LéXPLORE

LéXPLORE Platform

Scientific report 2024

LéXPLORE platform ©Natacha Tofield-Pasche, 2024

Reporting from 32 projects from July 2023 to June 2024

Compiled by Laurence Glass-Haller and the project leaders

Current running projects

1. Florian Breider, Jonathan Hanahan, Karine Vernez, Sylvain Coudret, Jean-Luc Loizeau **: Deposition and Accumulation of Microplastics in Lake Sediments (Microsed)**
2. Damien Bouffard, Piccolroaz Sebastiano, Miguel Gil Coto, Sébastien Lavanchy, Guillaume Cunillera, Christian Dinkel, Bieito Fernandez Castro: **LéWalk: autonomous turbulence profiling**
3. Nicolas Adam, Jonathan Selz, Sofian Lecine, Timothée Hirt, Christophe Deloose, Rizlan Bernier-Latmani, Sebastian Maerkl: **GenoRobotics CoWaS - Continuous Water Sampling**
4. Céline Weyermann, Nicolas Estoppey, Fabienne Pfeiffer, Ines Tascon, Vick Glanzmann , Naomi Reymond, Sofie Huismann: **Aqua-Gabs/MONET in Lake Leman**
5. Natacha Tofield-Pasche, Guillaume Cunillera, Nathalie Dubois, David Janssen: **Temporal and spatial variations of the settling particles fluxes in Lake Geneva (SEDTRAP)**
6. Daniel Odermatt, Alexander Damm, Natacha Tofield-Pasche , Krista Alikas, Tuuli Soomets, Evangelos Spyrakos: **Monitoring Lake Primary Production using the PACE satellite (Lake3P)**
7. Laureen Mori-Bazzano, Bastiaan Willem Ibelings: **Characterization of Biofilm formation on different types of plastic substrate**
8. Brunetti Maura, Babanin Alexander, Jérôme Kasparian: **Wind2Waves**
9. Andrii Neronov, Jean-Paul Kneib, Lesya Shutska, Florian Bernard, Jean Lesrel, Guido Haefeli: **LAC TELescope**
10. Didier Jézéquel, Paris Jean-Daniel, Lozano Mathis, Ruffine Livio, Fandino-Torres Olivia, Grilli Roberto, Chappellaz Jérôme, Mettra François, Perga Marie-Elodie, Berg Jasmine, Khatun Santona, Tran-Khac Viet : **CarboLéX**
11. Florybeth La Valle, Aaron Strong, Julian Jacobs: **Quantification of Lake Geneva biological metabolism and validation of novel pCO2 sensor system (SIPCO2)**
12. Jérôme Chappellaz, Sébastien Lavanchy: **Tests and improvements of the SubOcean probe (SubOcean++)**
13. Alexandre Tellier, Sébastien Lavanchy, Jérôme Chappellaz: **Design and construction of a probe for continuous monitoring of dissolved CO2 in seawater from a sailboat or a small ship (SENSE-pCO2)**
14. Pierre Rossi, Emmy Oppliger: **Quantification of Quagga mussels within the EPFL water cooling system**
15. Lisa Morales, Matteo Gios, Bastiaan Ibelings: **Asterionella chytrids**
16. Helmut Bürgmann, Damien Bouffard, Sasikaladevi Rathinavelu: **Antimicrobial Resistance Tracking and Fate modeling in the Urban flows – Lake interface**
17. Santona Khatun, Jasmin Berg, Marie-Elodie Perga: **Measurement of methane oxidation rate to understand the greenhouse gas emission from Lake Geneva**
18. Nicolas Escoffier, Jérémy Keller, Santona Khatun, Isabel Herr, Marie-Elodie Perga: **CALCIGEN**

19. Natacha Tofield-Pasche, Marc-Antoine Courtois, Louise Noël du Payrat, Guillaume Cunillera: **Lake snow - dynamics of the settling particulate matter in Lake Geneva**

20. Gregoire Mariethoz, Erwan Koch, Alexis Berne: **Installation of a drip-based rain gauge on LéXPLORE**

21. Jenny Maner, Carolin Drieschner, Christian Ebi, René Schönenberger, Levin Angst, Simon Bloem, Miguel Solsona, Philippe Renaud, Kristin Schirmer: **Rainbow$_{flow}$ chip$_{online}$: Fishcell biosensor for automated water quality testing**

Current projects without detailed reports

22. Bastiaan Ibelings, Mridul Thomas, Roxane Fillion, Jorrit Mesman, Matthieu Devanthery, Sebastien de Loes, MUSE-Master students, Beat Müller: **POETICS - PlanktOn vErTICal Structure**

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

Final report for completed projects

24. Mary-Lou Tercier-Waeber, Bastiaan Ibelings, Nicolas Layglon, Tanguy Gressard: **Synergic interaction between arsenic species and microorganisms in freshwater contrasting dynamic conditions (SyBAM)**

25. Nathalie Dubois, Benedict Mittelbach , Timothy Eglinton, Margot White, Timo Rhyner: **Radiocarbon Inventories of Switzerland (RICH)**

26. Jeremy Keller, Nicolas Escoffier, Violaine Piton, Santona Khatun, Isabelle Herr, Gaël Many, Jake Vander Zander, Marie-Elodie Perga: **ZOOPS – temporal dynamics of zooplankton**

27. Beauvais Rébecca, Ferrari Benoît, Casado-Martinez Carmen, Rohrbach Emmanuelle: **LéXPOSTRAC: Tracking ecotoxicological effects of lake suspended particulate matter on the ostracod *Heterocypris incongruens***

Discontinued projects

28. Bouffard Damien, Bieito Fernandez Castro, Piccolroaz Sebastiano, Michäel Plüss, Sebastien Lavanchy, Wüest Alfred: **Skin2Bulk: investigating the surface boundary layer**

29. Bahr Alexander, Schill Felix, Lavanchy Sébastien and Cunillera Guillaume: **SUBMULE – easy access to submerged data**

30. Perga Marie-Elodie, Frech Benoit, Vittoz Jérôme, Gravey Mathieu: **the sounds of LéXPLORE**

31. Bellouard Yves, Rey Samuel, Ayer Baptiste, Sala Federico, Ibelings Bastiaan, Pomati Francesco: **PhytoWaveTaxa: all glass sensors for algae population monitoring**

32. Mridul Thomas, Pomati Francesco, Suarez Ena, Fillion Roxane, Ibelings Bastiaan: **Plankton in Lake Geneva : you can't have it both ways.**

LéXPLORE

Microsed project - Deposition and Accumulation of Microplastics in Lake Sediment

Florian Breider, Lucas Aebischer, Sylvain Coudret, Karine Vernez, Jean Luc Loizeau

The full impact of plastics on the environment, particularly in aquatic ecosystems, remains uncertain. To enhance our understanding of the behaviour of plastics in freshwater environments, the LeXPLORE platform on Lake Geneva offers a unique opportunity to study a significant freshwater lake, fed by one of Europe's largest rivers, the Rhône. The objective of this study is to quantify the distribution of microplastics in the water column by analysing the variation in size and quantity of plastics collected in the photic zone, the thermocline of the lake, and the sedimentation of plastics at various depths.

Microplastic samples are collected using pumps that draw water from depths of 2 and 30 meters, passing it through filters with pore sizes of 500 and 150 µm every 12 hours. Additionally, monthly samples are gathered using cylindrical sediment traps deployed at four depths (12, 27, 47, and 87 ± 0.5 meters) beneath the LeXPLORE platform. Microplastics are extracted from these samples, quantified, and characterized using infrared quantum cascade laser spectroscopy to determine the abundance of polymers. To date, only the water samples have been analysed by infrared spectroscopy, while the analysis of samples collected with the pumps and sediment traps is ongoing. New data will be presented in a future report.

In 2023 and 2024, the research focused on analysing sediment cores taken from a depth of 110 meters. The sediment cores were extruded and dated using radioactive isotopes (^{210}Pb and ^{137}Cs) and further characterized by measuring water content, grain size, organic matter, and $CaCO_3$ content. Preliminary results indicate that polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), and rubber are the most abundant polymers in the sediment cores. Additionally, polymer diversity appears to be lower in older sediments compared to more recent ones, though this observation requires validation through statistical analysis. The concentration of microplastics increases from a depth of 55 cm to the surface layer, with concentrations ranging from 2 to 60 MPs/g of dry sediment, which are comparable to those reported in other lakes. In the coming months, further sample analysis and statistical analysis of the concentrations and properties (size, shape, composition) of microplastics will be conducted. These results will allow for the calculation of microplastic sedimentation rates and comparison with existing models.

EPFL

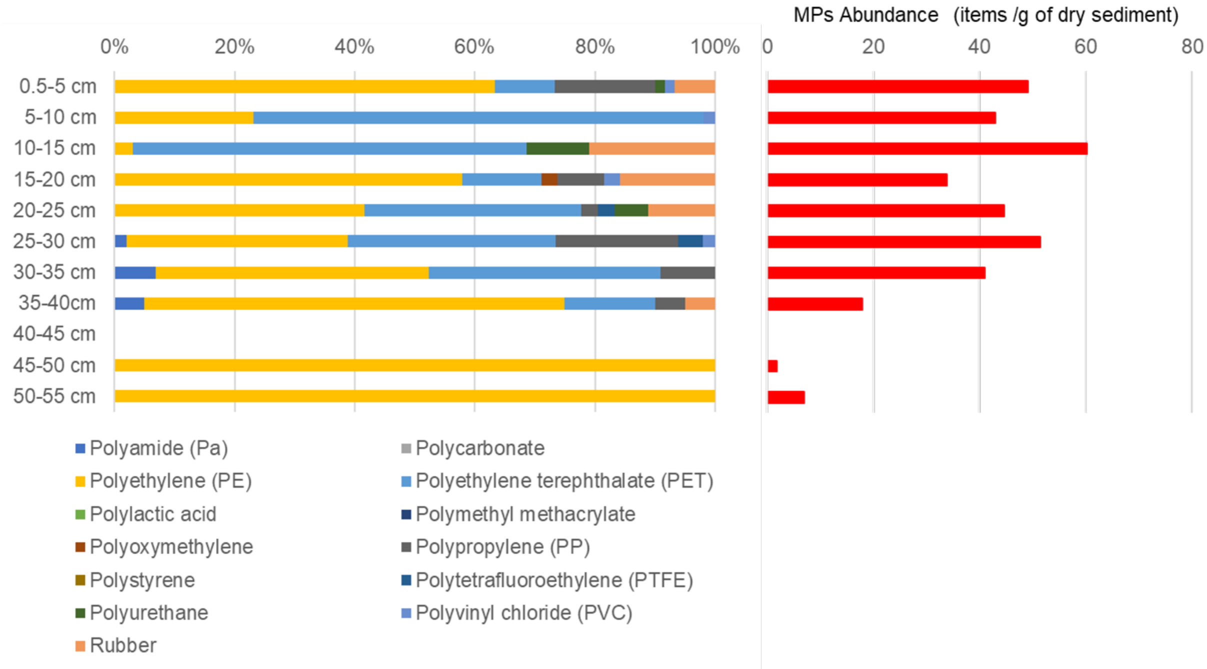


Figure 1. Distribution of the polymers (left) and microplastics abundance > 150 microns (right) in the sediment core.

In addition to microplastics, additives associated with tyres were quantified in the sediment cores. Preliminary analysis of the data shows that tyre-related compounds are present in the sediments at concentrations in the ng/g range (Figure 2). Higher concentrations were detected in surface sediments. This trend could be the result of the increase in traffic over the last few decades and the potential degradation of these micropollutants in the sediments.

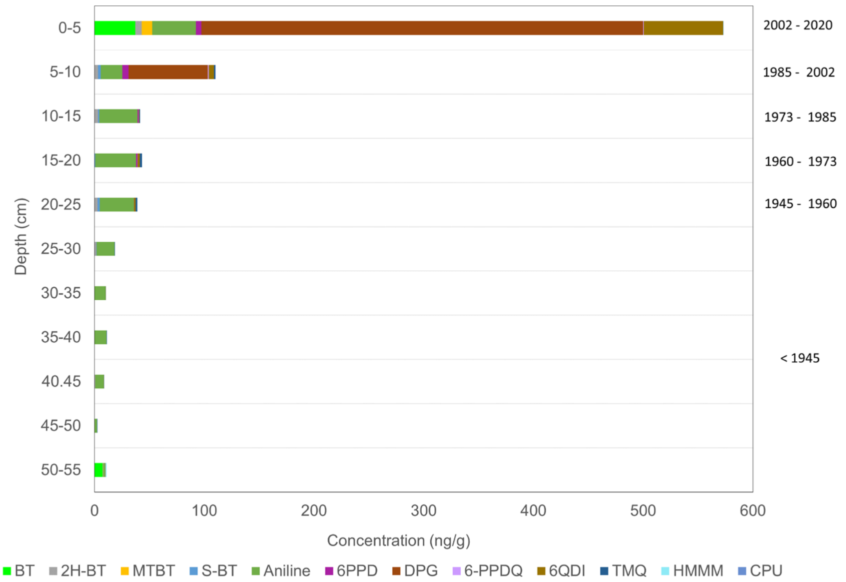


Figure 2. Distribution of additives associated to tire particles in the sediment core.

LéWALK: autonomous turbulence profiling

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

LéWalk is a preliminary project that aims at improving the quantification of turbulence and mixing in lakes. Turbulence affects the transport of heat, dissolved constituents and particles in lakes. Yet, turbulence intensity is challenging to measure in the field and we specifically lack information during extreme events (for instance during wind storm). This preliminary project aims at (i) testing and comparing existing methods of turbulence estimation (microstructure profilers, ADCP, wire-walker), (ii) developing a method to compute turbulence intensity continuously and in near real-time and (iii) combining estimates of turbulent diffusivity with measurements of dissolved constituents to calculate vertical turbulent fluxes useful for biogeochemists. Once the proof of concept established and assuming a continuation of the platform, an SNSF project will be submitted (April 2025, project period 2026 - 2030).

The main outcomes will be: (i) to develop an autonomous turbulence profiling system specifically designed for lakes and (ii) to gather continuous turbulence profiles, particularly during windy conditions that are typically challenging to monitor using conventional methods.

The system has undergone testing in the previous year and is now fully operational, successfully collecting data. This autonomous profiler utilizes the energy from surface waves to descend. Upon reaching a depth of 50 meters, the system automatically detaches from the rope and begins its ascent to the surface while simultaneously recording microstructure temperature data. We use 4 FP07 mounted on a Micropod from Rockland to capture temperature fluctuations at a rate of 512Hz, while the device moves at an approximate speed of 20 cm/s. This configuration enables us to detect temperature variations at a scale of millimeters with a resolution of a few thousands of a degree Kelvin (mK) and thereby to estimate the level of turbulence in the water column.

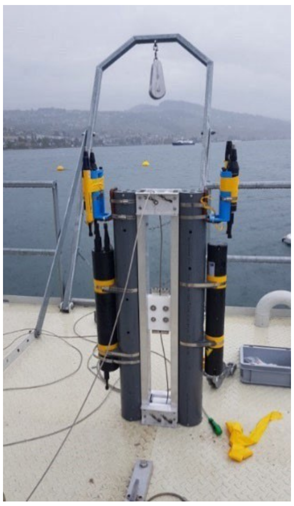


Photo of the autonomous turbulence profiler used on the LéXPLORE platform

The primary advantage of this system is its ability to conduct profiling primarily during windy (wavy) conditions, where obtaining traditional turbulence measurements from small boats poses challenges. By doing so, this project aims to address the longstanding issues of undersampling and external forcing bias commonly encountered in turbulence measurements.

In addition to the wave-based energy harvesting system used to propel the profiler, another system has been developed for this project. Inspired by the principle of Argo floats commonly employed in oceanography, this new system has been customized specifically for lake applications. The profiler regulates the buoyancy with a piston powered by a battery. It is designed to accommodate various payloads, such as CTD (Conductivity, Temperature, and Depth) sensors, microstructure sensors, and more.

Collaborations with the Wind2Waves project, which aims to better quantify the surface wave field, will be undertaken to better understand and constrain the role of wind waves in the air-water energy transfer process. Other collaborations with biogeochemists should also arise from the distribution of dissipation and diffusivity estimates within the LéWALK project.

CoWaS – Continuous Water Sampling

Nicolas Adam, Viviane Blanc, Felix Schmeding, Sebastian J. Maerkl, Rizlan Bernier-Latmani

Context

The goal of the CoWaS project is to develop and autonomous sampler for the collection of aqueous microbial communities on 0.22µm filters. A significant challenge in advancing this prototype is designing a robust tool that is user-friendly while remaining highly customizable, allowing users to easily modify the system to meet their specific experimental needs.

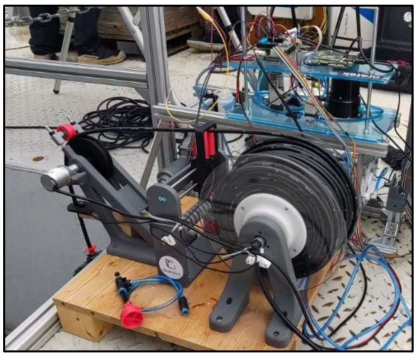


Figure 1: CoWaS prototype

Figure 2: PCB shield

Development

Over the past year, several key advancements have been made:

- A 3D-printed arm was developed for the manifold module (Figs. 4 & 5) to enable a watertight hydraulic connection, which reduces both costs and the potential for cross-contamination between samples.
- A custom, open-source PCB shield was designed (Fig. 4) to integrate all electronic components, increasing the robustness of the prototype.
- A micropump system (Fig. 3) was developed to incorporate a DNA shield for sample preservation. This system allows for the injection of reagents into the filter, with precise control over reagent volume.

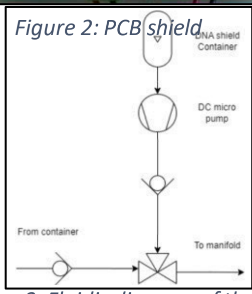


Figure 3: Fluidic diagram of the DNA micropump system

Testing

To assess the usability of the CoWaS system in scientific experiments, two tests were designed:

- The first test focused on evaluating the potential for cross-contamination between filters.
- The second was a field experiment aimed at evaluating bacterial community dynamics at a depth of 5m over a 24-hour period, with a sampling rate of 1 hour, comparing automated sampling with manual sampling.

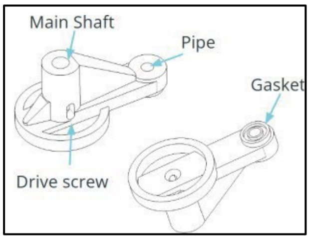


Figure 4: 3D drawing of the hydraulic connection arm;

Results & next steps

The cross-contamination experiment demonstrated the reliability of the prototype, with no contamination observed. The field experiment, while limited to five samples due to logistical constraints and weather conditions, produced promising results, as automated and manual sampling yielded similar outcomes, with the automated system significantly reducing sampling time. Additionally, this test highlighted the use of a flowmeter in place of a cartridge, enabling tunable inner volume. Moving forward, the prototype will need to be encapsulated for easier handling and waterproofing.

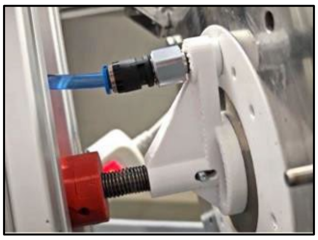


Figure 5: 3D printed arm + coupling

Aqua-Gaps/MONET in Lake Leman

Fabienne Pfeiffer, Ines Tascon, Vick Glanzmann, Naomi Reymond, Sofie Huisman, 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 persistent organic pollutants (POPs) as well as compounds of emerging concern. Aqua-Gaps/MONET has taken advantage of the key benefits of passive samplers 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 results of the first years of sampling (2016 to 2021) have been published recently[4].

Since 2021, passive samplers are deployed at LéXPLORE instead of Buchillon station. Passive samplers are deployed – for 1 year – at a depth of 3 m below surface level using an 'open cage' (see Figure 1). Three types of samplers are deployed. Silicone sheets sample hydrophobic compounds (e.g. PCBs), Speedisks sample polar compounds (e.g. pharmaceuticals) and microporous polyethylene sample per- and polyfluoroalkyl substances (PFASs). 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. The first deployment at LéXPLORE occurred between October 2021 and November 2022 and samplers were sent to RECETOX for extraction. New samplers were installed in November 2022, to provide precious additional data on levels of contaminants in 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.

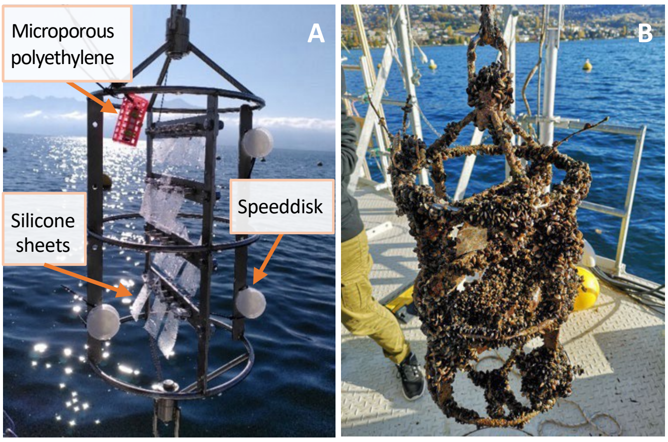


Figure 1: Passive samplers during installation (A) and retrieval (B) at LéXPLORE.

[1] Lohmann, R., & Muir, D. (2010). Global Aquatic Passive Sampling (AQUA-GAPS): Using Passive Samplers to Monitor POPs in the Waters of the World. *Environmental Science & Technology*, *44*(3), 860–864. https://doi.org/10.1021/es902379g

[2] Lohmann, R., Muir, D., Zeng, E. Y., Bao, L. J., Allan, I. J., Arinaitwe, K., Booij, K., Helm, P., Kaserzon, S., Mueller, J. F., Shibata, Y., Smedes, F., Tsapakis, M., Wong, C. S., & You, J. (2017). Aquatic Global Passive Sampling (AQUA-GAPS) Revisited: First Steps toward a Network of Networks for Monitoring Organic Contaminants in the Aquatic Environment. *Environmental Science and Technology*, *51*(3), 1060–1067. https://doi.org/10.1021/acs.est.6b05159

[3] Sobotka, J., Smedes, F., & Vrana, B. (2022). Performance comparison of silicone and low-density polyethylene as passive samplers in a global monitoring network for aquatic organic contaminants. *Environmental Pollution*, *302*, 119050. https://doi.org/https://doi.org/10.1016/j.envpol.2022.119050

[4] Lohmann, R., Vrana, B., Muir, D., Smedes, F., Sobotka, J., Zeng, E. Y., Bao, L. J., Allan, I. J., Astrahan, P., Barra, R. O., Bidleman, T., Dykyi, E., Estoppey, N., Fillmann, G., Greenwood, N., Helm, P. A., Jantunen, L., Kaserzon, S., Macías, J. V., Maruya, K. A., Molina, F., Newman, B., Prats, R. M., Tsapakis, M., Tysklind, M., van Drooge, B. L., Veal, C. J., Wong, C.S. (2023) Passive-Sampler-Derived PCB and OCP Concentrations in the Waters of the World–First Results from the AQUA-GAPS/MONET Network. *Environmental Science & Technology,* 57(25), 9342-9352. https://pubs.acs.org/doi/10.1021/acs.est.3c01866

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

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

Within this project, we have quantified the temporal variations in the settling particles fluxes at LéXPLORE platform at four different depths. Since the last report, we have continued to deploy the sediment traps at the same sampling rate. Unfortunately, the year 2022 had two large gaps. The laboratory analyses of the different composition in 2023 and 2024 are still under way.

We have also analyzed the results from 2020 until 2023. The mass fluxes in the four years showed high inter-annual variations depending on the climatic conditions. The total sedimentation rates indicated peaks from June to September for the four years, which corresponds to higher discharge of the Rhône River during the melting season. The total mass flux was usually lower at 30 m depth and higher below 50 m, where larger fluxes of minerals were observed. This depth interval correspond to the Rhône intrusion depth (from 20 to 40 m), bringing additional terrestrial inputs. In conclusion, the sedimentation rates and the composition of the settling particles in Lake Geneva varied seasonally and between years. These variations reflect the fluctuations from the Rhône River discharge and intrusion depth, primary production and carbonate precipitation. Natacha Tofield-Pasche presented this work during the SIL2024 conference in Brazil in May 2024.

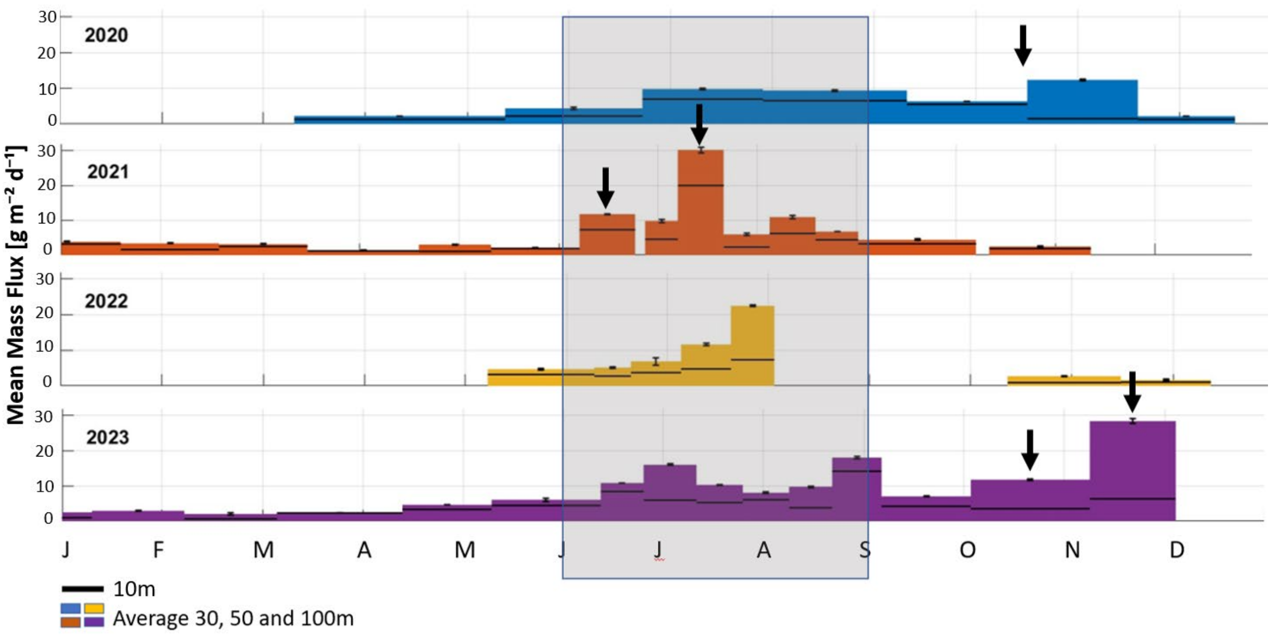


Figure 1: Total mass flux of settling particles at LéXPLORE from 2020 to 2023 for trap at 10 m and traps averaged below 30 m.

Project: Lake Primary Production using PACE (Lake3P)

Daniel Odermatt, Mortimer Werther, Jonas Wydler, Guillaume Cunillera, Natacha Tofield-Pasche

Optical Earth observation satellites provide a very efficient means to model aquatic primary production based on direct estimates of photosynthetic pigment absorption, downwelling irradiance, and light attenuation. The Lake3P project aims to investigate these models' performance in and their adjustment for stratified water bodies, and how the latest generation of hyperspectral satellite sensors can improve the direct estimates of the three input parameters.

In 2023 we performed regular 14C incubation measurements of PP on Lake Geneva and Greifensee. We transitioned to 13C during winter 2023/2024. We restarted regular sampling in summer 2024. During all campaigns, we sample also vertical profiles of bulk spectral absorption, attenuation and scattering, and concentrations of optical agents in order to parameterize bio-optical primary production models. In between campaigns, we rely on measurements acquired by the Thetis profiler and the above-surface spectroradiometers *WISPstation* and *So-rad* installed on LéXPLORE. In combination with the new PACE satellite launched by NASA in February 2024, these instruments provide daily and nearly simultaneous measurements of spectral reflectance at the top of the atmosphere, above and at different depths below the surface. Furthermore, we developed a flow-through system that can operate the same optical sensors as Thetis on a slowly cruising boat rather than on a profiler, allowing for complementary transect measurements at a single depth.

Figure 2 : the 'so-rad' is an arrangement of three spectrometers with which the upwelling radiance above the water, the downwelling radiance from the opposite segment of the sky and the total incident irradiance are each measured in all wavelengths of the visible to near-infrared spectrum.

Using these measurements, we performed a comprehensive validation exercise for atmospherically corrected Sentinel-2 and Sentinel-3 satellite data, which is used for the development of processing chains in a new lake data portal www.alplakes.eawag.ch. Atmospheric correction for Lake Geneva imagery was most effectively accomplished using the POLYMER algorithm. Water transparency products derived from Sentinel-2 for Lake Geneva between 2015 and 2023 demonstrate strong concordance with *in situ* measurements, exhibiting a median symmetric accuracy with less than 20% error.

We tested primary production models commonly used in both freshwater (developed for eutrophic and shallow lakes) and marine systems across various water bodies, including Lake Geneva. While these models, based on standard IOP, AOP, and irradiance data, successfully captured the main patterns, Lake Geneva — characterized by relatively low productivity, large depth, and seasonal mixing — presents additional complexities for bio-optical primary production models. The detailed set of additional parameters we are gathering in this project, along with necessary model adaptations, will be the next step in addressing these challenges.

Future efforts will leverage the recently launched NASA PACE mission to test and develop prototype approaches applicable to Lake Geneva. These approaches will be primarily calibrated using measurements from LéXPLORE.

The Plastisphere of Lake Geneva

Laureen Mori-Bazzano, Bastiaan Ibelings

This project investigates the plastic-associated microbial community in Lake Geneva and examines the time scale of colonization under various seasonal and spatial conditions. Utilizing the LéXPLORE platform, researchers study biofilm formation on two common types of plastics, low-density polyethylene (LDPE) and polyethylene terephthalate (PET), which differ chemically and interact differently with the aquatic environment. Samples of these plastics, along with glass as a control, have been incubated at different lake depths (2m, 30m, and 100m) since January 2023. These depths represent different environmental conditions, allowing for a comprehensive analysis of microbial colonization and plastic degradation over time.

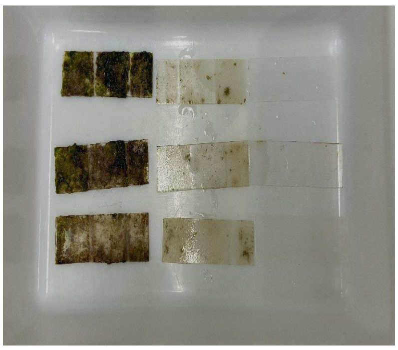
The study employs Next Generation Sequencing (NGS) and qPCR to analyze the biofilm's microbial composition. NGS identifies bacteria, algae, and fungi, while qPCR measures the abundance of genes involved in plastic degradation. Initial results show that the biofilm community varies significantly with depth and season but is not influenced by the plastic material. At 2m depth, a dense biofilm develops, dominated by seasonal algae changes, such as diatoms in winter and green algae in late summer. At 30m, biofilm growth is steady, consisting mainly of bacteria and fungi, while at 100m, biofilm growth is minimal.

Surface analysis of the plastics includes contact angle measurements, Fourier Transform Infrared (FTIR) spectroscopy, and Scanning Electron Microscopy (SEM). A decrease in the contact angle on LDPE at 2m indicates increased hydrophilicity due to biofilm formation. FTIR and SEM analyses at 30m reveal signs of oxidative degradation and surface damage on LDPE, suggesting that mechanical or microbial activity, rather than light-driven photooxidation, could be responsible for the observed degradation.

Preliminary data indicate that LDPE degrades more readily than PET, likely due to its amorphous structure, which is less resistant to environmental conditions. Further analyses, including TOF-SIMS and additional molecular studies, are needed to confirm these results and elucidate the mechanisms of microbial and abiotic degradation.

Photo of the biofilm September 2023

2m 30m 100m



LéXPLORE

WIND2WAVES

Maura Brunetti, Jérôme Kasparian, Damien Bouffard, Alexander Babanin

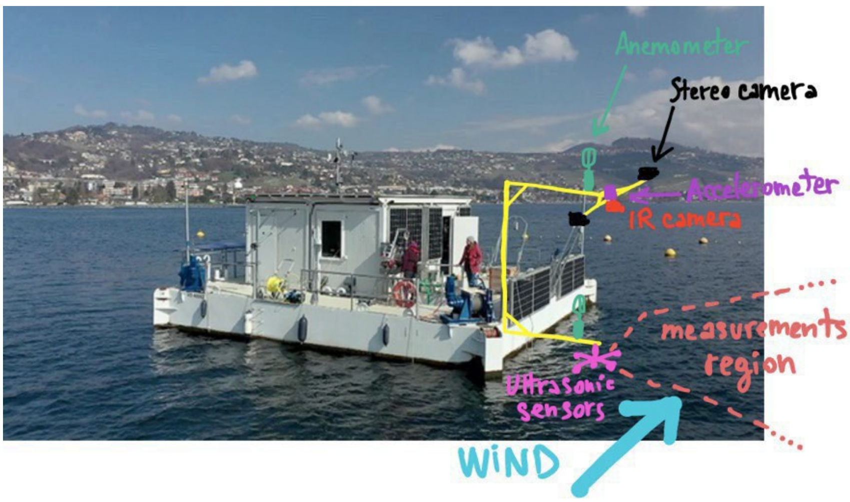
The interaction of wind and waves is a complex process at the interface of two turbulent fluids. Theoretical approaches require the assumption of simplified configurations (laminar regime, one-dimensional propagation, negligible back-reaction from waves to wind, etc.) to obtain analytical formulae, which are generally not applicable in real conditions. Observational and phenomenological approaches are often the only way to gain insight into this complex problem.

The objectives of the project are

1) to investigate the correlations between wind and waves intensity and how these are affected by directionality, wave breaking, non-linearity/linearity conditions, in order to disentangle and quantify the effect of source and sink processes in the evolution of directional wave energy spectra
2) to estimate the contribution of waves to the total energy balance within the water column
3) to improve the formulation of air-water interactions for the modelling of Lake Geneva and, more generally, in the sub-grid parameterisations of general circulation models
4) to provide the scientific community with a complete database of continuous measurements of wind, waves, energy exchanges and meteorological conditions, with annual (or longer) coverage.

This year we bought some of the instruments: the stereo camera system to reconstruct the temporal evolution of the wave surface, one of the two anemometers to be placed on the near-surface horizontal extension (see figure), and one of the two rugged embedded computers to control all the instruments, store the raw data and perform pre-processing and quality control of the measurements. We (re)submitted the project to the Swiss National Science Foundation in April 2024. We are in contact with two potentially interested master students to install these instruments and start the first measurements. Collaborations with the LéWALK project, which aims to measure turbulence in the water column, will be undertaken to better understand and constrain the role of wind waves in the air-water energy transfer process.

Figure 1. LéXPLORE platform and schematic of the instruments implementation (provisional).



UNIVERSITÉ DE GENÈVE

THE UNIVERSITY OF MELBOURNE

Prototype elementary cell of Water Cherenkov Detector Array (WCDA) for study of cosmic ray electrons and gamma-ray observations

Andrii Neronov, Jean-Paul Kneib, Florian Bernard

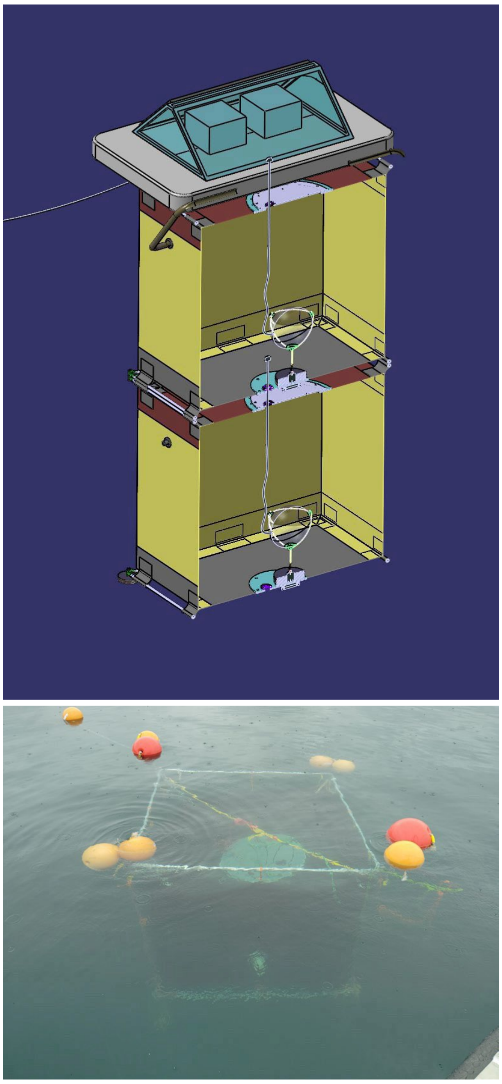


Fig. 1. Top panel: CAD drawing showing cross-section of the EC with the optical module of ANTARES contained in a light-tight tarpaulin. Bottom panel shows the mechanical setup currently deployed for “survival test” at LéXPLORE site.

The project is aimed a testing an improvement for a technique of WCDA for detection of cosmic rays and gamma-rays, high-energy particles emitted by distant sources in the Milky Way and other galaxies. These particles penetrate the Earth atmosphere and induce “showers” of secondary electrons, positrons, muons that reach the ground (water) and produce short pulses of blue Cherenkov light that can be detected by WCDA. There are two currently operating WCDAs: HAWC in Mexico and LHAASO in China. These detectors have revolutionised the field of very-high-energy gamma-ray astronomy, providing detections of sources in our Galaxy capable of accelerating particles to PeV energies (about 100 times larger than those attainable at the Large Hadron Collider at CERN). However, both detectors have a limited capability for measuring the identity of the primary cosmic ray particles initiating the showers (protons, atomic nuclei or electrons or gamma-rays). Our project aims to improve this capability by adding a deep second layer to WCDA. Such two-layer detector will be able to measure separately the electron-positron content (with the top layer detector) and muon content (with the bottom layer) of the cosmic ray induced showers[1]. Proton or nuclei induced showers yield factor-of-ten more muons than electron or gamma-ray-induced showers. Large (hundreds of square meters) WCDA will be assembled from smaller “Elementary Cells” (EC). During the last year, we have started a joint Franco-Swiss collaboration around development and testing of such ECs in realistic conditions, funded by the Swiss National Science Foundation and Agence National de Recherche. The project involves EPFL, University of Geneva, Astroparticle and Cosmology laboratory in Paris and Centre for Particle Physics in Marseille.

The optical modules to be installed in the tarpaulin are heritage of ANTARES experiment[2], a neutrino detector that was previously deployed in the Mediterranean. We have already managed to deploy the first prototype of mechanical setup of the EC on LéXPLORE site which currently undergoes "survival test" since end of May 2024 (see Fig. 1). We had to revise the initial design that included a floating platform for mounting the solar panels, power supply and readout electronics, with a set of buoys that are nearly immersed in the lake, to reduce the forces excreted on the tarpaulin by waves. Next stage of the project (in course) is to proceed with installation of the optical module with associated power supply and readout electronics. These items are currently developed at the Astroparticle and Cosmology Laboratory and will be delivered during fall 2024.

[1] A.Neronov, D.Semikoz, https://arXiv.org/abs/2102.08456

[2] ANTARES neutrino telescope https://antares.in2p3.fr/

LéXPLORE

CarboLéX

Jézéquel Didier, Paris Jean-Daniel, Lozano Mathis, Ruffine Livio, Fandino-Torres Olivia, Grilli Roberto, Chappellaz Jérôme, Mettra François, Perga Marie-Elodie, Berg Jasmine, Khatun Santona, Tran-Khac Viet, Quetin Philippe.

This project has a double scientific and methodological objective: (i) provide new elements of understanding of the carbon cycle in Lake Geneva (water column and at the air-water interface), (ii) Characterize the representativeness of the measurement by eddy covariance (EC) of exchanges of CO_2 and CH_4 at the air-water interface.

The project consists of several parallel actions:
1) Long-term monitoring:
- Deployment of the CO_2 and CH_4 eddy covariance system on LéXPLORE. Water vapor fluxes will also be measured.
- Measurement of pCO_2 and pCH_4 (dissolved) by Contros probes (HydroC CO_2 and HISEM respectively) and (depending on progress), by developed prototype.
- Measurement of the CO_2 flux at the air-water interface using an automatic chamber by developed prototype (CARRTEL, depending on progress).

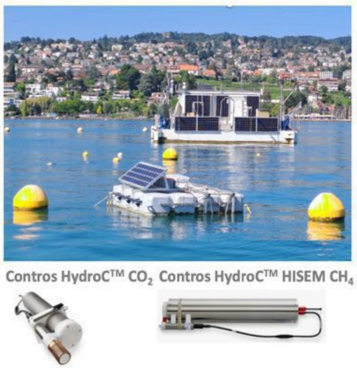
2) One-off campaigns:
- Spot measurements of CH_4 and CO_2 flows at the air-water interface with a manual floating chamber (model using the West Systems TDLAS sensor for CH_4 and a Licor LI820 for CO_2).
- Measurements of pCH_4 and $\delta^{13}C_{CH4}$ dissolved in the water column with the SubOcean spectrometer. The SubOcean measurements will be carried out at the LéXPLORE station from the platform and by mapping on surface waters using a boat (locations to be determined).
- These measurements will be compared to the samples (UNIL) for both the CH_4 concentration and the isotopic composition.

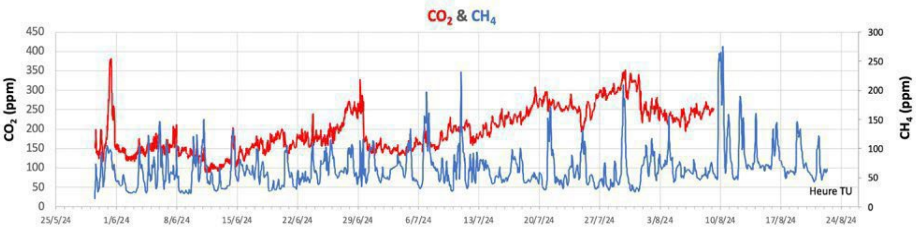
Monitoring of pCO_2 and pCH_4 in surface waters began on May 29, 2024, by installing two Contros probes from a small platform located near the main LéXPLORE platform (Fig. 1). Knowing the partial pressures in water, as well as the value of the transfer coefficient k_T between water and air, it is possible to calculate the flux of these two gases. The calculated values can be compared with the values obtained by the floating chamber, which is a direct method of determining fluxes.
In the figure 1, the temporal evolution of CO_2 and CH_4 is shown. First of all, one can notice that during the period from the end of May to the end of August, the CO_2 was always lower than the equilibrium value with the atmosphere, which implies a CO2 uptake by the lake. This period corresponds to a phase of photosynthetic production in the lake. On the contrary, CH4 was always higher than the equilibrium value, which implies an emission of this gas towards the atmosphere.

Especially for CH4, the peaks occurred at the same time as the temperature drops occurring during the night. This could correspond to small mixing of the upper layers of the lake, or to variations in biological activity. Increases in CO2 are linked to the respiration process, predominant at night.

LéXPLORE

For this summer period, CO2 fluxes were on average -8.3 mmol m-2 d-1, and CH4 fluxes were 0.09 mmol m- 2 d-1, which is low. These temporal variations in CO2 and CH4 concentrations highlight, one more time, the interest of continuous monitoring, in order to better determine the fluxes of these two greenhouse gases.





CO_2		
Mean =	197.3	ppm
Sd. Dev. =	56.8	ppm
CV% =	28.8%	
Min.	87.3	ppm
Max.	380.6	ppm

CH_4		
Mean =	65.2	ppm
Sd. Dev. =	32.0	ppm
CV% =	49.1%	
Min.	14.2	ppm
Max.	275.7	ppm

	Mean	Mean + 1σ	Mean - 1σ
CO_2 flux mean (mmol m^{-2} d^{-1})	-8,3	-6,2	-10,4
CH_4 flux mean (mmol m^{-2} d^{-1})	0,09	0,13	0,04

(calculation with k_T = 1 m d^{-1})

Figure 1: Temporal evolution of CO2 and CH4 from 29/05/24 to 22/08/24, and values of the derived fluxes.

LéXPLORE

Quantification of Lake Léman biological metabolism and validation of novel pCO_2 sensor system (SIPCO2)

Florybeth La Valle, Aaron L. Strong, Julian M. Jacobs

The high temporal variability of pCO2 and the large influence of CO2 outgassing from freshwater bodies on the global carbon cycle introduce a great need to develop reproducible and accessible high frequency pCO2 monitoring systems. In 2023, we developed a "SIPCO2" sensor system, modified from Hunt et al. (2017) for lotic environments, designed to obtain long-term high frequency pCO2 measurements from a mooring site. SIPCO2 uses a "facilitated diffusion" technique, involving bubbling air through water, to equilibrate a fixed volume of gas with the pCO2 of surface waters (Fig 1A) to achieve CO2 values in equilibrium with the underlying pCO2. SIPCO2 can be built from readily available materials for a low cost of 500 USD, making it a cheap and accessible alternative to commercial pCO2 sensors.

From June 2023 – December 2023, we successfully deployed two SIPCO2 sensor models in small lake systems in New York, USA and collected pCO2 data continuously at 15-minute intervals. As a next step for the project, we deployed SIPCO2 to the LéXPLORE platform from June 20th – June 26th to comparatively validate its measurements with other pCO2 sensor systems on the platform and evaluate its use in a larger lentic system.

SIPCO2 recorded pCO2 values in Lac Léman surface waters every 10-minutes spanning June 20th – June 26th, producing a total of 737 discrete measurements. According to SIPCO2, pCO2 concentrations ranged from slightly above values in equilibrium with the atmosphere (450 μatm) to well-undersaturated with respect to the atmosphere (225 μatm), suggesting the water body can be classified as both net heterotrophic as well as net autotrophic on short (i.e. hourly) time scales. Furthermore, pCO2 did not always follow the expected diel pattern according to the balance of photosynthesis and respiration across day and night cycles.

We are looking forward to both comparing our measurements to those of other pCO2 sensors on the platform and integrating meteorological and biogeochemical data into our analysis in the coming weeks. Through these efforts, we will evaluate the accuracy of SIPCO2 as a pCO2 monitor and unravel the mechanisms that drive this variability in pCO2 and the shift from classic diel CO2 cycling. We will also make our data publicly available upon completion of our analyses.

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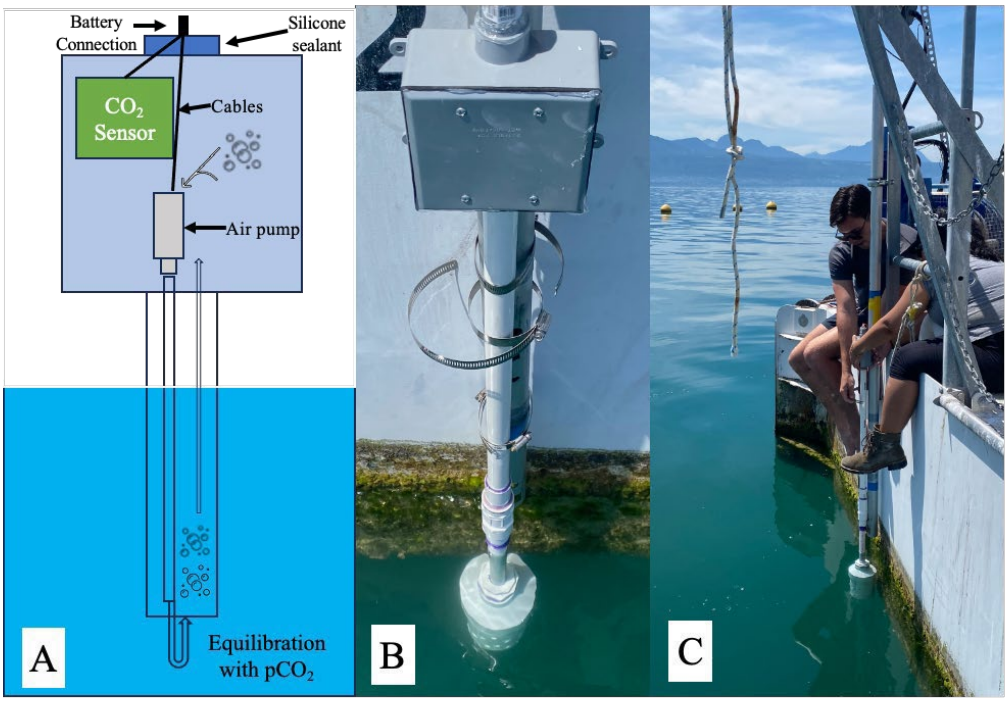


Figure 1. (A) Graphic of SIPCO2 operation using the facilitated diffusion technique from Hunt et al. (2017). (B) Close up photo of SIPCO2 deployment on Lac Léman. (C) Photo of data collection and system maintenance on the side of the LéXPLORE platform.

LéXPLORE

Tests and improvements of the SubOcean probe (SubOcean++)

Chappellaz Jérôme, Lavanchy Sébastien (EPFL / ENAC / IIE / SENSE research unit)

The SubOcean probe is an in-situ sensor embarking a laser spectrometer, able to continuously monitor the concentration of specific trace gases dissolved in water. SubOcean++ aimed at testing two new SubOcean probes being built by a small business unit in France: one dedicated to CH_4 and its stable carbon isotopes, the other dedicated to CH_4 and N_2O. The project also aimed to make evolve their design and specificities with the objective to increase performance and autonomy.

The proposal covering the time period from March to the end of 2024 (with possibility of extension) included 5 actions.

A. <u>When delivered, we aimed to deploy the new probes from LéXPLORE to evaluate their performances.</u>

Delivery took place on May 15th, 2024. We tested the two instruments on LéXPLORE and we could confirm their performances after a deployment throughout the whole water column.

B. <u>Thanks to a funding from CLIM-ACT, together with LAS we develop new custom-made membranes to separate dissolved gases from water. We aimed to test the SubOcean probe equipped with these new membranes using LéXPLORE.</u>

This action is delayed due to unexpected delay in delivery of critical items at LAS necessary to test the membranes in laboratory conditions. We have good hope to conduct these tests in the course of Fall 2024.

C. <u>SubOcean probe usually runs on its own battery and the data are recorded in the micro-PC of the probe. We aimed to equip the probe with a specific winch allowing to power it from the surface and to transfer the data in real time to the surface as well.</u>

We have interacted with a factory in Canada to build a specific winch adapted to our demand. The winch has been delivered at EPFL Valais Wallis. We expect the cable to be delivered in August. Tests of the whole equipment are expected to take place in Fall 2024.

D. <u>When deployed in water, it is important that the position of the SubOcean probes be accurately known. We planned to test a specific positioning system provide this critical information in 3D.</u>

We have acquired a specific 3D positioning system. It has been tested on the LéXPLORE platform on May 15th, in parallel with the tests of the two new SubOcean probes. These tests proved to be satisfactory.

E. <u>One of our aims is to allow the SubOcean probe to position itself in critical areas to monitor, independently from the boat at surface. We thus aimed to test a custom-made ROV extension with thrusters, allowing to move the probe in 3D from a reference position.</u>

Due to lack of time and priority given to prepare a field campaign in Greenland, this action has been postponed. It will become active probably starting in Fall 2024.

One of the two new SubOcean probes being tested on the LéXPLORE platform on May 15th, 2024

LéXPLORE

Design and construction of a probe for continuous monitoring of dissolved CO_2 in seawater from a sailboat or a small ship (SENSE-pCO_2)

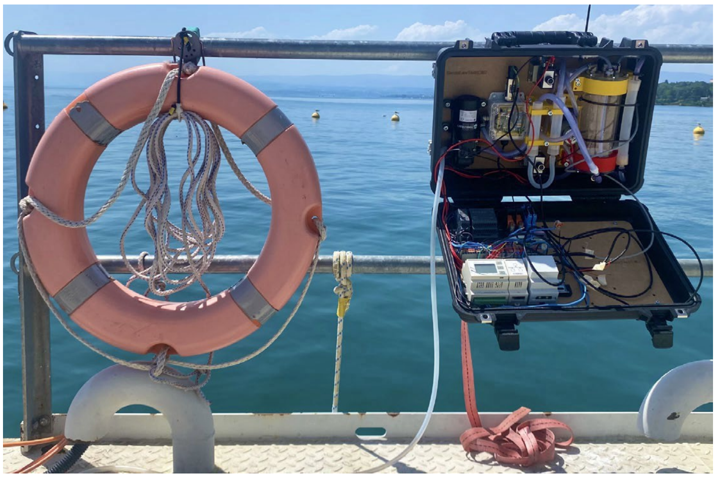
Tellier Alexandre, Lavanchy Sébastien, Chappellaz Jérôme (EPFL / ENAC / IIE / SENSE research unit)

Continuous monitoring of dissolved CO_2 in seawater is critical to evaluate how much anthropogenic CO_2 will be absorbed by the global oceans in the future (about 25% today), as the natural phenomenon contributes to partly mitigate increased greenhouse gas radiative forcing. However, the oceans are strongly under sampled. There is a need to acquire more autonomous and inexpensive observations notably from ships of opportunity such as sailboats.

We aimed at designing and constructing a small probe which can easily include a sailboat platform, being able to continuously collect surface seawater and measure the amount of dissolved CO_2 (pCO_2) in a well-calibrated and reliable manner. The LéXPLORE platform would provide a test site during the development. The project was expected to run from March to July 2024.

From February to May 2024, EPFL Master student Alexandre Tellier designed and built the small probe with the aim that the whole system would fit in a small Pelicase and would use parts being easily accessible on the market and at low cost.

A first attempt at testing the device on the LéXPLORE platform took place on May 15th, 2024. However, software issues did not allow to conduct any measurements. The second attempt took place on June 20th, 2024. We observed that the slight variations in surface water CO_2 concentration measured by the Pro-Oceanus probe (approximately ±30 ppm) - which equips the LéXPLORE platform - were also detected by our instrument. Nevertheless, following a period of approximately one hour during which the test was under way, the correlation ceased to be present, with the measurement by our probe subsequently increasing. It turned out that a small leak at one of the inlets was the cause of the trend. Still, the tests proved to be much encouraging.



The prototype SENSE-pCO2 sensor in its Pelicase, attached to the LéXPLORE platform for tests

LéXPLORE

Quantification of Quagga mussels within the EPFL water cooling system

Rossi, Pierre; Oppliger, Emmy; Breider, Florian, Spaak, Piet; Holliger, Christof

The quagga mussel (*Dreissena rostriformis bugensis*) is a species of freshwater mussel, an aquatic bivalve mollusk. Today, this animal is considered as an invasive species found throughout Western Europe, first identified in Switzerland in 2015. Negative impacts of this mussel is the clogging of water intake structures, such as pipelines and screens, reducing pumping capabilities for power and water treatment facilities. The EPFL lake water collection and distribution system is particularly affected by the invasion and colonization of pipes by this animal

EPFL-VPO asked GR-CEL to assess and quantify the presence of this animal (using environmental DNA) in the lake water pipe system, including the measurement of lake levels at the depth at which the water is pumped (-75m) from the LéXPLORE platform. This one-year project aims to measure the extent and rate of spread of this animal, and to propose corrective measures.

Seven samples are taken monthly along the distribution system, from the point of entry (CCT) to distribution node 5 (PDD-5).

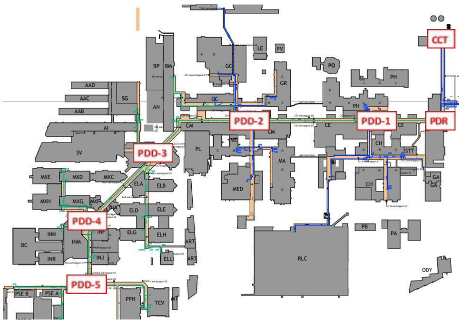
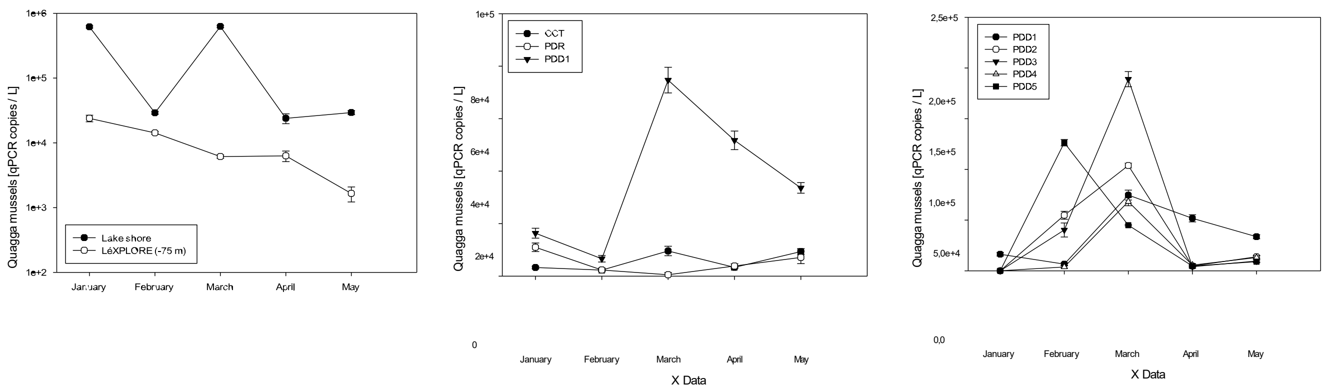


Figure 1: Map of the EPFL water distribution system. Samples are taken from the CCT (above right) to PDD-5 sampling locations (down left) following the longest possible route.

Results



Figures: Left - qPCR copies of the cytochrome oxidase I (COI) gene of the Quagga mussel *measured in 2024 in Lake Geneva, at the lakeside and at LéXPLORE (- 75m). Middle: copies measured at the entrance of the water cooling system. Right - qPCR copies measured along the water cooling system.*

Measurements are taken once a month for the cooling system, and from June 2024 onwards, twice a month from LéXPLORE. These measurements will continue throughout 2024 to provide a long-term view of mold evolution in the system.

Quagga mussels released from the LéXPLORE platform during the Easter 2024 foehn storm, and caught in the sediment traps. (photograph by Sylvain Coudret, EPFL - GR-CEL)

Asterionella-parasitic chytrid interactions under changing temperatures.

Morales Lisa, Thomas Mridul, Ibelings Bastiaan

Diatoms are globally important primary producers. They possess relatively large, heavy cells and tend to be favoured during spring and autumn, when water columns in temperate lakes are unstratified, and water mixing prevents sedimentation losses. Therefore, spring diatom blooms are a regular and well-recognised feature of temperate lakes, with cell densities increasing by several orders of magnitude in a few weeks. These blooms are terminated by the onset of stratification, grazing, or infection by parasites, with cells sinking to the sediment or being recycled at the lake surface. The termination and sinking of these diatom blooms is an important contributor to aquatic carbon export. In recent years, the importance of freshwater phytoplankton (including diatoms) for global carbon budgets has increasingly been recognised. Lakes often remain net emitters of carbon because of high gas fluxes, but carbon fluxes to lake sediments may exceed fluxes to ocean sediments despite their vastly smaller area. Since warming alters thermal regimes and causes an earlier onset of stratification, climate change may alter the magnitude of diatom carbon export at a globally meaningful scale.

Asterionella formosa is a large, common diatom species that dominates spring blooms in many temperate lakes worldwide. These blooms are often terminated by a fungal parasite, the chytrid Zygorhizidium, characterized by producing motile zoopopres in their life-cycle. As a consequence, this host-parasite interaction shifts phytoplankton community composition and likely affects the amount of carbon exported to lake sediments in spring. Increasing temperatures are likely to alter this interaction, with uncertain consequences for ecosystems. In a cold winter, Zygorhizidium is present as inactive resting spores. This allows Asterionella a window of unimpeded growth during the winter- spring transition, leading to the formation of a spring diatom bloom. Once the chytrid resting spores hatch, they rapidly infect Asterionella cells and the prevalence of infection increases, untill they kill- off the bloom. Most of the carbon may be transferred to chytrid zoospores, thereby reducing carbon sedimentation. In contrast, warmer winters allow Zygorhizidium to maintain infections over winter, preventing Asterionella from expanding . This shifts the community composition, often towards smaller diatom species that sink more slowly. Thus, both high and low levels of infection have the capacity to alter the magnitude of carbon fluxes. We aim to test the hypothesis that winter temperatures above 3 °C prevent the formation of spring Asterionella blooms by uninterruptedly enabling chytrid growth. We will use a combination of field observations, lab experiments and models to understand how temperature affects Asterionella- Zygorhizidium dynamics. Furthermore, we aim to provide an initial estimate of how warming-driven changes in these biotic interactions may alter future aquatic carbon fluxes.

We study two lakes, Lake Geneva and Lake Maarsseveen in the Netherlands. Our work attempts to understand how a changing abiotic environment (temperature) affects a complex ecological interaction (parasitism) to ultimately alter a globally important ecosystem parameter (carbon flux). It will develop a fundamental theoretical and empirical understanding of the temperature-dependence of host-parasite interactions, while addressing the consequences of environmental change for ecosystem processes.

LéXPLORE

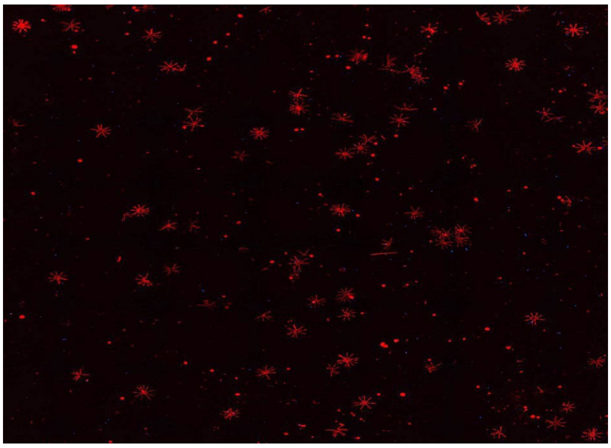


Fig. 1. Image of a lake Geneva sample from February 2024, showing a high density of Asterionella Formosa under fluorescence for chlorophyll a and in blue chytrids attached that were stained with calcofluor-white.

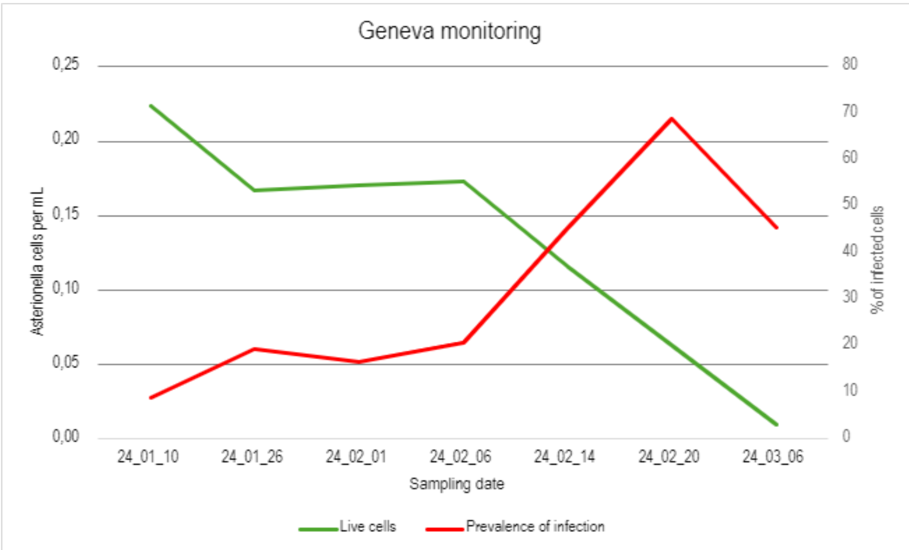


Fig. 2. Asterionella Formosa live cells density and prevalence of infection along the sampling period. Asterionella formosa density was high in January and followed by a rapid infection that peaked at 69% in February, followed by Asterionella formosa's bloom termination.

Antimicrobial Resistance Tracking and Fate modeling in the Urban flows – Lake interface (ARTFUL)

Helmut Bürgmann, Damien Bouffard, Matthew Blair, Sasikaladevi Rathinavelu

Antimicrobial resistance (AMR) is a pressing global public health issue. Action requires a One Health approach, as AMR circulates between human and animal populations and the environment. In contrast to human and animal, environmental AMR surveillance is underdeveloped and requires further research. The aquatic environment is an important reservoir and conduit of AMR and Wastewater (WW), both treated and untreated is a major source of AMR determinants, i.e. antibiotic resistant bacteria and antibiotic resistance genes. The Léman near Lausanne receives treated/untreated WW from the STEP Lausanne. At the same time, it is a resource of potable water and used for recreation. Understanding the dynamics of wastewater-derived AMR in the lake is a prerequisite to determine and calculate the associated risk of spreading AMR. The objectives of ARTFUL are therefore to i) monitor the AMR dynamics in VidyBay, Lake Geneva that receives WW from Lausanne wastewater treatment plant ii) determine the spatial and temporal distribution of AMR in the lake iii) to evaluate long read sequencing as an environmental AMR monitoring tool iv) to establish hydrodynamic lake model-supported sampling approaches and to use modeling to assess AMR contamination transport and exposure risks.

Work carried out last year

In 2023/2024 we have conducted three sampling campaigns at LéXPLORE and in the Vidy Bay area. Based on hydrodynamic model predictions, we sampled water at various points along the predicted location of the wastewater plume (Figure 1) at three different depths (e.g. surface, thermocline and below thermocline (determined from the continuous measurement conducted by LéXPLORE). The LéXPLORE was used as a reference sampling site and as a floating laboratory (e.g. for sample filtration and preservation) and base of operations. At our laboratory at Eawag Kastanienbaum, we performed DNA extractions and molecular analyses to quantify the abundance of antibiotic resistance genes, characterize the resistome with metagenomic analyses and characterize the composition of the microbial community.

Results

First results show that we can correctly predict the general location, direction and the vertical stratification of the wastewater plume. The qPCR method for quantification of various AMR indicator genes was shown to allow for sensitive detection of AMR in the water contaminated by the plume over several kilometres of transport (Figure 1). The sampling performed at different times of the year revealed different scenarios of directional movement, vertical stratification and dilution regimes. Work on a publication of this data has begun with submission foreseen for fall 2024. Metagenomic characterization of the resistome using the Oxford Nanopore sequencing platform has been shown in principle (processing and data analysis in progress).

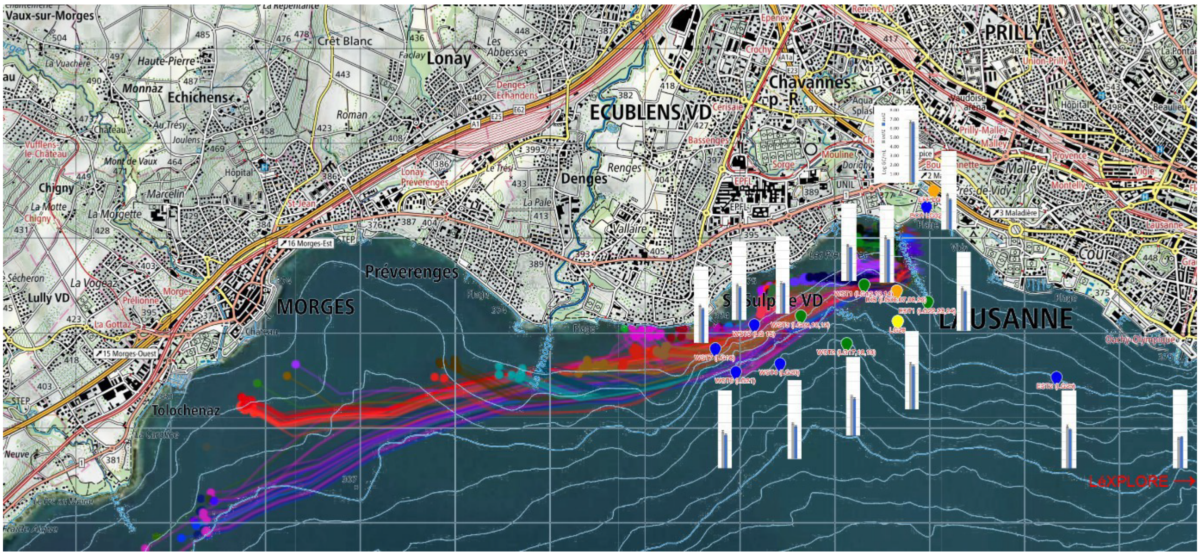


Figure 1 Particle tracking results for the sampling campaign on May 1st, 2024 (colored tracks in background), sampling locations (colored markers) and AMR indicator gene abundances (barcharts of log_{10} concentrations of sul1 *and* intI1 *genes) in surface water at 2 m depth.*

Planned work

The ARTFUL project has received funding by SNSF. The SNSF-funded part of the project officially launches July 1st 2024 and runs over 4 years. In fall 2024, we plan an additional sampling campaign, this time including a (He) tracer experiment. During the further course of the project the following activities involving LéXPLORE are currently foreseen:

- Additional sampling campaigns using the Platform as data hub, floating laboratory and operational base.
- An experiment deployed at LéXPLORE for in-situ incubation of wastewater in the Léman to study temporal changes in wastewater microbiomes and resistomes.
- Microbiome / resistome sequencing experiment on LéXPLORE using Oxford Nanopore sequencing technology, demonstrating the feasibility of on-site, real time, sequencing-based monitoring. Perhaps using automated sampling technology on the platform.

LéXPLORE

Measurement of methane oxidation rate to understand the greenhouse gas emission from Lake Geneva

Santona Khatun[1]*, Jasmine S. Berg[1], Marie-Elodie Perga[1]

[1]University of Lausanne, Switzerland

Global estimates of methane (CH4) emissions from freshwater lakes have indeed been challenging due to the lack of comprehensive data sets about the sources and sinks of both greenhouse gases. Natural freshwater lakes can emit significant greenhouse gases such as CH4 into the atmosphere compared to anthropogenically transformed lakes (Woszczyk and Schubert 2023). The freshwater CH4 paradox has become controversial because the methane (CH4) emission from lake ecosystems (103 Tg/yr) is greater than the annual oceanic CH4 emission (Saunois et al. 2020). Although CH4 is mainly produced in anoxic sediments, a metalimnetic methane supersaturation in oxic waters has been repeatedly detected in Lake Geneva (Donis et al 2017). Particularly, the distribution pattern of suspected water-sediment microbes to metalimnetic CH4 accumulation remains unclear (Khatun et al 2024). To identify the sources of oxic CH4 in the metalimnion and responsible microbial communities, we collected water and sediment microbes spatially from the Rhône River delta towards the LéXPLORE station and the wetland of Rhône River.

We here estimated the abundance of CH4-related bacterial communities was greater in sediments than in waters, representing high CH4 concentrations with more depleted isotopic values, indicating metalimnetic CH4 sources in Lake Geneva (Fig. 1). Our results indicates that the wetlands can't be the source as CH4 isotopic values were more positive than in lake waters and sediments. Thus, CH4 from the deltic sediment can be the source of metalimnetic methane accumulation in Lake Geneva. Most probably, the transportation of deltic CH4 within the Rhône River intrusion while oxidation is inevitable, may explain the metalimnetic CH4 accumulation even at the LéXPLORE. We observed that sediment microbes such as SAR11, hgcI clade, and Flavobacterium are the main microbial communities that might control CH4 accumulation in the metalimnion of Lake Geneva (Fig. 2). During the time of stratification, high turbid waters of the Rhône River may flow within the metalimnion to bring the deltaic methane towards the lake center may cause the metalimnetic CH4 accumulation in Lake Geneva. All of these results will be published in an international journal.

The next steps will be to clarify the pathways of deltaic CH4 transportation in the metalimnion. Even if these biogeochemical hotspots for methane production represent only a very limited fraction of the surface area of large and deep lakes, the efficiency of the lateral transport within a well-constrained metalimnion due to turbulent diffusion, internal waves, and advection, can expand the dispersion of sublittorally produced methane to > 20 km away from the production area. Elucidating the directional transportation pathways of deltaic methane from the Rhone River delta toward the lake center is the next critical step to deepen our understanding of how the riverine and the in-lake processes interact in transporting sublittoral methane to form metalimnetic methane peaks in large lakes.

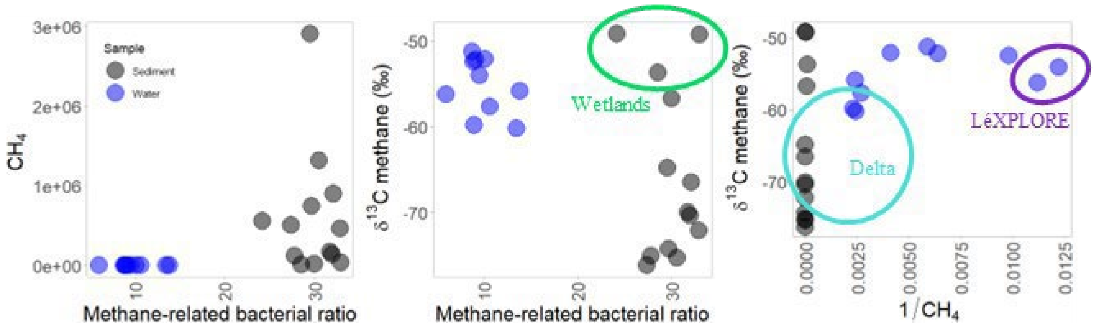


Fig. 1: Methane-related microbial communities in waters and sediments of Lake Geneva. Sediment in the microbes showed higher abundance than in waters and the isotopes indicate oxidation of deltaic methane can be the source of metalimnetic methane even at the LéXPLORE.

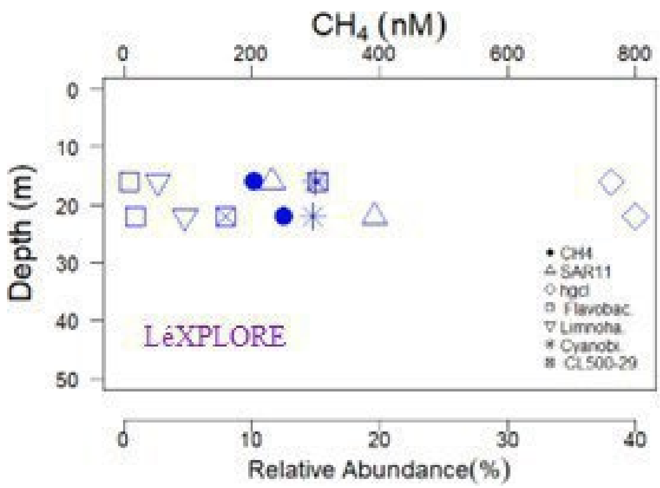


Fig. 2: Different sediment microbial communities are suspected to be the source of metalimnetic methane accumulation even at the LéXPLORE station.

Calcite precipitation dynamics in Lake Geneva (CALCIGEN)

Nicolas Escoffier, Jérémy Keller, Santona Khatun, Marie-Elodie Perga

Calcite precipitation (CP) represents a major component of the carbon budget of hardwater lakes such as Lake Geneva. To date, however, our understanding of the spatial and temporal dynamics of the process and its environmental drivers remains incomplete.

The goal of the CALCIGEN project is to combine high frequency (HF) sensor data with discrete sampling to refine these questions in Lake Geneva. In particular, the project relies on HF conductivity and pH data to trace CP at fine scale and to constrain the carbonate system. In addition, discrete vertical profiling and water sampling coupled to flow cytometry and microscopy analytical techniques are expected to provide insight into the link between CP and primary production.

In 2023, sensors have been deployed between July and November at five depths covering the uppermost 30 m of the water column. A total of six campaigns was conducted to deploy and retrieve the sensors, maintain them and assess their metrology. Overall, the sensors provided satisfying covering rates of data, which, once fully qualified, will allow obtaining CP and net ecosystem production rate timeseries. Seven campaigns were also performed during the same period for vertical profiling and water sampling. The obtained data and samples (still under analyses) should complement the description of the environmental conditions underlying CP and especially the role of phytoplankton communities.

This work should be valorised in a publication in preparation and continue in 2024 - 2025 to deepen data acquisition and observations.

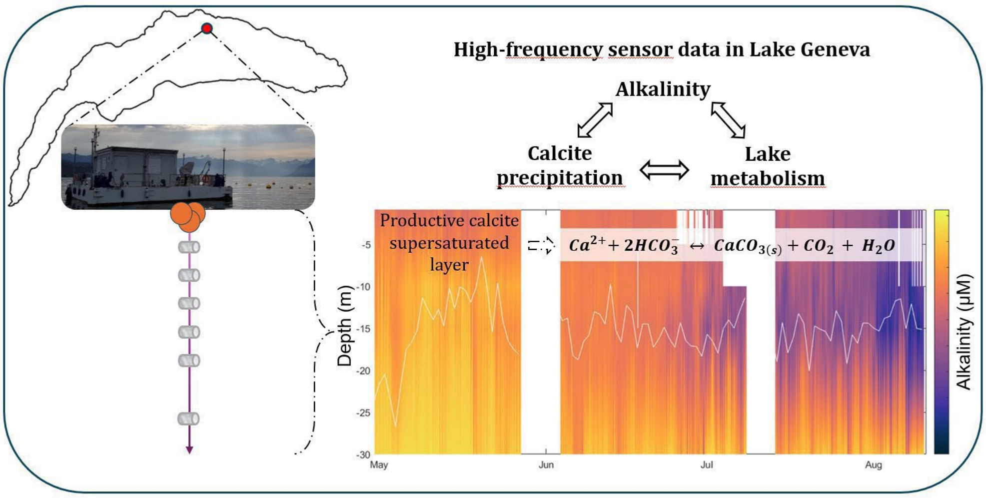


Figure 1. Schematic of the CALCIGEN sampling strategy at LéXPLORE aiming at describing calcite precipitation dynamics at fine scale and resolving its environmental drivers.

LéXPLORE

Lake snow - dynamics of the suspended particulate matter in Lake Geneva

Natacha Tofield-Pasche, Marc-Antoine Courtois, Louise Noël du Payrat, Guillaume Cunillera

Holographic microscopy has emerged as a tool for in situ imaging of microscopic organisms and other particles in the lacustrine environment. The submersible camera LISST-Holo2 was used for particles ranging from 25 µm to 2500 µm. The goal of this project is to analyse the spatio-temporal dynamics of the settling particulate matter (lake snow) in Lake Geneva, and to investigate the influence of the Rhone River plume on the flocculation and sedimentation of settling particles.

Marc-Antoine Courtois performed his semester project with six field campaigns on 07.09.2023, 27.09.2023, 11.10.2023, 23.10.2023, 8.11.2023 and 13.11.2023. And Louise Noël du Payrat followed with holographic acquisitions on 29.02.2024, 14.03.2024, 21.03.2024, 8.04.2024, 25.04.2024 and 01.05.2024. A large variety of particles could be observed (Fig 1) and their settling velocity could be estimated (Fig 2). We continue to investigate the summer during the Rhone River high flows.

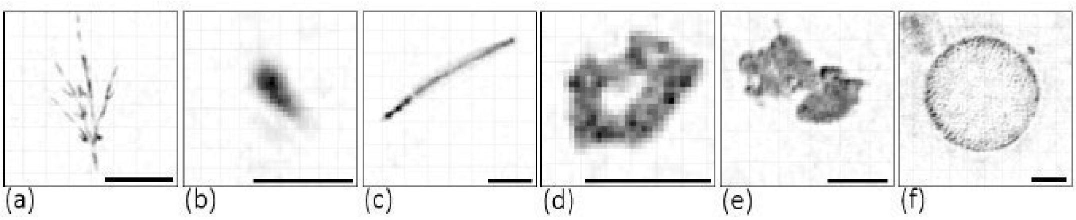


Figure 1: Examples of holograph reconstructed images of five suspended particulate matter and one bubble,

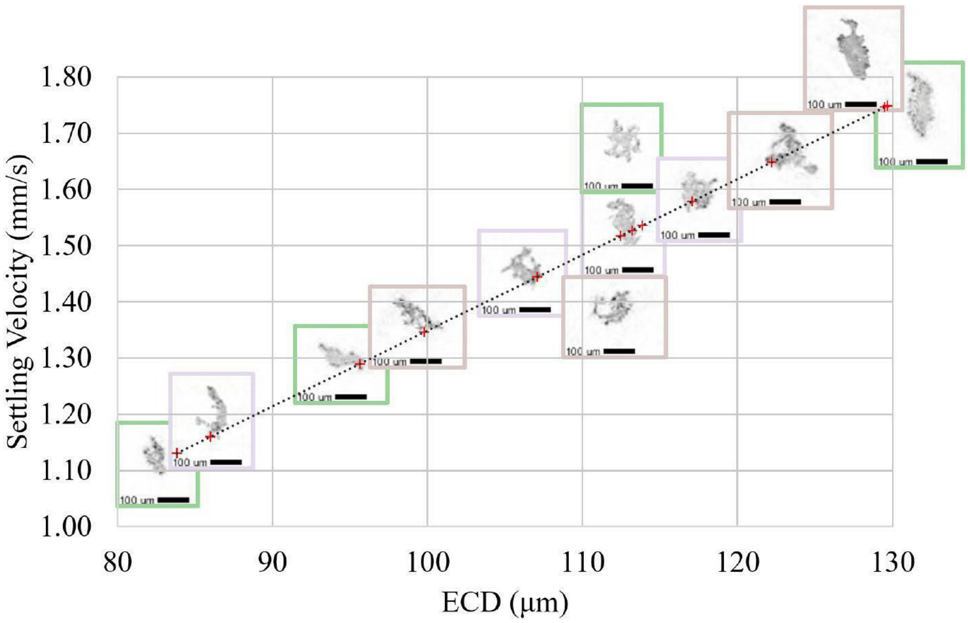


Figure 2: Settling velocities of flocs estimated with the Winterwerp equation (mm/s) in function of the equivalent circular diameter ECD

EPFL

LéXPLORE

Installation of a drip-based rain gauge on LéXPLORE

Gregoire Mariethoz, Nadav Peleg, 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 precipations 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 in installed on LExplore 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, with the goal to collect a multi-years time series, in combination with an additional 9 gauges throughout the city of Lausanne. A UNIL MSc thesis (Charlotte Grosjean) will start in the fall 2024 to use this dataset to build an urban rainfall model of the greater Lausanne area.

Drip counting rain gauge as currently set on the platform

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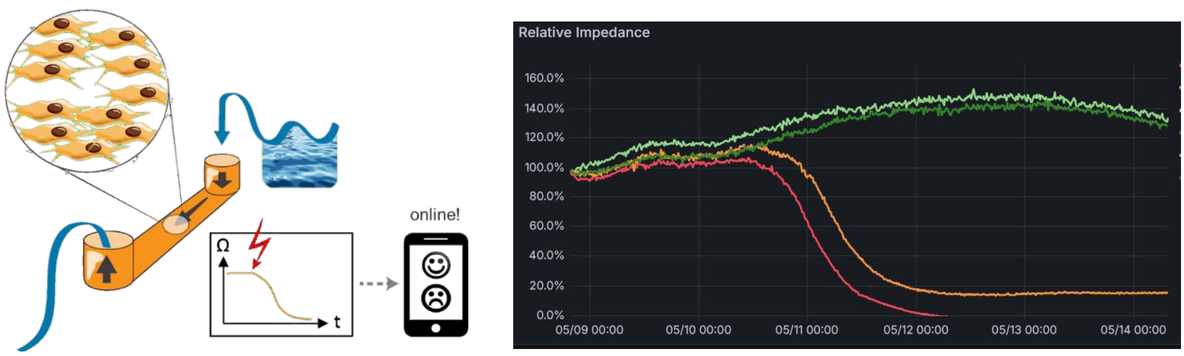
EPFL

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

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

The RAINBOWFLOW CHIPONLINE is a portable field biosensor which uses fish cells for online water quality monitoring. Permanent cell lines from the rainbow trout (*Oncorhynchus mykiss*) can predict toxic effects to fish elicited by chemicals. We are therefore using the gill cell line RTgill-W1 as a sentinel to monitor the presence of toxic chemicals in surface water. Cells are exposed to water samples in a microfluidic channel of an electronic chip, and cell viability is measured by electric cell-substrate impedance sensing (ECIS). The biosensor continuously and automatically samples water, prepares the samples, flushes it through the channels containing cells, measures cell viability, analyses the data, and uploads them to a server.

A field-testing campaign with the first prototype on LéXPLORE in 2021 showed some promising results, but also revealed some issues to be addressed. After completion of a proof of principle study to show the cells' reaction to dissolved chemicals, troubleshooting for the automated monitoring in the field instrument is currently ongoing. An investigation into factors affecting cells' survival suggests that unsterile conditions may cause early decline of impedance. Hence, changes are currently implemented and tested to allow the extend the cells' lifetime and thus the monitoring period. A second field testing campaign is planned later this year.



Left: Working principle of the RAINBOW$_{FLOW}$ CHIP$_{ONLINE}$ biosensor for water quality monitoring: fish cells are exposed to water from lake Geneva and cell viability is measured continuously, data are available online in real-time. Right: Sample data of RTgill-W1 cells' impedance over 5 days under sterile (green) vs unsterile (red/orange) conditions.

LéXPLORE

SyBAM: Synergic interaction Between Arsenic species and Microorganisms in freshwaters, under contrasting dynamic environmental conditions

Mary-Lou Tercier-Waeber, Tanguy Gressard, Nicolas Layglon, Laura Maloriol

The occurrence of arsenic (As) in aquatic systems is of great concern due to its persistence, high bioavailability, bioaccumulation, and trophic transfer from the base of aquatic foodweb to higher trophic levels, to ultimately human exposure. In natural waters, arsenic mostly exists in inorganic and organic pentavalent As(V) and trivalent As(III) forms. The thermodynamically stable form of As in oxygenated water is inorganic arsenate (iAs(V)). However, inorganic arsenite (iAs(III)) have been detected in all oxic natural waters. This is related to iAs(V) phytoplankton up-take due to the chemical similarity of iAs(V) with phosphate, and subsequent biotransformations of the accumulated iAs(V). These biotransformations involve mainly the reduction of iAs(V) to iAs(III) and methylation of iAs(III) in successive steps to ultimately MMAs(V) and DMAs(V), with As(III) and DMAs(V) being more easily excreted. These processes significantly influence the biogeochemical cycles of As and its toxicity as the trend in toxicity of As species to organisms is: As(III) >> As(V) > MMA(V) = DMA(V). Environmental studies were performed in discrete samples collected in waters heavily polluted with arsenic. The interaction between As speciation and phytoplankton has been mainly conducted in artificial medium, inoculated with a uni-algal culture and exposed to high As.

The SyBAM specific goal was two-fold; (1) the study of the spatial and temporal behavior of the dynamic fractions of inorganic arsenic and micro algal-bacterial species; (2) the investigation of the feedback interactions between dynamic arsenic species and microorganisms and their influence on the hazardous iAs species and phytoplankton abundance, communities, activities and blooms in contrasting seasonal dynamic conditions. To achieve this goal, we applied a submersible sensing probe (TracMetal) developed by us to the seasonal and spatial – over lake depth - hourly *in situ* voltammetry quantification of the dynamic (potentially bioavailable) fractions of inorganic As (iAs(III)dyn, iAs(V)dyn). *In situ* monitoring of master lake environmental variables as well as water sampling for (i) the complementary quantification of total dissolved and methylated As species in raw and filtered <0.2 µm and <0.02 µm samples; (ii) water composition analyses; and (iii) phytoplankton characterization and internalized As concentration quantification in laboratory.

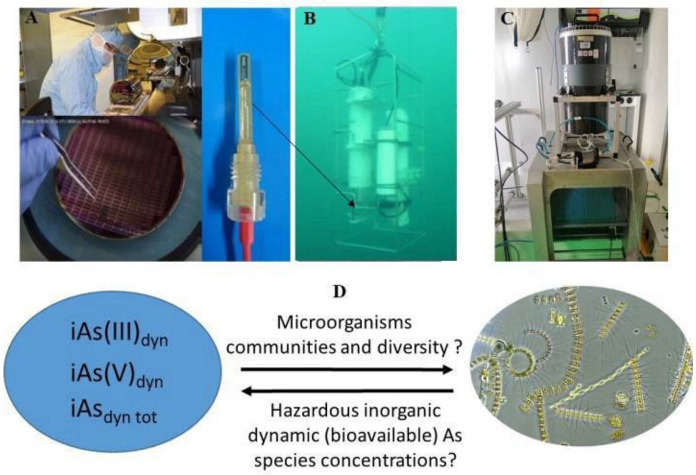


Figure 1: Multi-method approach to study (D) the synergic interaction between As and microorganisms. (A) Pictures of the on-chip interconnected Ir-based microdisk array substrate production and of a gold nano-filament antifouling-gel microelectrode array (Au-NF-GIME). (B) The TracMetal monitoring the dynamic iAs species in the productive surface water. (C) Cytobuoy.

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Main results

We optimized and validated an analytical protocol to enable the *in situ* sequential quantification of iAs(III) and iAs(V) using voltammetry on on-chip gold-nanofilament antifouling gel-integrated microsensor arrays (AuNF-GIME) incorporated in the submersible TracMetal sensing probe. The *in situ* data recorded on the AuNF-GIME was successfully evaluate and validate by intercomparison with the As speciation measured by HPLC-ICP-MS in collected samples

Sequential chemical extraction approaches were applied and evaluate with the aim to decipher the biogenic and non-biogenic fractions of particulate trace metals and especially As. The ultimate objective is a more rigorous assessment of trace metals adsorbed and internalized in phytoplankton. Final evaluation is underway using various phytoplankton cultures and lake Leman collected samples. One of the main challenges is to preserve plankton cell integrity until the last extraction steps and minimize passive-diffusion of internalized trace metals toward the extraction solutions. If successful, the optimized approach will be applied to the large number of particulate material samples collected by filtration during the various campaigns performed over the last two years on the LeXPLORE. The aim is to evaluate the seasonal concentration of metals and metalloids internalized by the phytoplankton.

Characterization of the phytoplankton. Synchronized measurements of the dynamic fractions of iAs species and phytoplankton communities coupling the TracMetal and the Cytobuoy planned during the second year of SyBAM could unfortunately not be achieved due to Cytobuoy malfunction. As an alternative, chlorophyll-a data, FlowCam and scanning electron microscopy (SEM) were used to characterize phytoplankton biomass, activities and communities. The evaluation of phytoplankton groups is in progress. The species mainly found are diatoms belonging to the families of Diatomophyceae and Dinophyceae. Cyanobacteria colonies were observed in summer and even in winter (January 2024).

Seasonal and spatial – over lake depth – of the concentrations of the potentially bioavailable inorganic arsenic species and other arsenic species. Six field campaigns were performed under contrasting conditions of biological activities. Twenty to thirty hours measurements cycles were performed during each campaign. High resolution (1 to 2 h time scale) of dynamic iAs species concentrations were recorded *in situ* with the AuNF-GIME-TracMetal integrated system. As total concentrations and As speciation were quantified in the various collected fractions by, respectively, ICP-MS and HPLC-ICP-MS. Selected results are presented in Figure 2 and briefly summarized. Seasonal data show that even though total As concentrations, in the various collected fractions, were year-round relatively constant and comparable (Fig. 2 B1-5), highly dynamic changes in concentration of the inorganic As species available for bio-uptake (iAs(III)dyn, iAs(V)dyn) occurred (Fig. 2 A1-5, C1-5).Their sums were > 98% during winter and ranged from 62 to 95% and 30 to 70% during, respectively, during the spring and autumn phytoplankton blooms (logarithmic growth phases; Fig. 2 C1,3) and the summer phytoplankton growth stationary phase (Fig. 2 C2,4). The highly hazardous iAs(III)dyn represented < 10% (winter) and 10 to 25% in the surface water, characterized by the maximum seasonally occuring Chorophyll-a concentrations (Fig. 2 C1-4). It reached up to 75% in deeper water, coinciding with a peak in major nutrients like N and P (Fig. 2 C5). Biotic release of significant DMAs (up to 35 to 50% of Astot) and low MMAs (up to 5% Astot) species occurred mainly during the summer stationary growth phase (Fig. 2 C2,C4), suggesting detoxification processes by the plankton. Collected As species data coupled to phytoplankton characterization support the notion that the production and presence of reduced iAs and methylated As species are biota and major-nutrient concentrations dependent. This highlights that measurements of total As are inappropriate to assess the toxicity impact of As. High-resolution spatial and temporal monitoring of specific As species, especially iAs(III) and iAs(V), are required.

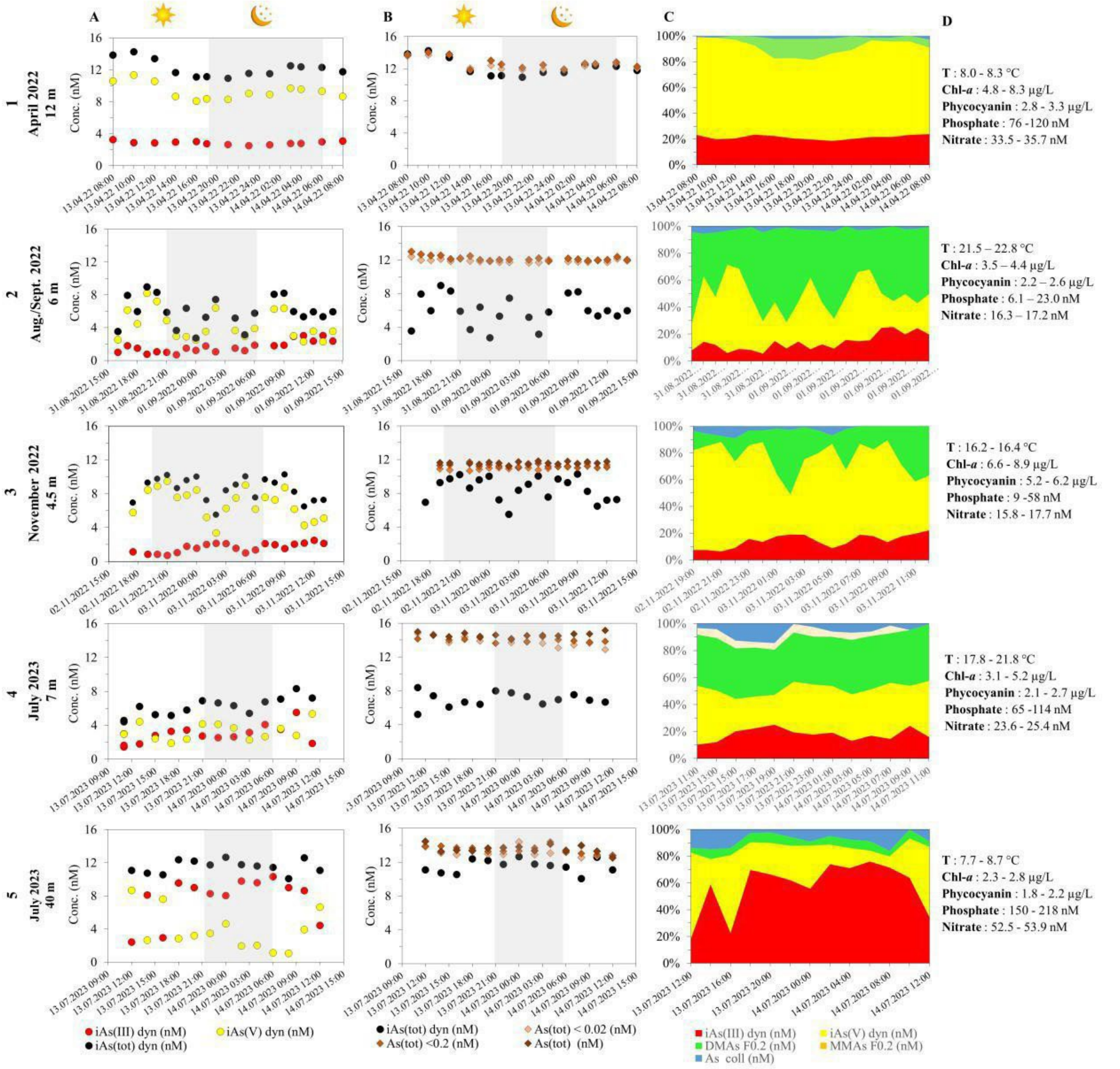


Figure. 2. Seasonnal and spatial – over lake depth - high-resolution concentrations of: (A1-5) the dynamic (bioavailable) fractions of inorganic arsenite ($iAs(III)_{dyn}$) and arsenate ($iAs(V)_{dyn}$) and their sum ($iAs(tot)_{dyn}$) recorded in situ from LeXPLORE at depths with various levels of productivity and macronutrient contents; (B1-5): total concentrations of the hazardous dynamic inorganic As species ($iAs(tot)_{dyn}$) and the total As(As_{tot}) quantified in the raw and filtered collected samples; (C1-5) arsenic speciation. D1-5: Data of selected master variables and nutrient concentrations.

Publications

Analytical protocol and autonomous fluidic system control for *in situ* sequential monitoring of inorganic arsenic species available for biouptake in aquatic systems.
Tanguy Gressard[*], Nicolas Layglon, Eric Bakker, Mary-Lou Tercier-Waeber[*], *under final revision*.

Other publications are under development

Analytical protocol and autonomous fluidic system control for *in situ* sequential monitoring of inorganic arsenic species available for biouptake in aquatic systems.
Tanguy Gressard[*], Nicolas Layglon, Eric Bakker, Mary-Lou Tercier-Waeber[*], *under final revision*.

Other publications are under development.

Conferences

In Situ Metal Bioavailability-Oriented Sensing Tools: Novel Approach to Study Metal Geochemical Cycles and Ecotoxicity.
Mary-Lou Tercier-Waeber. ISE: Marine and environmental electrochemistry in the are of new technology, 26-29 May 2024, Sibenik-Croatia. (Keynote)

Analytical Strategy to characterize Lake Geneva Colloidal Matter and Associated Trace Metals.
Isabelle Worms, Nicolas Layglon, Kevin Trindade, Vera Slaveykova, Laura Maloriol, Mary-Lou Tercier- Waeber. CHAnalysis, 10-12 April 2024, Beatenberg-Swizerland. (Poster)

Multichannel trace metal-bioavailability-sensing system: Application to *in situ* autonomous monitoring of the dynamic inorganic fractions of mercury, arsenite and arsenate.
Mary-Lou Tercier-Waeber, Tanguy Gressard, Nicolas Layglon, Melina Abdou, Fabio Confalonieri, Alexandra Coynel, Jörg Schäfer. Joint International Conference of Biogeochemistry of Trace Elements (ICOBTE) & International Conference of Heavy Metals (ICHMET): Clean environment, Human health, Our future. 6-10 September 2023, Wüppertal-Germany. (Oral presentation)

Trace metal monitoring in aquatic systems: emphasis on the development and application of *in situ* metal bioavailability-oriented sensing tools.
Marylou Tercier-Waeber. Euroanalysis 2023, 27-31 August 2023, Geneva-Switzerland. (Keynote)

How to decipher the biogenic and non-biogenic fractions of particulate trace metals?
Faustine Fauché, Nicolas Layglon, Mary-Lou Tercier-Waeber. XVI International Estuarine Biogeochemistry Symposium, 23-26 May 2023, Sibenik-Croatia. (Poster)

Submersible trace metal bioavailable-assessment sensing probes
Mary-Lou Tercier-Waeber. SENSORMEET 2023: International Conference on Sensors and Sensing Technology, 15-17 May 2023, Brussels-Belgium. (Keynote)

In situ assessment of the behavior and fate of the dynamic fraction of inorganic arsenic species.
Tanguy Gressard, Nicolas Layglon, Eric Bakker, Marylou Tercier-Waeber.
20th Swiss Geoscience Meeting, 18-20 November 2022, Lausanne-Switzerland. (Oral presentation)

Collected data

A data file including all parameters/compounds monitored - especially: master variables, SPM, water composition (DOC, nutrients, major cations, etc..), dynamic iAs species, As speciation, phytoplankton characterization - has been created for each field campaign. These data are available on request if useful for other projects. They will be available in open access and/or for integration in www.datalakes- eawag.ch after submission and acceptance of publications.

LéXPOSTRAC: Tracking ecotoxicological effects of lake suspended particulate matter on the ostracod *Heterocypris incongruens*

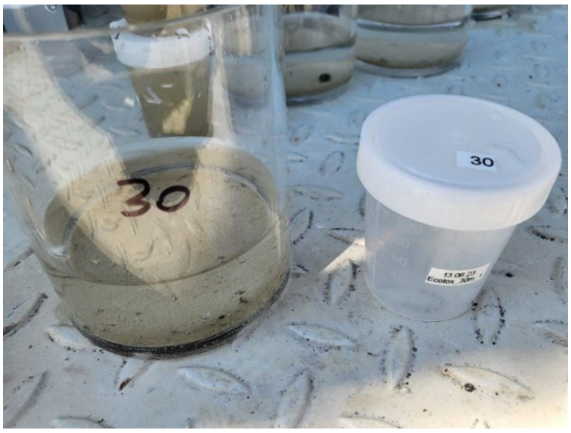
Beauvais Rébecca, Lafargue Océane, Carmen Casado-Martinez and Ferrari Benoît J.D.

Abstract

In this project, we exposed the ostracod *Heterocypris incongruens* in the laboratory to suspended particulate matter (SPM) collected (bi-)monthly. Freshly hatched organisms are exposed to SPM in microplates in the laboratory for 6 days. At the end of the exposure, surviving organisms are collected, counted, fixed in Lugol's and examined under a microscope. Using image analysis, we compare the growth of the exposed organisms with that of the control organisms. In addition to assessing SPM quality monthly, we repeated the experiment carried out in 2021 with the insect *Chironomus riparius* (LéXPOCHIRO). We assessed the effects of SPM on the growth of 4th instar chironomid larvae (4-day exposure) and on the emergence success of the flying adults (up to 15-day exposure). Synchronized 4th instar chironomid larvae were also exposed for 2 or 4 days for gene expression and stress enzymes analyses.

For the ostracod bioassay, the mortality rate varied over the months and seasons but also with depth. Growth inhibition results showed similar dynamics except for April and December 2023, where growth was inhibited at all depths (toxicity threshold of 35% exceeded). On the opposite, in the summer, we observed growth induction. We however observed an important variability of the growth in the control vessels that may lead to false negatives or positives. The dataset generated by this work will help us to improve the bioassay interpretation. For the chironomids, unlike in 2021, we didn’t observe any mortality, allowing to obtain enough exposed larvae for sub-individual endpoints (activity of stress enzymes and gene expression). These results could be linked to the use of a different experimental set-up.

Overall, the bioassays showed that the ecotoxicological quality of Lake Geneva SPM was dynamic over time and space. We observed good agreement among toxicity tests for a same sampling and among years. Thanks to this project, we could (i) confirm the seasonal differences observed in 2021, (ii) discriminate, on a smaller scale, samples with high ecotoxicological impact and (iii) study the chemical profiling of SPM in time and space. Next steps include the in-depth analysis of non-target screening data to discriminate potential confounding factors for ostracod growth but also identify pollutants that may be present at some environmental conditions only (i.e. low organic carbon content, algal blooms, etc.).



Example of sample collected in June from the 30m-depth sediment trap.

Main results

Effects of SEDTRAP-collected SPM on *H. incongruens*

- We noticed that the growth of the ostracods in the control vessels were highly variable among samplings over the course of the project. This can mislead the interpretation of the bioassay's results in two different ways. First, because we calculate growth inhibition rates and use toxicity thresholds (if the growth inhibition exceeds 35 %, we classify the sample as toxic). Second, because this decrease in growth may be linked to a different sensitivity of the test organisms to pollution. Thanks to the large dataset obtained within this project, we will gain more information on how to interpret and use ostracods growth as sublethal endpoint with a higher confidence level.
- For mortality, we observed a highly dynamic pattern over time and space (Fig. 1). Among the 59 samples, ¼ of the samples (15) showed a mortality higher than the toxicity threshold of 20 %. Two samples showed extreme values of 63 and 77 % for October 10 m and November 30 m, respectively. Overall, there is no relationship between depth and mortality. Data from SEDTRAP are not complete yet to test other parameters, like organic carbon content or fluxes of metals or major elements (P, N).

Fig. 1. Mortality rates of H. incongruens exposed to lake SPM collected at different depths in 2023 and 2024.

	Year	2023													2024			
	Month	3	4	5	6	6	7	7	8	8	9	10	11	12	1	2	3	4
	N days	27	37	26	32	12	15	13	13	12	14	26	35	25	36	27	26	36
Depth	10 m	13	13	20	33	7	7	10	3	0	23	63	13	3	7	0		
	30 m	0	3	10	47	7	10	7	23	7	7	23	77	7	27	10	10	7
	50 m	0	23	33	27	10	7	7	3	0	3	10	17	15	10	10	15	10
	100 m								3	0	17	17	20	13	20	40	17	10

Mortality (%): 0 – 77; TT = 20%

For the 4.5-month integrated samples, the mortality was higher for season 2 (July-Nov 2023, 15 %) than for season 1 (Feb-July 2023, 7 %). Even though the mortality didn't reach the toxicity threshold, the higher mortality for the second season agrees with the results obtained in 2021, for both test organisms.

Effects of SPM on *C. riparius*

- For both seasons, the growth of the larvae and the emergence rate of the adults were not affected. In 2021, we observed high mortality that was attributed to bias related to the test set up, which was improved for the second campaign. .
- The activity of the enzyme phenoloxidase was affected in the 4th instar larvae upon exposure to SPM. Gene expression analyses are still ongoing because they were delayed by the need of changing the RNA extraction protocols.

Non-targeted analysis of selected SPM samples

- Because of low material amount for each sampling, we had to pool samples, regrouping following months and depths. We analyzed a first batch consisting of 6 samples. From the chemical profiling (Fig. 2), we see that sample 1 is well separated from the others. This sample was composed of 30-m and 50-m SPM from Mai and June (1st part) 2023. We suspect than the signature may be related to organic matter, as it corresponds to a period of algal blooms. Following months, i.e., 2 to 4 and 5 and 6 are clustered together suggesting differences between the seasons (July to September and October to January 2024, respectively).

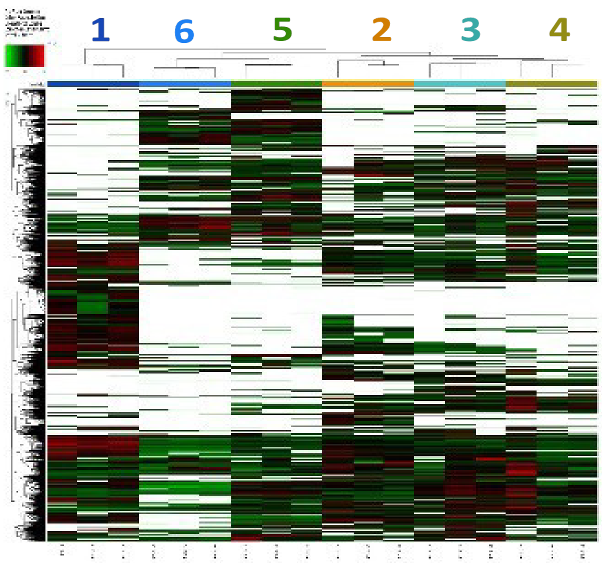


Fig. 2. Hierarchical clustering of peak rates based on Euclidean distance of 6 SPM samples (3 replicates).

Conference

Beauvais, R., O. Lafargue, C. Casado-Martinez et B.J.D. Ferrari, 2024. Tracking Temporal and Spatial Ecotoxicological Effects of Suspended Particulate Matter in Lake Geneva (oral presentation). SETAC Europe 24th annual meeting, Seville, Spain, May 6-9 2024.

Collected data

- Grain-size for 4.5-month samples (2)
- Concentrations of metals and total Hg for 4.5-month samples (2)
- Non-targeted profiling of 6 SEDTRAP samples (6)

Data can be provided upon request; they are saved at the Ecotox Centre in Lausanne.

Radiocarbon Inventories of Switzerland (RICH)

Margot White, Benedict Mittelbach, 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 Radiocarbon Inventories of Switzerland (RICH) project, RICH Hydro has worked to 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 collected a time series of radiocarbon content in various water column reservoirs including dissolved inorganic carbon and material retrieved from sediment traps. We completed a full year of monthly water column measurements in April 2023 and a year timeseries of sediment trap material in July 2023. We find that dissolved inorganic carbon (DIC) at LéXPLORE is significantly ^{14}C- depleted relative to the atmosphere due to the dissolution of carbonate rocks in the lake's catchment. Variability in $DI^{14}C$ is largely tied to the Rhône River inflow, which we found to be consistently ^{14}C- depleted compared to the lake. This indicates the addition of ^{14}C-enriched DIC to the lake, likely through exchange with atmospheric CO_2. Dissolved organic carbon (DOC) has a ^{14}C signature largely similar to that of DIC, indicating that much of the lake DOC pool is autochthonous. However, more ^{14}C- depleted DOC was observed in July, tied to increased river discharge and snow and glacier melt within the Upper Rhône River basin. We further measured ^{14}C of sedimenting material at two locations in the lake: a sediment trap in the center of the lake and another one in the vicinity of the Rhône inflow into the lake. Using ^{14}C measurements of particulate organic carbon (POC) and particulate inorganic carbon (PIC) and combining these with our information on $DI^{14}C$, we were able to quantify deposition of allochthonous and autochthonous carbon at both locations. We found that deposition of autochthonous POC was similar at both locations. Allochthonous POC however, was deposited in large quantities near the river mouth, associated with high discharge episodes during spring and summer, and was significantly preaged. Similarly, deposition of allochthonous PIC, i.e. detrital carbonate rocks, was significantly higher near the river inflow. Autochthonous PIC, derived from calcite precipitation in the water column, was present in both locations, but was more abundant near the Rhône inflow. We interpret this as a combination of higher calcite precipitation due to river inflow, and a better preservation due to the shallower position of this sediment trap.

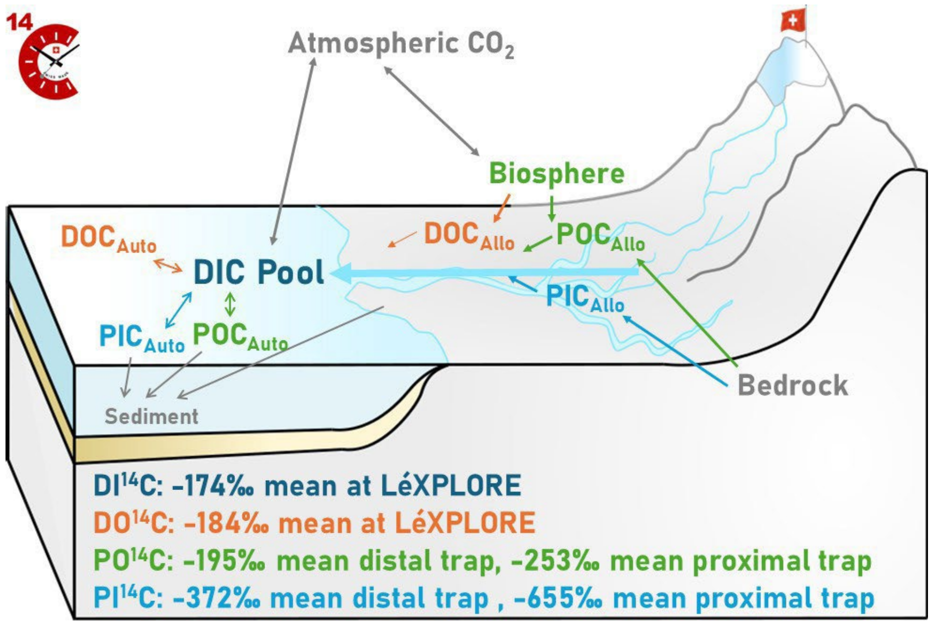


Figure 1. Summary of results from RICH investigations at LéXPLORE and Lake Geneva. A one year timeseries of monthly radiocarbon measurements was used to distinguish sources of carbon to lake waters and sediments and to examine seasonal controls on these inputs.

Main results

Over a 12-month period, $DI^{14}C$ in Lake Geneva ranged from -201 ± 7 to -150 ± 7 ‰. Despite different sources of water during high and low flow periods, ^{14}C values of inflowing riverine DIC did not vary greatly during our study period, ranging from -297 ± 7 to -268 ± 7 ‰. However, riverine values were consistently ^{14}C-depleted compared to lakewater DIC by around 100 ‰. Observations of river water downstream of the lake sampled in the Rhône River at Chancy indicate similar values compared to the lake. Lake $DI^{14}C$ was most depleted in summer months when the influence of the Rhône River plume was greatest as determined by turbidity. We used a simple mass balance calculation comparing the lake and river $DI^{14}C$ values to estimate the exchange with the atmospheric CO_2 pool that occurred and found that approximately 49-53 % of the lake DIC pool would have to exchange with the atmosphere to result in the observed enrichment. By combining this information with the DIC reservoir size, the surface area of the lake, and the water residence time, we estimate an approximate exchange rate of 20-24 moles per m^2 per year. This is consistent with early estimates using a similar approach from lakes in Calfornia, USA (Broecker & Walton, 1959; Peng & Broecker, 1980), and with rates for the surface ocean, estimated to be ~20 moles per m^2 per year on average (Broecker et al., 1986).

Lakewater $DO^{14}C$ values showed greater variability than $DI^{14}C$, ranging from -423 ± 6 to -99 ± 21 ‰ between April and November 2022. The most depleted values were observed during July, and the most enriched values in September, while the rest of the year values were largely similar to those of DIC. The ^{14}C signature of DOC that is produced by phytoplankton within lake waters would be expected to mimic that of DIC, making radiocarbon a particularly useful tool for differentiating allochthonous and autochthonous DOC sources. In the case of Lake Geneva, we saw that for most of the year, DOC $\Delta^{14}C$ values were similar to DIC, indicating that the dominant source of DOC to the lake is likely from primary productivity within lake waters.

There are two time periods during which measured $DO^{14}C$ values fall outside the observed range of $DI^{14}C$. The most notable of these is in July 2022, when $DO^{14}C$ values were very depleted compared to $DI^{14}C$. DOC at 15 m, the depth most influenced by the river plume, had a ^{14}C signature of -423 ± 7 ‰. One possible source of this aged (^{14}C-depleted) DOC is glacial melt. In fact, Summer 2022 was a record year for glacier loss in Switzerland, where nationally glaciers lost 6% of their total volume (Cremona et al. 2023). Although the reactivity and fate of this aged DOC is not known, some studies have suggested that a large component of ancient glacial DOM is bioavailable (Hood et al., 2009; Singer et al., 2012).

Sediment traps were deployed at two sites in Lake Geneva: one near the Rhône inflow (proximal) and another in the center of the lake (distal). Total mass flux at the proximal site ranged from 2.1 g m² day^{-1} in December 2022 to 43.7 g m² day^{-1} in August 2022, with an annual average of 13.7 ± 13.2 g m² day^{-1}. The distal site exhibited lower fluxes, ranging from 0.8 g m² day^{-1} in December 2022 to 3.4 g m² day^{-1} in June 2022, with an annual average of 1.4 ± 0.6 g m² day^{-1}. Particulate organic radiocarbon ($PO^{14}C$) in the distal trap ranged from -179 ‰ to -214 ‰, which closely matches $DI^{14}C$ of the water column, indicating that POC was primarily autochthonous. At the proximal site, POC was more depleted, with values as low as -299 ‰ in April 2023, reflecting the presence of pre-aged material.
Using a two-endmember mixing model, allochthonous POC was determined to have a ^{14}C signature between -294 ‰ and -469 ‰ (mean -298 ‰ ± 106 ‰), indicating pre-aged riverine carbon transported during high-flow events. For particulate inorganic carbon (PIC), fluxes at the proximal site averaged 0.24 ± 0.18 g m² day^{-1}, significantly higher than the distal site's average of 0.06 ± 0.05 g m² day^{-1}. $PI^{14}C$ values at the distal site were mostly similar to $DI^{14}C$, with an average of -251 ‰ ± 77 ‰, suggesting that autochthonous PIC from calcite precipitation dominated. However, in specific periods (e.g., November 2022 and January 2023), highly depleted values down to -828 ‰ were observed, reflecting reduced autochthonous or increased allochthonous inputs. At the proximal site, PIC was generally more depleted, averaging -645 ‰ ± 149 ‰, indicative of a substantial contribution from detrital carbonates transported by the Rhône River.

Publications

Large hardwater lakes rejuvenate carbon along the land to ocean aquatic continuum
M. E. White**,** B. Mittelbach, N. Escoffier, T. Rhyner, N. Haghipour, D. J. Janssen, M.-E. Perga, N. Dubois, and T. I. Eglinton. In preparation for submission to *JGR: Biogeosciences.*

Using sediment traps and 14C to identify sources of sedimentary organic and inorganic carbon
B. V. A. Mittelbach, M. E. White, T. Rhyner, N. Haghipour, N. Dubois, and T. I. Eglinton. In preparation.

Conferences and Presentations

Goldschmidt Conference 2024: Are perialpine lakes a net source or sink of carbon? A sediment trap study of Lake Geneva, Switzerland (Chicago, USA), August 2024. *Presenter: Benedict Mittelbach*
University of Geneva Environmental and Aquatic Sciences Seminar: RICH Hydro: Insights from the Radiocarbon inventory of Swiss Lakes (Geneva, Switzerland), May 2024. *Presenter: Benedict Mittelbach*
Biogeochemistry Seminar ETH Zurich: Is Lake Geneva a source or sink of atmospheric CO2?: Insights from a year of sediment trap ^{14}C data (Zurich, Switzerland), May 2024. *Presenter: Benedict Mittelbach*
Swiss Geoscience Meeting: Radiocarbon Inventories of Switzerland: sources and cycling of dissolved organic carbon in Swiss lakes (Mendrisio, Switzerland), November 2023. *Presenter: Margot White*
Swiss Geoscience Meeting: Radiocarbon Inventories of Switzerland: Insights from a year of sediment trap data in Lake Geneva (Mendrisio, Switzerland), November 2023. *Poster Presenter: Benedict Mittelbach*
Current Topics from Accelerator Mass Spectrometry and its Applications: Sources and cycling of (radio)carbon in Switzerland's lakes (Zurich, Switzerland). October 2023. *Presenter: Margot White*

Aquatic Sciences Meeting: Sources and fate of young and old carbon in Switzerland's lakes (Palma de Mallorca, Spain), June 2023. *Presenter: Margot White*

EAWAG SURF Seminar: A Radiocarbon Inventory of Switzerland's Lakes (Kastanienbaum, Switzerland), May 2023. *Presenter: Benedict Mittelbach*

European Geosciences Union General Assembly: A Radiocarbon Inventory of Switzerland's Lakes (Vienna, Austria), April 2023. *Presenter: Margot White*

University of Georgia Department of Marine Sciences Seminar: Radiocarbon-based insights into aquatic carbon cycling (Online). March 2023. *Presenter: Margot White*

Swiss Geoscience Meeting: Radiocarbon measurements of dissolved inorganic and organic carbon from the LéXPLORE platform on Lake Geneva (Lausanne, Switzerland), November 2022. *Presenter: Margot White*

24th International Radiocarbon Conference: Time-series measurements of dissolved organic and inorganic radiocarbon from Switzerland's two largest lakes (Zürich, Switzerland), September 2022. *Presenter: Margot White*

Collected data

Water sampling was conducted at the LéXPLORE platform near the city of Lausanne, Switzerland, where the maximum water depth is 125 m (Wüest et al. 2021). Sampling for this study was conducted once per month from April 2022 to March 2023 during which a CTD cast was performed and water samples were collected from 1, 5, 10, 15, 20, and 50 m depth using a Niskin bottle. No sampling was conducted during January 2023. All water samples were filtered directly from the Niskin bottle using pre-combusted GF/F filters and collected into pre-combusted vials or bottles. DIC samples were collected into brand new 12 mL exetainer vials and stored at 4°C until analysis. Samples for ^{14}C of DOC were collected into 250 or 500 mL acid-washed amber Nalgene bottles and kept frozen until analysis.

Samples for DOC concentration measurements were filtered into 40-mL borosilicate vials before being acidifed to pH 2 using HCl and sealed using acid-washed vial caps with silicone septa. Sediment traps were sampled monthly from July 2022 to July 2023. Each trap consisted of four PVC tubes with a diameter of 9cm that were placed 5m above the lake floor in depths of 100m (proximal) and 300m (distal). After collection sediment was stored frozen in PE containers and subsequently dried using a Christ Alpha freeze-drier with an oil- free pump and stored in precombusted 60 mL borosilicate vials.

DIC concentrations were analyzed on a Shimadzu TOC-L Analyzer using the total inorganic carbon (IC) mode with a typical uncertainty of 1 mgC/L. DOC concentrations were also analyzed on a Shimadzu TOC-L Analyzer with a typical uncertainty of 0.05 mg C/L. The DOC concentrations were determined using the high-temperature combustion method (Sharp et al. 2002). The instrument blank and DOC measurements were validated with low-carbon water (high-purity Milli-Q water), and reference materials NT170A and NT170B from the Umwelt Bundesamt.

Radiocarbon analyses were conducted using a MICADAS (MIni CArbon DAting System) Accelerator Mass spectrometer (AMS) equipped with a Gas Interface System (GIS) and CO_2- accepting ion source at the Laboratory for Ion Beam Physics (LIP) in the Department of Physics at ETH Zurich (Synal and Wacker 2010; McIntyre et al. 2017). For DIC and PIC samples, 6 mL of water or 5 mg of sediment sample was transferred to a 12 mL exetainer vial and the headspace was purged with He for 3-4 minutes. Then 250 µl of phosphoric acid (85%) was added and the liberated CO_2 introduced to the gas interface system (GIS) and measured with the gas ion source of MICADAS. C1 (IAEA) was used as a blank and C2 (IAEA) was used as a secondary reference material. For $DO^{14}C$, samples were first freeze-dried to concentrate organic matter

using a Christ Alpha 1-2 LDplus freeze dryer equipped with an oil-free diaphragm pump, and then acidifed to below pH 2 using phosphoric acid (85%) to remove DIC. Wet chemical oxidation (WCO) using aqueous persulfate was employed to convert DOC to CO_2, after which the water was purged with He and ^{14}C measured on the released CO_2 as described above for DIC. Results for $DO^{14}C$ samples were corrected for constant contamination. For analysis of $PO^{14}C$ 10-40 mg of sediment sample were transferred into silver capsules (Elemental Microanalysis) and vapor acidified over 12M HCl to remove PIC (Komada et al., 2008). Following neutralization with NaOH, samples were wrapped into tin boats (Elemental Microanalysis) and measured on the MICADAS system.
Radiocarbon measurements are reported as age corrected $\Delta^{14}C$ in per mil (‰) (Stenström et al. 2011). Water column data are available through www.datalakes-eawag.ch

References

Broecker, W. S. and others. 1986. Isotopic versus micrometeorologic ocean CO2 fluxes: A serious conflict. J Geophys Res Oceans **91**: 10517–10527. doi:10.1029/JC091IC09P10517

Broecker, W. S., and A. Walton. 1959. The geochemistry of C14 in fresh-water systems. Geochim Cosmochim Acta **16**: 15–38. doi:10.1016/0016-7037(59)90044-4

Cremona, A., M. Huss, J. M. Landmann, J. Borner, and D. Farinotti. 2023. European heat waves 2022: contribution to extreme glacier melt in Switzerland inferred from automated ablation readings. Cryosphere **17**: 1895–1912. doi:10.5194/TC-17-1895-2023

Hood, E., J. Fellman, R. G. M. Spencer, P. J. Hernes, R. Edwards, D. Damore, and D. Scott. 2009. Glaciers as a source of ancient and labile organic matter to the marine environment. Nature 2009 462:7276 **462**: 1044–1047. doi:10.1038/nature08580

Komada, T., M. R. Anderson, and C. L. Dorfmeier. 2008. Carbonate removal from coastal sediments for the determination of organic carbon and its isotopic signatures, δ13C and Δ14C: comparison of fumigation and direct acidification by hydrochloric acid. Limnology and Oceanography: Methods 6: 254-262.

McIntyre, C. P., L. Wacker, N. Haghipour, T. M. Blattmann, S. Fahrni, M. Usman, T. I. Eglinton, and H.A. Synal. 2017. Online 13C and 14C Gas Measurements by EA-IRMS-AMS at ETH Zürich. *Radiocarbon*. Cambridge University Press. 893–903.Peng, T. H., and W. Broecker. 1980. Gas exchange rates for three closed-basin lakes. Limnol Oceanogr**. 25**: 789–796. doi:10.4319/LO.1980.25.5.0789

Rhyner, T. M. Y. and others. 2023. Radiocarbon signatures of carbon phases exported by Swiss rivers in the Anthropocene. Philosophical Transactions of the Royal Society A **381**. doi:10.1098/RSTA.2022.0326

Sharp, J. H., C. A. Carlson, E. T. Peltzer, D. M. Castle-Ward, K. B. Savidge, and K. R. Rinker. 2002. Final dissolved organic carbon broad community intercalibration and preliminary use of DOC reference materials. Mar Chem **77**: 239–253. doi:10.1016/S0304-4203(02)00002-6

Singer, G. A., C. Fasching, L. Wilhelm, J. Niggemann, P. Steier, T. Dittmar, and T. J. Battin. 2012. Biogeochemically diverse organic matter in Alpine glaciers and its downstream fate. Nature Geoscience 2012 5:10 **5**: 710–714. doi:10.1038/ngeo1581

Stenström, K. E., G. Skog, E. Georgiadou, J. Genberg, and A. Johansson. 2011. A guide to radiocarbon units and calculations.

Synal, H. A., and L. Wacker. 2010. AMS measurement technique after 30 years: Possibilities and limitations of low energy systems. Nucl Instrum Methods Phys Res B **268**: 701–707. doi:10.1016/J.NIMB.2009.10.009

Wüest, A., D. Bouffard, | Jean Guillard, | Bastiaan, W. Ibelings, S. Lavanchy, M.-E. Perga, and N. Pasche. 2021. LéXPLORE: A floating laboratory on Lake Geneva offering unique lake research opportunities.doi:10.1002/wat2.1544

LéXPLORE

High-resolution monitoring of zooplankton in Lake Geneva

List of authors (Jérémy Keller, Marie-Elodie Perga, Nicolas Escoffier, Violaine Piton, Santona Khatun, Isabelle Herr, Gaël Many, Jake Vander Zanden)

Abstract

The project focuses on the integration of digital imaging (ZooScan) and acoustic signals (Acoustic Doppler Current Profilers - ADCPs) for high-resolution monitoring of zooplankton dynamics in Lake Geneva. Traditional methods for studying zooplankton are often limited by their inability to capture fine-scale spatial and temporal dynamics. These limitations arise primarily from the challenges associated with manual sampling and analysis techniques, such as microscope counting, which are time-consuming and may miss critical variations due to the low frequency of sampling.

The objective of this project is to develop a methodology that combines ZooScan's imaging technology with ADCP's acoustic backscatter data to provide more detailed insights into the population dynamics of zooplankton. ZooScan allows for high-throughput imaging and identification of zooplankton species, while ADCPs offer continuous, non-invasive measurements of zooplankton distributions through acoustic backscatter signals (Figure 1).

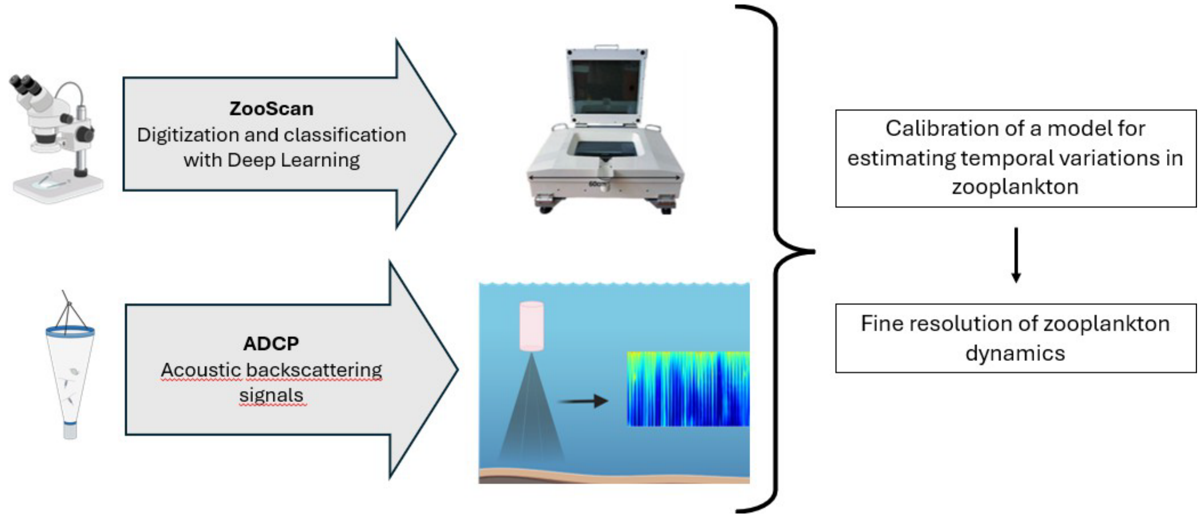


Figure 1: Integration of digital imagery and acoustic signals for high-resolution monitoring of zooplankton dynamics

Sampling was conducted from the LéXPLORE platform on Lake Geneva, combining low-frequency (over a year) and high-frequency (night-time) campaigns to capture both seasonal variations and diurnal vertical migrations (DVM) of zooplankton. Low-frequency sampling focused on capturing long-term trends, while high-frequency sampling was designed to capture short-term ecological events, such as daily vertical migrations of species like Cyclops prealpinus and Eudiaptomus gracilis.

ZooScan's semi-automated imaging system was used to classify zooplankton species and calculate key metrics like biovolume. The images obtained were processed and classified using the EcoTaxa web platform, which employs machine learning algorithms to assist with species identification.

The ADCP data were processed to extract acoustic backscatter signals, which reflect the density of zooplankton in the water column. Polynomial regression models were developed to relate these acoustic signals to the biovolume of specific zooplankton groups, notably Cyclops and total zooplankton populations.

Main results

This research successfully combined ZooScan imaging technology and Acoustic Doppler Current Profilers (ADCPs) to monitor zooplankton dynamics in Lake Geneva, yielding several important findings. One of the key results was the strong correlation observed between acoustic backscatter signals from ADCPs and zooplankton biovolume, particularly for Cyclops populations. A polynomial regression model developed to estimate biovolume from acoustic signals demonstrated that the model for Cyclops biovolume performed better than the model for total zooplankton populations, with a coefficient of determination (R^2) of 0.62. This finding indicates that species-specific characteristics significantly influence the acoustic detectability of zooplankton.

Another important discovery was the marked seasonal variability in zooplankton concentrations, dominated by species such as Eudiaptomus gracilis, Cyclops, and copepod nauplii, with Daphnia and Bythotrephes longimanus being less common. The use of ZooScan allowed for detailed morphological analysis, providing insights into the changes in individual volume over the year. In addition to seasonal variations, the study also captured significant diel vertical migration (DVM) patterns, especially in Cyclops prealpinus, whose biovolume peaked at night in the upper water layers, indicating a strong migration behavior. Eudiaptomus gracilis showed similar, though less pronounced, vertical migration.

The integration of ZooScan and ADCPs also enhanced the temporal resolution of zooplankton monitoring, enabling the capture of rapid fluctuations in zooplankton biovolume that would have been missed by traditional low-frequency sampling methods. These high-frequency data revealed ecological events such as short-term population peaks, particularly for Cyclops, that occurred in early April and mid-May, highlighting the importance of continuous monitoring for understanding dynamic changes in zooplankton populations.

Despite the success of the study, several limitations were identified. The sensitivity of ADCP signals decreased with depth, making it challenging to detect zooplankton in deeper water layers. Furthermore, a gap in the data between 7 and 11 meters due to the ADCP setup required interpolation, which may have introduced errors in the analysis. To improve future studies, the use of multi- frequency acoustic signals would allow for a more comprehensive detection of different zooplankton species and sizes. Additionally, the implementation of automatic sampling systems could enhance data collection and further improve the accuracy of predictive models.

In conclusion, the research demonstrated the effectiveness of combining ZooScan imaging and ADCP acoustic data to provide a detailed, high-resolution view of zooplankton dynamics in Lake Geneva. The findings underscore the potential of these methods to overcome the limitations of traditional sampling techniques and offer new insights into zooplankton behavior and population changes.

Collected data

https://ecotaxa.obs-vlfr.fr/prj/6742