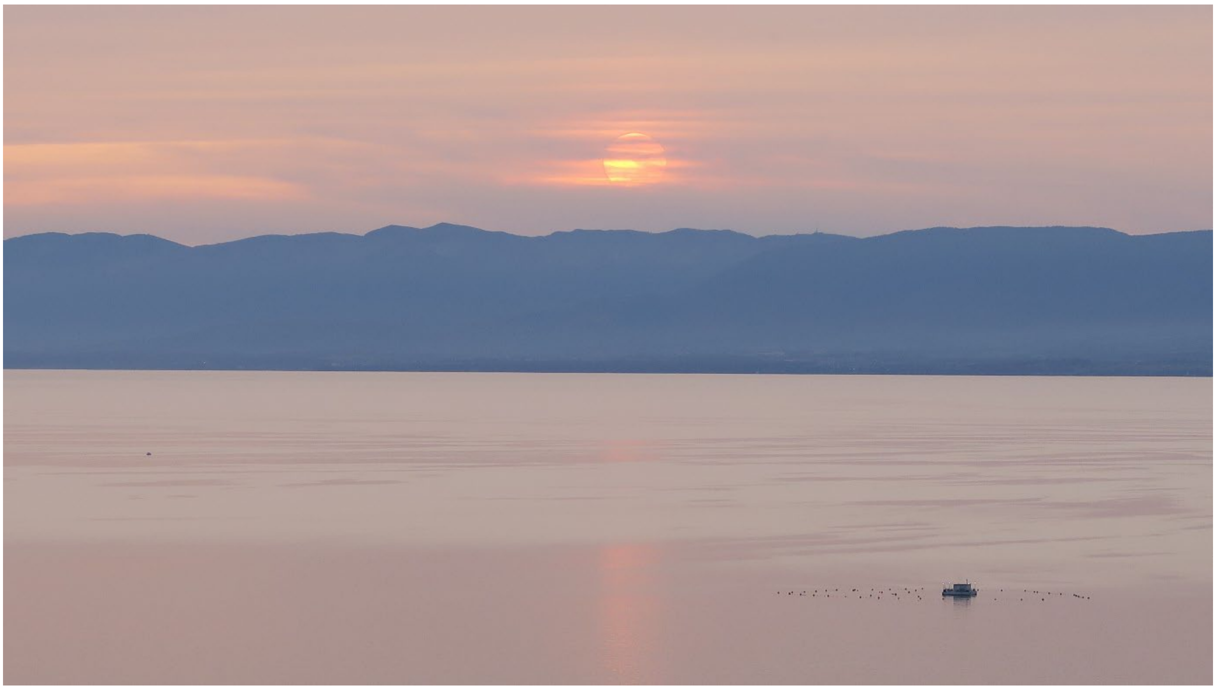
LéXPLORE

LéXPLORE platform

Scientific Report 2022



Sunset on LéXPLORE platform, ©Yves Bellouard, EPFL, 2021

Reporting from 34 projects from July 2021 to June 2022

Compiled by Natacha Tofield-Pasche and the project leaders

Annual reporting from the current projects

1. Perga Marie-Elodie, Perolo Pascal, Lambert Thibault, Escoffier Nicolas, Chmiel Hannah, Fernandez Castro Bieito, Bouffard Damien: **CARBOGEN: carbon cycling in Lake Geneva**
2. Breider Florian, Hanahan Jonathan, Vernez Karine, Coudret Sylvain, Loizeau Jean-Luc: **Deposition and Accumulation of Microplastics in Lake Sediments (Microsed)**
3. Bouffard Damien, Sebastiano Piccolroaz, , Gil Coto Miguel, Lavanchy Sébastien, Cunillera Guillaume, Dinkel Christian, Fernandez Castro Bieito: **LéWalk: autonomous turbulence profiling**
4. Ibelings Bastiaan, Thomas Mridul, Fillion Roxane, Mesman Jorrit, Devanthery Matthieu, de Loes Sebastien, MUSE-Master students, Müller Beat: **POETICS - PlanktOn vErTICal Structure**
5. Guillard Jean, Rautureau Clément, Tran-Khac Viet, Goulon Chloé: **LéXfish: monitoring fish presence below LéXPLORE**
6. Bouffard Damien, Bieito Fernandez Castro, Piccolroaz Sebastiano, Michäel Plüss, Sebastien Lavanchy, Wüest Alfred: **Skin2Bulk: investigating the surface boundary layer**
7. Thomas Mridul, Pomati Francesco, Suarez Ena, Fillion Roxane, Ibelings Bastiaan: **Plankton in Lake Geneva : you can't have it both ways**
8. Maner Jenny, Drieschner Carolin, Ebi Christian, Schönenberger René, Angst Levin, Bloem Simon, Solsona Miguel, Renaud Philippe, Schirmer Kristin: **Rainbow$_{flow}$ chip$_{online}$: Fishcell biosensor for automated water quality testing**
9. Adam Nicolas, Selz Jonathan, Lecine Sofian, Hirt Timothée, Deloose Christophe, Ovide Sanchez Elio, Coudray Armand, Mermoud Paco, Bernier-Latmani Rizlan, Maerkl Sebastian: **GenoRobotics CoWaS - Continuous Water Sampling**
10. Weyermann Céline, Estoppey Nicolas, Ines Tascon, Pfeiffer Fabienne, Glanzmann Vick, Reymond Naomi, Huismann Sofie: **Aqua-Gabs/MONET in Lake Leman**
11. Larivé Odile, Wynn Htet Kyi, Li Chaojie, Tamar Kohn**: Effect of lake exposure on Enterovirus population**
12. Tercier-Waeber Mary-Lou, Ibelings Bastiaan, Layglon Nicolas, Gressard Tanguy: **Synergic interaction between arsenic species and microorganisms in freshwater contrasting dynamic conditions (SyBAM)**
13. Mariethoz Gregoire, Koch Erwan, Berne Alexis: **Installation of a drip-based rain gauge on LéXPLORE**
14. Dubois Nathalie, Mittelbach Benedict, Eglinton Timothy, White Margot, Rhyner Timo: **Radiocarbon Inventories of Switzerland (RICH)**
15. Carratalà Anna, Ibelings Bastiaan, Odermatt Daniel, Janssen Elisabeth: **Remote sensing and risk assessment of toxic Cyanobacteria in Lake Geneva (CYANOSENSE).**

16. Schuback Nina, Oxborough Kevin, Moore Mark, Ibelings Bastiaan, Odermatt Daniel, Lavanchy Sébastien: **Single Turnover Active Fluorescence of Enclosed Samples for Aquatic Primary Productivity (STAFES-APP)**

17. Forrest Tara, Jeanneret Stéphane, Polyxeni Damala, Zdrachek Elena, Cherubini Thomas, Bakker Eric: **Submersible Probe with In-line Calibration and Symmetrical Reference Element for Long-term Continuous Measurement of Environmentally Relevant Ions (Multiple ion)**.

18. Tofield-Pasche Natacha, Cunillera Guillaume, Dubois Nathalie, Janssen David: **Temporal and spatial variations of the settling particles fluxes in Lake Geneva (SEDTRAP)**

Current projects without detailed reports

19. *Bellouard Yves, Rey Samuel, Ayer Baptiste, Sala Federico, Ibelings Bastiaan, Pomati Francesco:* ***PhytoWaveTaxa: all glass sensors for algae population monitoring.*** *The system is currently being prepared for deployment.*

20. Piccolroaz Sebastiano, Cunillera Guillaume, Chmiel Hannah, Perolo Pascal, Lavanchy Sébastien: **caGAStrophic: designing a low-cost, automated, floating chamber for gas flux measurements at the air-water interface of water bodies**

21. *Bahr Alexander, Schill Felix, Lavanchy Sébastien and Cunillera Guillaume:* ***SUBMULE – easy access to submerged data****. No activities during this period.*

22. *Perga Marie-Elodie, Frech Benoit, Vittoz Jérôme, Gravey Mathieu:* ***the sounds of LéXPLORE****. Mainly artificial sounds were identified so far.*

23. *Hedou Maxime, Luterbacher Jeremy, Manker Lorenz:* ***Biodegradability assessment of PBX, a sustainable bio-polyester developed at EPFL****. Last sample will be collected in July 2022.*

24. *Odermatt Daniel, Damm Alexander, Pasche Natacha, Alikas Krista, Soomets Tuuli, Spyrakos Evangelos:* **Monitoring Lake Primary Production using the PACE satellite (Lake3P).** *Project will start later in 2022.*

Final report for completed projects

25. Wüest Johny, Fernandez Castro Bieito, Ulloa Hugo, Minaudo Camille**,** Lavanchy Sébastien, Shubham Krishna, Piccolroaz Sebastiano, Chmiel Hannah: **Primary production under oligotrophication in lakes**
26. Haltiner Linda, Zhang Hui, Kaeser Silvana, Dennis Stuart, Rothhaupt Karl-Otto, Spaak Piet,: **Life in the deep: colonisation by Dreissena along a depth gradient**
27. Lattaud Julie, de Groot Lissie, Zborowski Beata, Bolandini Marco, Eglinton Timothy**: Variability in stable isotopic composition of long-chain diols as a proxy for environmental conditions in lakes**
28. Odermatt Daniel, Runnalls James, Abolfazl Irani Rahaghi, Remika Gupana, Anita Schlatter, Camille Minaudo: **Whitening detection and optical characterization (W-DOC)**
29. Gallorini Andrea, Arpagaus Philippe, Loizeau Jean-Luc: **MetOxiC : Methylmercury in Oxic water Column**
30. Carratalà Anna, Chmiel Hannah, Joost Stéphane, Janssen Elisabeth, Kohn Tamar: **Unravelling the diversity, functioning and toxin production of cyanobacteria populations in lake Geneva (CYANOFUN)**
31. Beauvais Rébecca, Casado-Martinez Carmen, Lüthi Christina, Ferrari Benoît: **LéXPOCHIRO: Effects of lake suspended matter quality on growth, emergence and molecular endpoints in *Chironomus riparius***
32. Cruz Hugo, Bouffard Damien, Perga Marie-Elodie, Runnalls James, Russo Stefania: **REPRODUCE - léxploRE PRODUct ACcESs**
33. Piccolroaz Sebastiano, Fernandez Castro Bieito, Alfred Wüest, Chmiel Hannah, Minaudo Camille, Pascal Perolo, Troy Cary: **Surface Turbulence and CO_2 Lake Exchange Experiment (CO_2LEX)**
34. Jézéquel Didier, Moiron Marthe, Perga Marie-Elodie, Escoffier Nicolas: **DynaMeth - Dynamics and origin of methane in the water column of Lake Geneva**

LéXPLORE

CARBOGEN: Carbon Cycle of Lake Geneva

Perga Marie-Elodie, Escoffier Nicolas, Many Gael, Bouffard Damien, Lambert Thibault, Perolo Pascal.

The overall goal of the CARBOGEN project is to delineate the origin and processes sustaining Lake Geneva's positive CO_2 emissions to the atmosphere. On an annual scale, Lake Geneva emits 20-60 GgC of CO_2 (Perolo et al, 2021), i.e. as much as the whole transportation sector of the City of Lausanne. Yet, Lake Geneva is autotrophic and receives very little CO_2 from its surrounding catchment or underground waters. As such, the mechanisms sustaining the lake's positive CO_2 emissions escape our general understanding of carbon cycling in lakes. As a blatant illustration, the current generation of water quality models inaccurately simulate Lake Geneva as being a CO_2 sink rather than a source (Many et al, in prep).

Our hypothesis is that CO_2 emissions are supported by alkalinity inputs to the lake, inherited from carbonate weathering in its catchment. The puzzle concerns the processes by which alkalinity can be converted into CO_2, and whether those transformations are of sufficient magnitude to fuel the observed CO_2 emissions. Using high-frequency measures of CO_2, O_2 and conductivity at the lake surface over the years 2019 and 2020, Perolo et al (in review) demonstrate that alkalinity (especially bicarbonates) rather than CO_2 is the major inorganic carbon source to gross primary production for >75% of the year, both in the littoral and pelagic habitats. From high-frequency data of pH, CO_2 and conductivity, Escoffier et al (submitted) estimate the daily calcite precipitation over the years 2019 and 2020 and demonstrate that CO_2 released by calcite precipitation provides 50-100% of the inorganic carbon requested for primary production when the lake is stratified. Both processes thereby contribute to producing organic matter withdrawing alkalinity while generating excess CO_2 when decomposing in the hypolimnion (i.e. what we called the alkalinity-primary production pump). The knowledge on alkalinity processes obtained from the high-frequency surveys is used to compute a new module accounting for calcite processes which, when introduced in the water quality model, allows an accurate simulation of carbon processes and fluxes at the lake scale (Many et al, in prep). Simulations show that alkalinity processes are of sufficient magnitude to sustain the positive CO_2 emissions. Altogether, our program finally demonstrates the mechanisms by which hardwater lakes end up as CO_2 sources to the atmosphere.

Perolo, P., B. Fernández Castro, N. Escoffier, T. Lambert, D. Bouffard, and M. E. Perga. 2021. Accounting for surface waves improves gas flux estimation at high wind speed in a large lake. Earth Syst. Dynam. 12:1169-1189.

Many, G., Escoffier, N., Perolo, P., Hipsey, M., and M.E. Perga (in prep). Alkalinity, the forgotten half of Lake Geneva's carbon cycle.

Perolo, P., Escoffier, N., Chmiel, H.E., Many, G., Bouffard, D. and M.E. Perga (in review). Alkalinity supports gross primary production in a deep hardwater lake. L&O Letters.

Escoffier, N., Perolo, P., Many, G., Tofield-Pasche, N., and M.E. Perga (submitted). Unveiling the fine scale dynamics of calcite precipitation in a large hardwater lake.

LéXPLORE

Microsed project - Deposition and Accumulation of Microplastics in Lake Sediment

Florian Breider, Sylvain Coudret, Karine Vernez

The full extent of the disruptive effective of plastics on the environment, and particularly aquatic environments, is still uncertain. In order to better understand the fate of aquatic plastics, LéXPLORE platform located on Lake Geneva, provides a unique opportunity to study a critical freshwater lake, supplied by one of the biggest rivers in Europe, The Rhône. The aim of this study is to quantify the distribution of microplastics in the water column by studying (i) the variation in size and quantity of plastics collected in the photic (2 m) and in the thermocline (30 m) of the lake and (ii) the sedimentation of plastics at different depths.

To collect the microplastic samples, pumps pull water from 2 and 30 m depth successively through filters of 500 and 150 µm pore size every 12 hours. Additionally, samples are collected every month using cylindrical sediment traps deployed beneath the LéXPLORE platform at four depths (12, 27, 47, 87 ± 0.5 m). Microplastics are extracted from the samples and quantified and characterized by infrared quantum cascade laser spectroscopy to establish the abundance of polymers in the samples. So far only the water samples have been analysed by infrared spectroscopy. The analysis of the samples collected with the sediment traps have yet to be completed and will be added to more detailed reports in the future.

The analysis of water samples shows that the concentrations of microplastic >500 µm range between 0.69 and 6.95 part./m^3 at 2 m depth (Figure 1a) and between 0.78 and 1.70 part./m^3 at 30 m depth (Figure 1c), for a confidence level between 85 and 99%. The concentrations of microplastic for the fraction between 150 and 500 µm range from 1.21 to 4.66 part./m^3 at 2 m (Figure 1b) depth and between 0.67 and 3.69 part./m^3 at 30 m depth (Figure 1d)(identification confidence level 85-99%). No significant difference was observed between the concentrations measured at 2 and 30 m depth. Moreover, no significant temporal variation was observed during the sampling period. These results indicated that microplastics were relatively homogeneously distributed in the water column. The concentrations of microplastic measured in this study are lower than the median concentration in freshwater lakes (1'442 part./m^3) determined by Ducausy et al. (2021) from published data for 98 worldwide lakes. Twenty-three different polymers were detected in the water samples. However, 72% of the microplastics detected are made of three polymers; polycarbonate (PC, 45%), polyethylene (PE, 13%), polypropylene (PP, 14%) (Figure 1e). The analysis of the aspect ratios (width/height) of the microplastics identified with confidence level of 85 to 99% shows that only 10% of the microplastics have an aspect ratio <0.3 or >3.0 (Figure 1f). This indicates that less than 10% of the microplastics detected in the water column are fibres. Over the coming months, a greater quantity and variety of data will be collected in order to better observe the goals outlined, with the eventual goal of publishing a paper.

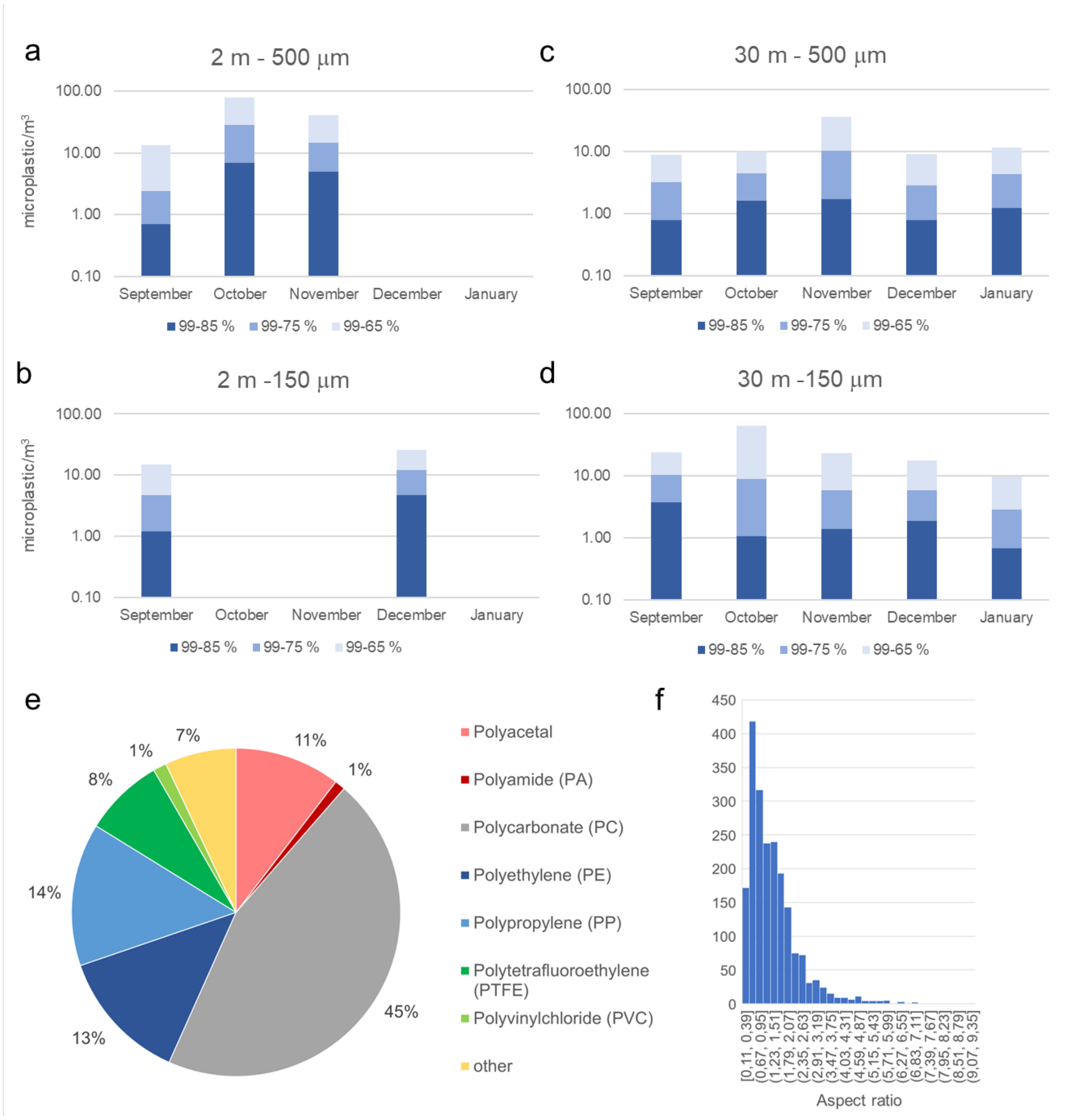


Figure 1. Microplastic concentrations >500 µm and between 500 and 150 µm in water at 2 m depth (a and b) and 30 m depth (c and d) measured between September 2021 and January 2022 at LéXPORE (Lake Geneva). The blue scale corresponds to the confidence level of the particle identification. Average proportion of the different polymers identified in the water samples (e) and aspect ratio distribution (f) for the fraction of microplastics identified with a confidence level of 85 to 99%.

LéWALK: autonomous turbulence profiling

Damien Bouffard, Sebastiano Piccolroaz, Miguel Gil Coto, Sébastien Lavanchy, Guillaume Cunillera, Christian Dinkel and Bieito Fernandez Castro

The goal of this project is to (i) develop an autonomous turbulence profiling system for lakes and (ii) to collect one year of turbulence profile especially under windy conditions, which are conditions typically challenging to monitor with classical methods.

The system has been tested in 2021. While the profiler works efficiently, we had to add an external trigger to start and stop the datalogger not to drain the battery in a few days. The smart trigger wakes up, and stops the logger based on rising and following the speed and pressure.

We have already collected a long dataset and will continue for 2022 and 2023. A PhD student will be hired to analyse the data.

Photo of the autonomous turbulence profiler used on the LéXPLORE platform

LéXPLORE

POETICS - PlanktOn vErTICal Structure

Fabio dos Santos Correia, Mridul Thomas and Bastiaan Ibelings

Lake Geneva, like other peri-alpine lakes in Switzerland, is undergoing rapid environmental change, driven by amongst others re-oligotrophication, increasing levels of micropollutants, and the direct and indirect effects of climate change. The ~80 % reduction in phosphorous has not yet resulted in a decrease in chlorophyll-a levels of the lake. There are, however, indications that higher trophic levels, notably small crustaceans like Daphnia and their crustacean predators Bythotrephes longima - an important food source for coregonid fish in the lake – are declining. In this project, we investigate whether an increase in the carbon: phosphorous (C:P) ratio may create trophic bottlenecks, where the quality of the seston as food for zooplankton is insufficient to sustain optimal population development. Furthermore, we investigate how the phytoplankton community (seston) defines the C:P ratio in the water column.

For this, we apply the following methods: (i) Time series: compute and validate long-term trends in seston C:P in Lake Geneva through OLA data from INRAE, (ii) Laboratory experiments: vary C:P of phytoplankton and test the effects on life-history of zooplankton, (iii) from January to December 2021, field sampling from LéXPLORE for seasonal changes in C:P, and high-frequency data via Cytobuoy installed on the platform to discriminate the phytoplankton communities.

The initial results (from OLA data) indicate that the C:P of Lake Geneva seston has increased since the peak of the eutrophication in the 1980s, and that both the food quantity and food quality (C:P) have clear effects on the life history of Daphnia from Lake Geneva. Currently, we are experimenting with Daphnia in the laboratory, to evaluate the somatic and population growth rate under different treatments (C:P ratio and concentrations of the seston). The Daphnia experiment will be completed by the end of the summer and we hope to publish our results in a scientific paper before the end of 2022. Concerning the phytoplankton data from the Cytobuoy, we are building a model for the identification of the main groups and genera of the community. The model is well advanced (Figure 1), and we expect to be able to use it soon with the C:P ratio data collected on the platform, with an article to follow.

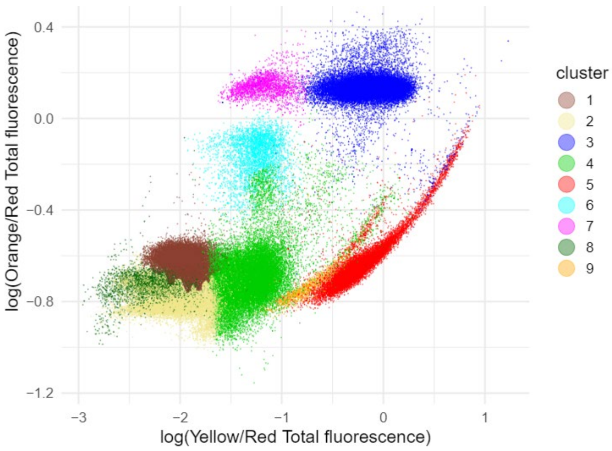


Figure 1: Plot generated by the model, here 9 groups were discriminated with x and y-axis ratios of fluorescence values measured by Cytobuoy. Each point represents an organism of the phytoplankton community, individual, or colony.

LéXFish

Guillard Jean, Rautureau Clément, Viet Tran-Khac, Goulon Chloé

The two echosounders (*Simrad Kongsberg Maritime AS, Horten, Norway*), set in early March 2021 on LéXPLORE, have recorded data for a year now. The remote connection through LéXPLORE Wi-Fi, allows us to check the devices daily. Early in the period, a few one-time issues due to the platform's power supply (the problem is now resolved) caused some missing data, only for short periods. In the spring, we also observed a signal attenuation due to the accumulation of bubbles under the sounder (fig. 1). The bubbles were removed and the acquisition was able to continue. Fortunately, quagga mussels do not stick to the surface of the transducer.

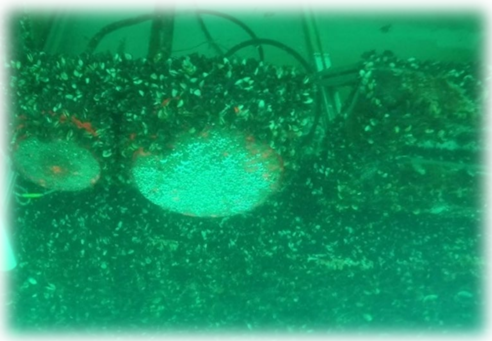


Figure 1: both sides of the transducer with bubbles sticked underneath

We now have a year's worth of data to analyze, but since we had detected huge fish aggregations in early summer 2021 (fig. 2), it was decided to continue recording data until mid-summer 2022. The main objective will be to understand when and why fish aggregations are under the platform and what are their impacts on abiotic and biotic parameters (NH_4, dissolved oxygen levels, zooplankton density...). The data could be analyzed in collaboration with a data scientist using new generation tools for acoustic studies, as Echopy (https://github.com/open-ocean-sounding/echopy).

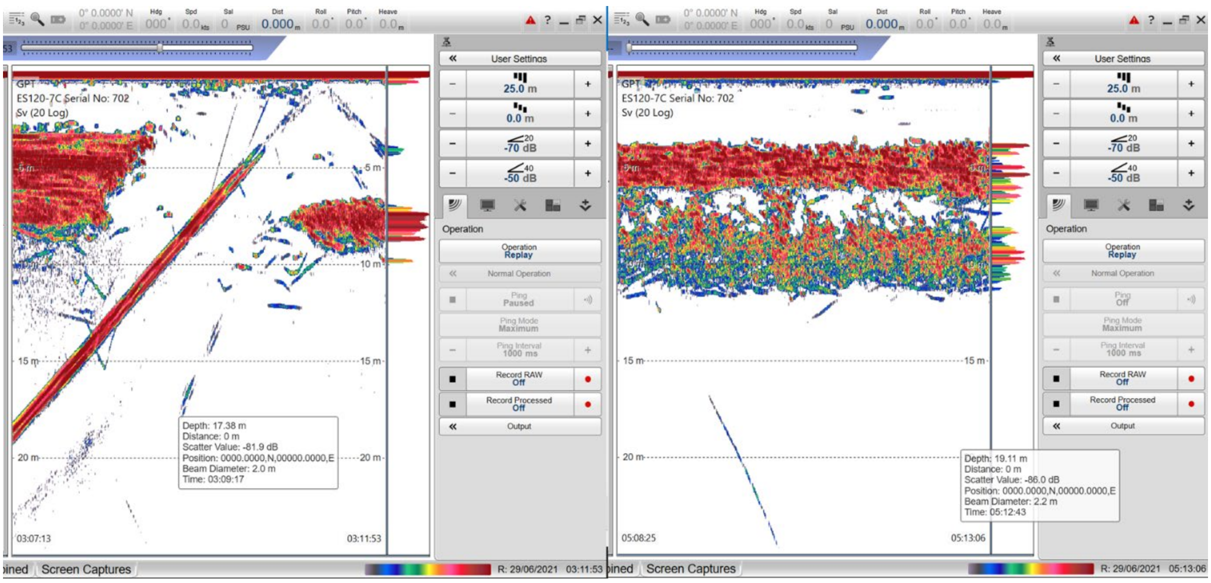


Figure 2: two examples of echograms (end of June 2021): on the left, the school avoided the sampler (red line) and on right the aggregation is split in two levels (two fish populations?)

Skin2Bulk : Investigating the surface boundary layer

Damien Bouffard, Sebastiano Piccolroaz, Sébastien Lavanchy, Michael Plüss and Bieito Fernandez Castro

Infrared satellite provide information of the temperature at the surface over the first micrometers in a layer called "skin layer". This temperature slightly differ from what is observed by in-situ sensors in the top layer (a few cm below the surface) called "bulk layer". The aim of this project is to measure both skin and bulk temperature over a long period with radiometers and a thermistor chain, and finally provide a robust lake-base parameterization of the skin to bulk conversion.

The project started in April 2021. The data are now automatically quality checked, and pushed in near real time into Datalakes.

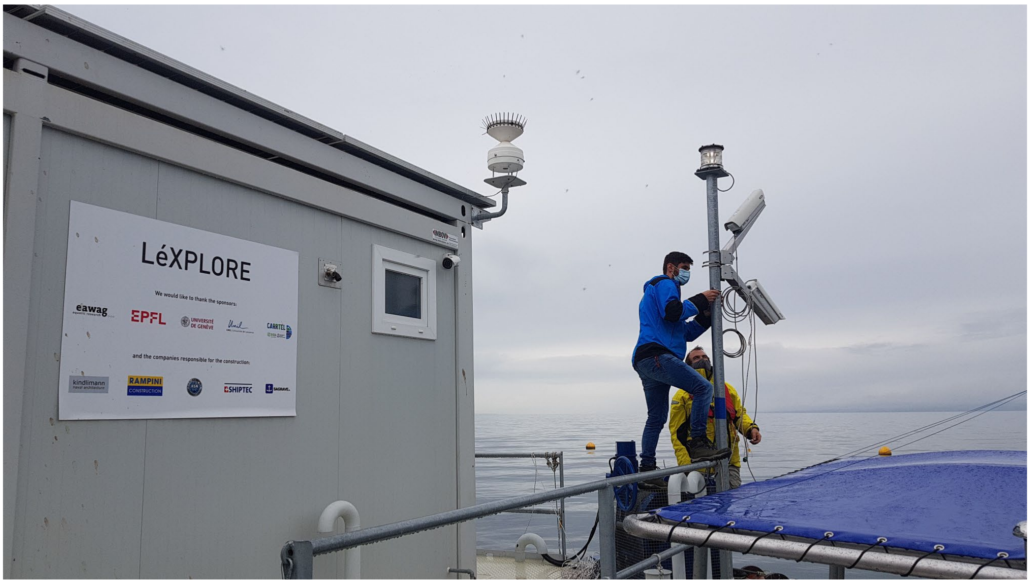
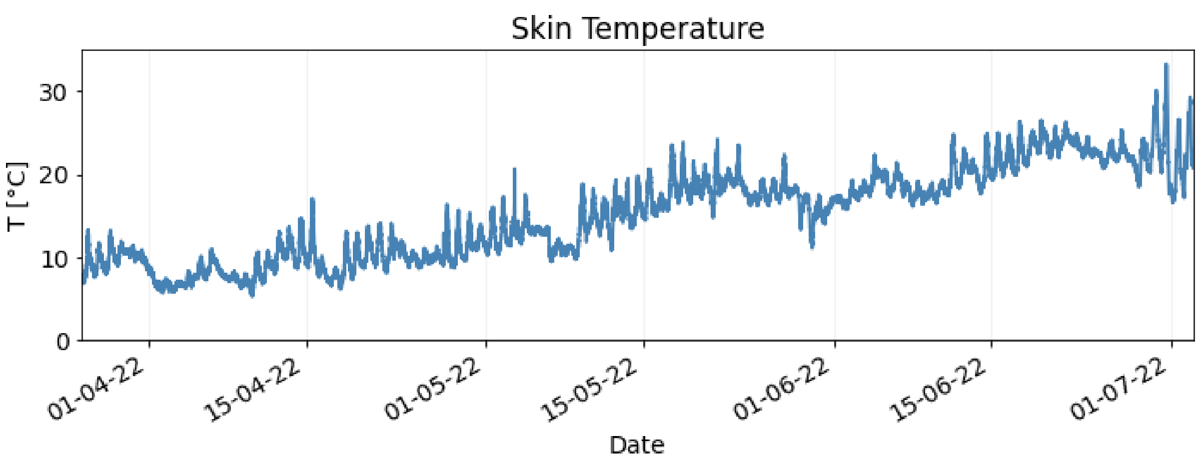


Photo of the radiometers installed on LéXPLORE



Example of skin temperature recorded from LéXPLORE during the period 01-04-2022 to 02-07-2022.

LéXPLORE

Plankton in Lake Geneva: you can't have it both ways

Bastiaan W. Ibelings, Mridul K. Thomas, Francesco Pomati

1. Overview

Our goal is to understand the determinants of community assembly in the phytoplankton of Lake Geneva, and how environmental variation shapes coexistence and biodiversity patterns in the lake.

2. Progress

In summer-autumn 2021, we:

1) installed an automated sampling system for regular Cytobuoy measurements across depths.

2) acquired an automated water sampler that enables the quantification of nutrients at high frequency, which fills an important measurement gap. Nutrients are one of the main drivers of phytoplankton community change and we previously had no way to track high-frequency changes over time.

3) deployed the Cytobuoy to measure phytoplankton cell properties (scattering and fluorescence) across 10 depths over time, with multiple measurements per day.

4) Analyses of this phytoplankton community data (taking advantage of semi-automated clustering techniques and machine learning) has already found that:

- There are distinct clusters of cells in the lake with similar fluorescence and scattering properties.
- At least some of these clusters (and probably most) correspond to specific taxa that play important roles in lake ecosystems. This includes toxic cyanobacteria such as *Planktothrix* sp. and *Cyanobium* sp., and diatoms such as *Asterionella formosa* that are important food sources for higher trophic levels.
- We are therefore able to track the dynamics of important taxa at high frequency, which revealed a large shift in the second half of September from a cyanobacterium-dominated community to one dominated by diatoms and cryptophytes. Total community biovolume also declined from October onwards.
- These are consistent with well-established seasonal succession patterns, providing strong evidence that flow cytometry monitoring of the phytoplankton provides useful information on lake ecosystem changes.

3. Next steps

We will extend this validation process to identify the taxa corresponding to all clusters we have identified. Next, in combination with further monitoring data (both on the phytoplankton and the physico-chemical environment), we aim to quantify the response of each taxon to environmental variation using machine learning, and to identify trade-offs by comparing species' responses to multiple environmental axes.

RAINBOW$_{FLOW}$ CHIP$_{ONLINE}$

Jenny Maner, Carolin Drieschner, Christian Ebi, René Schönenberger, Levin Angst, Simon Bloem, Miguel Solsona, Philippe Renaud, Kristin Schirmer

The aim of the RAINBOW$_{FLOW}$ CHIP$_{ONLINE}$ project is to build a portable field biosensor system for online water quality monitoring using fish cells. Permanent cell lines from the rainbow trout (*Oncorhynchus mykiss*) have been shown to predict toxic effects to fish, and can thus be used as sentinel for toxic concentrations of chemical substances in the water. We use a microfluidic setup whereby cells are exposed to surface water in a channel through which the water flows, while cell viability is monitored by impedance sensing. The biosensor consists of an instrumental setup for automatic and continuous water sampling, sample preparation and exposure of the cells, monitoring cell viability and upload of data to a server.

The first prototype of this biosensor was constructed in 2020 and installed on the LéXPLORE platform in September 2021 for the first field testing phase. Between September and November 2021 several runs of exposure of cells to lake water were carried out. The correct functioning of the instrumental setup as well as the live online viewing of data could be confirmed; some minor technical issues could successfully be resolved on site. However, there was an issue with biological functioning of the biosensor. Due to unknown factors the cells - including control cells not exposed to lake water - only survived few hours in field conditions. The instrument was thus retrieved from LéXPLORE in January 2022 to identify factors which may contribute to the decline in cell viability under controlled laboratory conditions. Troubleshooting is currently ongoing. The aim is to find ways to eliminate or minimise factors negatively affecting cell survival and re-install the biosensor for a second round of field testing later this year.

The RAINBOW$_{FLOW}$ CHIP$_{ONLINE}$ biosensor (in its protective case) installed above the moonpool inside the cabin on the LéXPLORE platform

CoWaS – Continuous Water Sampling

List of authors Timothée Hirt, Christophe Deloose, Elio Ovide Sanchez, Armand Coudray, Paco Mermoud, Nicolas Adam and Jonathan Selz

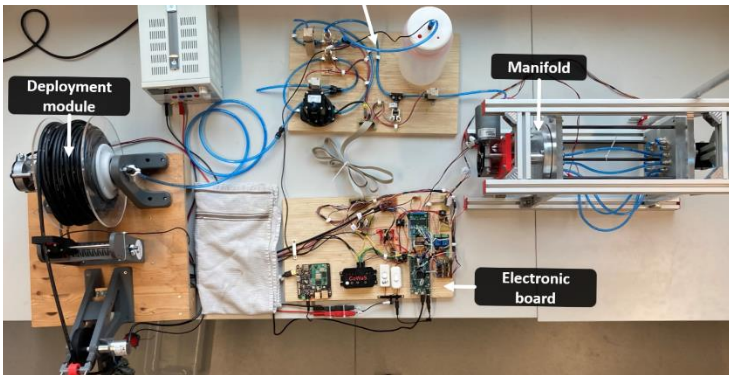


Fig1. Full CoWaS prototype with the deployment module to control the depth, the pumping module with all the fluidic components to collect a clean 2 litre sample and the multiplexing cartridge containing the filters

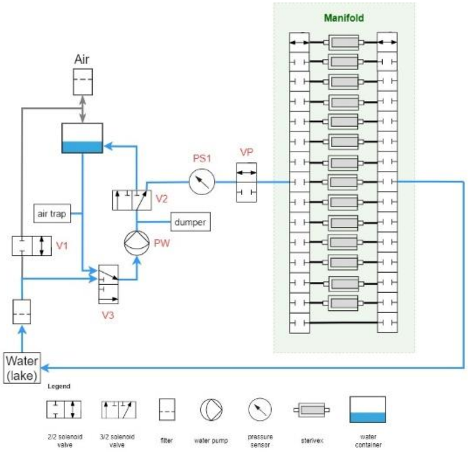


Fig2. Fluidic circuit of the overall system

The goal of the CoWaS project is to develop an autonomous sampler for the collection of aqueous microbial communities on 0.22µm filters. Currently lab-based, the downstream process includes the DNA extraction from the organic matter collected on the filters, the amplification of the 16S gene and its sequencing for identification and monitoring purposes.

During this past year, we developed a functional prototype of the autonomous water sampler with the following specifications:

- Sample volume of 2 litres pushed through a 0.22µm Sterivex filter
- Variable sampling depth between 0 and 40 meters
- Multiplexing cartridge with 14 filters (Manifold)
- User interface for remote control

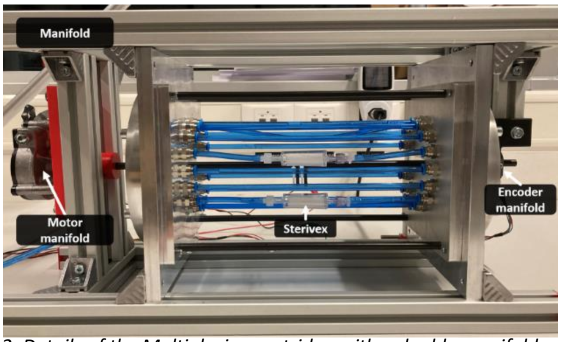


Fig2. Details of the Multiplexing cartridge with a double manifold system allowing to selectively pass water through each filter individually

The future steps will expand the following developments on the following areas:

Tests directly on the LéXPLORE platform were performed during the development phase and the prototype is ready to be deployed for a longer sampling and testing period. Samples collected during the testing phase will be analysed (16S sequencing) and the generated data will be uploaded to a database being developed. This will enable us to make the data available to the scientific community.

- We are currently developing a system to preserve the samples on the platform by drying the filters with a combination of vacuum and heat. Initial tests were performed with a 1-week storage period, which indicated a sufficient stability of the samples. Further tests will be performed to assess the reliability of this method with more samples and over longer periods. This system will then be integrated to the sampler on the platform.
- We will also continue the instrument's development to adapt it to rivers (turbidity) and sea water (salinity) as well as work towards the automation of the DNA extraction step.

Aqua-Gaps/MONET in Lake Leman

Fabienne Pfeiffer, Vick Glanzmann, Naomi Reymond, Sofie Huisman, Ines Tascon, Nicolas Estoppey, Celine Weyermann

Global water quality and aquatic food webs are increasingly threatened by the release of synthetic chemicals into the environment. The 'Aquatic Global Passive Sampling (Aqua-Gaps/MONET)' network aims at understanding geographical distribution and temporal trends of (i) persistent organic pollutants (POPs) – both legacy (e.g. PCBs) and emerging (e.g. PFASs) – as well as (ii) compounds of emerging concern – both hydrophilic (e.g. pharmaceuticals) and hydrophobic (e.g. novel flame retardants). Aqua-Gaps/MONET has taken advantage of the key benefits of passive samplers (i.e. in-situ enrichment of target compounds, exposition of the same matrix in all waters, good cost effectiveness) to establish a global monitoring program in the waters of the world[1]. The 'Ecole des Sciences Criminelles (ESC)' of the University of Lausanne (UNIL) is in charge of the deployment of samplers in Lake Geneva since 2016 (Buchillon station)[2,3]. The deployment of these samplers at the LéXPLORE station has started in autumn 2021 and will provide precious additional data on levels of contaminants in the Lake Geneva. Combining this data with results from passive sampling-based monitoring campaigns in tributaries (ESC and CIPEL's partners) will allow a better understanding of the extend and magnitude of contamination problems at the basin level.

At LéXPLORE, passive samplers are deployed – for 1 year – at a depth of 3 m below surface level using an 'open cage' (see Figure 1). Silicone sheets sample hydrophobic compounds, Speedisks sample polar compounds, and microporous polyethylene sample per- and polyfluoroalkyl substances (PFASs). Every year, exposed samplers are retrieved, and new samplers are installed (first deployment occurred in autumn 2021). Quantification of contaminants in exposed samplers is centrally done by RECETOX (Czech Republic) to ensure a good comparability among all sampling sites around the globe. Produced data are 'concentrations of dissolved contaminants in water', expressed in pg/L or ng/L depending on the contaminants.

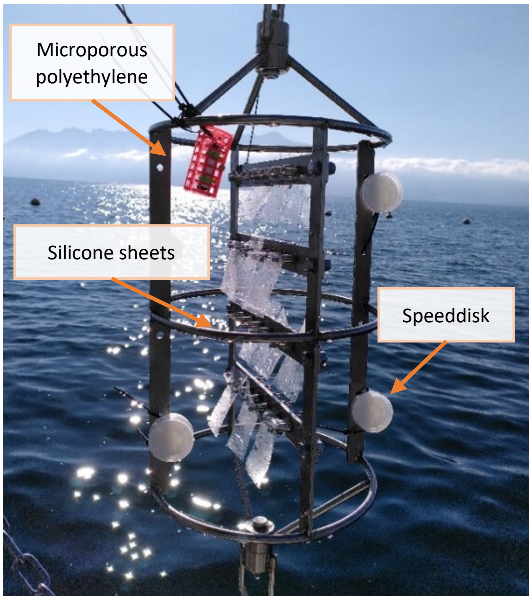


Figure 1: Passive samplers deployed at LéXPLORE to measure concentrations of persistent organic pollutants and compounds of emerging concerns.

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LéXPLORE

Monitoring the infectivity of enteroviruses in the lake

Odile Larivé, Htet Kyi Wynn, Tamar Kohn

The objective of this work is to establish inactivation kinetics for an enterovirus population in the lake environment at different periods of the year, and the differences in inactivation efficiencies between different genotypes. For this purpose, an environmental chamber was constructed, to allow exposing safely the viruses to the lake environment.

Over the last year, the environmental chamber was tested in the lake without viruses to ensure that the setup was safe to use. We determined that a two meters' depth was too risky and that in case of bad weather, the membranes could break at that depth, probably due to the waves. 15m depth and 6 m depth were safe to use the chambers. The environmental chamber was also successfully tested in the laboratory with viruses to ensure that the they did not escape the device.

We submitted a request to the OFEV to obtain permission to carry out the experiments in the lake with the viruses. The request was granted on the 21st of December 2021, to carry on experiments until September 2022.

We performed three experiments in the lake: two experiments in March for the winter campaign with respectively two chambers and five chambers at 15 m depth; one experiment in June for the summer campaign with five chambers at 6m depth and five chambers at 15m depth.

The results from these campaigns need to be analysed and formatted for a publication, which should be submitted in Autumn. A report is also due to the OFEV at the end of the campaign.

Environmental chamber ready to be moored for a few days in the lake.

LéXPLORE

SyBAM: Synergic interaction Between Arsenic species and Microorganisms in freshwater contrasting dynamic conditions.

Mary-Lou Tercier-Waeber, Nicolas Layglon, Tanguy Gressard, Bastiaan Ibelings

Scientific context. The occurrence of As in aquatic systems is of great concern due to its persistence, bioavailability, bioaccumulation and trophic transfer from the bases of aquatic food chains through to higher trophic levels and ultimately human. Arsenic exists naturally in various oxidation states and under inorganic (iAs) and organic (oAs) forms. The proportion of the various As species are function of the bio-geochemical conditions of the media and thus may vary continuously in space and time. The inorganic arsenite (iAs(III)) and arsenate (iAs(V)) oxyanions are generally predominant in aquatic systems and more toxic than most of the organic forms. The presence of As(III) in oxic natural waters is attributed to As(V) phytoplankton uptake, due to the chemical similarity of As(V) with o-phosphate, and subsequent biotransformation and excretion of As(III).

Objectives and proposed approach. This project aims at synergizing state of the art analytical sensing tools to monitor at high resolution the bioavailable fractions of specific arsenic species and characterize the microorganisms. The specific goal is two-fold; (1) to assess bio-chemical processes which regulate the behavior and speciation of arsenic and it potential (eco)toxicity; (2) to study relationships between As speciation, macro-nutrients, and plankton communities.

To achieve this, we propose to apply an innovative multi-channel submersible sensing probe, called TracMetal. Incorporation of unique antifouling gel-integrated gold nano-structured microelectrode arrays in the TracMetal enables the in situ spatial and temporal monitoring of the so-called dynamic fraction of inorganic As species: $iAs(III)_{dyn}$, $iAs(V)_{dyn}$, $iAs(tot)_{dyn}$. These fractions are important for the assessment of the (eco)toxicological impact of As, because they correspond to the inorganic As species that are available for uptake by the microorganisms. Data recorded with the TracMetal will be coupled with those of (i) a multiparameter probe (OS316 probe, Idronaut-Milan) deployed conjointly to record the bio-physicochemical master variables, (ii) the CytoBuoy and possibly the Aquascope applied as part of on-going LéXPLORE project(s) to characterize the plankton, and (iii) lab complementary measurements in collected samples. Short-term seasonal studies (spring, summer, autumn, winter) are planned during the year 2022 and beginning of the year 2023. Depth profiles and 24h measurement cycles at fixed depth of inorganic dynamic As species as well as master bio-physicochemical parameters will be recorded. Long-term TracMetal-OS316-CytoBuoy(-Aquascope) autonomous synchronised studies are planned during the year 2023 in spring and summer. Ancillary measurements of spatial and temporal As speciation, water and plankton composition will be performed in the collected samples.

Progress. The first short-term study was performed April 12-14, 2022. Depth profiles reflected the presence of $iAs(III)_{dyn}$ and $iAs(V)_{dyn}$ in the productive surface water (Fig.1). $iAs(V)_{dyn}$ were in the range of 3.5 to 10.2 nM. $iAs(III)_{dyn}$ ranged from 1.9 to 2.7 nM and represented 20 to 46% of the $iAs(tot)_{dyn}$. Data recorded during the 24h measurement cycle suggest an increase and decrease of the proportion of $iAs(III)_{dyn}$ during, respectively, photosynthetic and respiration plankton activities, while opposite trends are suggested for $iAs(V)_{dyn}$. These first data support the influence that microorganisms may have on As speciation and (eco)toxicity. Analyses of the collected samples are underway.

LéXPLORE

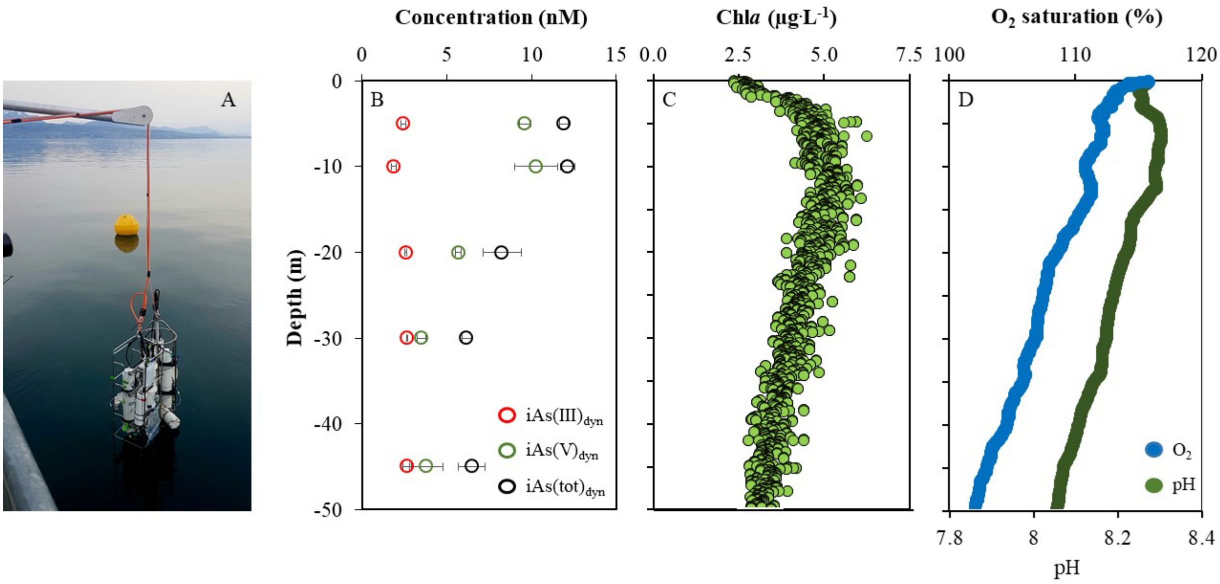

Figure 1: (A) Deployment of the TracMetal with other submersibles probes. (B) to (D) Depth profiles of the inorganic dynamic (bioavailable) fractions of As(III), As(V), As(tot), chlorophyll-a, oxygen saturation and pH.

LéXPLORE

Installation of a drip-based rain gauge on LéXPLORE

Gregoire Mariethoz, Erwan Koch, Alexis Berne

We have installed a network of low-cost and small-footprint rain gauges in the city of Lausanne, to characterize the statistical properties of precipitations in this area. A dense network is needed to adjust parameters related to the spatial heterogeneity (of the order of 100m) and temporal intermittence (of the order of 2-3 minutes). In this context, one of our rain gauges is installed on LéXPLORE, as is an ideal location to capture the transition area lake/shore where specific convective processes may occur. Furthermore, the platform is regularly maintained and visited, which is logistically convenient.

The rain gauge was installed in March 2022 and did not yield a very long time series yet, but we expect that by September, in combination with an additional 9 gauges throughout the city of Lausanne, we will have enough data to build a first urban rainfall model of the greater Lausanne area.

One Masters project is related to this model, which will end in February 2023. We hope to be able to publish the results during the year 2023.

Drip counting rain gauge as currently set on the platform

Radiocarbon Inventories of Switzerland (RICH)

Benedict Mittelbach, Margot White, Timo Rhyner, Timothy Eglinton, Nathalie Dubois

The turnover and exchange of carbon reservoirs in terrestrial and aquatic ecosystems with the atmosphere represents the greatest uncertainty in the global carbon cycle. Within the larger context of the SNF funded RICH project, RICH Hydro will establish radiocarbon inventories of dissolved and particulate carbon phases in major river watersheds draining different ecoregions of Switzerland, as well as in corresponding receiving lake basins. At Lake Geneva, RICH is collecting a time series of radiocarbon content in various water column reservoirs (DIC, DOC, POC) and material retrieved from sediment traps. We use optical measurements and mass spectrometry to characterize lake DOM. Complementing this time series, compound specific radiocarbon measurements in sediments will be used to reconstruct past lake water $DI^{14}C$ (chlorins) and to investigate riverine inputs of organic carbon (e.g., n-alkenoic acids, lignin phenols) over the industrial period.

RICH began this monthly time series of water column measurements in April 2022 and we plan to continue until at least summer 2023. Initial measurements of DIC reveal a radiocarbon signature that is significantly depleted compared to atmospheric CO_2 (-165 ‰ compared to approx. 0 ‰). From these results, we can estimate that approximately 84% of Lake Geneva DIC is of atmospheric origin. Further time series measurements will reveal seasonal signals in the concentration and isotopic composition of these various carbon pools. Measurement of the optical properties of lake water will give insight into changes in the chemical composition of DOM, which we hope to link to its carbon isotopic signature.

In collaboration with Natacha Tofield-Pasche, we plan to deploy two sediment traps to complement the traps already deployed below the LéXPLORE platform. Analysis of this material will be used to constrain the isotopic composition and flux of aquatic biomass entering the sedimentary reservoir. Further, comparison of sinking particulate organic matter at locations experiencing different degrees of fluvial input can be used to assess sources of sedimentary organic carbon.

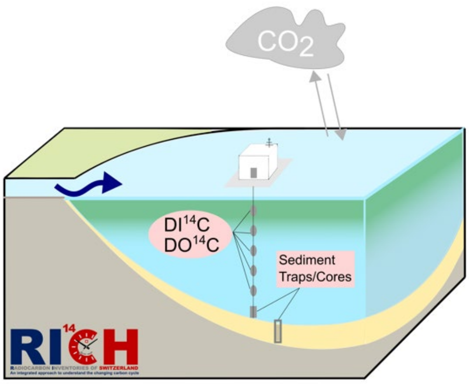

Figure 1. Schematic of RICH sampling strategy at Lake Geneva. Water column samples are collected monthly from 6 depths (1, 5, 10, 15, 20 and 50 m) below the platform. Samples from sediment traps will be collected monthly from a total of three locations for bulk and compound specific radiocarbon measurements.

LéXPLORE

Remote sensing and risk assessment of toxic Cyanobacteria in Lake Geneva (CYANOSENSE)

Anna Carratalà, Bastiaan Ibelings, Daniel Odermat and Elisabeth Janssen.

The project has officially started on June 2022 instead of January 2022, as initially expected due to some technical complications with the perimeter of the LéXPLORE. We are thus not able to report on our results but we here detail our planning for the next forthcoming months.

In this project, we aim to (i) to develop for the first-time a risk assessment of toxic cyanobacteria species and the toxins they produce in Lake Geneva, and (ii) to obtain a remote sensing- based method to rapidly detect and follow the formation of blooms and mats of toxic cyanobacteria in the lake. To achieve our objectives, we will (i) identify the diversity of both planktonic and benthic cyanobacterial populations by metagenomics and characterize the production of toxins and bioactive secondary metabolites throughout the year, (ii) develop new protocols for the early detection of cyanobacterial blooms and mats by remote sensing, and (iii) incorporate our findings into risk assessment protocols. Ultimately, the results of our project will enhance our preparedness for the emergence of both planktonic or benthic toxic cyanobacteria in Lake Geneva.

To this end, our plan is to develop 2 campaigns of weekly sampling from the beginning of August 2022 until the end of October 2022 and from January 2022 to April 2023. This sampling strategy will allow us to monitor the dynamics of two main Cyanobacteria genus that are abundant in Lake Geneva and which are potentially toxic: *Cyanobium* (which is abundant in late summer and early autumn) and *Planktothrix* (mostly dominant in winter). We are particularly interested in describing the community dynamics during the complete summer stratification and winter holomixis. In each sampling campaign, we will collect composite water samples at different depths selected based on ACS measures. The composition of the Cyanobacteria communities in the lake will be determined using NGS selecting primers which are specific for Cyanobacteria.

We will also inspect the shores of Lake Geneva in order to determine the potential presence of cyanobacteria mats which may represent hotspots for high cyanotoxin concentrations and have been recently involved with the death of some dogs in Lake Neuchatel. If present, mats sections will be collected for further genetic analysis and identification. Toxin analysis will be determined in biomass samples obtained both from the water collected from LéXPLORE and in the mat samples.

In addition to our microbiological analysis, we will determine the physicochemical state of the water column using the Thetis profiler installed in the water column and compare our environmental measures with remote sensing data, in order to identify the optical properties of cyanobacteria in the lake and work on early warning protocols based on remote sensing.

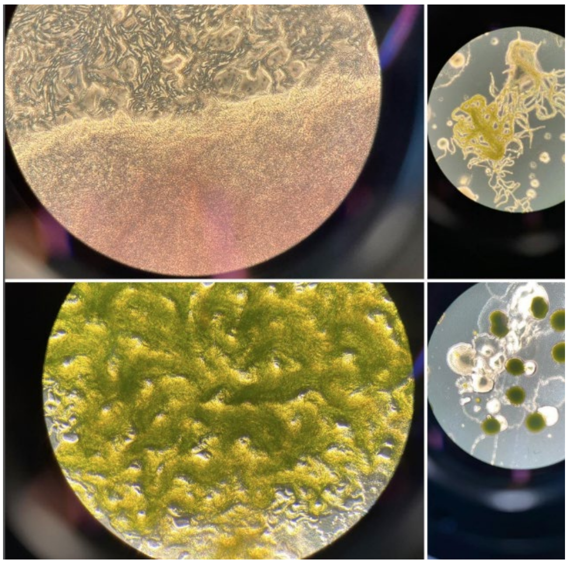

Figure 1. *Microscope image of Cyanobacteria cultures.*

Single Turnover Active Fluorescence of Enclosed Samples for Aquatic Primary Productivity (STAFES-APP)

Nina Schuback, C. Mark Moore, Mary Burkitt-Gray, Kevin Oxborough

Phytoplankton primary productivity (PhytoPP) is a fundamental component of biogeochemical cycles and aquatic ecosystem functioning and carrying capacity. Despite its recognized importance, however, it remains challenging to accurately quantify PhytoPP at the temporal and spatial resolution needed to relate its variability back to external environmental conditions.

Bio-optical approaches like active fluorescence hold potential to provide autonomous, instantaneous, non-destructive, and sensitive observations of phytoplankton photosynthetic physiology, which can be interpreted in terms of PhytoPP [e.g. 1].

The aim of the STAFES-APP project is the development of next generation active chlorophyll fluorometers which can be deployed autonomously (e.g. from moorings, ROVs, etc.) and generate meaningful parameters with acceptably low errors [2, 3].

LéXPLORE would provide the ideal platform for field trails of prototype autonomous instruments which require minimal maintenance while providing data of interest to multiple other projects.

After acceptance of our project in December 2021, the lifting of COVID related travel restrictions led to a flurry of re-scheduled deployments for the few prototypes of the AutoSTAF instruments, which prevented us from initiating the planned deployment on LéXPLORE so far. The instrument was however successfully tested integrated into an AutoSub LR during research cruise DY149 on board the RV Discovery in the Atlantic Ocean in March 2022 (Figure 1) and deployed during a recent joint mesocosm experiment with AQUACOSM-plus [4] and JERICO-RI [5], aiming to provide support in the continuous monitoring of phytoplankton responses in mesocosms (Figure 2).

We hope to be able to deploy one of the instruments on LéXPLORE later in 2022.

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[2] https://www.southampton.ac.uk/oes/research/projects/stafes-app.page

[3] T. G. Boatman, R. J. Geider, and K. Oxborough, “Improving the accuracy of single turnover active fluorometry (STAF) for the estimation of phytoplankton primary productivity (PhytoPP),” *Front. Mar. Sci.*, vol. 6, 2019.

[4] https://www.aquacosm.eu/project-information/aquacosm-plus/

[5] https://www.jerico-ri.eu/about/

Figure 1 : Deployment of the AutoSTAF instrument integrated into AutoSub LR during research cruise DY149 on board RV Discovey, March 2022.

Figure 2 : Deployment of AutoSTAF during a JERICO-RI & AQUACOSM-plus mesocosm experiment in Crete, May 2022.

Submersible probe with in-line calibration for long-term continuous measurement of environmentally relevant ions (Multiple ion).

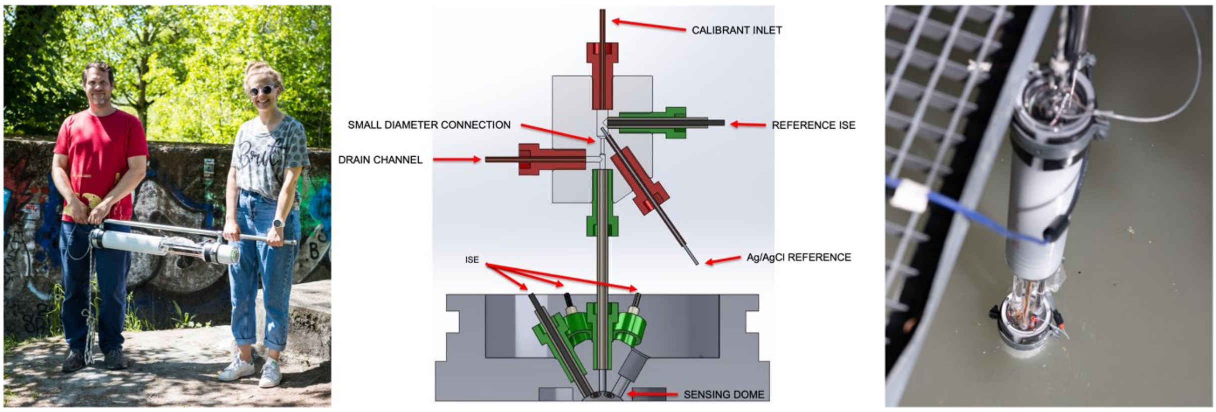
Tara Forrest, Thomas Cherubini, Stéphane Jeanneret, Elena Zdrachek, Polyxeni Damala, Eric Bakker

The aim of this project is to test in real conditions a multi-elements submersible potentiometric probe that has the ability to autonomously perform continuous monitoring for extended periods of time. In the proposed design, the potentiometric sensors are located in a small recess and in direct contact with the sample allowing for continuous monitoring without any additional power required. To reduce the influence of a number of uncontrollable factors such as temperature on the sensor signal, a one-step calibration protocol and a new reference element based on the principle of electrochemical symmetry have been implemented. Owing to low power consumption and the drift correction method, this system may run maintenance-free for a couple of weeks. We are planning to monitor the long-term fluctuations of environmentally relevant species such as nitrate, pH and carbonate.

Until now, only one parameter has been monitored using this device (nitrate). We are currently working on a new design of the sensing head to monitor simultaneously two parameters that will be linked to two individual symmetrical references (pH and carbonate). A raft to anchor the probe is currently under construction in our lab. The raft will be equipped with solar panels to power the probe and the ZigBee antenna located on it. A receptor located on the platform will be connected to a small Raspberry Pi that will allow remote connection. We are hoping to be able to control the probe remotely with this setup and only have to go on site for regular maintenance. With these new solar panels, we hope to be completely independent of any external battery source.

Some tests will normally be conducted on the platform in August-September 2022. After some initial optimisation of the probe and profiling (different depth), the probe will be attached to the raft and left on site to measure for at least a month.

We are planning to soon publish the working principle of the probe as well as data from nitrate monitoring during a previous field campaign.



From left to right: 1) Probe during previous field campaign 2) Scheme of working principle of sensing head 3) Immersion of probe in Arve river.

Temporal and spatial variations of the settling particles fluxes in Lake Geneva (SEDTRAP)

Natacha Tofield-Pasche, Nathalie Dubois, David Janssen, Guillaume Cunillera

The goal of this project is to quantify the temporal and spatial variations in the composition and fluxes of the settling particles in Lake Geneva. The sediment traps were already deployed at LéXPLORE within the Primary Production Project from end 2018 until mid-2021, with a 5-months gap in 2019. With this new project, we aims at collecting at least 3 more years of sediment traps data, in order to characterize more robustly the observed inter-annual and seasonal variations. We plan to characterize the composition of settling particles by measuring organic and inorganic carbon, total nitrogen, total phosphorus, biogenic silica and metals. This dataset will help to constrain the net ecosystem production, the mineralisation of organic matter within the water column, and the flux of calcite precipitation.

At LéXPLORE, the sediment traps were deployed from June until 11th November 2021, and had to be removed due to the unsafe safety perimeter. The sediment traps could be redeployed on 9th May 2022. During the fall semester 2021, the EPFL student Pierre Veron performed his semester project to analyze the data from the sediment traps. In addition, biogenic silica and metals were analyzed at Eawag, to fully determine the composition of the collected material. The data showed a seasonal variability with higher flux in summer and larger sedimentation rates at below 30 m (Fig 1). These results together with the composition indicate a strong inputs of material from the Rhône River below 30 m, which corresponds to its intrusion depth.

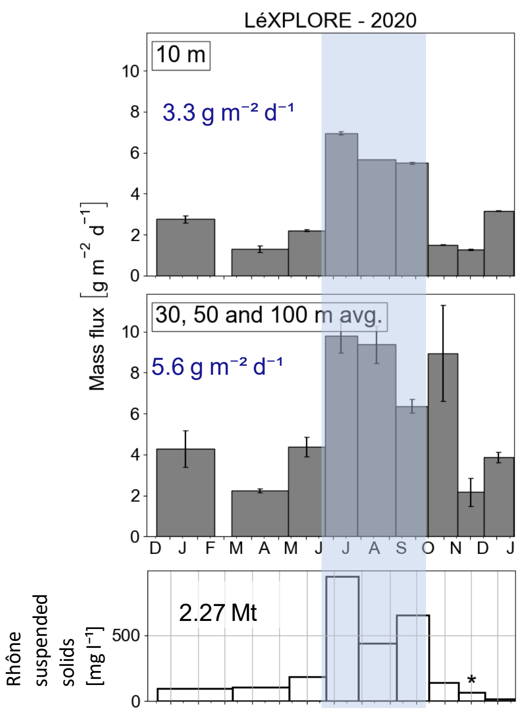


*Figure 1: total mass flux of settling particles at LéXPLORE in 2020 for trap at 10 m (a) and traps averaged below 30 m (b). Suspended solids in the Rhône River (c) measured at Port du Scex (*estimated value).*

Primary production under oligotrophication in lakes

Alfred Wüest, Hannah Chmiel, Bieito Fernández Castro, Camille Minaudo, Shubham Krishna, Sebastiano Piccolroaz

Abstract

This SNF-funded project has been targeting the quantification of primary production (PP) rates from new observation approaches with the overall goal, to better understand the dynamics of PP in stratified lakes under simultaneous climate warming and oligotrophication. The project lasted officially from Oct 2018 to Aug 2021 and consisted of several parts, which focused on i) the improvement and application of the diel oxygen method for daily-scale PP and net ecosystem production (NEP) estimates, ii) the development of new tools to quantify PP from bio-optical measurements and remote sensing, and iii) the investigation of physical processes (energy transfer, vertical diffusion, gas exchange), which shape the environment for primary producers and impact PP quantification. The LéXPLORE platform served as primary study site for these projects playing a crucial role for fieldwork realization, secured on-line sampling and automatic data transmission.

Automated recording (Fig 1a) of oxygen (O_2), carbon dioxide (CO_2), photosynthetically active radiation (PAR) and water temperature from moored instruments (multiple depths from 0-30/50m) lasted from October 2018 until the end of 2020 within the project scope. In addition, a multiparameter autonomous profiler (Thetis, WetLabs) was operated during the same period and is still under operation. The profiler consists of a suite of bio-optical and classical CTD sensors mounted on a buoyant frame equipped with an electric winch. The profiler instruments measure hyperspectral absorption and attenuation, backscattering, fluorescence by chlorophyll-a, coloured dissolved organic matter (CDOM), hyperspectral downwelling irradiance and upwelling radiance, PAR, conductivity, temperature, pressure, and O_2. From October 2018 to June 2021, over 2200 Thetis profiles were collected of the top 50 m of the water column, with an ~8 cm s^{-1} ascending rate every 3 hours from October 2018 to June 2020, and every 6 hours afterwards.

In parallel to the automated sensor recordings, velocity and turbulence measurements were acquired. These include in-continuous velocity profiles in the range 0-100 m depth through two Acoustic Doppler Current Profilers (ADCPs), near-bed temperature, current velocities and turbulence measured with a bottom-mounted high-resolution ADCP including a series of thermistors (from August 2019), and regular microstructure profiles of temperature and shear with the micro-profilers MicroCTD and VMP on approximately a weekly basis (from March 2019). This unique dataset was completed by continuous records of meteorological variables measured directly at the platform, from which the main (heat and mechanical) energy fluxes between the lake and overlying atmosphere were estimated.

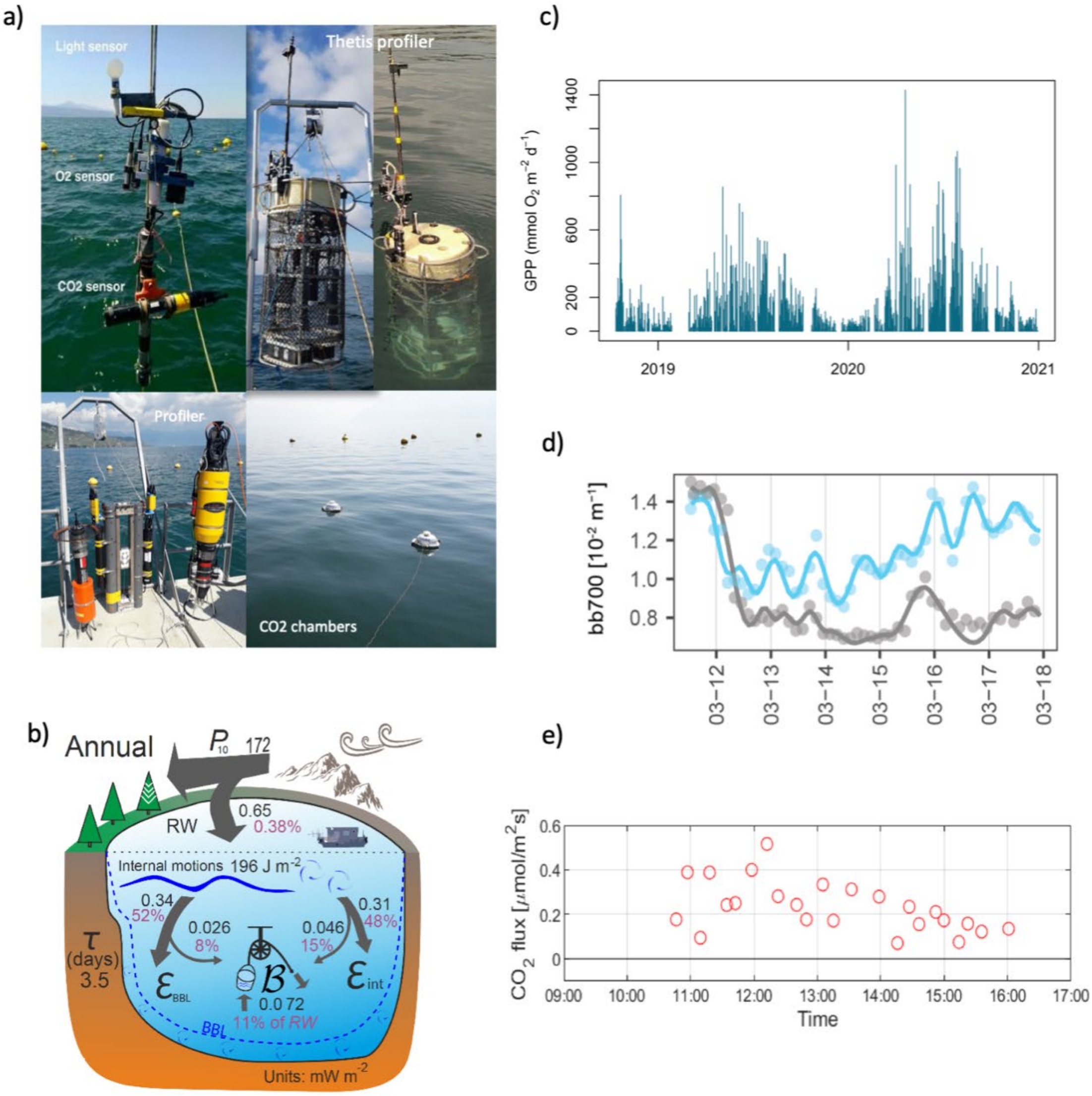


Fig. 1: Instrumentation used in the primary production project (a) and illustration of selected results: b) sketch of the annual wind energy supply, storage and transfer in Lake Geneva, c) seasonal curves of daily rates of gross primary production over the top 30m of the water column, d) example in March 2020 of diel patterns in particulate backscattering at 700 nm in the photic (blue line) and aphotic (grey) layer of Lake Geneva, e) sub-daily variability of air-lake CO_2 fluxes.

Main results

The dataset of the fixed mooring served to trace O_2 and CO_2 during hours of light and darkness from which PP and NEP can be deducted. However, we found that high-amplitude vertical motions also affected the temporal course of these variables and hindered the direct calculation of metabolic rates. To overcome these difficulties, we developed two correction routines allowing to estimate NEP from a fortnight-scale DO budget and daily PP rates with a spectral approach. These methods and the results of a complete summer NEP and PP rates in Lake Geneva (Fig. 1) were published in the journal of *Water Resources Research* in 2021. Using the extended dataset from Oct 2018 to Dec 2021, our upcoming work targets the role of environmental drivers for the daily, inter-seasonal and -annual variability of productivity in Lake Geneva (Fig 1c). Selected data from the mooring were also shared and analysed within the CARBOGEN project, to target the question how the alkalinity controls primary production in Lake Geneva.

From the unparalleled density of Inherent Optical Properties (absorption, attenuation, backscattering) profiles in Lake Geneva, we identified systematic diel patterns within the photic layer in absorption line height at 676 nm (aLH676, known as a good proxy for Chlorophyll-a) and in attenuation at 700 nm, that we successfully connected to the lake PP (Fig 1d). Diel amplitudes in these IOPs were compared to GPP estimates based on the diel O_2-method. Although direct comparison of daily values leads to weak correlations between IOPs diel amplitudes and O_2-derived GPP, temporal dynamics were comparable. These results prove the usefulness of high-frequency IOP measurements in lakes to better quantify lake carbon budgets and were published in Environmental Sciences and Technology in 2021.

Both mooring and Thetis PAR and O_2 data were shared within the GLEON network to support two projects targeting general ecological theory as well as the control of climate change on lake metabolism. The Thetis dataset serves as exemplary *in situ* dataset in several remote sensing publications either published or under review.

The analysis of velocity and turbulence data aimed at resolving the energy pathways across seasons in Lake Geneva (Fig. 1b) and at understanding the physical drivers of CO_2 turbulent fluxes at the lake-atmosphere interface at various temporal and spatial scales (Fig. 1e). As for the first aspect, results were published in *Nature Communications Earth & Environment* in 2021, and provide a complete picture of lake mechanical energy pathways over one full year, showing that they are strongly modulated by temperature stratification and wind intensity and contributing to improving our understanding of the sensitivity of such ecosystems to changes in the external forcing. Analysis of the CO_2 turbulent fluxes are still ongoing, and a manuscript is in preparation for *Environmental Fluid Mechanics*. The combination of high-resolution microstructure profiles acquired in upward mode (to allow measuring near-surface turbulence) and CO_2 fluxes at the lake-atmosphere interface measured with low-cost floating chambers shows that both fine-scale near-surface stratification and long-lasting large-scale motions are relevant in affecting CO_2 fluxes, thus challenging the application of existing gas flux models, which typically do not consider these aspects. More details are explained in the subproject *CO_2LEX: surface turbulence and CO_2 Lake Exchange Experiments.*

LéXPLORE

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Lehmann M.K., Gurlin D., Pahlevan N., C. Minaudo et al. GLORIA - A globally representative hyperspectral in situ dataset for optical sensing of water quality. Submitted to *Scientific Data*

Safin, A., Bouffard, D., Ozdemir, F., Ramón, C. L., Runnalls, J., Georgatos, F., Minaudo C., and Šukys, J. A Bayesian data assimilation framework for lake 3D hydrodynamic models with a physics-preserving particle filtering method using SPUX-MITgcm v1. Submitted to *Geoscientific Model Development*.

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Articles in preparation

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Piccolroaz, S., Fernández Castro, B., Chmiel, H. E., Perolo, P., Perga, M.-E. and A.Wüest. CO2 flux in a large perialpine lake governed by near-surface stratification and internal motions. In preparation for *Environmental Fluid Mechanics*.

Gupana R., Irani Rahaghi A., Damm A., Minaudo C., Odermatt D.: Non-photochemical quenching estimates from in situ spectroradiometer measurements: implications on remote sensing of sun-induced chlorophyll fluorescence in lakes. In preparation for *Optics Express*.

Conferences

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Chmiel, H. E., Fernandez-Castro, B., Minaudo, C., Krishna, S., Perolo, P., Rasconi, S., Wüest, A. Motion sick: How to estimate ecosystem metabolism in large and energetic lakes. ASLO Summer meeting, June 2021.

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Minaudo, C, Odermatt, D., Fernandez-Castro, B., Chmiel, H. E., Bouffard, D., Rahaghi, A.I., Lavanchy, S., Wüest, A., Primary production inferred from high-frequency water optical properties in a large lake. ASLO Summer meeting, June 2021.

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LéXPLORE

Fernández-Castro B., Bouffard D., Troy C., Piccolroaz S., Lavanchy S., Chmiel H.E., Ulloa H.N., Sepúlveda Steiner O., Wüest A. Seasonality of the mechanical energy budget in a large lake: Lake Geneva (Switzerland-France). 18th Swiss Geoscience Meeting, Zurich, 6-7 November 2020. Online Meeting.

Fernández-Castro B., Troy C., Doda T., Chmiel H., Minaudo, C., Ulloa, H. N., Serra L., Sepúlveda-Steiner O., Bouffard D., Wüest, A. Seasonality of the mechanical energy budget in a large lake, Lake Geneva (Switzerland-France). Workshop on Physical Processes in Natural Waters 2020. 15-18 June 2020. Online meeting.

Minaudo C., Odermatt D., Bouffard D., Rahaghi A.I., Lavanchy S., and Wüest A. Diel patterns in inherent optical properties of Lake Geneva water and their physical and biogeochemical drivers. 18th Swiss Geoscience Meeting, Zurich, 6-7 November 2020. Online Meeting.

Minaudo C., Odermatt D., Fernandez Castro B., Chmiel H.E., Lavanchy S., Bouffard D., Wüest A. High-resolution spatiotemporal heterogeneities of water optical properties in a large lake to infer physical and biogeochemical drivers of primary production. EGU General Assembly 2020, Geophysical Research Abstracts, Vol. 21, EGU2020-15063, 2020.

Minaudo C., Odermatt D., Fernandez Castro B., Chmiel H.E., Lavanchy S., Bouffard D., and Wüest A. Measuring high-resolution spatiotemporal heterogeneities of water optical properties in a large lake to infer physical and biogeochemical drivers of primary production. ASLO Meeting 2020, Madison. Online Meeting.

Piccolroaz S., Fernández Castro B., Chmiel H.E., Wüest A. Lake-atmosphere CO2 fluxes in Lake Geneva: disentangling the role of physical and biological processes in affecting diel and seasonal patterns. 18th Swiss Geoscience Meeting, Zurich, 6-7 November 2020. Online Meeting

2019

Chmiel, H.E., Camille Minaudo, Pascal Perolo, Shubham Krishna, Hugo N. Ulloa, Marie-Elodie Perga, Alfred Wüest. Spatiotemporal high-resolution data provide new insights on primary production in Lake Geneva (Switzerland). EGU General Assembly 2019. Geophysical Research Abstracts, Vol. 21, EGU2019-15679, 2019

Minaudo, C., Hugo N. Ulloa, Hannah E. Chmiel, Damien Bouffard, Théo Baracchini, Daniel Odermatt, Alfred Wüest, High-resolution scanning of the optical water column properties of a large lake: interplay between biological and physical processes. EGU General Assembly 2019, Geophysical Research Abstracts, Vol. 21, EGU2019-15855, 2019

Minaudo, C., Daniel Odermatt, Damien Bouffard, Théo Baracchini, Alfred Wüest, Sub-daily variability of Inherent Optical Properties in Lake Geneva. Sentinel 3 Validation Team meeting 2019, ESA Frascati-Roma.

Collected data

I. Sediment trap data from 4 depths at two to six weekly resolution starting in Oct 2018
II. Nutrient data (nitrogen and phosphorous) of water samples from 15 depths at bi-weekly resolution between 0-100m starting from May 2019 to Oct 2020
III. PP Mooring data contain fixed depth values between 0-30m starting in Oct 2018:
Temperature at 13 depths: https://www.datalakes-eawag.ch/datadetail/327
O_2 at 2 to 6 depths: https://www.datalakes-eawag.ch/datadetail/402
PAR at 6 depths: https://www.datalakes-eawag.ch/datadetail/329
CO_2 at 2-6 depths, YSI Sonde data (pH, T, NO_3, Chla,T, Cond) at 1 depth.
The OxyPAR mooring measurements continue to date with a modified setup (only PAR at 4 depths, and O_2 at 5 depths) with data management at INRAE (Thonon).
IV. Thetis Vertical Profiler data contain:
OCR Upwelling Profiles: https://www.datalakes-eawag.ch/datadetail/806
OCR Downwelling Profiles: https://www.datalakes-eawag.ch/datadetail/805
CTD Profiles: https://www.datalakes-eawag.ch/datadetail/803
ACS Profiles: https://www.datalakes-eawag.ch/datadetail/822
PAR Profiles: https://www.datalakes-eawag.ch/datadetail/807
O2 Profiles: https://www.datalakes-eawag.ch/datadetail/804
Backscattering Profiles: https://www.datalakes-eawag.ch/datadetail/808
Backscattering, Chla, CDOM Profiles: https://www.datalakes-eawag.ch/datadetail/809
V. CTD profiles: https://www.datalakes-eawag.ch/datadetail/875
VI. Meteo station: https://www.datalakes-eawag.ch/datadetail/459
VII. Surface energy fluxes: https://www.datalakes-eawag.ch/datadetail/886
VIII. Near surface ADCP velocities: https://www.datalakes-eawag.ch/datadetail/375
IX. Deep ADCP: https://www.datalakes-eawag.ch/datadetail/599
X. CO_2 flux data from floating chambers

Life in the deep: colonisation by Dreissena along a depth gradient

Linda Haltiner, Hui Zhang, Silvana Kaeser, Stuart R Dennis, Karl-Otto Rothhaupt, Piet Spaak

Abstract

In this project, the aim is to understand how highly invasive bivalves colonise substrates in deep areas of a lake where temperature is low, no light is available and water pressure is high. This deep lake habitat was previously unoccupied by bivalves, and it is therefore interesting how an invasive bivalve as the quagga mussels can start to occupy this niche. The quagga mussel originates from the Ponto-Caspian region and is a highly invasive species in Europe and North America with huge impacts on whole ecosystems by their large populations. Large populations come with high filtration capacity, their ability to colonise various substrates and depths, and their fast dispersal between and within lakes, makes them successful invaders.

Here we want to know A) how fast quagga mussels colonise and grow on new substrates at varying depths and B) whether they adapt to different depths. In June 2020 we installed three replicated ropes in the perimeter of the LéXPLORE platform and three ropes in Lake Constance in December 2019.

The objective of experiment A) was to evaluate seasonal variations in colonisation rates of dreissenids along a depth gradient in deep lakes (>100m), which were recently colonised by quagga mussels. We studied Lake Geneva and Lake Constance in which adult quagga mussels were firstly recorded in 2015 and 2016. We expected that Dreissenids show higher colonisation rates in the shallow parts than in the deep parts of the lake and reach higher colonisation rates during warm seasons than cold seasons. We tested our expectations about colonisation rates by counting mussels on Plexiglas plates along a rope (100m long) every 3 months.

In the second experiment B) quagga mussels' potential adaptation to depths is tested with a reciprocal transplant experiment, in which mussels are collected from two depths (10m and 60m) and then mounted to 10m and 60m on the experimental ropes. In time intervals of 2-4 weeks, we assessed growth and survival of the transplanted mussels. The experiment started in August and ended in November 2020.

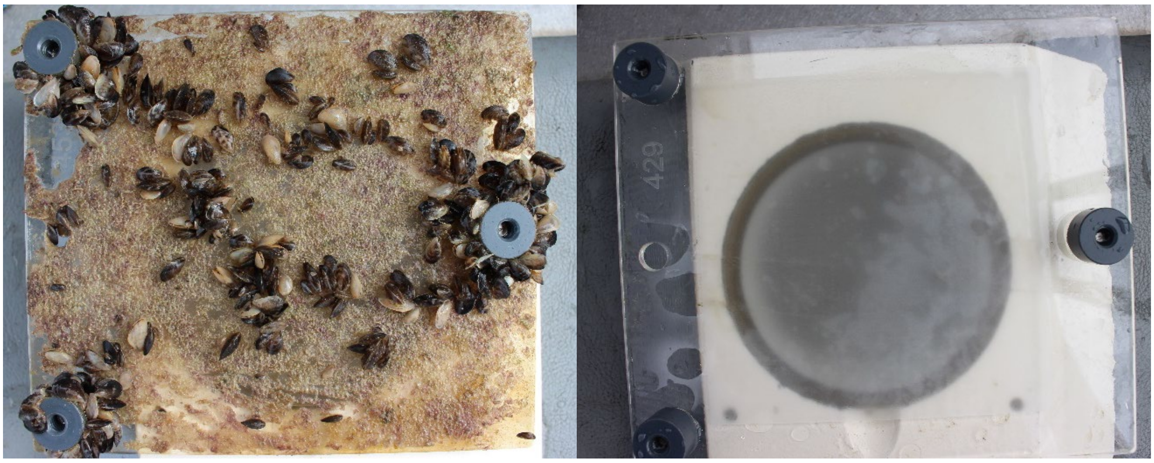


Figure 1 shows the colonisation of Dreisenids within the period June to September 2020. The left panel shows a plate from 9m depth including a lot of quagga mussels and biofilm. On the right, the plates is retrieved from 60m and does not show any visible biofilm nor mussel settlement.

Main results

Experiment A) Colonisation of Dreissena followed a depth dependent pattern: colonisation rates were highest in 5-8m (>10’000 mussels /m^2/month) and then decreased to almost zero in depths >20m in Lake Geneva (in Lake Constance this threshold was a bit deeper than 30m). Overall, the experiment in Lake Constance ran without any further incident, while we lost many colonisation plates in Lake Geneva. We assume, the currents and storms around the LéXPLORE platform were stronger compared to the relatively wind protected site in Lake Constance in the lake basin of Überlingen. Further, we analysed variations in colonisation rates of *Dreissena* and environmental variables, where temperature seems to be very important for colonisation. While data for Lake Geneva from the datalakes platform is highly frequent, data for Lake Constance is sparse and incomplete which complicates the analysis and reduces the power of our findings.

Experiment B) Overall survival in 10m was lower than in 60m irrespective of the mussel’s origin. While looking at shell size, growth was lower in 60m without differences between mussels’ origin. This result would not indicate an adaptation to the depth and rather would point out that plasticity is the key to the morphological differences between deep and shallow living mussels. However, the results still need to be confirmed by statistical tests.

Publications

Zhang H, Haltiner L, Kaeser S, Dennis SR, Rothhaupt K, Spaak P. (2022). Settlement of *Dreissena* along a depth gradient. *In preparation*

The reciprocal transplant experiment will be part of a population genetics study across Switzerland also looking at local adaptation to depth:

Haltiner L, Spaak P, Dennis SR, Feulner PGD. (2022). Population genetic insights into dispersal pathways of the invasive quagga mussel within and across lakes. *In preparation.*

Collected data

The data: colonisation rates (mussels/cm^2/month) of Dreissenids in Lake Geneva and Lake Constance and the reciprocal transplant experiment (survival and mussel sizes) will be uploaded and freely accessible on https://opendata.eawag.ch/ once the manuscripts are published.

LéXPLORE

Variability in stable isotopic composition of long-chain diols as a proxy for environmental conditions in lakes

Lattaud Julie, de Groot Lissie, Zborowski Beata, Bolandini Marco, Eglinton Timothy

Abstract

Rising global temperatures as a consequence of anthropogenic activities will have a profound effect on the hydrological cycle, with stark regional differences in its expression expected (IPCC report, 2014). However, changes in precipitation, seasonality, drought, storm intensification are difficult to predict despite their importance for societies. To improve predictions, a better mechanistic understanding of the regional response of the hydrological cycle to global changes is needed, which can be achieved by reconstructing changes in the hydrological cycle during the past using proxy records from geological archives. The stable isotopic composition of environmental water (i.e. δ^2H value) is an important tracer of the hydrological cycle. In the last decades lipid biomarker δ^2H compositions have become particularly effective tools in lacustrine and marine archives to reconstruct paleohydrologcial changes throughout Earth history. This is because δ^2H values of environmental water are recorded in the δ^2H values of lipids from photosynthesizing organisms. These lipids can be extracted to reconstruct past environmental water δ^2H values in order to decipher the changes in the various compartments of the water cycle. Seasonal sampling of surface water (100 L) during summer to autumn 2020 in Lake Geneva has been realized to track seasonal variation in δ^2H in various biomarkers.

Sampling at LéXPLORE

LéXPLORE

Main results

Lake Geneva was sampled every two weeks from July 2020 until September 2020 and once a month during October and November 2020. The water was sampled at two depths from the LéXPLORE platform (surface and deep chlorophyll maximum, DCM) with a bucket for the surface and with a 5 L Niskin bottle at the deep chlorophyll maximum (when present) assessed using a CTD run through the water column each time. 100 L was sampled for each depth and filtered on site on a pre-ashed GF/F 142 mm diameter filter (using a peristaltic pump). Water isotopes were also measured to track the presence of stratification between surface and DCM. The filters were sonicated two times with 9 : 1 (DCM : MeOH) and the total lipid extract was treated as described in Lattaud et al. (2021). GDGT, long-chain diols and fatty acids were identified and quantified. In addition, fatty acids hydrogen isotopes were measured, long-chain diols hydrogen isotopes will be measured soon.

There was stratification during the summer until end of August, starting September the surface and DCM presented the same water isotopes.

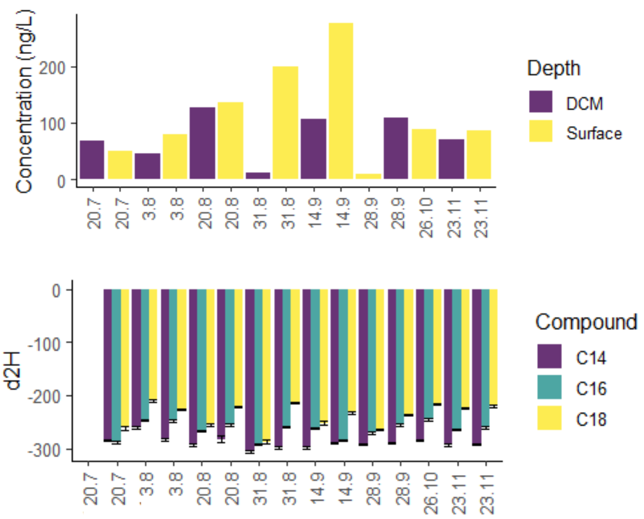


Figure 1 Fatty acid concentration and hydrogen isotope values (δ^2H)

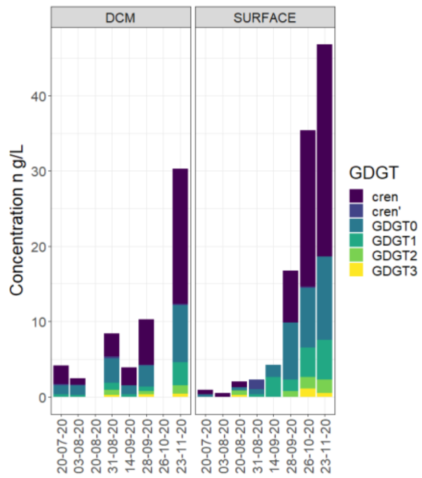


Figure 1 Isoprenoid GDGT concentrations

<u>Fatty acids:</u> Mainly short-chain fatty acids (14 < nC < 20), characteristic of primary production have been detected in the samples, indicating very few terrestrial input by higher plants in the surface water, which was unexpected. Concentration was higher in surface water during peak production (August and September, Fig. 1). The hydrogen isotope signatures of the C_{14} fatty acids is more depleted than C_{16} and C_{18}, with an average offset from the δ^2H of the water of -200 to -160‰, respectively (Fig. 1). Only the C_{18} fatty acids in the surface waters seems to be follow the δ^2H of the water (r^2 = 0.4). More points are needed to create a significant calibration curve.

<u>GDGT</u>: During the months of stratification very low amount of isoprenoids GDGT were detected at both sampling points, but as soon as mixing happened large quantities were detected (Fig. 2) indicating production in the deeper water column in agreement with observations in other Swiss lakes (Sinninghe Damsté et al., 2021).

Publications

Planned publication:

Seasonal biomarker variation and stable isotopic signature in two Swiss lakes (Geneva and Seelisberg) (in preparation for organic geochemistry) J. Lattaud, C. Martin, L. De Groot, M. Bolandini, T. I. Eglinton

Conferences

Presentation in a poster during the 2022 Gordon Seminar in organic geochemistry:

Freshwater long-chain diols in Swiss lakes: Useful proxies? J. Lattaud, C. Martin, L. De Groot, M. Bolandini, T. I. Eglinton

Collected data (will be deposited on PANGEA when published)

Water isotopes

Bulk organic carbon isotopes

Concentration of lipid biomarkers (short-chain fatty acids, long-chain diols, GDGT)

Hydrogen isotopes of fatty acids and long-chain diols

Water isotopes and bulk organic carbon isotopes can be deposition in datalakes-eawag before if of interest for others.

LéXPLORE

Whiting detection and optical characterization (w-doc)

Daniel Odermatt, Runnalls James, Abolfazl Irani Rahaghi, Remika Gupana, Anita Schlatter, Camille Minaudo

Abstract

Calcite precipitation, also referred to as whiting, is a common yet understudied process in hardwater lakes. The first satellite observations of whitings in North American lakes were reported as early as in the late 1970. In the past years, several new Earth observation satellites have become available, and the temporal and spatial resolutions for lake remote sensing have strongly improved. We characterized a comprehensive study of a whiting event in Lake Geneva in June 2014 (Nouchi et al., 2014). The w-doc project aimed first to develop a near-real time processing chain for daily whiting indicators based on Sentinel-3 data. Second, we wanted to acquire spectral absorption and backscattering measurements in the lake surface layer during whiting periods.

The Sentinel-3 processing environment implemented for the w-doc project is publicly available as a Python package named *Sencast*. It is in operational use as the backend for the EO data that is routinely made available in the *Datalakes* portal (www.datalakes-eawag.ch). The data made available in *Datalakes* comprises two layers related to whitings, namely 'Whiting' and 'Whiting Area', which represent a spectral whiting index and a whiting classification, respectively. The data are updated daily for the whole of Switzerland. The functionality of *Sencast* reaches however into many other application domains, including lake and rivers, Sentinel-2 and Landsat-8, chlorophyll-*a* and Secchi depth retrievals. It is still in further development and has enabled a number of side activities.

The Thetis profiler moored at LéXPLORE has acquired spectral absorption and scattering measurements several times a day, with certain interrupts due to maintenance, but including some periods during which our Sentinel-3 products indicate whitings near the platform. We performed seven field campaigns in the vicinity of LéXPLORE during periods in which limited calcite precipitation has occurred, mostly in 2021. Hyperspectral imagery was acquired in collaboration with UZH during this weak precipitation event. We however missed to acquire optical measurements of the project period's most intensive whiting event in summer 2019. But we supported a study by UNIL on this event by means of Sentinel-2 and Sentinel-3 data. We furthermore supervised a literature review of scientific literature on remotely sensed lake whitings. It confirmed the number of available studies is very limited to North America and Central Europe, but the results are consistent enough to support further up-scaling of remote sensing analyses.

Further research should target the analysis of the existing airborne hyperspectral data, and the in situ measurements available for summer 2021. Furthermore, we consider extending the whiting detection to global Earth observation satellite data.

Sentinel-2A true colour composite, 29 June 2019.

Main results

The most prominent whiting event during the w-doc project happened in Lake Geneva between early June and July 2019. It had a similar spatial extent like the one in 2014 (Nouchi et al., 2019), but lasted even longer. Our first field campaigns were carried out on 12-14 June, 2019, during the 24-hour measurement campaign by the EPFL Aquatic Physics team. On June 12 we performed some test measurements for comparison with Thetis IOP measurements on the LéXPLORE platform (Minaudo et al., 2021). On June 13 we collected measurements in three sites, namely the LéXPLORE platform, the Rhone estuary and in SHL2. According to the Sentinel-3 product of June 13 the whiting threshold of 13000 was only reached in the Rhone sampling location, but neither at SHL2 nor at LéXPLORE.

During the next campaign, on 4 July 2019, the whiting was already past its peak intensity and extent. This time we only sampled on and near LéXPLORE and in the Rhone estuary. Unfortunately, we did not manage to acquire reflectance measurements during this cruise due to a sensor failure, and the IOP measurements are of limited use because the profiler’s depth measurements were invalid. In consequence, our contribution to the study by Escoffier et al. (2022) on this whiting event was limited to satellite data analyses.

On May 20, June 11 and June 16, 2021 we carried out three AVIRIS-NG campaigns with concurrent in situ measurement campaigns (Figure 1, P1 is at LéXPLORE). The flight patterns were chosen in north-south direction in order to minimize sun-glint for overflight times around noon. They cover the central part of the lake including the location of the LéXPLORE station and the main monitoring station SHL2. We were unable to cover the full stretch between LéXPLORE and the Rhone estuary in such manner, because of cost constraints, and because we were aiming to balance the chances to observe either pelagic or inflow-related processes at the time of planning, which was several months before the flights. Technical issues with the AVIRIS-NG sensor occurred during the first flight, when moisture inside the optics caused strong ghosting effects in all flight lines, making the AVIRIS-NG data practically useless. AVIRIS-NG data acquired on June 11 and 16 are faultless and they were already processed to water-leaving reflectance, but we did not manage to conclude the analyses within the w-doc project.

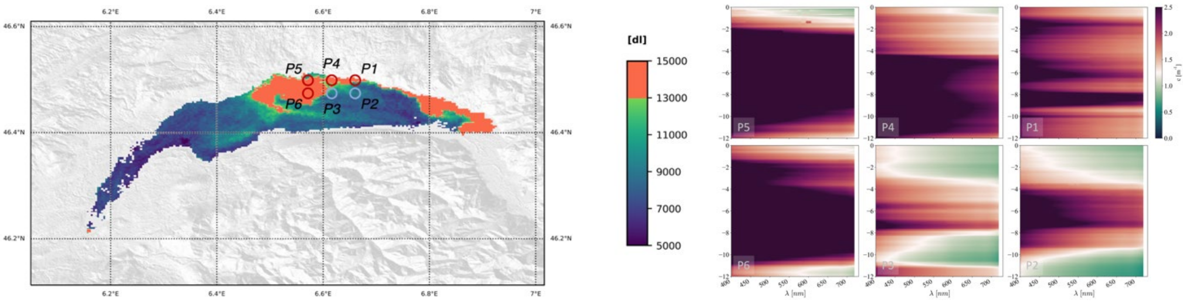


Figure 1, left*: Lake Geneva BGR-area from Sentinel-3A, 16 June 2021, during one of the AVIRIS-NG flights. Whitings according to Heine et al. (2017) are shown in red. Reference sampling locations are indicated as P1-P6, two of which have BGR-area values below whiting threshold (P2, P3, blue). Right: Spectral attenuation measured with an AC-S on 16 June 2021, representing the same locations P1-P6.*

Publications

Escoffier, N., Perolo, P., Lambert, T., Rüegg, J., Odermatt, D., Adatte, T., Vennemann, T., and Perga, M.-E. (2022). Whiting Events in a Large Peri-Alpine Lake: Evidence of a Catchment-Scale Process. J. Geophys. Res. Biogeosciences *127*, e2022JG006823. https://doi.org/10.1029/2022JG006823.

Minaudo, C., Odermatt, D., Bouffard, D., Rahaghi, A.I., Lavanchy, S., and Wüest, A. (2021). The Imprint of Primary Production on High-Frequency Profiles of Lake Optical Properties. Environ. Sci. Technol. https://doi.org/10.1021/acs.est.1c02585.

Nouchi, V., Kutser, T., Wüest, A., Müller, B., Odermatt, D., Baracchini, T., and Bouffard, D. (2019). Resolving biogeochemical processes in lakes using remote sensing. Aquat. Sci. *81(2)*, 27. https://doi.org/10.1007/s00027-019-0626-3.

Collected data

Daily Sentinel-3 ‘Whiting’ and ‘Whiting area’ products since 2016, available at www.datalakes-eawag.ch.

AVIRIS-NG water-leaving reflectance products acquired on June 11 and 16, analysis and publication pending.

LéXPLORE Thetis AOP and IOP measurements. Downwelling spectral irradiance, upwelling spectral radiance and spectral absorption available from www.datalakes-eawag.ch. Spectral attenuation and backscattering data available on request.

Campaign measurements of AOP and IOP, including downwelling spectral irradiance, upwelling spectral radiance, spectral absorption, spectral attenuation and backscattering data, analysis and publication pending.

LéXPLORE

MetOxic: Methylmercury in Oxic water Column

Andrea Gallorini, Jean-Luc Loizeau

Abstract

Hg methylation has been classically considered to occur in bottom sediments of aquatic environments due to the presence of anoxic layers at the interface between water and sediment. In fact, Hg methylation is commonly recognized as resulting from the activity of microorganisms that are obligate anaerobes and require anoxic niche to live and methylate. In the last decades, marine snow, and subsequently lake snow, have been identified as the main source of MeHg in the oxic water column of aquatic systems. In order for marine and lake snow to methylate Hg, it needs to maintain an anoxic environment capable of hosting Hg methylators. Following this hypothesis, we designed a sampling setup and an analytical procedure to collect lake snow from Lake Geneva water column and to determine the presence of anoxic micro-environments inside it. Four sampling campaigns were carried out from the LéXPLORE platform during July and September 2020 and 2021. For each sampling campaign, six sediment traps were deployed at three different depths in order to investigate epilimnion, metalimnion and hypolimnion, over a one week exposure time. The bottom of two of these six traps were coated with a thin film of polyacrylamide gel. This gel is a stable, transparent and viscous medium capable of retarding biological activity and avoiding changes in the redox condition of the samples. Thanks to the presence of the gel, we could determine the dissolved oxygen (DO) concentrations inside the lake snow aggregates using an oxygen microprobe, with a ≈50 µm tip, coupled with a microscope and a manual micromanipulator to make the insertion of the probe as precise as possible into the lake snow aggregates. Hypoxic and anoxic micro-environments were found inside the lake snow aggregates sampled in Lake Geneva water column, highlighting the possibility to host Hg methylation. Furthermore, thanks to the Scanning Electron Microscopy (SEM) technique, we were able to observe the presence of bacteria in the particulate matter sampled in the water column of Lake Geneva, embedded in thin films of organic matter (OM), which highlight mineralization of OM that could lead to the formation of anoxic micro-environments.

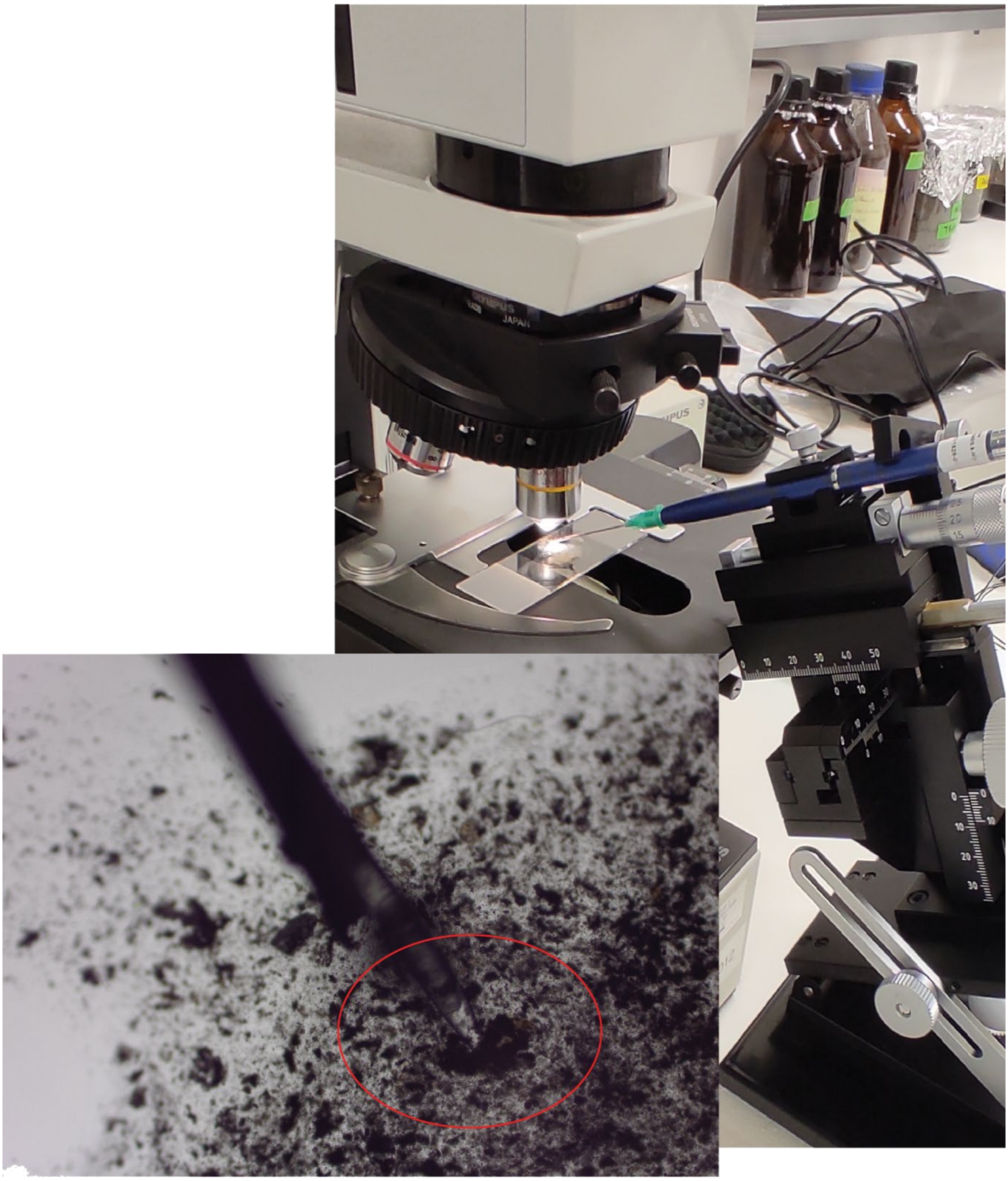


Figure 1: On the right, the analytical setup used in the determination of DO in the lake snow aggregates, composed of a microscope, a manual micromanipulator and the oxygen microprobe. On the bottom left, an example of the insertion of the microprobe in an aggregate inside the polyacrylamide gel. The tip of the microprobe is underlined by the red circle.

Main results

The selected sampling setup proved extremely useful in the collection and preparation of the samples. The use of the polyacrylamide gel made possible to avoid redox variation of the samples and to retard any biological activity. Moreover, its dense composition made possible to embed aggregates reducing as much as possible the loss in structure and form that normally occur in a normal sediment trap.
The analytical setup was successfully used to measure the DO concentrations inside lake snow aggregates. The use of a microprobe with a small tip (≈50 µm) helped to increase our analytical resolution and made possible to investigate aggregates with a diameter of 100 µm or more. The use of the microscope and the micromanipulator ensured that every insertion was as precise as possible.
With these setups, hypoxic and anoxic micro-environments were recognized inside lake snow aggregates, with DO concentrations ranging from 0.22 mg/L to 8.61 mg/L while the blank gel (gel without aggregates) showed DO concentrations ranging from 8.76 mg/L to 11.55 mg/L. The noticeable difference between the DO concentrations in the aggregates and in the blank gel is very important because it ensures that the gel is not feeding oxygen to the aggregates, maintaining their redox condition for prolonged periods of time. The DO concentrations determined in the lake snow aggregates were also lower that what we measured in the water column at the time of the sampling (8.24 to 9.99 mg/L). This tells us that most of the aggregates host micro-environments with lower oxygen concentrations than the water column. Across our analysis we found only one aggregate with a fully anoxic micro-environment (DO concentration of 0.22 mg/L), and despite an extensive search for similar aggregates, it was impossible to find other aggregates with the same characteristics. This paucity of fully anoxic aggregates is probably linked to the sampling method used. Our hypothesis is that these large aggregates are few in number relative to other particles and aggregate size fractions; they have a high organic content and thus low settling velocities, which reduces their downward flux in the water column and thus decreasing their presence in the sediment traps. Smaller high-OM aggregates could remain longer in suspension in the water column with fully anoxic micro-environments in their interior, allowing them to methylate Hg for longer periods of time and to be available to the lake biota as food in the water column. This, in turn, could represent an important entry point of MeHg into the lake food web and ultimately into the human diet.
Furthermore, the lake snow collected without the gel were analysed with the help of the SEM technique highlighting the ubiquitous presence of bacteria embedded in thin films of OM, which highlight the process of mineralization of OM and the possibility for an anoxic micro-environment to be formed.

LéXPLORE

Publications

A scientific article on this project has been prepared and it will be submitted to the journal Aquatic Sciences, with this title: "*Hypoxic and anoxic micro-environments in the water column of a peri-alpine lake: the potential role of lake snow in Hg methylation*". Moreover, this project has been included in my doctorate thesis with the same title as the scientific article.

Conferences

A poster illustrating the project will be presented at the ICMGP 2022 with this title: "*Suspended Particle Aggregates in Lakes as a Conducive Environment for Methylmercury Production*".

Collected data

		Sample depth	Sediment Flux	Standard Deviation	OM	Standard Deviation	DO concentrations Min.	DO concentrations Max.
		m	g m^{-2} d^{-1}	g m^{-2} d^{-1}	%	%	mg/L	mg/L
2020	July	28	12.70	0.92	4.17	0.45	4.28	6.89
		100	9.88	0.35	4.56	0.77	5.54	7.49
	September	13	3.22	0.12	1.60	0.54	0.22	5.40
		28	4.21	0.24	2.10	0.50	3.40	6.93
		100	5.46	0.30	2.23	0.62	6.85	8.13
2021	July	13	15.76	0.57	9.73	0.45	7.41	8.61
		28	19.63	0.70	8.72	0.50	4.63	8.15
		100	26.79	0.97	7.66	0.09	6.51	8.36
	September	13	4.54	0.26	8.99	0.45	6.44	7.38
		28	5.88	0.32	7.65	0.37	3.48	6.53
		100	8.02	0.35	9.23	0.72	5.82	8.10

Table 1 presents the dataset collected on the sample analysed during this project. Data are expressed in average per sample depth regarding the sediment flux and the OM percentage. The dissolved oxygen concentrations are expressed in minimum and maximum values determined on all the aggregates found in the specific depth. At the moment the data set is in my possession (AG) but if you need more detailed data I can provide them. Samples of July 2020 at 13 m depth were lost during recovery.

LéXPLORE

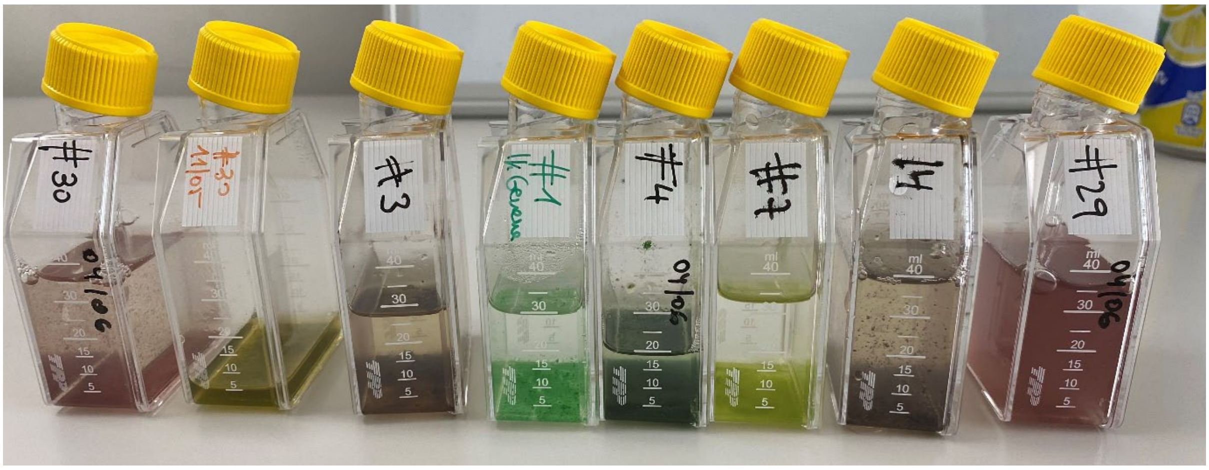
Unravelling the diversity, functioning and toxin production of cyanobacteria populations in lake Geneva (CYANOFUN)

Carratalà Anna, Chmiel Hannah, Joost Stéphane, Janssen Elisabeth and Kohn Tamar

Abstract

Freshwater cyanobacteria populations are known to be favored by climate change, thus cyanobacteria blooms in temperate lakes are expected to become more frequent in forthcoming years. Cyanobacteria may produce toxins that are harmful for mammals, including humans. However, less is understood about the effects of toxic cyanobacteria blooms on the abundance and composition of zooplankton communities. Since 2019 we have been monitoring the dynamics of cyanobacteria populations in Lake Geneva applying next generation sequencing, and discovered that diverse species of toxic cyanobacteria are present in the lake throughout the year. During the CYANOFUN project, our work has allowed us to characterize the spatiotemporal dynamics of cyanobacteria diversity and quantify the concentration of toxins in the biomass of the lake by mass spectrometry. In addition, we have conducted co-incubation experiments using cyanobacteria cultures obtained from the lake and two model organisms (Daphnia sp. and Tetrahymena pyriformis) to understand the effects of cyanobacteria and cyanotoxins on zooplankton. Our results have shown that cyanotoxin concentrations were higher in autumn, when both Planktothrix sp. and Cyanobium sp. coexisted in the water column. The results of microcosm experiments revealed that the cyanotoxins found in the lake prevented the growth of Tetrahymena pyriformis. Noteworthy, our sequencing data collected in 2021, showed that the relative abundance of SAR (Stramenopiles, Alveolata, Rhizaria) eukaryotes decreased when cyanotoxin concentrations were higher in the water column. These findings may contribute to improve the risk assessment and management of cyanobacteria in Lake Geneva and to improve our understanding of the microbial consequences of climate change in Lake Geneva.

A



B

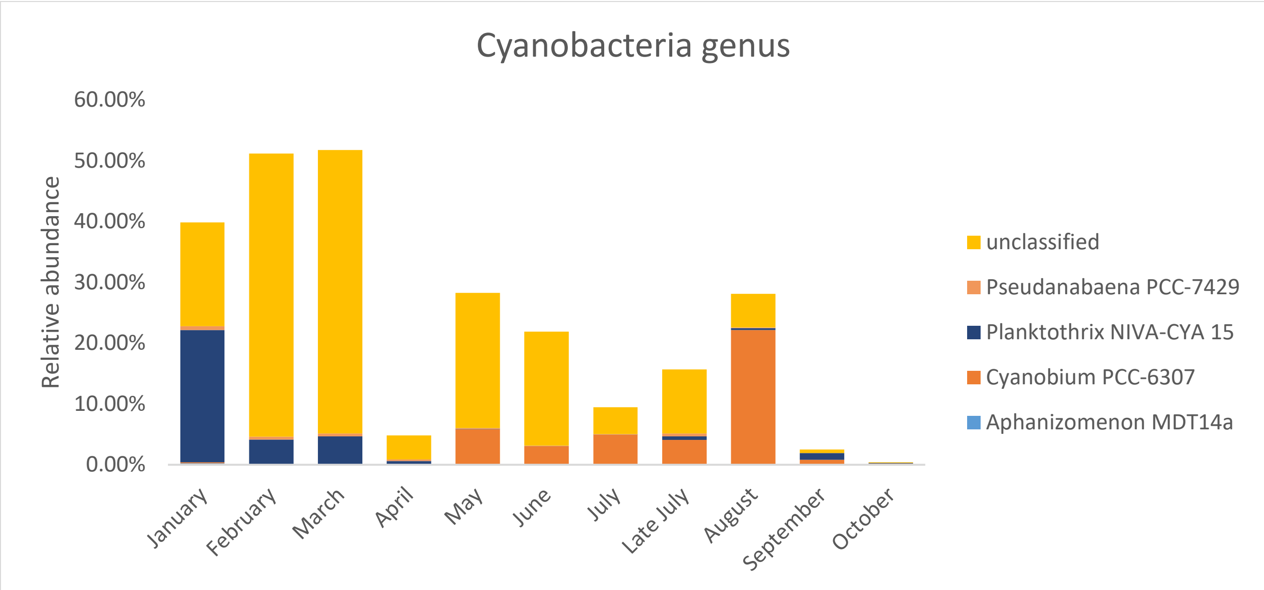


Figure 1. **(A)** *Cyanobacteria* cultures established and maintained in the Environmental Chemistry Laboratory. **(B)** Relative abundance of the main Cyanobacteria genus identified in Lake Geneva from January until October.

Main results

The ultimate goal of this project was to determine how variations in the cyanobacteria populations of Lake Geneva influence the functioning of the ecosystem. Our specific objectives of the project were to (i) investigate how seasonal environmental changes influence the diversity of cyanobacteria populations, (ii) determine how seasonal environmental changes modify the physiological state of cyanobacteria populations and finally, (iii) to link changes in the diversity and physiology of cyanobacteria with the functioning of the ecosystem. The fundamental knowledge that will be generated in this project represents the first step to establish and promote microbial conservation practices aiming to protect cyanobacteria biodiversity, ecosystem functioning and freshwater quality.

A total number of 143 samples were collected monthly throughout the year 2021 and out of these, 13 samples were analyzed for cyanotoxins. In addition, environmental information was collected at the time of sampling deploying a CTD profile. Each sample was filtered using Millipore filters (pore size 0.22 µm) and the biomass retained in the filters was used to perform nucleic acid extractions using the PowerWater extraction kit (QIAGEN). The obtained nucleic acids were sent to Fasteris (Geneva) for next generation sequencing. As mentioned above, 13 samples collected in the DCM layer were filtered in triplicate (2 liters each time) using the same method described above and the filters were frozen until shipped to EAWAG for LC-MSMS detection of Cyanotoxins. These samples were also sequenced to determine the composition of small eukaryotes by NGS amplicon sequencing (18S).

Our community analysis show that cyanobacteria in Lake Geneva are largely dominated by unclassified groups, suggesting that further identification efforts are needed. From the classified cyanobacteria, we can name two important genus; Planktothrix (particularly dominant in winter) and Cyanobium (particularly dominant in summer and early autumn). Both groups are known to be potentially producers of toxins. Noteworthy, during the project we isolated from Lake Geneva cyanobacteria belonging to the Cyanobium genus and analyzed them by qPCR targeting microcystins gene A. Our qPCR tests, showed that the isolated Cyanobium contain the target genes but no cyanotoxin production was identified in the cultures.

Regarding the cyanotoxin analysis, of the 17 targeted cyanopeptides, we identified 2 microcystins and 3 anabaenopeptins. None of the classical microcystins was detected but we did detect 2 other variants, [D-Asp^3,*E* Dhb^7] MC-RR as well as a minor contribution of [D-Asp^3] MC-LR. The maximum concentrations of total microcystin peaked at 147 ng/L in September but overall ranged between 6.4 to 30 ng/L from February until August 2021. These concentrations are all below the WHO guideline values for recreational as well was drinking water (24µg/L and 1µg/L, respectively). In addition to microcystins, three anabaenopeptins were detected throughout the seasons: Anabaenopeptin A, anabaenopeptin B and oscillamide Y. The variation of anabaenopeptin concentrations was comparable to that of microcystins, ranged between 20-150 ng/L overall but peaked at 1550 ng/L in September.

In CYANOFUN, we have conducted co-incubation experiments using water collected throughout the year in the lake and two model organisms (Daphnia sp. and Tetrahymena pyriformis) to understand the effects of cyanobacteria and cyanotoxins on zooplankton. Our results revealed that the cyanotoxins found at low concentrations in the lake in September and October prevented the growth of Tetrahymena pyriformis. Noteworthy, our sequencing data targeting the 18S gene of small eukaryotes showed that the relative abundance of the SAR group (Stramenopiles, Alveolata and Rhizaria) decreased when cyanotoxin concentrations were higher in the water column.

Overall, this project has allowed us to expand the understanding of the diversity and ecology of Cyanobacteria communities found in Lake Geneva. We have also identified a peak of unconventional microcystins in early autumn which could be associated with a picocyanobacteria belonging to the Cyanobium genus. Finally, even though the concentration of cyanotoxins in Lake Geneva is consistently below WHO guideline values for recreational waters, they could prevent the growth of one protist species in lab experiments and lead to variations in the community composition of small eukaryotes in suggesting that even at low concentration, the proliferation of toxic cyanobacteria can influence ecosystem functioning.

Publications

- Effect of toxic cyanobacteria on the communities of protists and zooplankton in Lake Geneva. *Publication in preparation.*

Conferences

- **Effects of toxic cyanobacteria on the communities of protists and zooplankton in Lake Geneva.** Paul Seguin, Jessica Aubouy, Anna Carratalà. 18th International Symposium on Microbial Ecology 8th International. Lausanne, August 14-18 2022.
- **Spatiotemporal dynamics of bacteria communities in Lake Geneva.** Carratalà, A. Swiss Geosciences Meeting. 19-20 November 2021, Geneva.
- **Spatiotemporal dynamics of bacteria communities in Lake Geneva by Next-Gen amplicon sequencing.** Carratalà, A. SEFS12 Symposium for European Freshwater Sciences, July 25th - 30th, 2021.

Collected data

- Next generation sequencing data of the bacteria communities in 143 samples collected from Lake Geneva from January 2021 until December 2021.
- Next generation sequencing data of the eukaryotic communities in 13 samples collected in the DCM of Lake Geneva from January 2021 until December 2021.
- qPCR data on the abundance of total Cyanobacteria in 143 samples collected from Lake Geneva from January 2021 until December 2021.
- qPCR data on the abundance of microcystin A gens in 143 samples collected from Lake Geneva from January 2021 until December 2021.
- qPCR data on the abundance of microcystin A gens in 143 samples collected from Lake Geneva from January 2021 until December 2021.
- qPCR data on the abundance of 18S gens (proxy for the abundance of small eukaryotes) in 143 samples collected from Lake Geneva from January 2021 until December 2021.
- Environmental dataset of CTD profile information for each sampling date.

For the moment all data is deposited in the ENAC servers. Sequencing data will be deposited to NCBI prior to the submission of our publication.

LéXPOCHIRO: Effects of lake suspended matter quality on growth, emergence and molecular endpoints in the midge *Chironomus riparius*

Beauvais Rébecca, Carmen Casado-Martinez, Benoît J. D. Ferrari

Abstract

In this project, we exposed benthic larvae of *Chironomus riparius* in the laboratory under controlled conditions to lake suspended particulate matter (SPM) that was collected seasonally in an integrative way (i.e. during the winter/spring = *LéX1* and during summer/fall = *LéX2* for 4 to 5 months) from the LéXPLORE platform in 2021. Two ExpoSET systems (see picture below) were deployed for each sampling period (12 tubes as settling particles traps per system) [1]. After 4 to 5 months, 24 tubes were then recovered and brought to the lab, containing each about 1.0 - 1.5 cm of SPM above the clean substrate added in the tubes and overlaying water. The quality of the SPM was characterized by physico-chemical analyses (grain-size, total organic carbon, S, N and P content and metals, including total Hg). In addition, SPM samples were submitted to non-targeted LC-HRMS screening and SPM-exposed larvae digested for analysis of potentially bioaccumulated contaminants (e.g. metals, pesticides). We investigated if the quality of the SPM, that we suppose different between these two periods (i.e. linked to the algal blooms dynamics and senescence, river suspended particles contributions, etc.) induced effects on larval survival, growth, emergence and level of biomarker gene expression in *C. riparius* exposed in the laboratory to the undisturbed SPM samples. Sixteen tubes were prepared with sand (same as used for the ExpoSET system) enriched with Tetramin® and 1.6 L of site water filtered at 1 µm were also installed in air-conditioned room as control exposures.

We therefore worked on two main objectives: (i) to describe the chemical and ecotoxicological quality of lake Leman SPM and (ii) to study the variability of biomarkers' responses in link with the seasonal parameters (www.datalakes-eawag.ch). Globally, this study demonstrated the relevance of using chironomid larvae as sentinel in the diagnostic of suspended matter chemical and biological quality, namely contaminants bioavailability and potential transfer to higher food chain levels. As a perspective, this project should pave the way for future projects, where chironomids are directly exposed to SPM directly in the field.

Main results

- Calculated SPM fluxes for both seasons agreed with the fluxes measured by the LIMNC (data from N. Tofield-Pasche), namely 19 and 13 g/m^2/d for *LéX1* and *LéX2*, respectively. The highest 2021 monthly flux recorded by the LIMNC was for July with 39 g/m^2/d corresponding to the season of highest suspended particles load in the Rhône river (www.hydrodaten.admin.ch/fr/2009.html). This suggests that most of the particles collected are allochthonous and originate from the Rhône river.

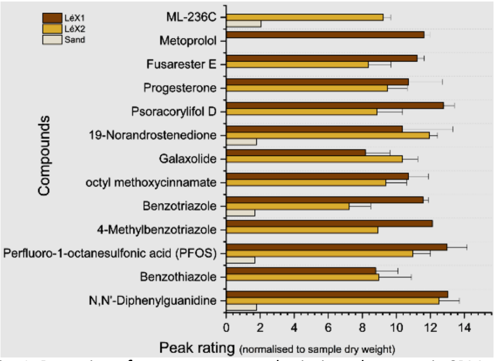


Fig. 1: Detection of some common and priority substances in SPM.

- Accelerated solvent extraction with methanol was used to digest SPM samples. Thanks to LC-HRMS (Orbitrap) analysis, we compared the features detected in the control (sand) and the SPM from the two periods. More than 1000 compounds were detected among which 510 were common to both seasons. *Fig. 1* illustrates results of some compounds validated by internal standards (e.g. benzotriazole) or listed as priority substances for sediments in Switzerland (e.g. PFOS) [2]. Further organic analyses will be performed as planned (at University of Bern) to measure quantitatively the substances detected in the qualitive method above. Also, concentrations of total Hg and other metals will be made available. First bioaccumulation results indicated that larvae accumulated Hg at a higher concentration in *LéX1* than *LéX2* SPM (158 ± 15 and 101 ± 13 $mg_{THg}/g_{biomass}$ (dry weight), respectively).
- For both seasons, the growth rate of the larvae was not impaired by the exposure to SPM when compared to the control (Co). While the emergence success was significantly impacted by *LéX2* SPM (Co=0.97 ± 0.01, *Léx2*=0.67 ± 0.12, t-test p-value <0.05), the variability between the replicates for *LéX1* was high and no significant effect on the emergence could be concluded (Co=0.93 ± 0.15, *LéX1*= 0.80 ± 0.21). We however noticed high larval mortality (up to 67% after 2 days) during *LéX1* exposure.

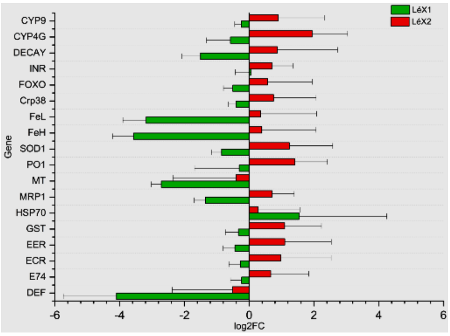


Fig. 2: Level of expression of selected genes.

Most of the analysed genes were down-regulated in *LéX1* (green), while up-regulated in *LéX2* (red) (*Fig. 2*) after a 2h exposure to the SPM. Mean log$_2$ fold-change values exceeded |1| for 7 genes in *LéX1*, involved manly in detoxification and apoptosis (e.g. MRP1, DECAY) and for 5 genes in *LéX2*, involved in response to oxidative stress (e.g. SOD1, GST) or coding for oestrogen-related receptors (EER). The gene expression profiling with 18 pre-selected biomarkers in chironomids exposed for two days to SPM allowed to discriminate samples from the first campaign from the second campaign (*Fig. 3*). For *LéX2* a higher variability in genes' responses was observed. Whether this is due to biological variability or intrinsic SPM properties needs further investigations. Methodological improvements (e.g. optimal exposure duration and biological replication) are to be tested.

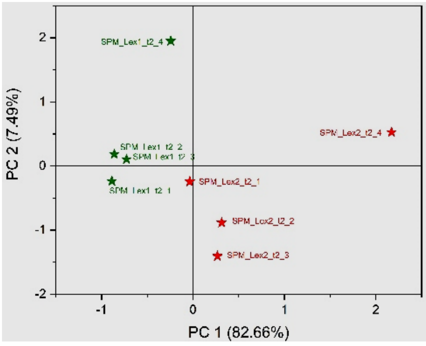


Fig. 3: Principal component analysis on the global gene expression.

[1] Ferrari, B. J. D., et al. (2017). Développement de systèmes *in situ* et *ex-situ* d'exposition aux matières en suspension et aux sédiments contaminés aux PCB utilisant la larve de *Chironomus riparius*. Etude réalisée sur mandat du LCME Université de Savoie Mont-Blanc. www.centreecotox.ch/media/194463/2017_ferrari_restolac-chiro.pdf, Centre suisse d'écotoxicologie appliquée, 1015 Lausanne.

[2] Casado-Martinez, C., et al. (2021). Stratégie d'évaluation de la qualité des sédiments en Suisse. Étude élaborée sur mandat de l'Office fédéral de l'environnement. www.centreecotox.ch/media/195475/2021_casado_final-report_sediment-strategy_fr.pdf, Centre suisse d'écotoxicologie appliquée, 1015 Lausanne.

Publications

-

Conferences

2022.24.03. - LéXPLORE Scientific workshop, EPFL. Poster and Poster pitch.

2022.30.06. -01.07. - Colloque annuel de la Société d'Écotoxicologie Fondamentale et Appliquée, Metz (France). Oral presentation.

Collected data

Grain-size, total organic carbon, total S, total N, total P and total C, metals, total Hg, non-target LC-HRMS screening available for the two samples (season 1, season 2). To come are concentrations in SPM and exposed larvae of plant protection products and metals.

LéXPLORE

REPRODUCE - léxploRE PRODUct aCcEss

Hugo Cruz, James Runnalls, Damien Bouffard, Marie-Elodie Perga, Stefania Russo.

Abstract

The Reproduce project is divided into two parts. The first is to propose a method to ensure a good quality check for environmental data. The second is to stop reinventing the wheel by proposing tools to implement higher level products of data.

WP1: The QAQC (Quality Assurance Quality Control) process for the LéXPLORE code datasets requires standardization. Before, each dataset has a very similar but not uniform QAQC processing script; this means that any improvements to the QAQC process means significant time updating every single individual script. By producing a simple python package independent of the current repositories, we can centralize the QAQC code and ensure that each dataset is subjected to the same rigorous QAQC process before being published on the Datalakes platform. The visualization capabilities of the Datalakes platform makes erroneous data exceedingly obvious and without a good QAQC process to remove these values we risk undermining trust in the quality of our data. The QAQC package: Envass (ENVironmental data quality ASSurance), is simple, and includes the following checks: real number, within physical bounds, structured in a way to facilitate further addition of more advanced checks once we have reached at least a basic level of quality control.

WP2: Environmental research does not rely on qualitative description of sensor output but rather on a tedious integration of different observations into meaningful quantities. In lakes, quantities such as heat fluxes, thermocline depth, Monin-Obukhov length scale (i.e respective contribution of the wind and buoyancy fluxes on the active mixed layer) are some of the basic information that scientists need for their specific studies. Processing such quantities is well documented but remains time consuming, a source of error and prone to subjective choices making results comparison challenging. Here we propose to integrate the most used products in the data pipeline, as we already did for the heat flux. Here we propose to deliver operationally (i.e. in near real time) the above-mentioned new data products. As for WP1, we do not plan to develop any code but will instead interface well established tools into the core dataset pipeline. Such data products will not only facilitate the research of lake scientists but also allow an easy integration of lake functioning into larger framework such as CLIMACT for instance.

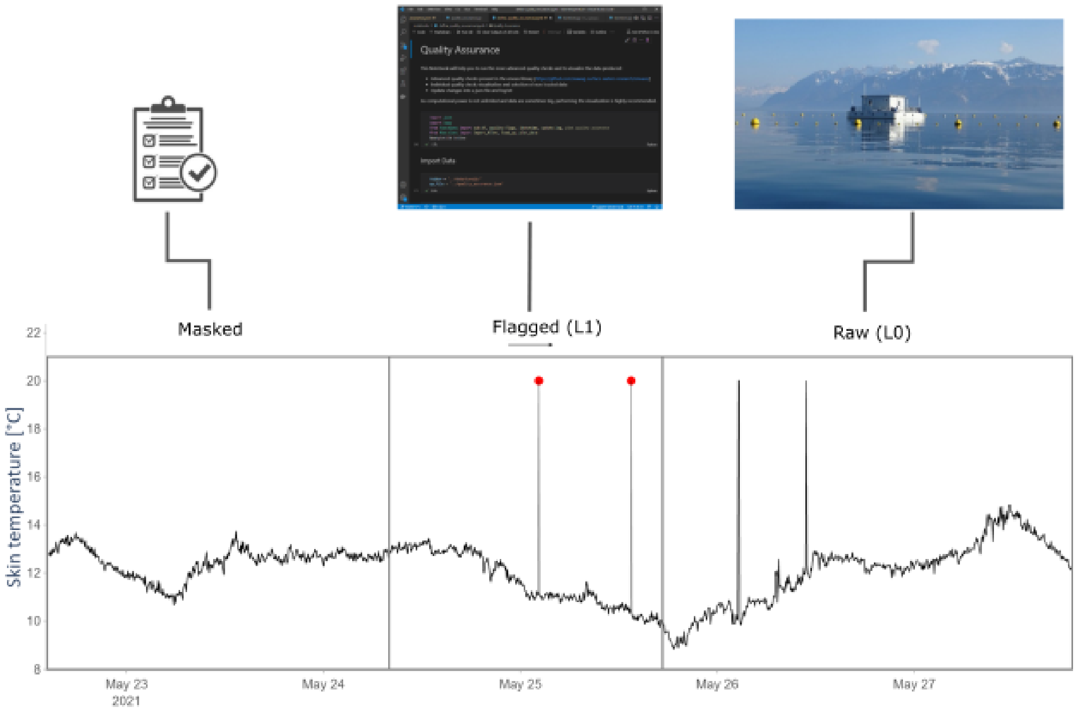


Figure 1: Workflow showing the application of a simple quality check contained in the Envass package to the Skin temperature. The raw data (right side) is the raw data. The quality check is presented in the middle as a moving window spotting the outliers (red points). The masked data on the left is the masked data available in Datalakes.

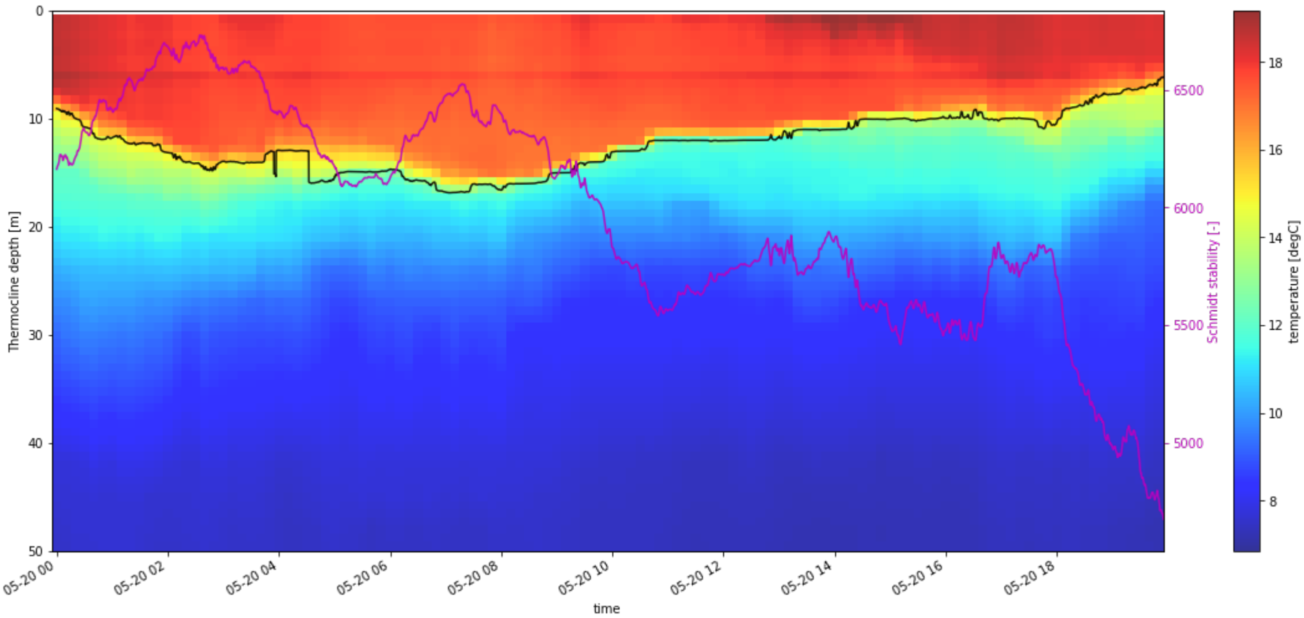


Figure 2: Temperature time series for the day 20th of May 2022 with its corresponding calculated products. The thermocline and Schmidt stability are computed and shown in black and magenta lines respectively.

Main results

Envass[1] (ENVironmental data quality ASSurance), a python library accessible to all, tries to answer the problem of data quality, by gathering more or less complicated algorithms which are now used to produce the data visible on datalakes. The architecture is simple and built in a way that new methods can be implemented easily.

However, it is important to bear in mind that the initial quality of the data varies greatly, and that despite the implementation of these methods, it is sometimes difficult to remove all outliers present. Work on the implementation of new methods or the parameterization of existing methods could improve the quality of the data. Envass offers simple algorithms, and is built to accommodate other algorithms. It is therefore compatible with further projects on environmental data analysis.

Pylake[2], a new python library created for this project, has the ambition to bring together robust algorithms to produce various products widely used in aquatic physics. Among others: thermocline, mixed layer depth, metalimnion extent, internal energy, Wedderburn Number, Schmidt stability, Seiche periode, Lake Number and Brunt-Vaisala frequency.

Lexplain is a code that serves as an example of the use of this library by integrating Pylake and data from LéXPLORE to produce higher level product such as described above.

To counteract the fact that several methods exist to generate a product, emphasis is placed on documenting these methods. Datalakes offers high temporal and spatial resolution data, with varying quality depending on the period (e.g. instrument maintenance). Pylake has been built on the basis of these data and is optimized to integrate spatial (1D) and temporal resolution, while avoiding bugs related to lack of data.

Making these algorithms optimized for application to modelled 3D data (xarray based) has been explored but not implemented.

Finally, a workshop will be organized early November to explore the data collected with LéXPLORE. The exact format of this workshop is still under discussion but should follow the principle of Agile Sprint session with a limited number of scientists focusing on analyzing the data over a week. Martin Wegmann will be closely involved in this activity

[1] https://pypi.org/project/envass/
[2] https://pypi.org/project/pylake/

LéXPLORE

CO_2LEX: Surface Turbulence and CO_2 Lake Exchange Experiments

Sebastiano Piccolroaz, Bieito Fernández Castro, Alfred Wüest, Hannah Chmiel, Camille Minaudo, Pascal Perolo, and Cary Troy

Abstract

Carbon dioxide (CO_2) fluxes between inland water bodies and the atmosphere largely contribute to the global carbon budget, hence influencing the climate system. Stimulated by ongoing climate change, in the last decades large efforts have been dedicated to i) the direct measurement of such fluxes and ii) the definition of empirical parameterizations for their quantification. Several of the existing parameterizations were traditionally based on wind speed but more recently surface renewal models based on turbulent kinetic energy dissipation rate have been proposed to account for other relevant processes (e.g., cooling-induced convection at night). Despite the advancements on this topic, understanding the interplay between the physical and biochemical processes governing CO_2 fluxes between lakes and the atmosphere still poses scientific challenges. This is particularly true in large water bodies, where complex three-dimensional processes interact at various temporal and spatial scales, questioning the assumptions underpinning gas exchange models.

The CO_2LEX project is focused on the quantification of the CO_2 fluxes at the lake-atmosphere interface with the objective to develop quantitative linkages between near-surface turbulence, meteorological conditions and the measured CO_2 exchange. To this aim, we simultaneously measured CO_2 exchange, near-surface water column turbulence, and meteorological conditions (wind speed and air temperature). High-resolution CO_2 flux and microstructure dataset have been acquired nearly weekly at the floating platform LéXPLORE. The dataset shows that both fine-scale near-surface stratification and persistent large-scale motions influence the rate of CO_2 exchange at the lake-atmosphere interface, thus challenging the application of existing gas flux models, which typically do not consider these aspects. The results show the significant benefits of having access to microstructure measurements to disentangle the complex interplay between physics, biology, and gas exchanges.

LéXPLORE

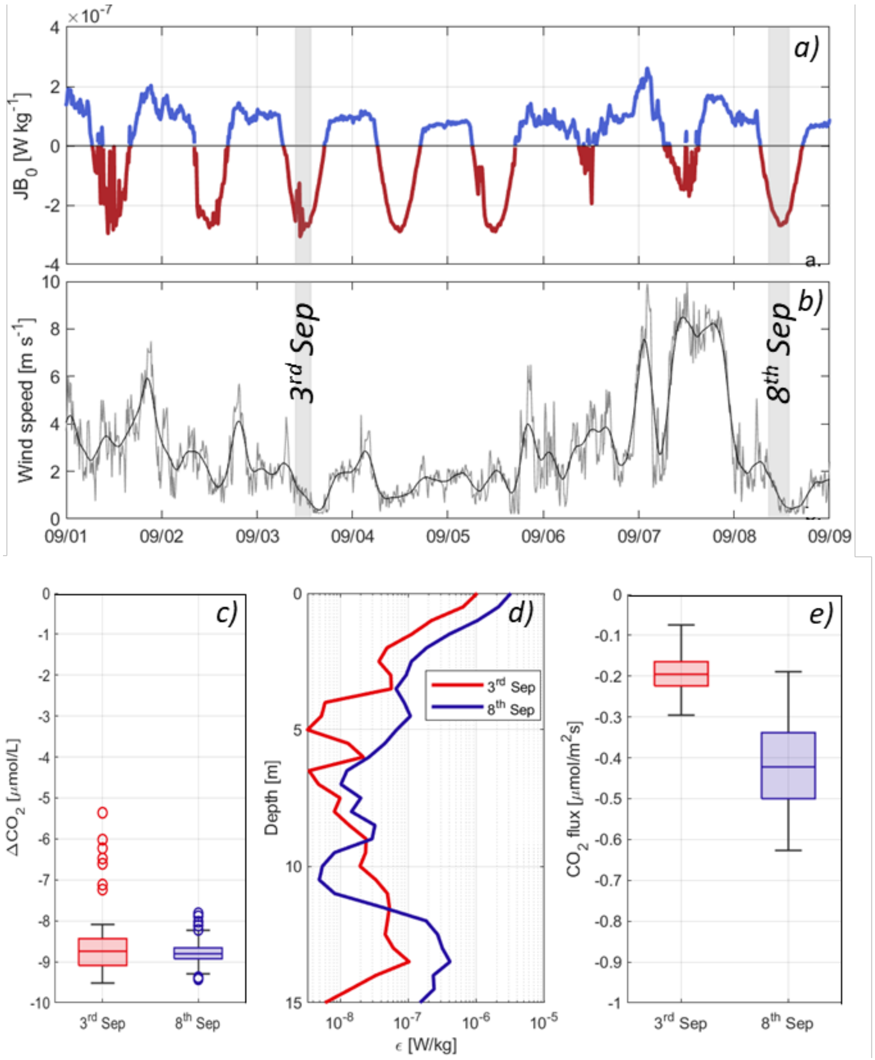


Figure 1: The effect of residual currents on air-water CO_2 fluxes. Besides similar concurrent weather conditions (a-b) and air-water CO_2 gradients (c), the effect of an antecedent strong wind event determines larger turbulence on the 8th than on the 3rd of September 2020 (d) thus resulting in larger air-water CO_2 fluxes (e).

Main results

The CO_2LEX project is a side-activity of the SNF-funded project "*Primary production under oligotrophication in lakes*" and is linked to the "*caGAStrophic low-cost, automated, floating chamber for gas flux measurements*" project, to which we refer the interested reader for details.

The original project started on April 2019 and continued until June 2020. Within this period, near-surface water column turbulence has been measured in continuous with an Acoustic Doppler Current Profiler (ADCP) and periodically with the MicroCTD microstructure profiler. In addition, in-situ CO_2 fluxes were measured using low-cost, homemade floating chambers, operated simultaneously with the MicroCTD. After June 2020, the project continued and the fieldwork activity has been concluded in June 2021. During this last year, the fieldwork operational protocol has been improved and standardized. Upward MicroCTD profiles have been acquired with higher frequency (nearly once every 10 minutes), following a weekly/biweekly schedule. Concurrently, in-situ CO_2 fluxes have been measured using the same low-cost, homemade floating chambers, and CO_2 concentration in the lake was measured using CO_2 sensors installed a few centimeters below the lake surface. A systematic seasonal dataset of near-surface turbulence and CO_2 fluxes is now available (including two 24-h campaigns and counting more than 900 microstructure profiles) and is used to characterize the CO_2 exchanges with the atmosphere across seasons and in presence of different meteorological and stratification conditions.

Preliminary results show that both fine-scale near-surface stratification and basin-scale internal motions (Fig. 1) are relevant in affecting CO_2 fluxes, thus challenging the application of existing gas flux models, which typically do not consider these aspects. Specifically, we found that residual currents lasting several days after storms or strong wind events are relevant in shaping turbulence in the surface layer of a large lake, and thus the gas exchanges with the atmosphere. In this respect, we claim that accounting for the role of antecedent weather conditions may be crucial to improve the current gas exchange parameterizations, particularly in large lakes. High frequency CO_2 flux and turbulence measurements allowed to acquire in a well-resolved way the sub daily patterns of CO_2 lake-atmosphere exchanges, and describe the mutual interactions between stratification, turbulence and phytoplankton dynamics. Similarly, the high-resolution temperature and turbulence profiles acquired in wintertime showed the importance of small-scale stratification of the upper layer (approximately 0.01°C/m) in damping turbulence and vertical diffusive exchanges within the lake and with the atmosphere. Overall, the project clearly highlighted the added value of having access to high-frequency microstructure profiles for a detailed understanding and description of the gas exchange dynamics in a lake.

Within the project, the team organized a two-day microstructure workshop (10-11 June 2021) on best practices to operate microstructure profilers (MicroCTD and VMP), and on data post-processing and data inter-comparison. The microstructure workshop and some of the activities carried out during the CO_2LEX project have been described in this newsletter published by Rockland Scientific (RSI), which also participated to the workshop https://rocklandscientific.com/news/swiss-limnologists-benefit-from-swift-support/

LéXPLORE

Publications

Piccolroaz, S., Fernández Castro, B., Chmiel, H. E., Perolo, P., Perga, M.-E. & A. Wüest. CO_2 flux in a large perialpine lake governed by near-surface stratification and internal motions. In preparation for *Environmental Fluid Mechanics*.

Conferences

2022

Piccolroaz, S., Fernández-Castro, B. Chmiel, H.E., Wüest A. CO_2 fluxes in a large perialpine lake: the role of near-surface stratification, circulation and biological activity disentangled by microstructure profiles. SIL 100, 36th Congress of the International Society of Limnology, 7 – 10 August 2022, Berlin.

2021

Piccolroaz, S., Fernández-Castro, B. Chmiel, H.E., Perolo, P. Wüest A. CO_2 fluxes in a large perialpine lake modulated by near-surface stratification, internal motions and biological processes. AIOL Congress, 30 June – 2 July 2021, Virtual Congress.

2020

Piccolroaz S., Fernández Castro B., Chmiel H.E., Wüest A. Lake-atmosphere CO_2 fluxes in Lake Geneva: disentangling the role of physical and biological processes in affecting diel and seasonal patterns. 18th Swiss Geoscience Meeting, Zurich, 6-7 November 2020. Online

Collected data

I. CO_2 flux data from floating chambers
II. Near surface CO_2 concentration measurements
III. Turbulence microstructure profiles (MicroCTD)
IV. CTD profiles: https://www.datalakes-eawag.ch/datadetail/875
V. Meteo station: https://www.datalakes-eawag.ch/datadetail/459
VI. Surface energy fluxes: https://www.datalakes-eawag.ch/datadetail/886
VII. Near surface ADCP velocities: https://www.datalakes-eawag.ch/datadetail/375

LéXPLORE

DynaMeth: Dynamics and origin of methane in the water column of Lake Geneva.

Jézéquel Didier, Moiron Marthe, Escoffier Nicolas and Perga Marie-Elodie

Abstract

The presence of an abnormally high concentration of methane in the aerobic parts of aquatic systems is known as the "methane paradox". Two main hypotheses are generally invoked to explain such a high concentration of CH_4 (either in surface waters or in the case of a CH_4 peak in an oxic lake water column): i) Lateral transport of CH_4 from a production zone (via classical anaerobic pathways in sediments), ii) CH_4 production in the water column under globally oxic conditions. The latter can proceed either by: a) archaeal methanogenesis in anaerobic microniches, b) direct transfer of substrates between phytoplankton and attached archaeal epibionts (phycosphere hypothesis), c) abiotic methanogenesis, and d) new reaction pathways and new microorganisms (without archaea), among these, demethylation of methylphosphonates is likely to occur. Indeed, the oxic production of CH_4 may be a common characteristic of various (micro)organisms, including several phytoplankton taxa (Günthel *et al*., 2020; Hartmann *et al*., 2020, Ernst *et al*. 2022).

Our goal was to try to decipher these hypotheses, by following the dynamics of CH_4 at the LéXPLORE station water column every month for a year (in practice from March to September 2021), combined with multiparameter probes profiles, and investigation in the month of the Rhône River area, as well as in the Rhône itself 6 km upstream the mouth.

For most of the periods, a CH_4 peak was present in the upper part of the water column. For several periods (July and September), the CH_4 peak coincided with the biomass peak (chlorophyll data from the fluorescence EXO2 and/or BBE sensor), and more precisely with Cryptophyta peak (30/09/21). For some other periods (especially in May), the CH_4 peak depth was clearly associated with the Rhône interflow, which corresponds to turbidity and conductivity peaks. In the first cases, the CH_4 would be linked to photosynthetic activity, whereas in the second cases, it would correspond to lateral transport by the Rhône plume. Higher CH_4 concentrations were found in the area in front of the mouth of the Rhône, especially near the bottom (CH_4 enrichment by diffusion from the sediments).

This study does not make it possible to unequivocally conclude on the origin of methane in the water column at the LéXPLORE station. Future work should combine these measurements with isotopic analyzes ($\delta^{13}C$ CH_4), metagenomic determinations on water samples as well as modeling of reactive transport in the water column.

Main results

CH_4 peaks have been observed in the Lake Geneva water column (Donis *et al*. 2017, fig. 6 of supp., and preliminary work performed at LéXPLORE station in July 2020) but are not well understood. Methane profiles for all the campaigns in 2021 are given in Fig. 1. In all cases, concentrations were lower in the bottom of the water column (*ca*. 9-36 nM) than in the upper part. Surface water concentration ranged from 48 nM (31/05/21 and 14/07/20) to 136 nM (10/05/21), *i.e*. clearly above the equilibrium concentration *vs*. atmosphere (*ca*. 3 nM). In addition, a CH_4 peak was present for most of the profiles, except on March and April.

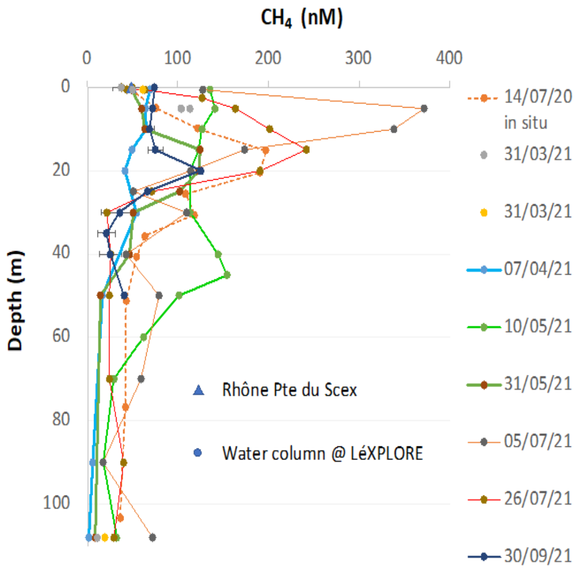


Figure 1: CH_4 profiles at LéXPLORE station.

In some periods (10 and 31 May 2021), the CH_4 peak depth were clearly associated with the Rhône interflow, which corresponds to turbidity and conductivity peaks. In these cases, the hypothesis of lateral transport by the Rhône plume is reinforced. As the concentration of CH_4 in the Rhône *ca*. 6 km upstream the mouth (Porte du Scex station) was in the 22-51 nM range, *i.e*. lower than within the interflow at LéXPLORE station, it means that the plume would acquire additional CH_4 between these two points, probably during its circulation near the bottom in the first km in the lake. This hypothesis was tested during a field campaign on 22-23/07/2021 by taking water samples from several stations located near the Rhône mouth. Relatively high CH_4 values were found in the area in front of the Rhone mouth (up to 3.2 µM at 108 m depth), some stations with higher CH_4 concentration near the bottom of the column of water, suggesting a benthic origin of methane (see Sollberger *et al*., 2014). Given the main circulation pattern in the eastern part of Lake Geneva, this area could feed the upper water column and CH_4 could be transported away from its production area. Nevertheless, reactive transport modeling must be performed to consolidate this hypothesis.

In others periods, the methane peak was more clearly associated to the biomass peak (chlorophyll). This was the case of 05/07/2021, that exhibited the highest CH_4 concentration (370 nM) and the shallowest CH_4 peak (5-10 m) of the series. Le chlorophyll maximum was located at the same depth, whereas the turbidity peak was deeper (10-18 m). The strongest evidence of a link between the biomass and methane was observed on 30/09/2021 (Fig. 2): the CH_4 peak was located around 20 m depth, clearly above the turbidity peak (*ca*. 33 m) and corresponding to one of the chlorophyll peaks, more precisely to the Cryptophyta (BBE data).

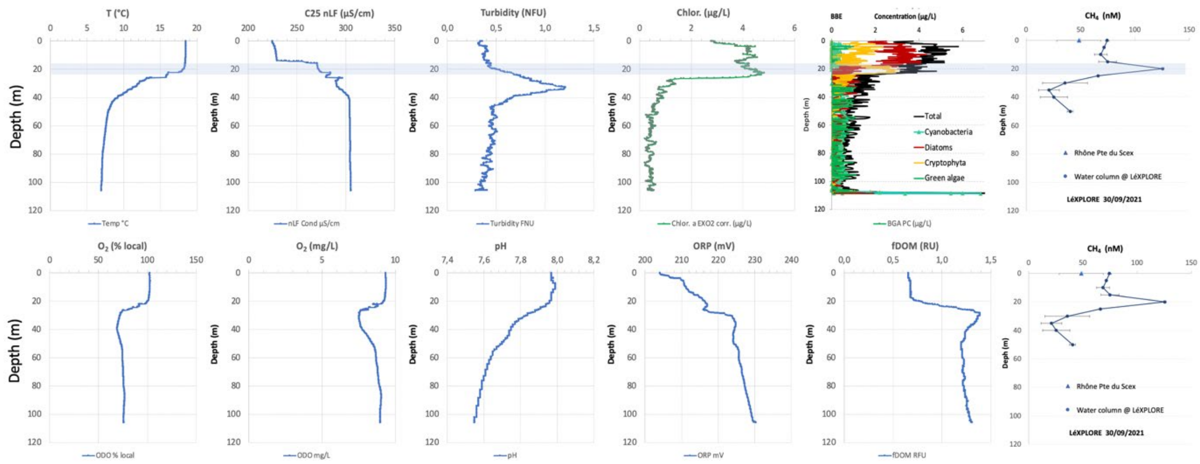


Figure 2: CH_4 profile *vs*. CDT Exo2 and BBE probes at LéXPLORE station on 30/09/2021.

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Publications

None

Conferences

LéXPLORE Workshop - EPFL (24/03/2022)

Collected data

9 field campaigns were performed at the LéXPLORE station (04/02, 03/03, 31/03, 07/04, 10/05, 31/05, 05/07, 26/07, 30/09 2021). In addition, water sampling in Rhône River were performed at the Porte du Scex station, *i.e*. about 6.2 km upstream from the mouth of the Rhône, at 6 dates (29/03, 10/05, 31/05, 05/07, 26/07 and 30/09 2021). Two determinations of air-water CO_2 and CH_4 fluxes were performed by the floating chamber method (03/03 and 02/06). A sediment core has been sampled on 2nd of June from the LéXPLORE station to determine CH_4 concentration in pore waters. In addition, one field campaign was performed in the zone of the Rhône month (22-23/07/2021), in order to investigate the spatial distribution of methane in this area in the hypothesis of lateral transport by the Rhône interflow.

Measured parameters:

- *In situ* for the whole water column (109 m depth at LéXPLORE station):

Temperature, conductivity, O_2, pH, oxidoreduction potential (ORP), turbidity, fDOM, chlorophyll, phycocyanine with an EXO2 probe (and other pigments with a BBE probe on 31/05 and 30/09), turbidity with an AQUAlogger 210 TYPT 1000 m Aquatec probe equipped with a SeaPoint turbidity sensor, PAR with a SPAR nke probe equipped with a Licor PAR sensor.

- *Ex situ* from discrete Niskin sampling:

• Dissolved CH_4 (Methane was quantified on board just after sampling by a Contros CH_4 HISEM probe (TDLAS), ±0.1 ppm resolution, ±0.5 ppm accuracy, using an equilibration technique on 2 L samples. Probe was calibrated using two CH_4 standards from GazDetect (100.7 and 1013 ppm) and N_2 AlphaGas as zero standard. For samples from the September 2021 campaign, CH_4 analysis were performed with a GC 2010 Shimadzu (equipped with FID), on poisoned samples (CuCl).

• Dissolved CO_2 (same equilibrating device than for CH_4; CO_2 was quantified with a LI 820 spectrophometer).