.4	3.2	1.81	0.11	0.01	0.06
4	A1+A2	SL	4.4	4	62	9.2	7.6	1.18	1.26	0.26	0.18
4	Bhs	LS	4.4	4	39	10.2	8	0.75	0.01	0.04	0.05
5	A+AE	SL	4.6	4.2	30	3.5	6.9	0.65	0.06	0.15	0.13
5	Bh	SL	4.8	4.6	42	6.3	10.4	0.72	0.05	0.09	0.08
6	A1+A2	SL	4.4	3.9	41	1.9	3	2.44	0.39	0.1	0.13
6	ABhs1	SL	4.6	4	48	5.2	4.4	0.85	0.14	0.03	0.12
7	AE	S	4.8	4.4	22	0.7	3.5	1.37	0.1	0.07	0.06
7	Bh+Bs	LS	4.6	4.2	37	2.1	4.3	1.8	0.26	0.13	0.08

Texture, horizon and chemical analysis of the soil profile, sample points 1-7 , TOC, Feox and Alox in g/kg, Ca2+,, Mg+, Na+ and K+ in cmol(+)/kg

Vegetation survey

Species identified in the Lago Nero Vegetation plot and their occurance frequency

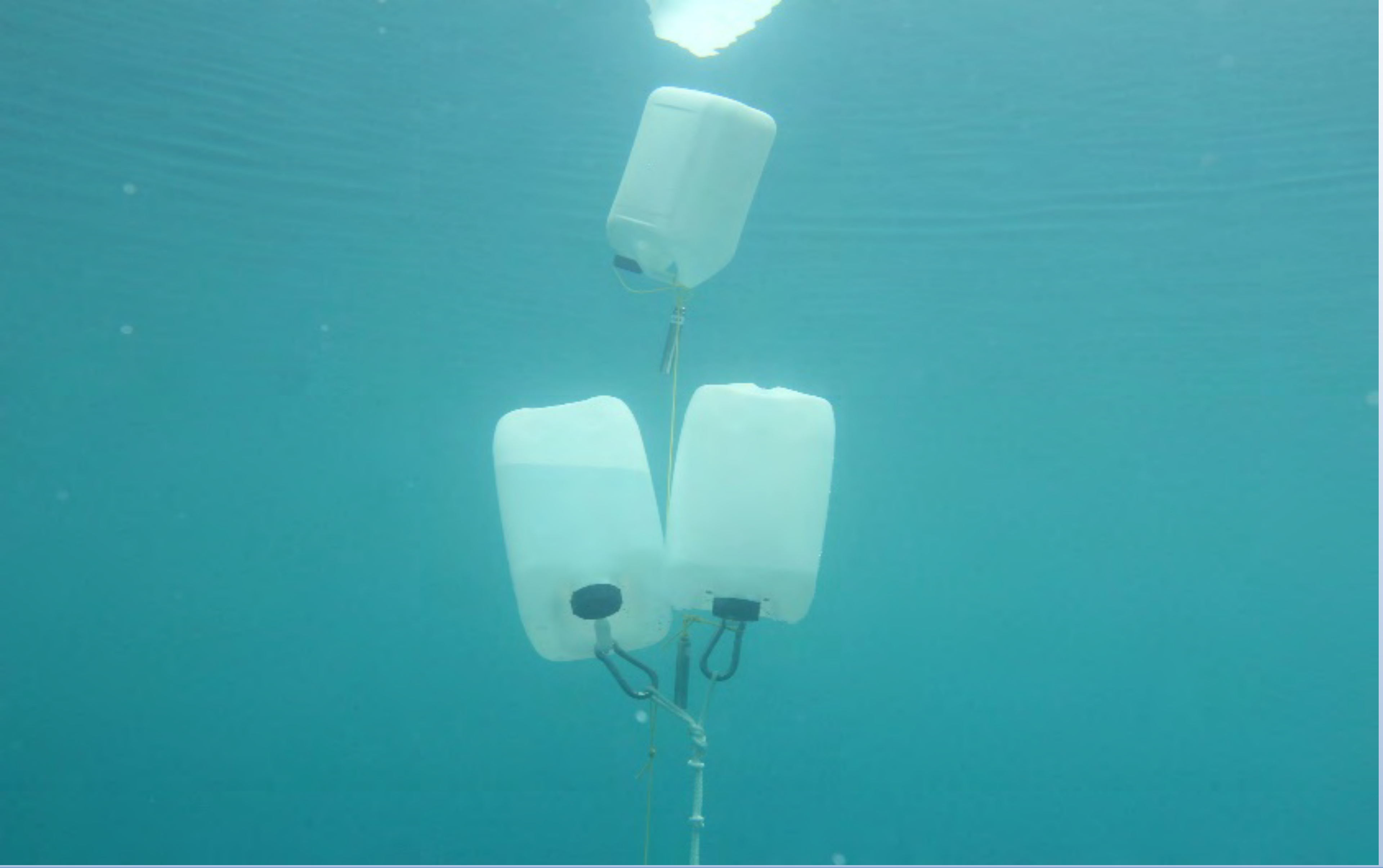
Species	Program center code list	Frequency of occurrence of all species for the whole intensive plot (%)
Agrostis rupestris All.	Added to the list	5.0
Alchemilla pentaphyllea L.	Added to the list	60.0
Anthoxanthum alpinum A. & D. Löve	Added to the list	15.0
Bartsia alpina L.	Already in the list	5.0
Campanula scheuchzer Vill.	Already in the list	5.0
Carex curvula All.	Added to the list	95.0
Gnaphalium supinum L.	Already in the list	70.0
Helictotrichon versicolor (Villars) Pilger	Added to the list	75.0
Hieracium glandulferum Hoppe	Added to the list	25.0
Homogyne alpina (L.) Cass.	Already in the list	85.0
Leontodon helveticus Mérat	Added to the list	95.0
Leucanthemopsis alpina (L.) Heywood	Added to the list	70.0
Ligusticum mutellinoides(Crantz) Villars	Added to the list	10.0
Minuartia recurva (All.) Schinz & Thell.	Added to the list	5.0
Minuartia sedoides (L.) Hiern	Added to the list	5.0
Potentilla aurea L.	Added to the list	10.0
Salix herbacea L.	Already in the list	80.0
Soldanella alpina L.	Added to the list	55.0
Vaccinium galtherioides Bigelow	Added to the list	15.0

Vegetation survey

- High altitude grassland on acid soil
- The quantitative survey has shown that species richness is relatively poor on the vegetation plot (average species richness per subplot: 7.8)
- The community is dominated by species adapted to nutrient-poor and rather acid soils (e.g. including species like *Carex curvula* and *Homogyne alpina*).
- Communities on other areas of the catchment differ due to different orientation, slope, and humidity of the soils.


Carex Curvula

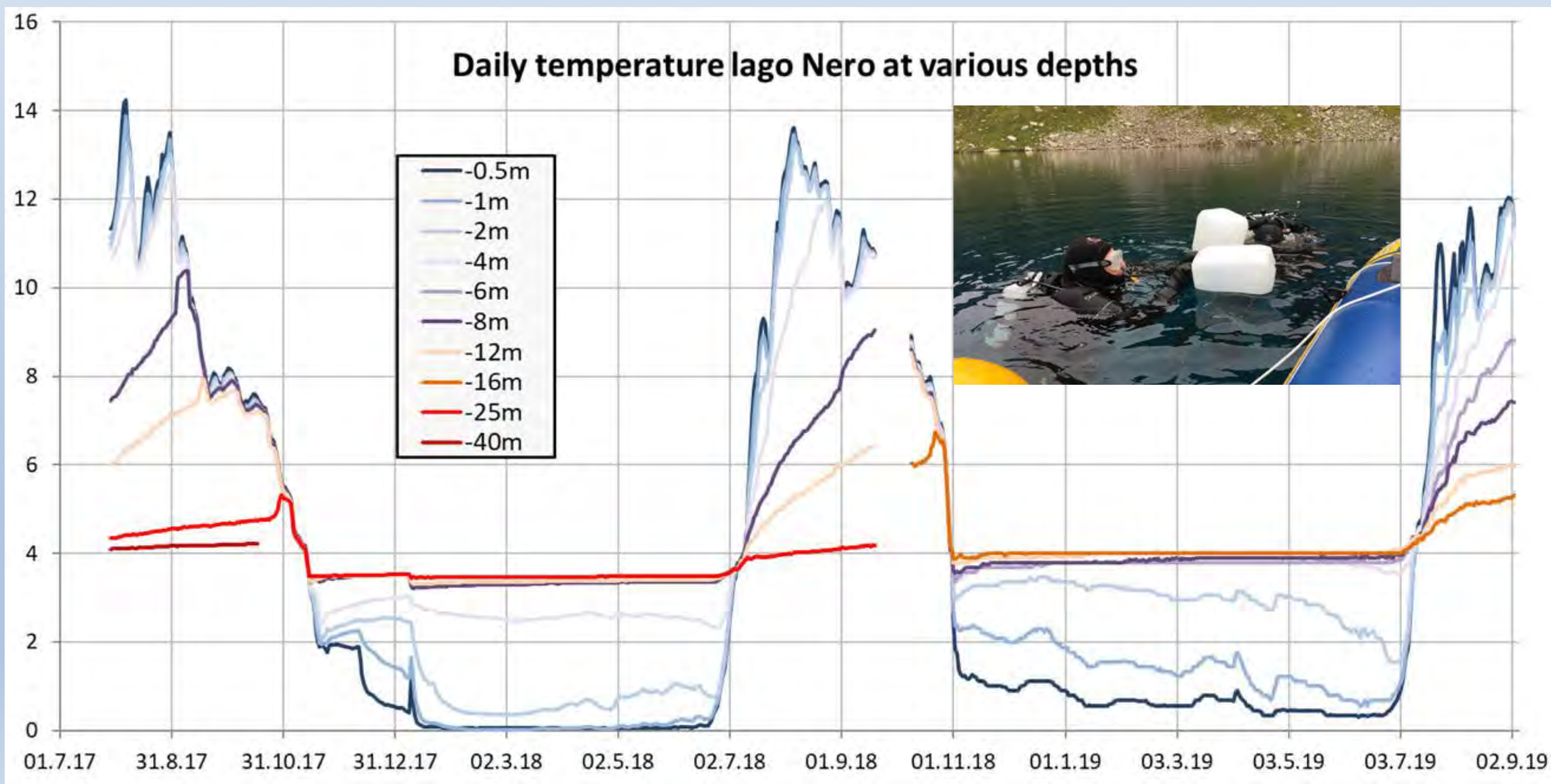
Vegetation survey



Lake temperature profiles

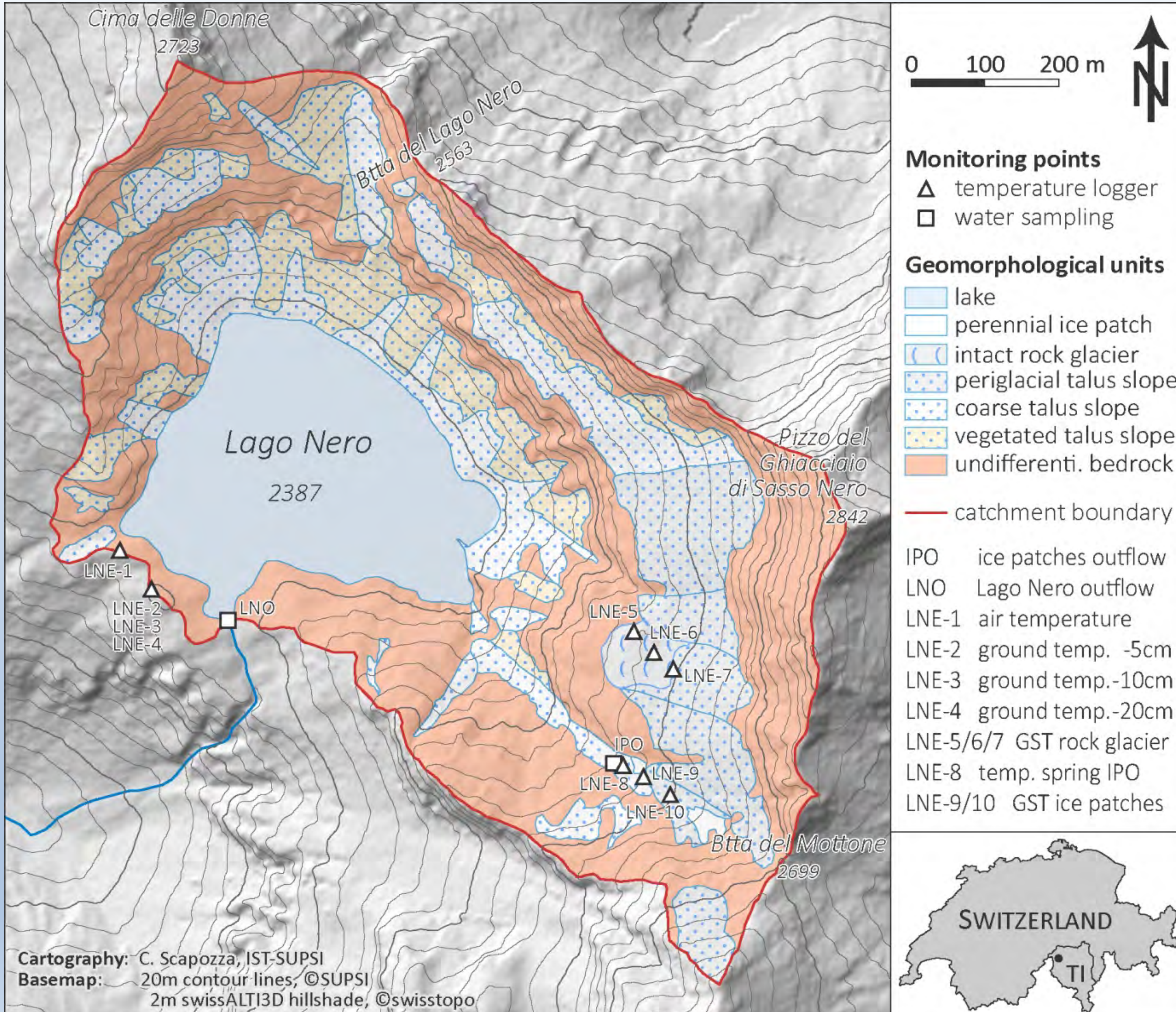
Lake temperature profiles 2017-2019

- Typical dimictic regime of a small mountain lake, mixing from the top to the bottom twice a year. First time in July and the second time in the fall (October-November).
- Turnovers separated by periods of winter/spring (November through June) and summer (July through October) stratification.
- The timing of the turnovers and duration of the summer stratification period identified interesting because they are potentially sensitive to climate change




Cryosphere studies at Lago Nero

- Geomorphology of the Lago Nero catchment

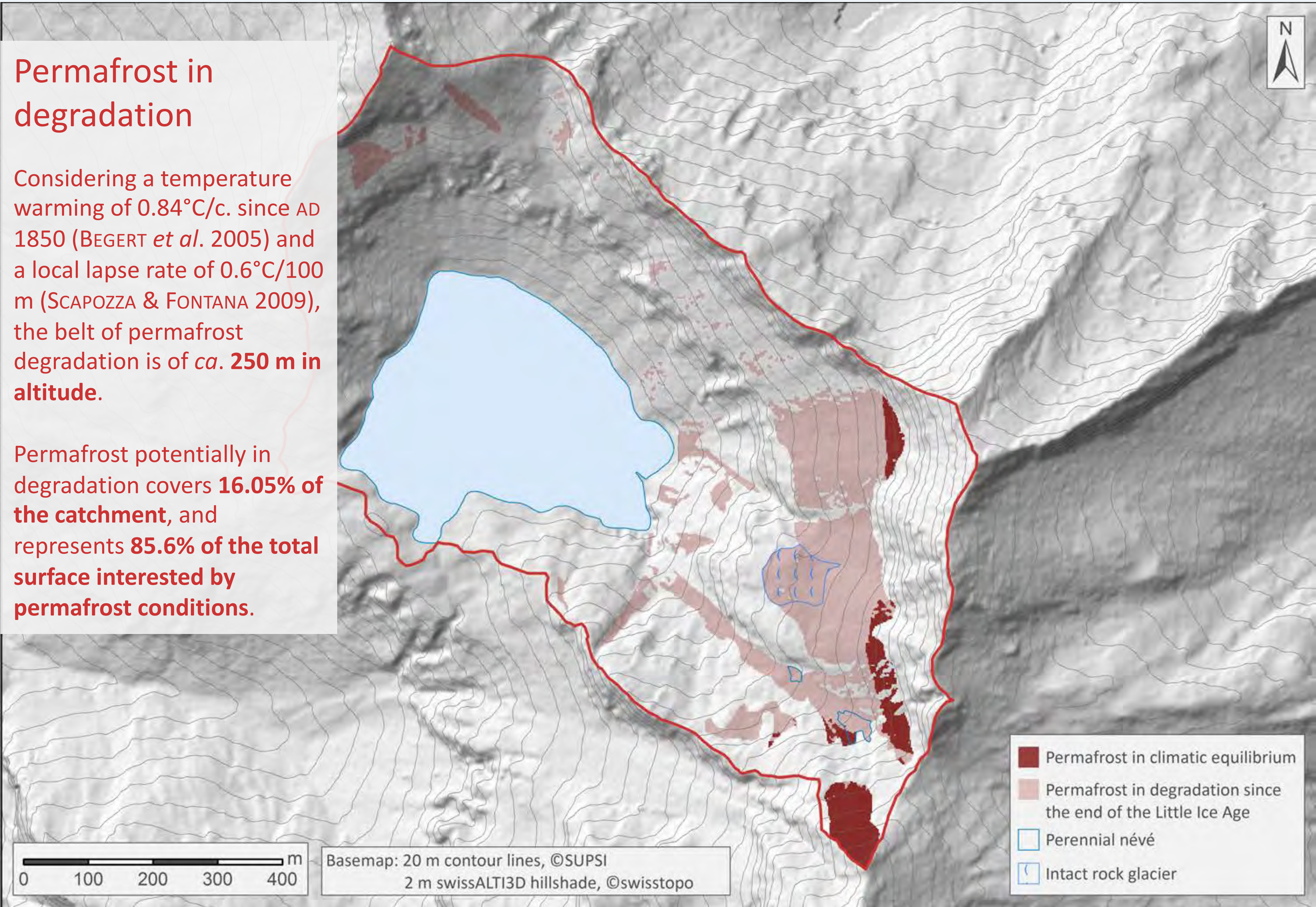


• Evolution of permafrost distribution in the Lago Nero catchment

Permafrost in degradation

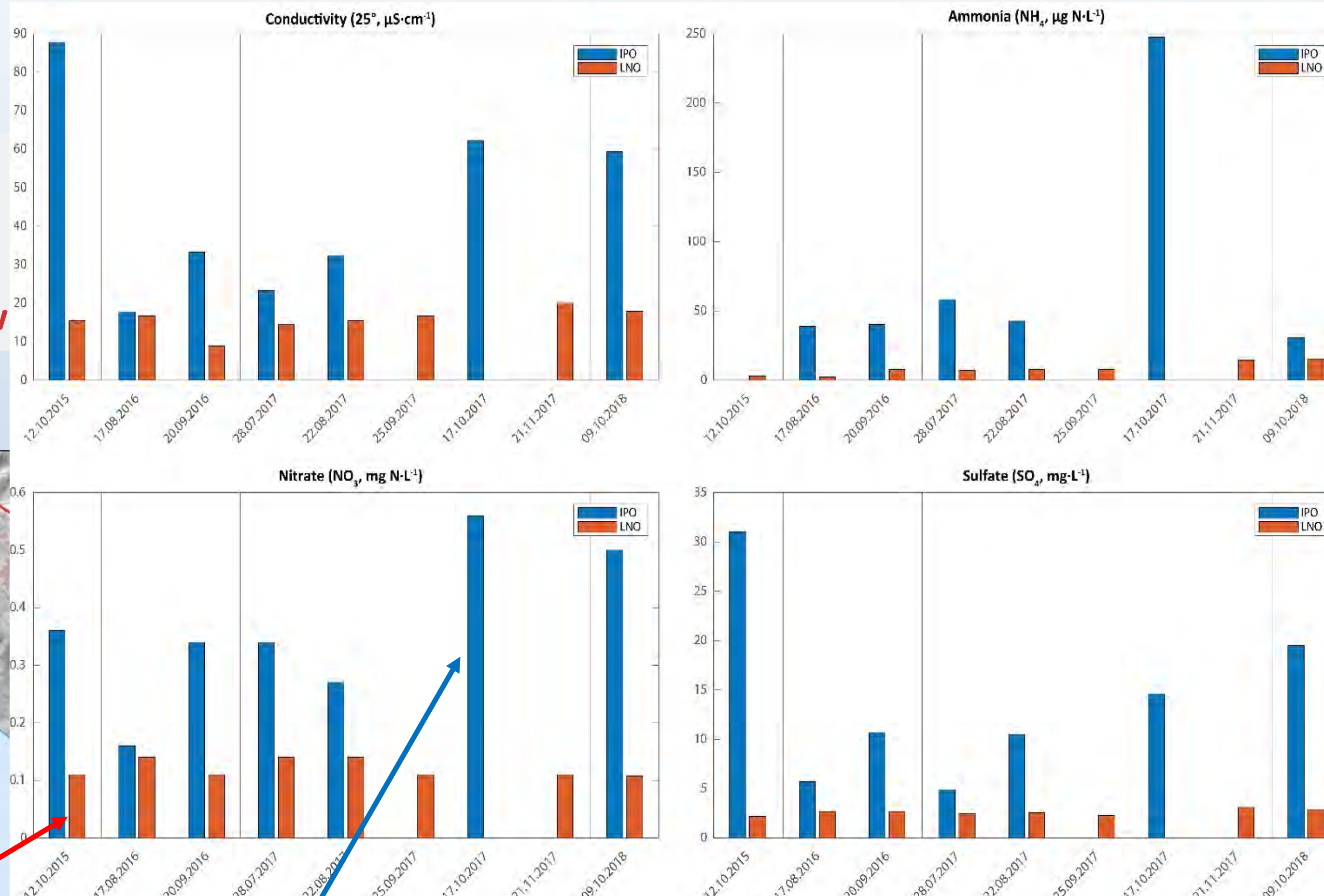
Considering a temperature warming of 0.84°C/c. since AD 1850 (BEGERT *et al*. 2005) and a local lapse rate of 0.6°C/100 m (SCAPOZZA & FONTANA 2009), the belt of permafrost degradation is of *ca*. **250 m in altitude**.

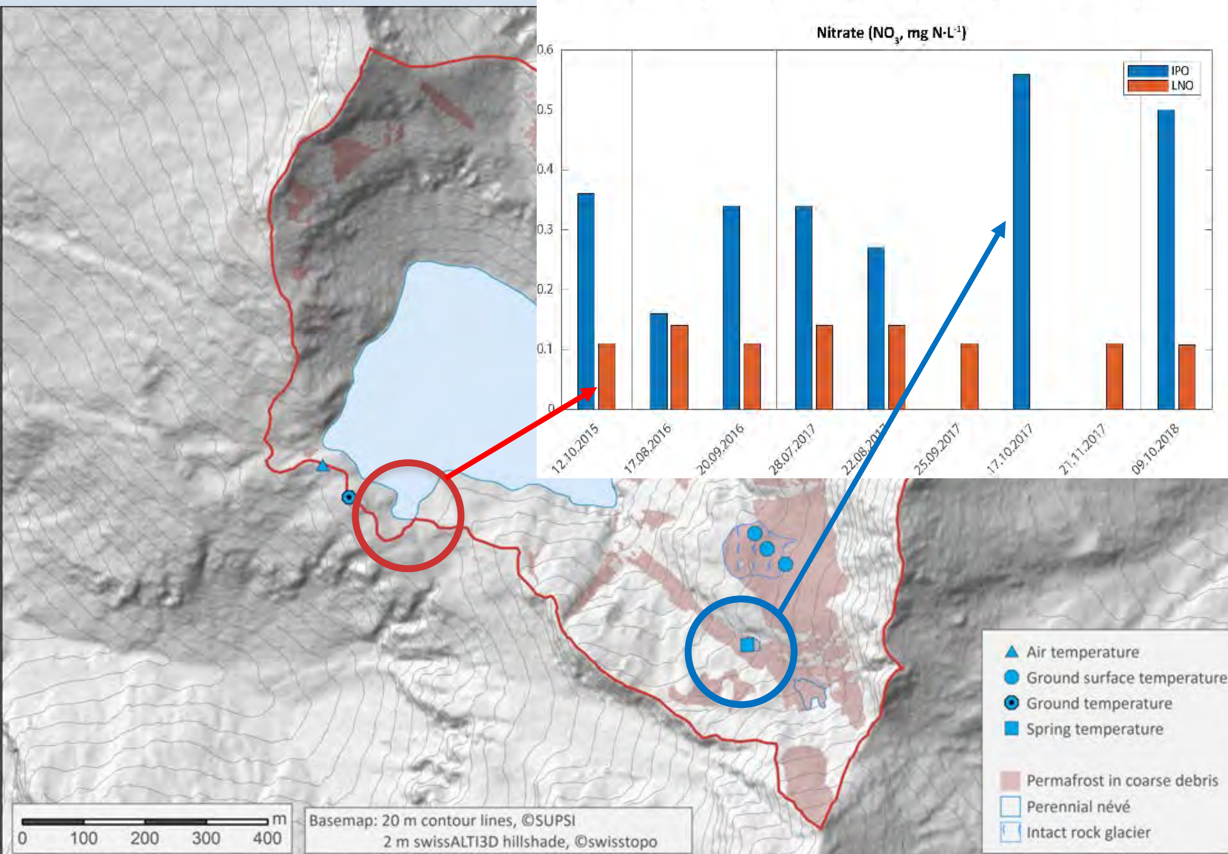
Permafrost potentially in degradation covers **16.05% of the catchment**, and represents **85.6% of the total surface interested by permafrost conditions**.

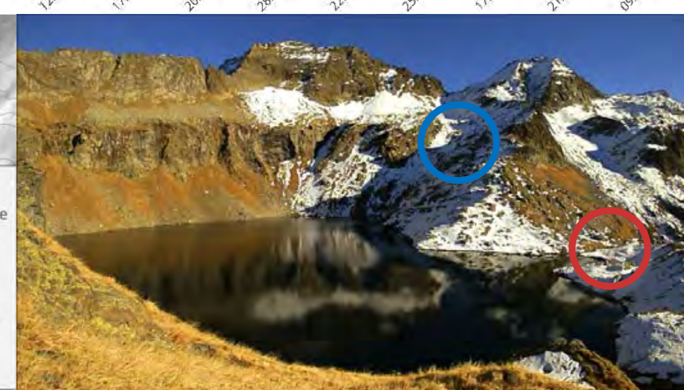


Climate and cryosphere monitoring in the Lago Nero catchment

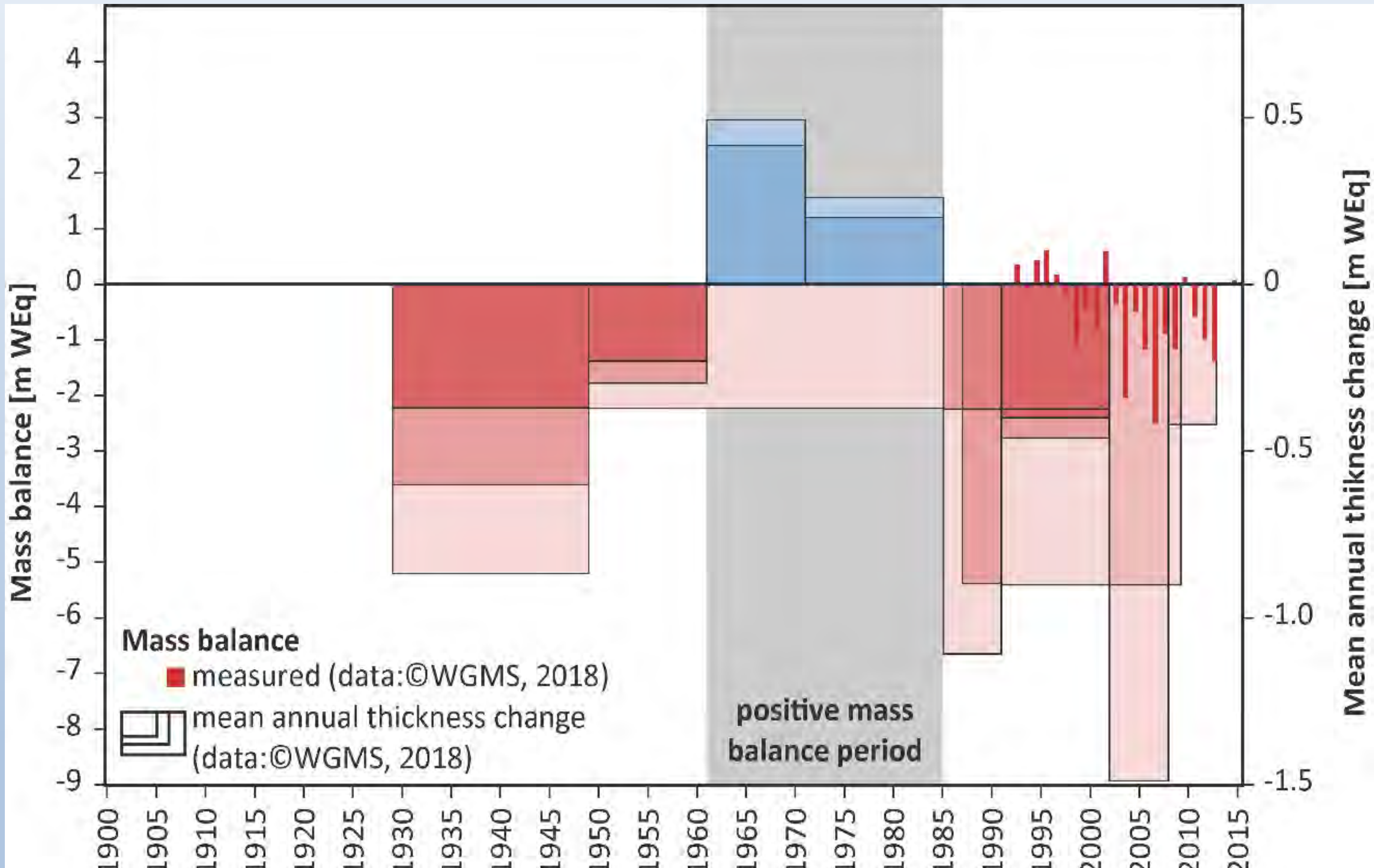
Very high amounts of ammonium and sulphate in the periglacial zone with respect with the lake outflow

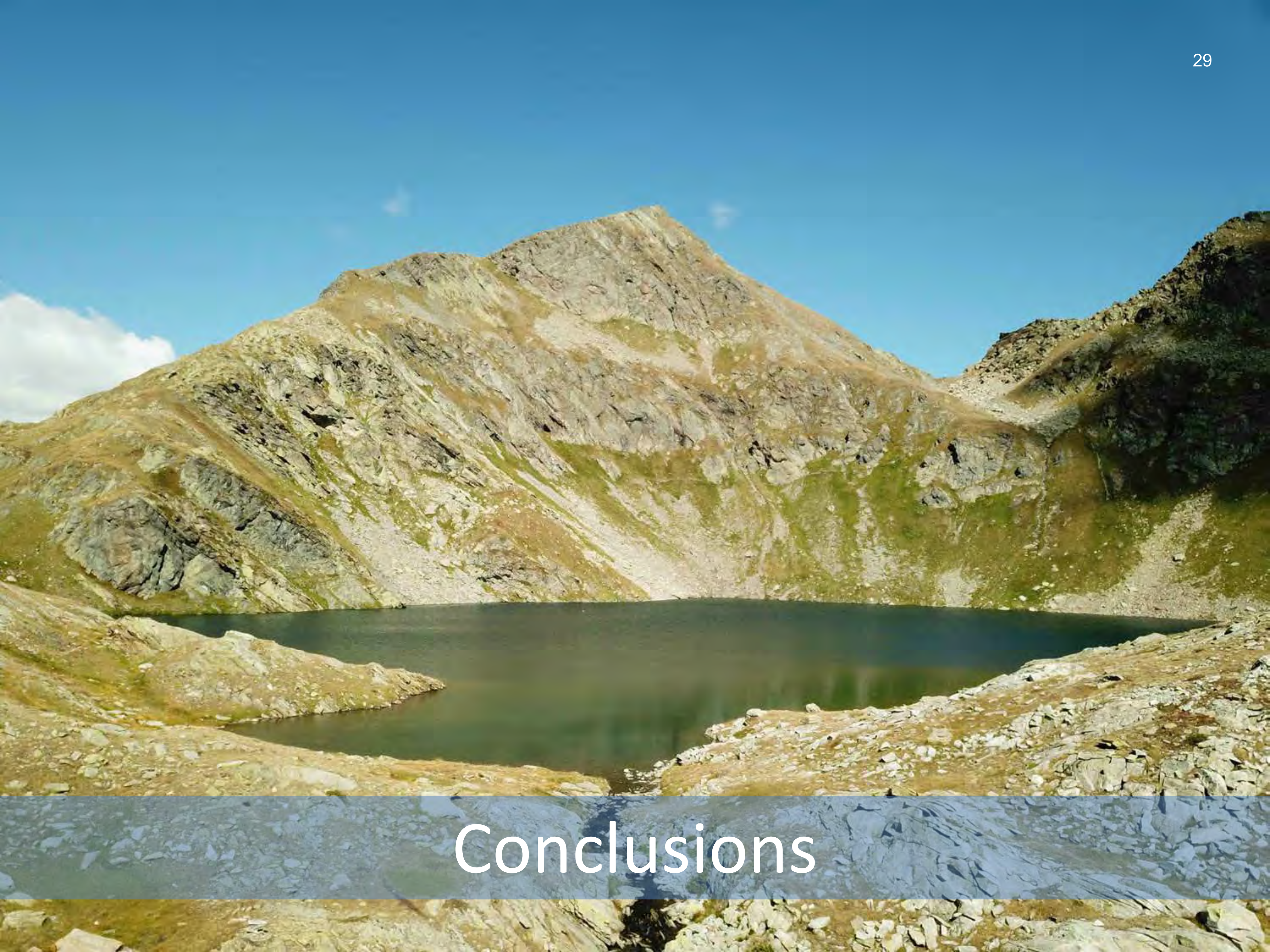






The cryosphere stores pollutants of 60ies to 90ies





Conclusions

Methodological conclusions

- From a methodological point of view the Lago Nero site has proven to be **suitable for long term monitoring of air pollution impacts on alpine ecosystems;**
- The Lago Nero monitoring site is **fully instrumented as agreed with ICP-IM program center**, considering the peculiar characteristics of this not forested high alpine site;
- During the period 2016-2019 the **mandatory sub-programs were accomplished as agreed with ICP-IM program center**.
- The results are relevant not only for the ICP-IM program but also for the ICPW program (e.g. underestimation of output budgets)

Scientifical conclusions

- **High degree of N enrichment;**
  - The pne of N ranges between -73% and -86%, showing a high retention rate.
  - The runoff and deposition chemistry integrated by the input-output budgets point out a very high deposition of N, ranging from 10.5 to 19.5 $kg_*ha^{-1}year^{-1}$;
  - the empirical critical load N for alpine lakes of 1-3 $kg_*ha^{-1}year^{-1}$ is still largely exceeded.
- **Watershed exported high amounts of S**;
  - In-output budgets shows that S exports exceeded by 34-158% the atmospheric input;
  - S net release may delay the acidification recovery and contribute to maintain high SO_4^{2-} concentrations in surface waters despite declining atmospheric deposition;
  - Presence of high concentration of S and partially N in the rock glacier and permafrost meltwater may contribute to maintain high release of acidifying elements in the catchment and is likely to have ecological effects on the sensitive biota.
- **Climate changes effects**;
  - Global warming with rapid and intense increase in MAAT (up to ~2°C) in the Alps;
  - ‘old’ atmospheric deposition accumulated in ground ice in the past and now is being released due to climate warming;

Conclusions

Future perspectives

Future perspectives

- In 2020 the ICP-IM research program set up at Lago Nero will end.
- In the near future, FOEN-funded research will be will be redirected towards shorter-term projects aimed at addressing unanswered questions raised by the five-year program.
- Three possible research lines are identified:
  - the impact of N deposition on contemporary biological communities;
  - the reconstruction of the effects of atmospheric deposition on the biological communities of the lake from pre-industrial conditions to the present based on fossil diatoms and other proxies;
  - the relative contributions of atmospheric deposition, natural weathering and melting ground ice to the S budget of the catchment and the effect of legacy effects on the recovery from past S deposition.

Basic monitoring at Lago Nero 2021-2024

	Sub-programme	Sampling frequency	Data source	status
1	Meteorology	▪ 10 min ▪ 2 h for temperature	MeteoSwiss SUPSI	✓
2	Air chemistry	▪ monthly for NO_2-N ▪ yearly for AOT40 ▪ 5-10 year for SO_2, NO_3^-, HNO_3, NH_3, NH_4^+	UACER (ICPW) MeteoTest MeteoTest (modelled)	✓ ✓
3	Precipitation chemistry	▪ weekly	UACER (ICPW)	✓
4	Runoff water chemistry	▪ 6-8 year for chemical parameters ▪ 30 min for temperature and discharge	SUPSI	✓
5	Surface lake chemistry	▪ Twice a year	UACER (ICPW)	✓
6	Cryosphere (rock glacier and permafrost)	▪ Once a year	SUPSI	✓
7	Ice cover (camera)	▪ daily	SUPSI	✓
8	Biological indicators: • macroinvertebrates • benthic diatoms	• Once a year	SUPSI	TBD

Proposal of additional activities and biological indicators

	Activity	Sampling frequency	Rationale
1	Benthic diatoms	▪ 5 samples yr^{-1}	Biological indicator (Swiss modular stepwise procedure, MSK, for rivers, Water Framework Directive)
2	Phytoplankton	▪ 2 samples yr^{-1}	Biological indicator of nutrient (N, N:P), acidification and thermal conditions (MSK for lakes, WFD)
3	Bacterial metagenomic	▪ 2-3x	Biological indicator of bacterial communities, microbial diversity
4	Bathymetry	▪ 1x	Suitability for sediment sampling, thermal and hydrochemical modelling
5	Coring of lake sediments	▪ 1x	Reconstruction of nitrogen deposition and communities of biological indicators


Thank you for your attention!