LéXPLORE

# LéXPLORE platform

# Scientific Report 2023

*LéXPLORE platform ©Guillaume Cunillera, 2023*

**Reporting from 31 projects from July 2022 to June 2023**

Compiled by Natacha Tofield-Pasche and the project leaders

EPFL eawag aquatic research UNIVERSITÉ DE GENÈVE Unil UNIL | Université de Lausanne CARRTEL INRAE UNIVERSITÉ SAVOIE MONT BLANC

***Current running projects:***

1. Breider Florian, Hanahan Jonathan, Vernez Karine, Coudret Sylvain, Loizeau Jean-Luc**:** **Deposition and Accumulation of Microplastics in Lake Sediments (Microsed)**
2. Bouffard Damien, Sebastiano Piccolroaz, , Gil Coto Miguel, Lavanchy Sébastien, Cunillera Guillaume, Dinkel Christian, Fernandez Castro Bieito: **LéWalk: autonomous turbulence profiling**
3. Bouffard Damien, Bieito Fernandez Castro, Piccolroaz Sebastiano, Michäel Plüss, Sebastien Lavanchy, Wüest Alfred**:** **Skin2Bulk: investigating the surface boundary layer**
4. Ibelings Bastiaan, Thomas Mridul, Fillion Roxane, Mesman Jorrit, Devanthery Matthieu, de Loes Sebastien, MUSE-Master students, Müller Beat: **POETICS - PlanktOn vErTICal Structure**
5. Mridul Thomas, Pomati Francesco, Suarez Ena, Fillion Roxane, Ibelings Bastiaan: **Plankton in Lake Geneva : you can't have it both ways.** *Report combined with project 4.*
6. Maner Jenny, Drieschner Carolin, Ebi Christian, Schönenberger René, Angst Levin, Bloem Simon, Solsona Miguel, Renaud Philippe, Schirmer Kristin: **$\text{Rainbow}_{\text{flow}}$ $\text{chip}_{\text{online}}$: Fishcell biosensor for automated water quality testing**
7. Adam Nicolas, Selz Jonathan, Lecine Sofian, Hirt Timothée, Deloose Christophe, Bernier-Latmani Rizlan, Maerkl Sebastian: **GenoRobotics CoWaS - Continuous Water Sampling**
8. Weyermann Céline, Estoppey Nicolas, Pfeiffer Fabienne, Glanzmann Vick, Reymond Naomi, Huismann Sofie: **Aqua-Gabs/MONET in Lake Leman**
9. Tercier-Waeber Mary-Lou, Ibelings Bastiaan, Layglon Nicolas, Gressard Tanguy: **Synergic interaction between arsenic species and microorganisms in freshwater contrasting dynamic conditions (SyBAM)**
10. Dubois Nathalie, Mittelbach Benedict, Eglinton Timothy, White Margot, Rhyner Timo: **Radiocarbon Inventories of Switzerland (RICH)**
11. Natacha Tofield-Pasche, Guillaume Cunillera, Nathalie Dubois, David Janssen: **Temporal and spatial variations of the settling particles fluxes in Lake Geneva (SEDTRAP)**
12. Odermatt Daniel, Damm Alexander, Pasche Natacha, Alikas Krista, Soomets Tuuli, Spyrakos Evangelos: **Monitoring Lake Primary Production using the PACE satellite (Lake3P)**
13. Bakker Eric, Forrest Tara, Zdrachek Elena, Damala Polyxeni, Cherubini Thomas: **Submersible Probe with In-line Calibration and Symmetrical Reference Element for Long-term Continuous Measurement of Environmentally Relevant Ions (Multiple ion)**
14. Laureen Mori-Bazzano, Bastiaan Willem Ibelings: **Characterization of Biofilm formation on different types of plastic substrate**
15. Jeremy Keller, Jake Vander Zander, Marie-Elodie Perga: **ZOOPS – temporal dynamics of zooplankton**
16. Brunetti Maura, Babanin Alexander, Jérôme Kasparian: **Wind2Waves**

17. Beauvais Rébecca, Ferrari Benoît, Casado-Martinez Carmen, Rohrbach Emmanuelle: **LéXPOSTRAC: Tracking ecotoxicological effects of lake suspended particulate matter on the ostracod *Heterocypris incongruens***
18. Neronov Andrii, Kneib Jean-Paul, Shutska Lesya, Bernard Florian, Lesrel Jean, Haefeli Guido: **LAC TELescope**
19. Bahr Alexander, Schill Felix, Lavanchy Sébastien and Cunillera Guillaume: **SUBMULE – easy access to submerged data**

### *Current projects without detailed reports*

20. *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,*** *Project will start later in 2023.*
21. *Bellouard Yves, Rey Samuel, Ayer Baptiste, Sala Federico, Ibelings Bastiaan, Pomati Francesco:* ***PhytoWaveTaxa: all glass sensors for algae population monitoring***
22. *Mariethoz Gregoire, Koch Erwan, Berne Alexis:* ***Installation of a drip-based rain gauge on LéXPLORE***
23. *Perga Marie-Elodie, Frech Benoit, Vittoz Jérôme, Gravey Mathieu:* ***the sounds of LéXPLORE***

### *Cancelled:*

24. Schuback Nina, Oxborough Kevin, Moore Mark, Ibelings Bastiaan, Odermatt Daniel, Lavanchy Sébastien: **Single Turnover Active Fluorescence of Enclosed Samples for Aquatic Primary Productivity (STAFES-APP)**
25. Piccolroaz Sebastiano, Cunillera Guillaume, Chmiel Hannah, Perolo Pascal, Lavanchy Sébastien: **caGAStrophic: designing a low-cost, automated, floating chamber for gas flux measurements at the air-water interface of water bodies**

### *Final report for completed projects*

26. Larivé Odile, Wynn Htet Kyi, Li Chaojie and Tamar Kohn: **Effect of lake exposure on Enterovirus population**
27. Guillard Jean, Rautureau Clément, Tran-Khac Viet, Goulon Chloé: **LéXfish: monitoring fish presence below LéXPLORE**
28. Carratalà Anna, Ibelings Bastiaan, Odermatt Daniel, Janssen Elisabeth: **Remote sensing and risk assessment of toxic Cyanobacteria in Lake Geneva (CYANOSENSE).**
29. Maxime Hedou, Jeremy Luterbacher, Lorenz Manker: **Biodegradability assessment of PBX, a sustainable bio-polyester developed at EPFL**
30. Perga Marie-Elodie, Perolo Pascal, Lambert Thibault, Escoffier Nicolas, Chmiel Hannah, Fernandez Castro Bieito, Bouffard Damien: **CARBOGEN: carbon cycling in Lake Geneva**
31. *Violaine Piton, Wynn Htet Kyi, Barry Andrew, Reiss Rafael:* ***Test measurements for Long-Range ADCP parametrization.*** *No report, as the project only tested a new instrument.*

# Microsed project - Deposition and Accumulation of Microplastics in Lake Sediment

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

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

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

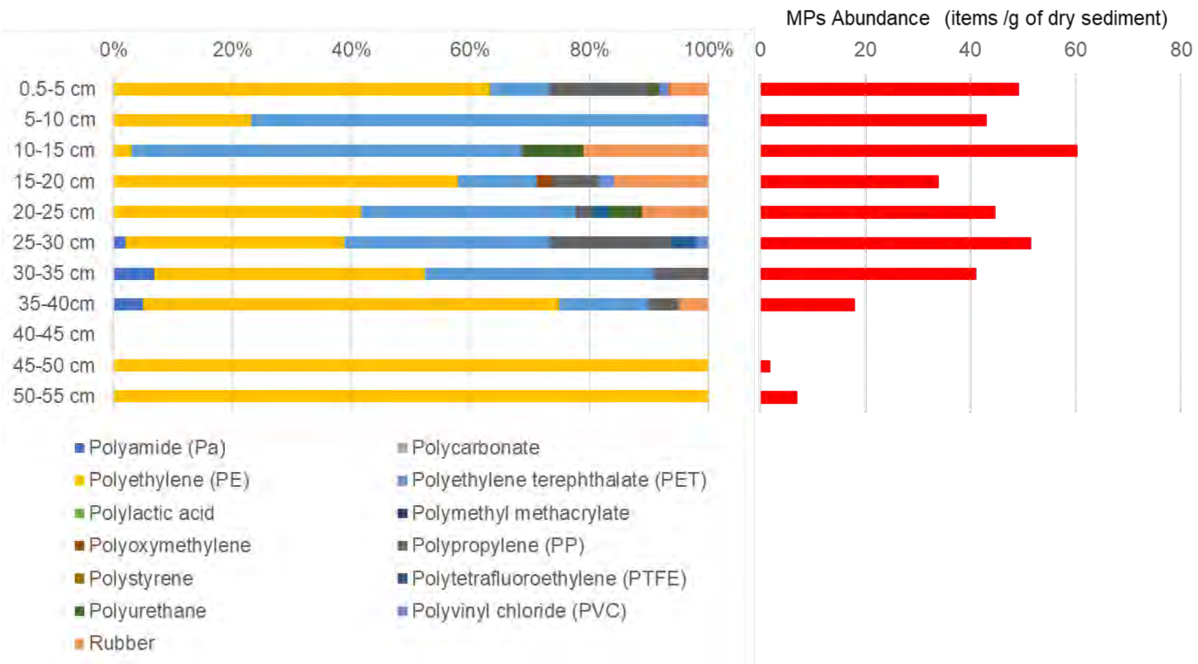


Figure 1. Distribution of the polymers (left) and microplastics abundance > 150 microns (right) in the sediment core.

In 2023, the focus was on analysing sediment cores taken from a depth of 110 m. The sediment cores were extruded and dated using radioactive isotopes ($^{210}Pb$ and $^{137}Cs$). The cores were also characterised by measuring water content, grain size, organic matter and CaCO3 content. Preliminary results show that polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP) and rubber are the most abundant polymers in the sediment cores. It also appears that polymer diversity tends to be lower in older sediments than in more recent ones. However, this finding needs to be validated by statistical analysis. The concentration of microplastics tends to increase from depth of 55 cm to the surface layer. These concentrations vary from 2 to 60 MPs/g of dry sediment. These results are of the same order of magnitude as the concentrations reported for other lake. Over the coming months, additional samples will be analysed, the dating results derived from the $^{210}$Pb models in the sediment cores will be validated and a statistical analysis of the concentrations and properties (size, shape, composition) of the microplastics will be carried out. These results will enable to calculate MPs sedimentation rate and compare it with existing model.

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# LéWALK: autonomous turbulence profiling

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

The objective of this project is twofold: (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 thousandths of a degree Celsius (mK) and thereby to estimate the level of turbulence in the water column.

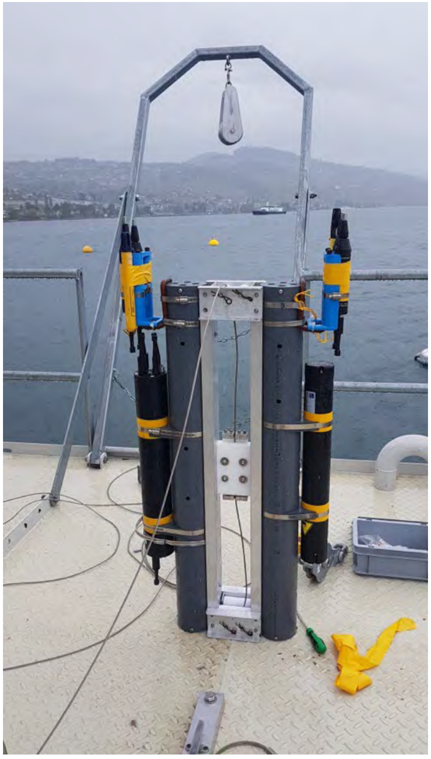

*Photo of the autonomous turbulence profiler used on the LéXPLORE platform*

The primary advantage of this system is its ability to conduct profiling primarily during windy (wavy) conditions, where obtaining turbulence measurements traditionally poses challenges (typically achieved from small boats). 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. It is designed to accommodate various payloads, such as CTD (Conductivity, Temperature, and Depth) sensors, microstructure sensors, and more. While this system is currently undergoing active development, we anticipate that the overall cost of implementing such an automated profiling system will be below 10,000 CHF.

To analyze the collected data, a PhD student will be recruited. This project is part of a larger project aiming at characterizing the dynamics of surface layer.

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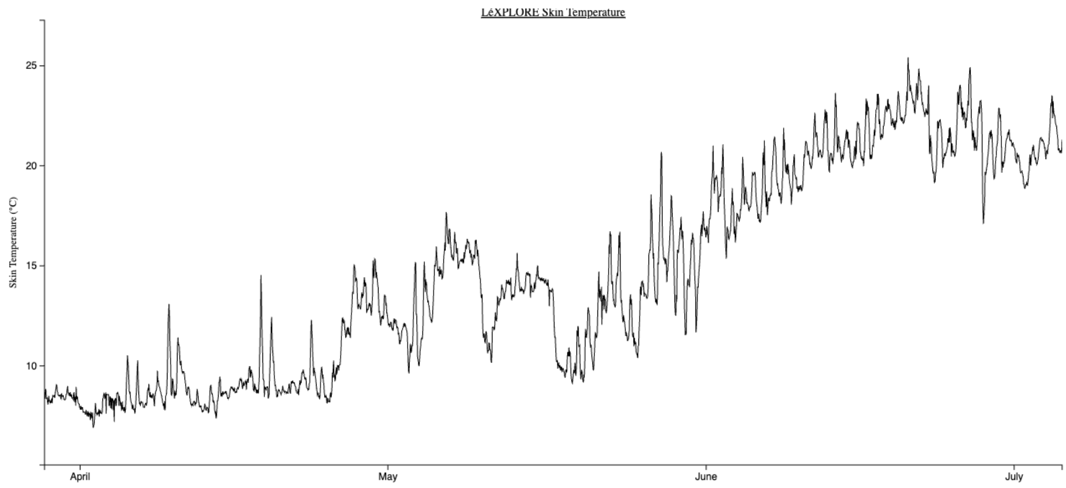
# Skin2Bulk : Investigating the surface boundary layer

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


*Photo of the radiometers installed on LéXPLORE*

Infrared satellite technology provides valuable information about surface temperature by measuring the temperature in the uppermost layer, known as the "skin layer," which extends only a few micrometers below the surface. This temperature measurement differs slightly from what is observed by in-situ sensors in the "bulk layer," located a few centimeters below the surface. The primary objective of this project is to measure both skin and bulk temperatures period using radiometers and a thermistor chain. The ultimate goal is to develop a robust parameterization technique that accurately converts skin temperature to bulk temperature for lakes.

LéXPLORE




*Example of skin temperature recorded on LéXPLORE. Data extracted from Datalakes*

After one year of collecting data, the results of the project present a challenging task in terms of interpretation. Although the overall trends are promising and should enable quantification of the temperature difference between the skin and bulk layers, there have been problematic spikes in the data that remain unexplained thus far. Interestingly, similar peaks have been observed with other infrared sensor deployed on other lakes and we are still working on understanding the sources of error.

The difference between the skin and the bulk temperature was tentatively parameterized using the approach described by Wilson et al (2013). Briefly, the skin effect is defined as the difference between the bulk and the skin temperature. This difference can be expressed as a function of the net heat flux at the air water interface and the thickness of the molecular sublayer. Interestingly both parameters can be inferred from other LéXPLORE products. The net heat flux is already a parameter operationaly provided in Datalakes: https://www.datalakes-eawag.ch/datadetail/886 and the thickness of the molecular sublayer can be estimated from turbulence profilers (See LeWALK project) and/or ADCP measurements (also available operationally) (https://www.datalakes-eawag.ch/datadetail/600 )

Dataset are openly available here

https://www.datalakes-eawag.ch/datadetail/854

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# Plankton in Lake Geneva and POETICS

Bastiaan W. Ibelings, Mridul K. Thomas, Fabio dos Santos Correia, Francesco Pomati

**1. Overview**

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

**2. Progress**

In 2022-23, we have programmed the Cytobuoy, a scanning flow cytometer, to sample phytoplankton at nine different depths ranging from 0 to 30 meters approximately every 3 hours. We have also installed a Watersam automated water sampler on LéXPLORE that collects and refrigerates samples till they are manually collected. We have configured the water sampler to collect daily samples at a defined depth within the mixed layer, with the goal of quantifying nutrients and phytoplankton communities at high frequency. Water samples are brought back to the lab every week to analyse them for total and dissolved nutrient concentrations and to collect images of the phytoplankton cells. This improves the present nutrient sampling frequency from weekly to daily, with the possibility of increasing this frequency in the future. For cell imaging of these daily samples, we have started to use a recently-acquired FlowCam.

**3. Next steps**

We are in the process of developing a machine learning-based classification model to discriminate between the major phytoplankton groups, as well as key species such as Planktothrix, from the Cytobuoy data.

We also aim to build a database of phytoplankton images from the lake and couple this with machine learning-based classification to identify all images and quantify the species dynamics at high frequency. The Cytobuoy does not allow species-level classification and so this improves the taxonomic resolution of our phytoplankton sampling efforts.

By the end of this year, we will have made progress towards finalising these models, enhancing our capabilities in tracking and understanding phytoplankton populations.

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

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

The RAINBOW$_{FLOW}$ CHIP$_{ONLINE}$ 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. The instrument was thus recovered in order to resolve these problems. A second field testing campaign was delayed in order to finalise a thorough proof of principle study to show the feasibility and sensitivity of impedance sensing for monitoring cells' reaction to dissolved chemicals. Following this, the field instrument will be prepared and some improvement made for the next application on LéXPLORE, envisioned in 2024.


*Left: The RAINBOW$_{FLOW}$ CHIP$_{ONLINE}$ biosensor installed on the LéXPLORE platform.*

*Right: RTgill-W1 cells covering the electrode of the ECIS chip.*

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# CoWaS – Continuous Water Sampling

Louis Duval, Andréa Montant, Daphné De Quatrebarbes, Nicolas Adam, Jonathan Selz, Sebastian Maerkl, Rizlan Bernier-Latmani

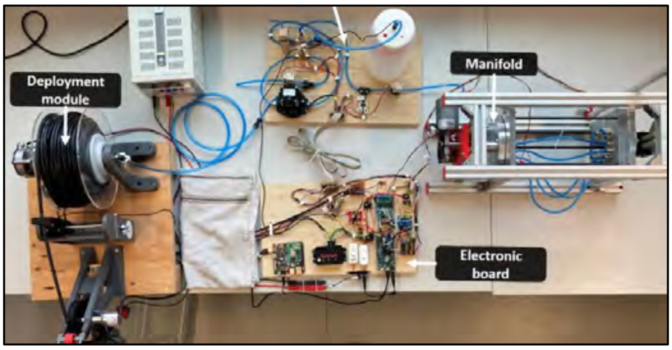


*Figure 1: CoWaS Proof of Concept*

## 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 major challenge for the widespread application of this concept is to effectively preserve the collected samples with limited equipment, simple manipulations, and easily obtainable reagents. The prospect of drying filters emerges as a viable medium-term strategy for conserving biological samples from aquatic environments.

## Development

The current study emphasizes the development of a drying device suitable for two distinct filter types within the 0.22 µm size fraction: Sterivex filter units (Merck-Millipore) and 47mm-diameter disc filters (Merck-Millipore). Additionally, the assessment of the impact of this drying approach on downstream DNA analysis is pursued. This downstream analysis includes DNA extraction through the DNeasy PowerWater Kit, followed by PCR targeting the 16S rRNA gene, finishing in nanopore sequencing of samples. The prototypes developed achieve temperatures up to 80°C while maintaining a vacuum pressure of 0.15mbar, with energy consumption remaining below 4.8W. An Arduino DUE-based software facilitates the control and monitoring of temperature and vacuum parameters.

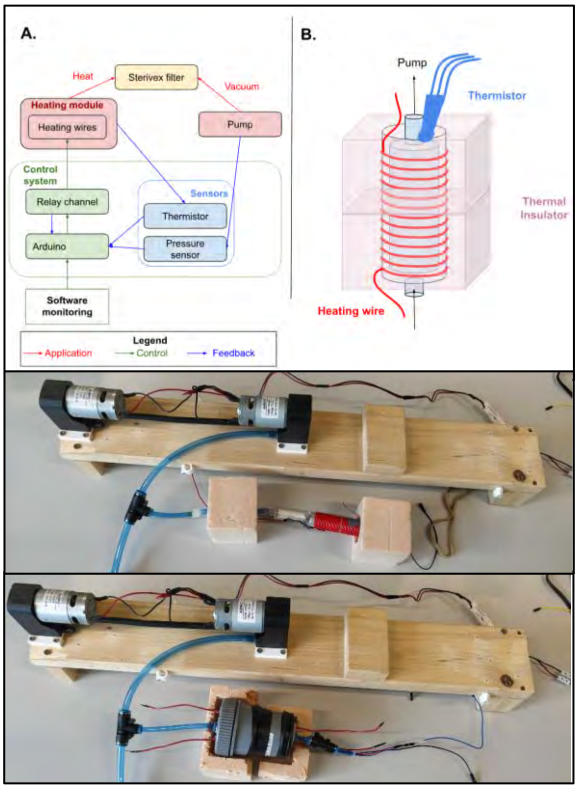


*Figure 2: Sterivex Heating device. A: Control Diagram; B : Func tional Scheme; Lower 1: Sterivex Prototype; Lower 2: Disk Prototype*

## Results

The results from testing campaigns reveal an optimal balance between drying efficiency and its impact on the quantity and quality of recovered 16S rRNA gene material when exposed to 55°C for 5 minutes. Furthermore, we discovered the significance of pressure, rather than temperature, in achieving thorough drying of the filter without compromising biological samples. However, the study also identifies limitations, such as potential biological selectivity bias, which tends to escalate as drying time increases. However, further investigation of these limitations is needed, particularly due to the potential influence of DNA extraction protocols on recovery ratios. Finally, the effectiveness of longer-term preservation will be addressed in a subsequent study.

EPFL

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# Aqua-Gaps/MONET in Lake Leman

Fabienne Pfeiffer, Ines Tascon, Vick Glanzmann, Naomi Reymond, Sofie Huisman, Nicolas Estoppey, Céline 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.

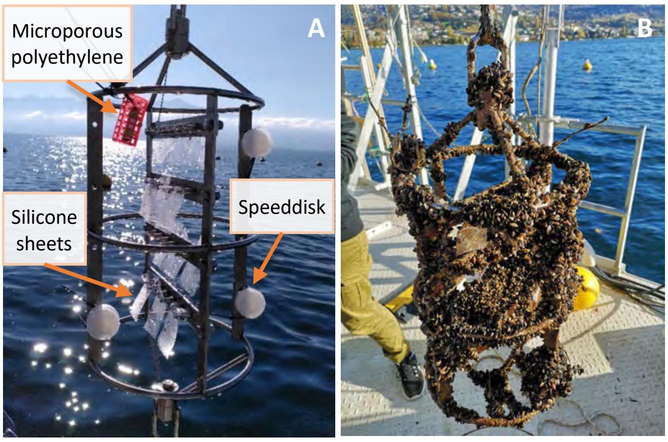


Figure 1: Passive samplers during installation (A) and retrieval (B) at LéXPLORE.

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.

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[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

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

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

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

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

***Progress.*** We successfully applied our multi-channel submersible sensing probe, TracMetal, incorporating antifouling gel-integrated gold nano-structured microelectrode arrays to the in situ spatial and temporal monitoring of the dynamic (potentially bioavailable) fraction of inorganic As species ($iAs(III)_{dyn}$, $iAs(V)_{dyn}$, $iAs(tot)_{dyn}$) during three more field campaigns: August 29 to September 2, 2002; October 31 to November 2, 2022; July 10 to 14, 2023. Depth profiles and 24h measurement cycles at fixed depth were performed during each of these seasonal campaigns. Data recorded with the TracMetal were coupled with those of (i) a multiparameter probe (OS316 probe, Idronaut-Milan) deployed conjointly to record the bio-physicochemical master variables and (ii) lab complementary measurements/analysis in collected samples of spatial and temporal As speciation, water and plankton composition.

As during the Spring campaign (April 12-14, 2022), profiles reflected the presence of $iAs(III)_{dyn}$ in the productive surface water with significant temporal variation in concentration as reflected by the data recorded during the 24h cycles (Figure 1 A, C). $iAs(III)_{dyn}$ represented up to 56% of the total $iAs(tot)_{dyn}$ in summer and up to 34% in autumn. $iAs(V)_{dyn}$ was the predominant fraction of $iAs(tot)_{dyn}$ and its temporal variation in concentration during the 24h cycle was in opposite trends of the variation of $iAs(III)_{dyn}$ (Figure 1 A, C). Total As concentrations measured in 0.2 and 0.02 µm by ICP-MS were similar and constant during the 24h cycles measurements, while significant variation of $iAs(tot)_{dyn}$ was observed (Figure 1 B, D). The concentrations of $iAs(tot)_{dyn}$ were significantly lower that the concentrations of $As_{tot}$ in the two fractions during the whole summer 24h cycle and during the day and the middle of the night during the autumn 24h cycle. These results suggest either sorbtion processes of the dynamic fraction of iAs species on small colloids or the excretion of significant amount of organic As species. Preliminary results of As speciation by HPLC-ICP-MS seem to support the second hypothesis. This suggests a more important biotransformation of the assimilated iAs(V) into organic As during summer that during the spring and autumn phytoplankton bloom. Further analyses by HPLC-ICP-MS of the collected samples will be performed to evaluate this hypothesis. Another study underway is the optimisation of sequential extraction to evaluate the proportion of As adsorbed on colloids, organic matter and finally internalized.

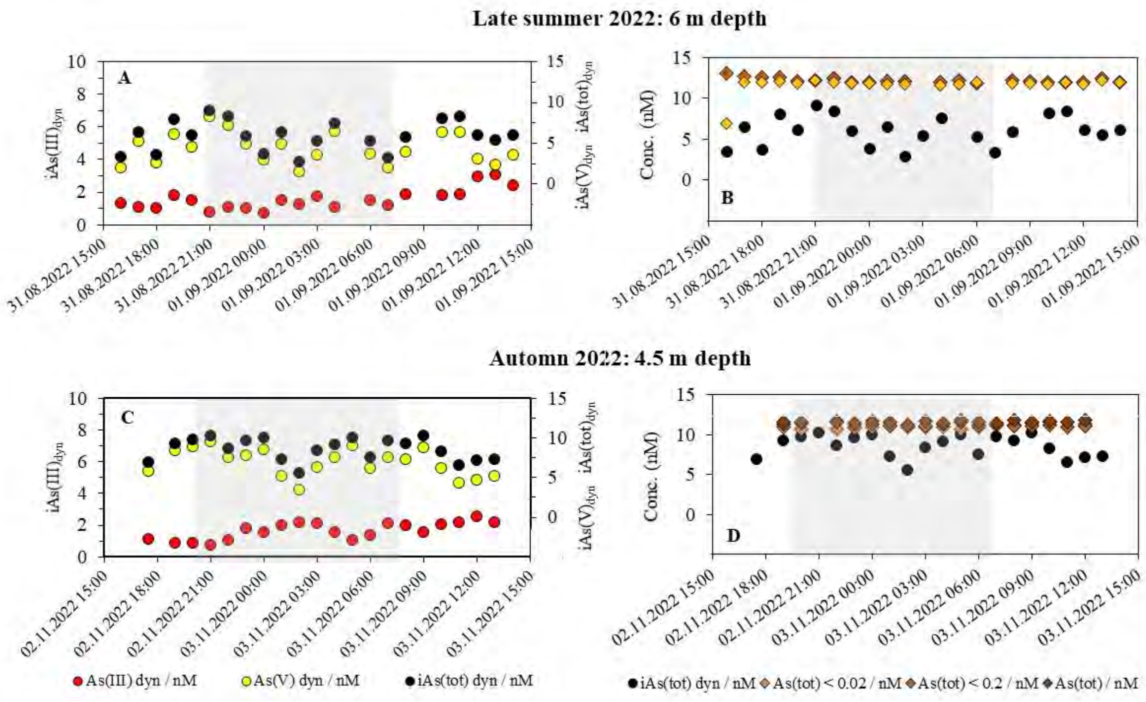



*Figure 1: Speciation of As monitored during the late summer and autumn 2022 24h cycles. (A, C) Temporal variation of the dynamic iAs species recorded in situ. (B, D) Comparison of the $iAs(tot)_{dyn}$ with the $As_{tot}$ measured in the 0.2 and 0.02 µm collected samples.*

## 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 RICH project, RICH Hydro will establish radiocarbon inventories of dissolved and particulate carbon phases in major river watersheds draining different ecoregions of Switzerland, as well as in corresponding receiving lake basins. At Lake Geneva, RICH is collecting a time series of radiocarbon content in various water column reservoirs (DIC, DOC, POC) and material retrieved from sediment traps. We completed a full year of monthly water column measurements in April 2023 and a year timeseries of sediment trap material in July 2023.

Initial measurements of DIC in lakewater at LéXPLORE reveal a radiocarbon signature that is significantly depleted compared to atmospheric $CO_2$ (-200 to -150 ‰ compared to approx. 0 ‰). From these results, we can estimate that approximately 84% of Lake Geneva DIC is of atmospheric origin. Further time series measurements have revealed that the Rhone inflow has a large influence on the $DI^{14}C$ of the lake water. Specifically, the Rhone River brings $^{14}C$-depleted DIC into Lake Geneva (Figure 1a-b), with the lowest values recorded during the month of June. Measurements of the radiocarbon content in DOC show some variability, likely also tied to river influence, but are largely consistent with lake primary production as the major source (Figure 1c-d). We plan to analyze the remaining samples over the next couple of months with the goal of submitting a manuscript describing this work later this year.

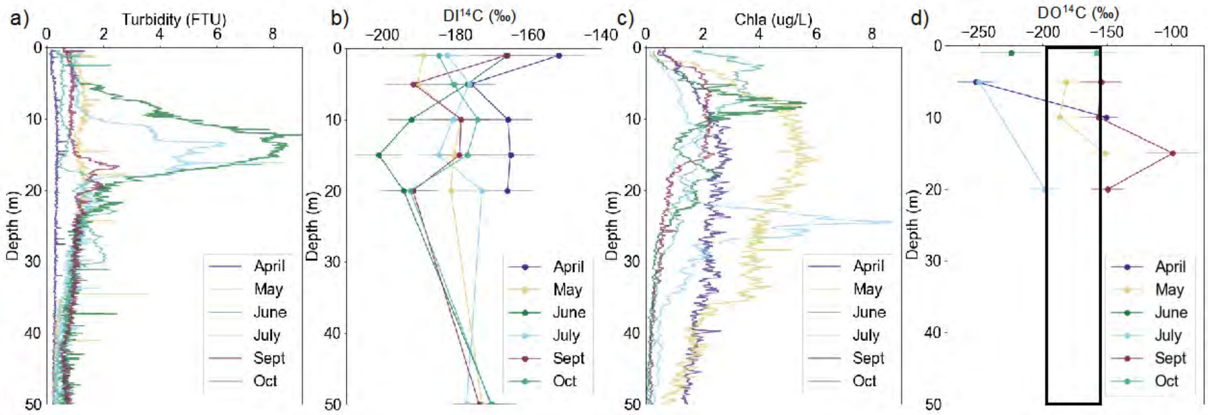



**Figure 1.** Monthly water column sampling at the LéXPLORE platform. CTD measurements of turbidity (a) and chlorophyll a concentration (c) give important context for radiocarbon measurements of DIC (b) and DOC (d). The black box in part d shows the range of values measured for DIC.

Sediment trap samples collected monthly in two locations from July 2022-July 2023 have been freeze-dried and will be analyzed for $^{13}C$ and $^{14}C$ content in the organic and inorganic fractions. These analyses will shed light on seasonal and spatial patterns in autochthonous and allochthonous sediment supply and can further be used to connect our water column observations and existing research on the lake carbon cycle, e.g., on the role of whiting events, to the sedimentary record.

LéXPLORE

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

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

The goal of this project is to quantify the temporal and spatial variations in the composition and fluxes of the settling particles in Lake Geneva. Since the last report, the sediment traps were deployed from 9$^{th}$ May 2022 until 12$^{th}$ July 2023, with only a 14 days gap in August 2023. The traps were usually retrieved every month. They were however collected every two-weeks from June to August, in order to get a finer resolution during the high discharge of the Rhone river. The analyses of the different organic and inorganic components are under way.

Escoffier et al. (2023)[1] quantified the fine-scale dynamic of the calcite precipitation. The high-frequency data were compared to the data from the sediment trap collected in 2020, which helped to constrain the total flux of calcite precipitation.

We also compared the data from the sediment traps in 2020 and 2021. Both year showed a seasonal variability with higher flux in summer and larger sedimentation rates below 30 m (Fig 1), due to the intrusion from the Rhône River. In the extremely wet year in 2021, the fluxes of particles were higher compared to 2020, which is similar to the Rhône River discharge.

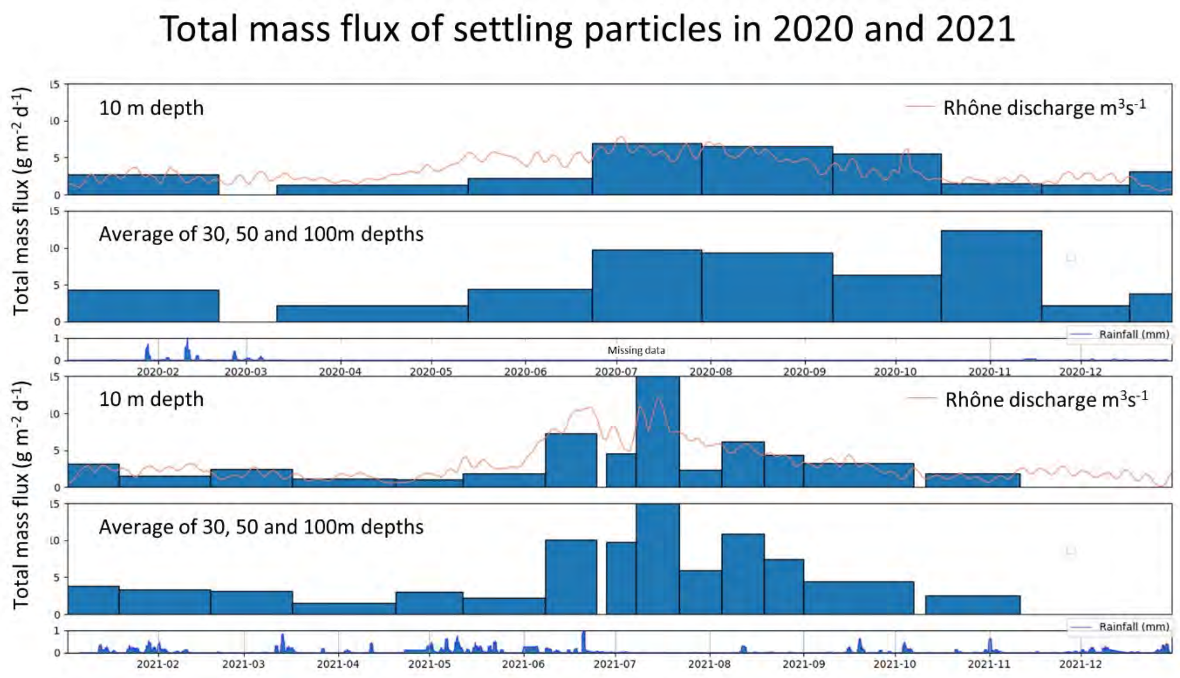



*Figure 1: Total mass flux of settling particles at LéXPLORE in 2020 and 2021 for trap at 10 m and traps averaged below 30 m. The Rhône River discharge (line in red) was divided by 10. Rainfall measured at LéXPLORE*

[1]Escoffier N, Perolo P, Many G, Tofield Pasche N, Perga M-E, 2023. Fine-scale dynamics of calcite precipitation in a large hardwater lake. Science of The Total Environment 864:160699.

LéXPLORE

**Project: Lake Primary Production using PACE (Lake3P)**

*Mortimer Werther, Daniel Odermatt*

*Progress: June 2022 - June 2023*

Lake3P started in September 2022 and combines satellite, modelling and *in situ* datasets to characterize algae primary production (PP) in Lake Geneva and Greifensee, both of which face eutrophication challenges. In the past year, we've laid significant groundwork to measure *in situ* primary production at LéXPLORE. These *in situ* measurements are used for essential model calibration and validation activities. The preliminary analysis of this data has allowed us to start testing different physically-based approaches for the inversion of multispectral satellite scenes over Lake Geneva. The findings enable us to develop a new hyperspectral PP model for NASA's PACE satellite mission (to be launched January 2024), which will improve the technical capabilities to estimate PP from space. We perform in situ PP measurements near LéXPLORE every month to obtain a continuous dataset. For the development and validation of input parameters (chlorophyll-a, Secchi depth) to the PP retrieval algorithms, we have installed automated above-surface radiometers (so-rad, WISPstation) on the platform, and we continue to support the operation of the Thetis profiler by EPFL.

*Achievements:*

1) Two new radiometric systems were installed on LéXPLORE (WaterInsight WISP station, Plymouth Marine Laboratory SoRad), and their data is automatically transmitted to www.datalakes-eawag.ch
2) Sampling protocols for in situ PP measurements were defined (based on IOCCG protocols), and regular measurements were performed since the beginning of 2023

*Publications:*

1. Wydler et al., (in work): Intercomparison and sensitivity assessment of lake primary production models for remote sensing.
2. Werther et al., (in work): Validation of Sentinel-2 and Sentinel-3 atmospheric correction products over perialpine lakes using automated radiometers and field campaign data

Fig. 1 | *In situ* primary production incubation at LéXPLORE, 26.04.2023

# Submersible Probe with In-line Calibration and Symmetrical Reference Element for Long-term Continuous Measurements of Environmentally Relevant Ions (Multiple Ion)

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

The goal of the “Multiple Ion” project on the LéXPLORE platform is to deploy a system that allows continuous measurements of carbonate and pH based on potentiometric sensors. Carbonate, being a key parameter in the carbon cycle, is important to measure but has always to be measured in tandem with pH to obtain its speciation. The submersible probe developed as part of a previous project is preprogrammable and includes a novel reference element designed to minimize temperature influence and performs automated one-point calibration steps daily. To reduce matrix interferences, the calibration solution is made of an acidified lake sample, providing a different concentration of carbonate and $H^+$ ions but exhibits a very similar ionic strength. As the pH and carbonate concentration of the calibration solution is characterized and known, this step is also used to directly estimate the concentration of carbonate and $H^+$ ions in the sample using the potential difference between these two solutions.

In previous work, the probe was deployed in a river and powered with simple Li-ion batteries, thus having a limited lifetime. To avoid this problem, a small raft designed to power the probe was tested and implemented at the LéXPLORE platform (Figure 1). This new addition to the system serves two purposes as it is used to anchor the probe as well as powering it. The small battery located in the top box powers the device and can be recharged by solar panel. Only 2 hours of sunlight daily are needed to keep the battery fully charged. In addition, this box includes a Bluetooth antenna that links the probe to a computer located on the platform, allowing one to virtually control the device from anywhere through distant access. Week-long tests were undertaken, but the strong fluxes exerted continuously on the device revealed some weak spots that needed redesigning and servicing. A new version of the probe will be tested at the platform in summer/fall 2023.

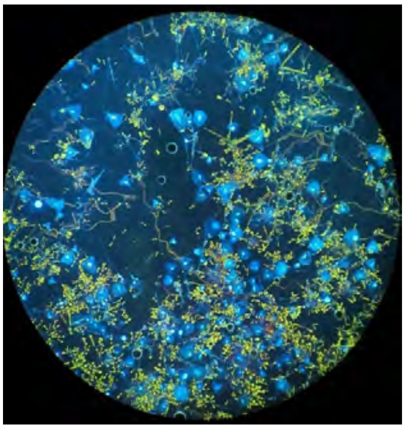
*Figure 1 : On the left, global picture of the LéXPLORE platform with the small raft used to power and anchor the probe. A close-up of the raft can be seen on the right picture with the two barrels used as floating devices and on top a small box including a battery and a Bluetooth antenna. Solar panels are located on top of the box to recharge the battery with solar energy.*

LéXPLORE

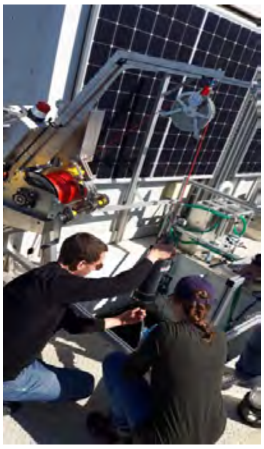
## Plastisphere

Laureen Mori-Bazzano, Bastiaan Ibelings

This project aims to understand the plastic-associated microbial community in Lake Geneva, which is why the platform LéXPLORE offers a unique opportunity to study biofilm colonization on plastic in the natural environment. Plastic found in the environment is mostly derived from packaging, that why we chose to work with low-density polyethylene (LDPE) and polyethylene terephthalates (PET). These two plastics have unique chemical properties, so it is likely that their interactions with the Lake microbiome will be different. LDPE and PET samples are cut to the same size as Glass microscopy slides, which are used as controls. The samples have been placed into three stainless steel cages and introduced into the lake on the 25th of January 2023 ($T_0$). These cages are attached at different depths along the water column; 2 meters, 30 meters, and 100 meters, in order to obtain different environmental conditions based on the lake stratification. The incubation of the samples will last one year to analyze the influence of seasonal variation on the biofilm composition. During this one-year incubation, 8 sampling sessions will occur with an interval of two months. The sampling will occur on the LexPLORE where physicochemical parameters are measured, and substrates samples are taken to the laboratory for further analysis. We observe through Cristal Violet staining the increase of the biofilm from January to May, with higher absorbance values for samples at 2 meters. These results are in accordance with the CTD profile indicating a chlorophyll peak at the end of Mars. Furthermore, we observe a high number of algae on the same samples thanks to fluorescent microscopy (DAPI staining) on all the substrates at 2 meters. We observe the presence of bacteria and protists for the other samples at 30 meters and 100 meters. DNA extractions are done right after sampling, in order to identify the microorganisms of the biofilm at the genus level and their potential for plastic degradation. Molecular biology analyses are made with the collaboration of the Technical University of Liberec. The identification of the microorganisms will be possible through Next Generation Sequencing. The potential of biodegradation of the biofilm is estimated through qPCR, by measuring the abundance of several genes that encode for polymer degradation. Furthermore, plastic degradation is also estimated through FTIR by measuring the plastic's surface chemistry at every sampling session. Four sampling sessions have been done; we are halfway through the incubation to finish the experiment.



*Biofilm on PET substrate, DAPI staining*



*Sampling the water on LeXPLORE*

# Zoops: Zooplankton population dynamic at high frequency by digital image analysis and Deep learning

Keller Jérémy, Perga Marie-Elodie

Zooplankton population dynamics in Lake Geneva are examined annually, as emphasized in CIPEL's reports. Traditional monthly samplings provide a general view but limit detailed insights due to the microscope-based identification, which is both time-consuming and constraining. These methods may underestimate biomass, variability in time and space, and consequently, the role of regulating factors. The present study seeks to overcome these limitations through high-frequency analysis and digital methods, employing the ZooScan imaging system and Ecotaxa for semi-automatic annotation. The sampling, carried out from LéXPLORE from September 2022 to August 2023, gathers samples at depths of 100-50m and 50-0m, with a frequency of 2 to 4 samples per month. The ZooScan system's capability to extract morphometric characteristics has also enabled volume estimation of individual specimens. Three-night sampling campaigns have also been conducted to observe the vertical migration of zooplankton. Several sampling every 20 meters, from a depth of 100 m to the surface, enables us to identify the individuals making this migration, as observable in the backscatter data (Figure 1a) from the ADCPs present on LéXPLORE. The estimated biovolumes of the species *Cyclops prealpinus* (Figure 1b) appear to correspond with the backscatter data.

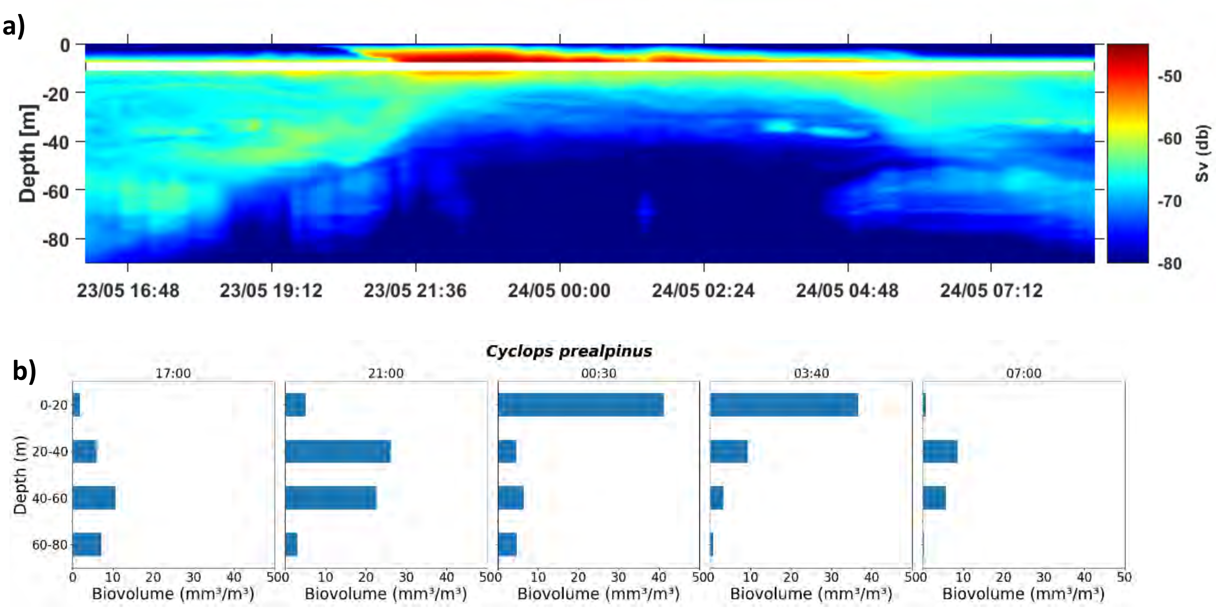



*Figure 1: Combined backscatter % from two ADCPs at the LéXPLORE platform a), including a downward-Looking ADCP located at 11m depth and an Upward-Looking ADCP situated at 7m depth, in comparison with the biovolume of Cyclops prealpinus b)*

In the upcoming stages of the project, the focus will be on exploring whether zooplankton's morphometric characteristics provide a more insightful explanation of the migration patterns observed in the backscatter data compared to conventional taxonomy. Specifically, the aim is to identify which types of individuals within the zooplankton population are accountable for this migration. Additionally, the project seeks to evaluate which environmental drivers might be responsible for the dynamics of the zooplankton population.

LéXPLORE

# WIND2WAVES

Maura Brunetti, Alexander Babanin, Jérôme Kasparian

Measuring the temporal evolution of the directional wave energy spectrum, that is the energy in each mode of oscillation of the water surface in different propagation directions, gives information on energy source and sink processes: wind blowing on the water surface, dissipation mechanisms, and nonlinear interactions between modes of oscillations. These processes are all interconnected and leave characteristic signatures on the wave spectrum.

*Figure 1. WIND2WAVES project : wind-wave interactions on Lake Geneva.*

The aim of the WIND2WAVES project is to perform observational experiments to disentangle and quantify the effect of each source and sink process in the evolution of directional wave energy spectra. We plan to use a stereo camera system to reconstruct the temporal evolution of the wave surface elevation, thus giving three-dimensional features, including amplitude and whitecapping. Directional wave spectra will be reconstructed independently from these measurements and from a specially designed network of five ultrasonic sensors measuring surface elevation. An infrared camera will quantify energy dissipation processes and their directionality during wave breaking. Anemometers will measure the three-dimensional wind-field profile above the water surface.

The LéXPLORE platform is ideally located for our study, being in deep water where bathymetry effects on wave propagation can be neglected, and at long fetch (for south-westerlies) where wind effect is maximised. Moreover, surface gravity waves in deep water can be scaled to ocean conditions, thus the results obtained on the lake can be generalised to different environments, and phenomenological formula can be applied to wave forecast models and to sub-grid parameterizations in climate models.

We visited the platform for the first time in January 2023 for planning the installation of the instruments with LeXPLORE technicians, and for testing our first prototype for surface elevation measurements with ultrasonic sensors. In April, we performed a second visit, where we continued to test and improve our ultrasonic sensors prototype, and discussed with Jean-Daniel Paris (LCSE/IPSL, Paris) and Jérôme Chappellaz (EPFL) for sinergies.  A request has been submitted to the Swiss National Science Foundation in April. Finally in June, two extra-muros students of the Claparède Collège in Geneva, Joshua Tripod and Ludovic Coll, made measuments with a first array of two ultrasonic sensors in order to find the optimal distance among them and with respect to the water surface.

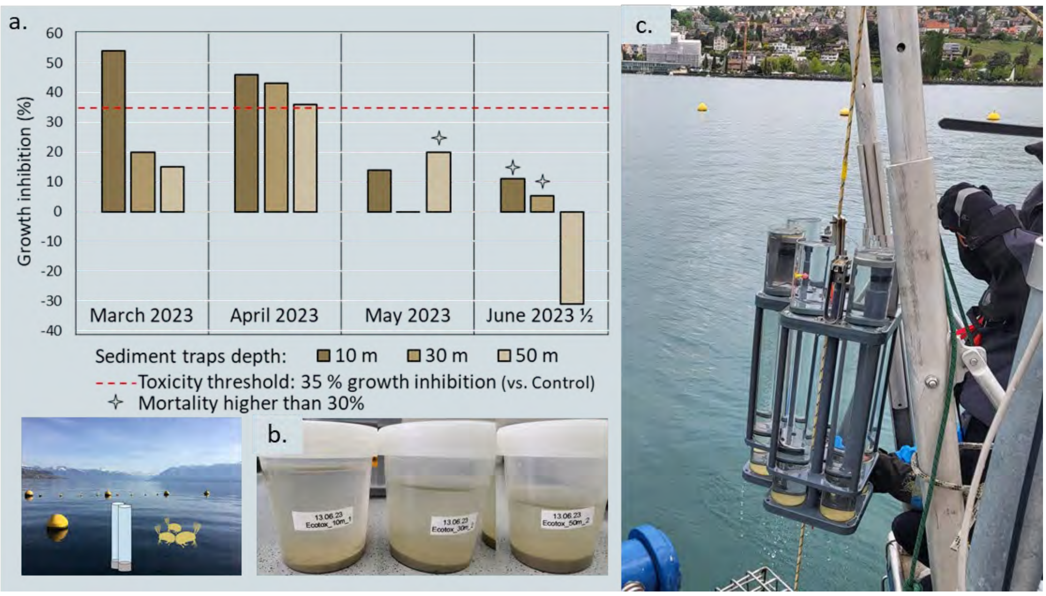
UNIVERSITÉ DE GENÈVE

THE UNIVERSITY OF MELBOURNE

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

Beauvais Rébecca, Ferrari Benoît, Casado-Martinez Carmen, Rohrbach Emmanuelle

In this project, we would like to understand the dynamic of the ecotoxicological quality of monthly or bi-monthly collected lake suspended particulate matter (SPM). To this end, we recover SPM from sediment traps deployed with those from the SEDTRAP project and the recovered SPM will be subjected to chemical analyses (non-targeted liquid chromatography–high resolution mass spectrometry) and ecotoxicity tests (Ostracodtoxkit F). We retrieved our first samples, i.e. 10 m, 30 m and 50 m depth, collected SPM on March 2023. Biotests are initiated no later than one week after sampling. The samples are stored in the dark at 4°C and overlaying water is discarded. Two days before the start of the test, ostracod cysts are "awaked" and the microplates are prepared. For this, 500 mL of SPM are placed in wells on top of reference sand and 2 mL of standard freshwater are added. The plates are incubated under test conditions (dark, 25°C) until 10 freshly hatched ostracods are added at test start. So far, we have run 5 tests and had enough remaining SPM for April to June to freeze them. The aim is to perform non-targeted analyses on selected samples in a second phase.
First results showed monthly differences in the response of the ostracods. We observed exceedance of the toxicity threshold for growth for March and April samples, while growth of the organisms was enhanced in the presence of 50 m collected SPM of first ½ of June (*Figure* a.). Since May, we observe strong mortality at 50 m in May and 10 m and 30 m in the SPM of first ½ of June. The results of the second sample of June are still pending to confirm or not this trend. We however expect to see such dynamic results for the remainder of the year. End of July, we will collect additional SPM thanks to the traps deployed in February 2023 to perform additional ecotoxicological tests with *Chironomus riparius* in order to repeat the previous LéXPOCHIRO project.




*a. First results of the ecotoxicological test with* H. incongruens *(growth inhibition and mortality) for March, April, May and first ½ of June 2023; b. retrieved SPM at three depths (10, 30 and 50 m); c. 50m-traps in May.*

**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*

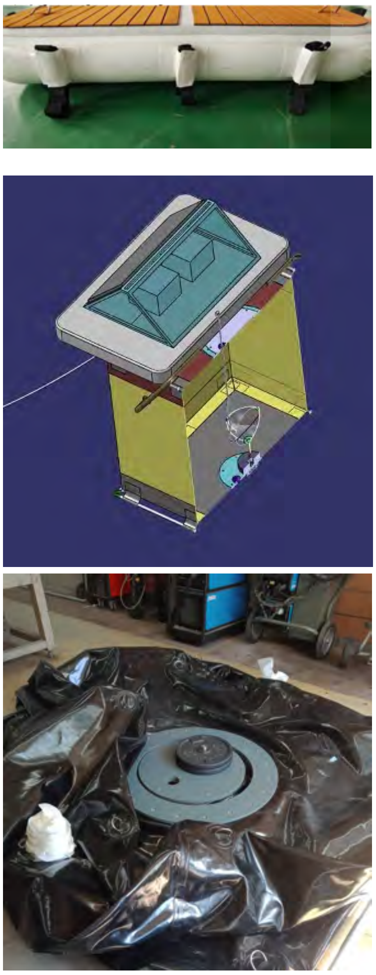


Fig. 1. Middle panel: CAD drawing showing cross-section of the EC with the optical module of ANTARES contained in a light-tight tarpaulin. Bottom panel shows the EC assembled at EPFL in the course of the first year of the project. The EC will be suspended under a floating platform (shown in the top panel, already at EPFL) carrying a hut with power supply and readout electronics modules, with a solar panel on its roof (still "to do").

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 first year of the project, we have made a detailed design of the EC (pictured in the middle panel), purchased its components and materials and finally assembled the cell (now at mechanical workshop in Cubotron building of EPFL/UNIL, bottom panel of the picture). We plan to deploy the cell at LeXPLORE after the summer break, first for testing the robustness of our design in real operational conditions and then proceeding with data taking with an optical module (OM). The OM that will sense the Cherenkov light from high-energy particles will be provided by the Astroparticle and Cosmology (APC) laboratory of the University of Paris City. They are heritage of ANTARES experiment, a neutrino previously deployed in the Mediterranean. APC has secured funding for refurbishing of the readout electronics of ANTARES and for a dedicated solar-panel-based power supply modules (semi-transparent in the middle panel of the picture). EPFL and APC have submitted a proposal to a joint funding by the Swiss National Science Foundation (SNF) in Switzerland and Agence Nationale de Recherche (ANR) in France (waiting for decision).

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

LéXPLORE

## Submule

Alexander Bahr, Felix Schill, Damien Doy

Longterm deployments of landers on lake beds can provide valuable data. Once they are deployed however, retrieving data or simply verifying the status of the lander or changing parameters becomes very difficult. Typically, this requires recovering the lander, offloading and/or making the required changes and redeploying it. This project investigates the use of wireless optical communication for data harvesting from submerged sensors, by sending an ROV with an optical modem, or by direct link to a central optical access point with long-range optical modems, to obtain regular downloads. As part of the investigation, the achievable range in varying turbidity conditions is investigated.

### Work carrried out in the last year

A number of experiments were carried out on multiple days to test the communication range of LUMA X optical modems at various bitrates, power levels, ambient light levels and turbidity. Two pods were constructed with LUMA X optical modems, battery power supply and ethernet tether to the surface. The top pod with the modem looking down was lowered to initially 30m depth, and 50m depth in following deployments. The bottom pod with the modem looking up was then positioned at multiple depths between the top pod and 90m depth, to test communication at ranges between 0 to 50 m between the modems. Communication bandwidth, signal strength, ambient light levels (as measured by the modem) and packet loss were recorded throughout the trial. CTD+Turbidity profiles were taken at the same time for reference, and uploaded to datalakes.

### Results

From the recorded performance measurements, we derived an approximate model for the light propagation of the modem's emitted light (475nm for LUMA X, and 395nm for LUMA X UV), the link budget, and expected range and communication speed for a given turbidity level. This model will help with the design of data harvesting options for underwater sensor networks.

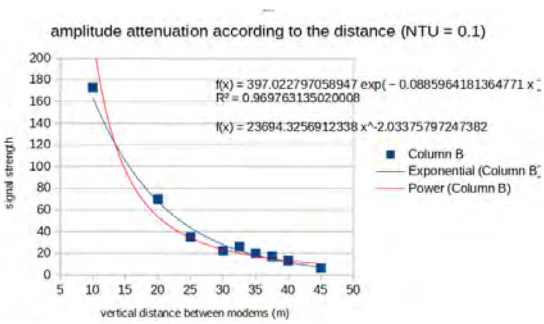



*Figure 1: Measured signal strength, and fitted model, for avg. turbidity of 0.1 NTU*

### Future work

We are planning to process the multi-spectral data from the THETIS instrument to get a better model of turbidity and blue light attenuation. We are also planning to investigate mitigation against biofouling on the optical window for long-term deployments. Finally, we are planning to combine optical communication, acoustic beacons, and the EXRAY autonomous underwater drone, to find a sensor with acoustic homing, and download the data via optical communication, working towards an automated data harvesting system.

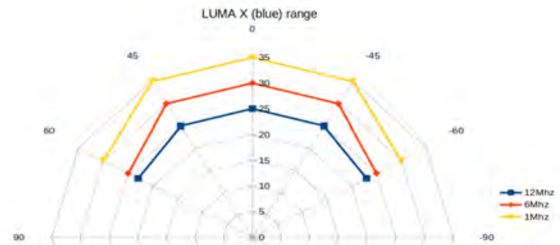



*Figure 2: Measured communication range*

EPFL

# Effect of lake exposure on a population of enteroviruses

Odile Larivé, Htet Kyi Wynn, Tamar Kohn

## Abstract

Enteroviruses are ubiquitous surface water contaminants, where they can persist for long periods of time and can pose a threat of human health. The sensitivity of different enterovirus genotypes to environmental stressors vary, and their persistence in the environment will too. To date, only few genotypes have been studied and most studies on environmental persistence were performed in the laboratory. The objective of this project was to evaluate the diversity in decay in Lake Geneva among a population of enteroviruses consisting of different genotypes. A population of eight enteroviruses was exposed to Lake Geneva using an environmental chamber for five days during winter and spring. We validated the use of our custom-made environmental chamber for the safe exposure of enteroviruses to the Lake, as well as the installation setup. We observed a wide range of inactivation among genotypes during both seasons, but the relative sensitivity of the genotypes differed between seasons. Inactivation was more globally important in spring, and at more shallow depth. Inactivation was not very important, with a maximal inactivation of 2.3 $\log_{10}$ and most genotypes being inactivated 1 $\log_{10}$ or less over five days. Furthermore, inactivation was found to be microbial mediated both in spring and in winter.

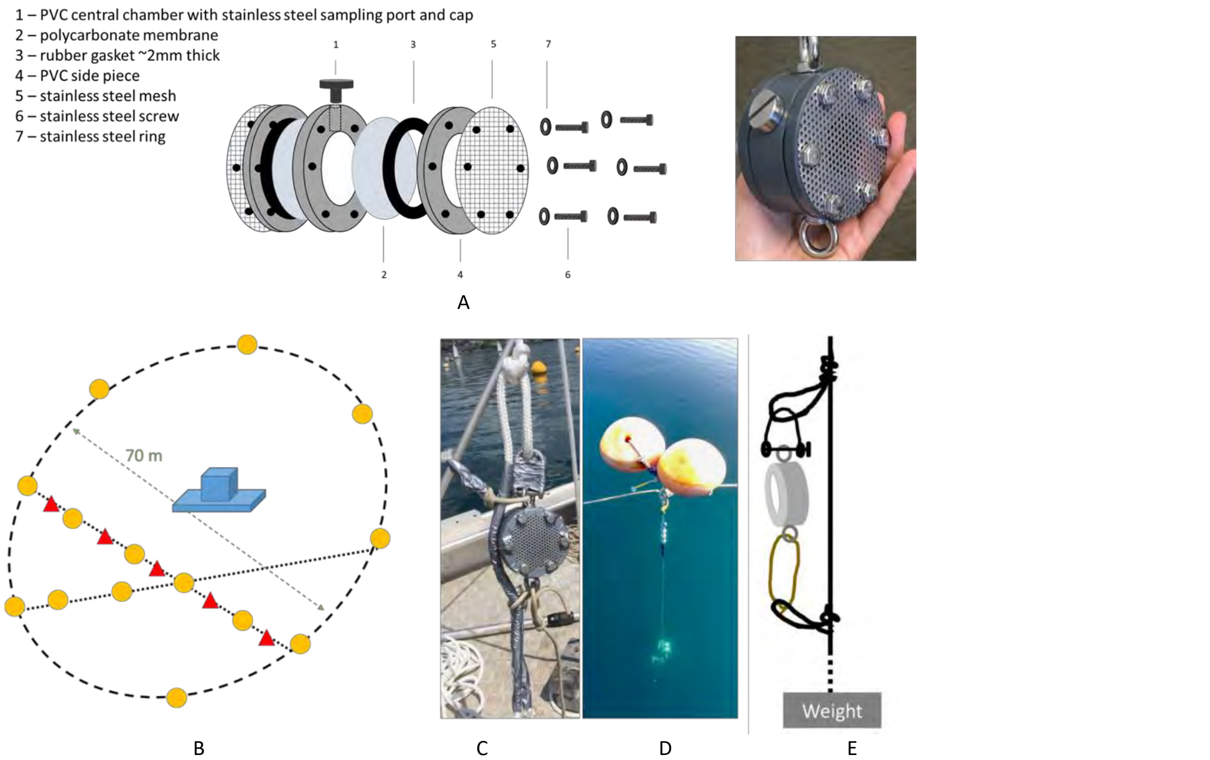



*Figure 1. (A) Schematic of the environmental chamber constituents and picture of the environmental chamber. (B) Schematic of the mooring site of the chambers at the Lexplore platform, the yellow circles and red triangles representing the main and secondary buoys. (C) Protection of the chamber and of the rope to avoid deterioration by friction. (D) Picture of a test chamber deployed at 2 m depth. (E) Attachment of the chamber to the rope to avoid tension due to the weight.*

## Main results

- **<u>We validated the use of diffusion chambers for the safe exposure of enteroviruses to the lake</u>** as well as the installation setup. Iterations were made to find the best configuration on site: a large distance between the chamber and the weight, an attachment of the chamber to the rope that avoids tension due to the weight, protection of the rope and chamber to avoid damage by friction, exclusion of the mooring depth of 2 m due to possible breakage of the membrane in windy weather, ideally a bit of slack between the buoy and the chamber mooring (chain) to lessen the impact of waves. The chamber itself has also been validated in the laboratory to ensure its water tightness. The tests went well without incident or release. It is an instrument that has a lot of potential to study in-situ virus inactivation.

- **<u>We obtained inactivation results in the lake for eight enteroviruses, during two seasons</u>**. Inactivation was observed for all genotypes in at least one season, but differences in inactivation patterns were observed between seasons. Some genotypes (CVA9, CVB3, CVB4 and CVB5) were more easily inactivated in the spring, while others (E25 and E30) were more easily inactivated in winter. The average water temperature at 15 m depth was about 7°C in winter and 13°C in spring. Microbial activity is expected to be low at these temperatures, but comparison with control experiments conducted in of sterile lake water suggest that the inactivation is primarily microbial. Differences in virus persistence were also observed depending on water depth. In spring, inactivation at 6 m depth was equal to or greater than inactivation at 15 m depth for all genotypes, although the differences observed were mostly subtle and not statistically significant. Just like in deeper water, the inactivation at 6 m was likely mediated by microorganisms in the lake. We found a wide range of inactivation rates across genotypes, both in spring and winter. Interestingly, the relative susceptibilities of different genotypes varied between winter and spring. Further work is needed to understand the effect of seasons on different genotypes. The underlying cause may be associated with changes in the composition of the microbial population between the two seasons.

This study shows that the season is an important factor governing the inactivation of enteroviruses in the lake. It further shows that the persistence of different genotypes varies greatly, but that the relative persistence genotypes depends on the season. As a result, enterovirus populations in the lake are expected to be dominated by different genotypes depending on the season (although the final population composition is also determined by genotype-specific excretion rates and removal efficiencies during wastewater treatment). Irrespective of the season, the inactivation observed in the lake was found to be mainly microbial.

The inactivation data obtained could be used to estimate inactivation rate constants for these viruses, which can be implemented in risk models, for example.

- **<u>Laboratory and on-site diffusion tests with methylene blue have shown the probable variability existing between the different membranes</u>**. This could have an impact on the inactivation of viruses inside the chamber. Despite this, exchanges between the lake environment and the chamber took place, given the volume variations observed in the chambers. Additionally, replica chambers show similar inactivation.

LéXPLORE

## Publications

Planned:

Effect of lake exposure on a population of enteroviruses. Odile Larivé, Htet Kyi Wynn, Tamar Kohn

## Conferences

Conference: Swiss Geoscience Meeting 2022. Effect of lake exposure on a population of enteroviruses. Odile Larivé, Htet Kyi Wynn, Tamar Kohn

## Collected data

- Description of the setup tests done with the chambers at the platform, description of the ideal configuration and of the things that have failed and why.
- Data of concentration of eight enteroviruses exposed to the lake environment for 0, 48h or 5 days, for three experiments during two seasons. The enterovirus included in the analysis were the following: coxsackieviruses A9, B1, B2, B3, B4, B5 (CVA9, CVB1, CVB2, CVB3, CVB4, CVB5) and echoviruses 25 and 30 (E25, E30). The following time points were taken:

| Experiment | Season | Timepoints and number of replicates |
|---|---|---|
| 1 | Winter | 0, 2x48h at 15 m depth |
| 2 | Winter | 0, 2x48h, 3x5 days at 15 m depth |
| 3 | Spring | 0, 3x48h, 2x5days at 15 m depth |
| | | 0, 3x48h, 2x5days at 6 m depth |

- Data of concentration of eight enteroviruses exposed to buffer and sterile lake water for 0, 48h or 5 days for three experiments at different temperatures. The following conditions and time points were taken:

| Experiment | Season | Matrix | Temperature | Timepoints |
|---|---|---|---|---|
| 1 | Winter | PBS | 4 °C | 48h, 5 days |
| 2 | Winter | PBS | 4 °C | 48h, 5 days |
| | | Sterile lake water | 4 °C | 48h, 5 days |
| 3 | Spring | PBS | 20 °C | 48h, 5 days |
| | | Sterile lake water | 20 °C | 48h, 5 days |

The data will be deposited on Zenodo.

EPFL

# LéXFISH

Jean Guillard, Chloé Goulon, Jake Vander Zanden, Martin Wegmann


## Abstract

The main goal of the project was to better understand fish aggregation behaviour in lakes below Fish aggregation devices (FADs) such as the LéXPLORE platform. After the installation of the sounders and a remoted control device, the first step was to post-process and analyse the recorded data using Echopype, a python library to analyse fishery acoustic data. Doing so, we could highlight daily fish migration behaviour for two meteorologically very different summers. While artificial signals (for example from other instruments close to the sensor) are difficult to exclude from the data, a relationship between hourly fish occurrence and thermocline depth seems to occur. Nevertheless, so far only preliminary results are available and more in-depth analyses are needed to substantiate this claim. Currently, different time resolutions and co-variates for fish occurrences are investigated. Eventually, these findings will be communicated to the scientific community.

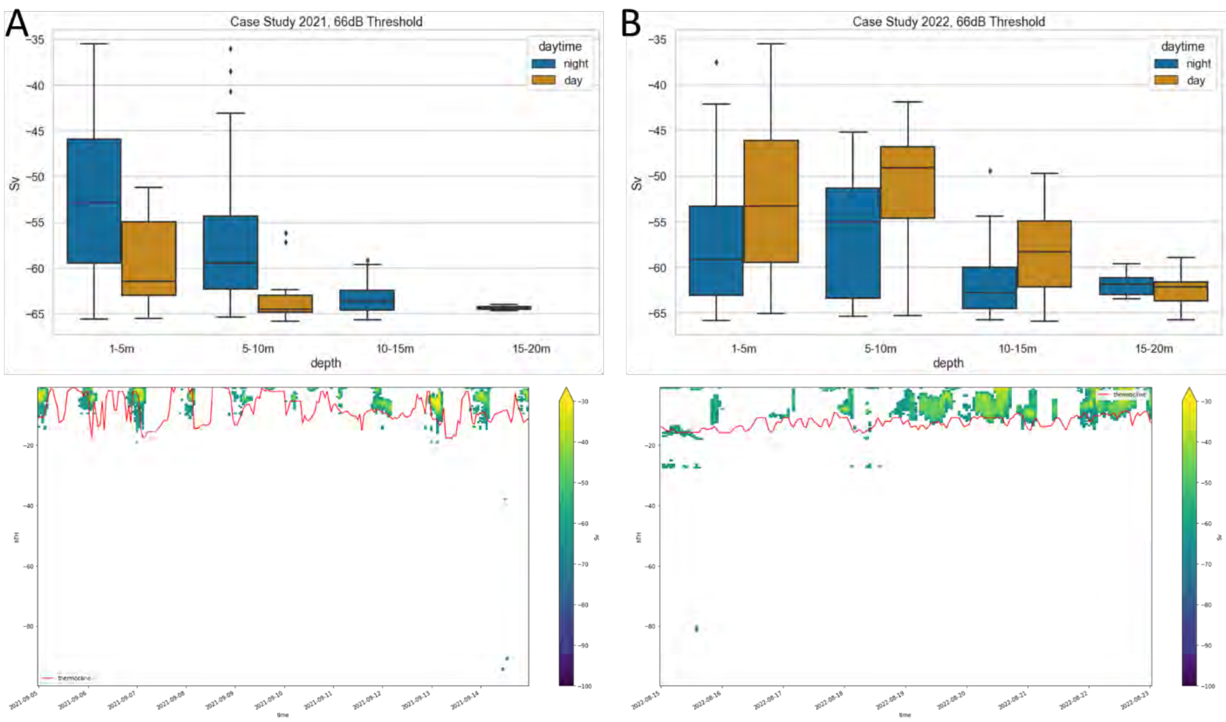




Figure: In 2021 (A), the upper graph shows the mean Sv (dB), a proxy of fish density, by depth for the whole period between day-time and night-time. At night, Sv values are higher than during day. In 2022 (B), it is opposite. Below, for the two periods, the fish densities (mean Sv by hour for the first 20 m) are shown by color (from purple to yellow, the maximum) with the thermocline (red line). Visually, the mean bottom school depth is related to the thermocline depth.

LéXPLORE

## Main results

Platforms, such as LéXPLORE, are floating devices where fish can aggregate (Dempster and Taquet,2004), known as Fish aggregation device (FAD) in a marine environment. However, less information and knowledge is available for ecological behaviour under lake FADs. As such, the main goal of the project was to better understand fish aggregation behaviours in lake. Two split-beam echosounders, 70 and 120 kHz, were set on the platform, using a medium pulse length (0.256 ms) (Godlewska et al., 2011), a high ping rate (5 pings /s), emitting permanently. Data from the sounders can be therefore analysed with the unique environmental data set presents on the platform. Data were recorded during one year and a half including two summers, with contrasting environmental conditions. Only the data from the 120 kHz sounder were analysed, the 70 kHz sounder, because of the transducer size and shape, had low quality data due to periodic accumulation of bubbles on its side. Data were first analysed during the LéXPLORE Hackathon in December 2022 and then step by step during spring and summer 2023. Additional results are still needed but preliminary results are available. The first step was to analyse data using Echopype (Lee et al., 2021), a new Python library to analyse fishery acoustic data. This library can be used to analyse a large data set and is more automated than common commercial analysis tools. The project focused on periods when fish schools were present in high abundance below the platform: two time periods were selected for detailed analysis, the 2021 case study (2021CS) period covering the 5$^{th}$ of September 2021 to the 15$^{th}$ of September 2021 and the 2022 case study (2022CS) period from the 15$^{th}$ of August 2022 to the 23$^{th}$ of August 2022. During these periods, the lake was stratified. First results show that night and day behaviours are contrasted between the two case studies (Fig A): For the 2021CS, a common behaviour of fish schooling during day-time was recorded, namely the urge of smaller fish to be protected from predators during daylight hours as well as scattering at night (Girard et al., 2020). Fish density is then lower during day (Sv values (MacLennan et al., 2002), the global energy of the sound reflected by targets, which are a proxy of fish densities, were lower): only a few schools were detected. At opposite, individual fish were detected throughout the night.. Schools were detected only a few times during day, scattered fish were always present during night. In 2022CS, the opposite was observed: higher fish densities were estimated during day-time. The hypothesis is that fish densities were globally much higher during this summer period due to higher recruitment as observed by fishermen and divers. For 2022CS fish were present at day- and night-time (mean Sv values were higher in 2022 than in 2021). As such, the common behaviour as previously described for 2021CS was not recorded in 2022CS. The second result, analyses are still in progress, is that the bottom depth of schools seemed to be linked to the thermocline depth. Analysis has begun to test this hypothesis of a correlation between bottom fish schools and the depth of thermocline. If visually it seems to be true, initial results showed that it is true for the 2022CS but not for the 2021CS, when thermocline showed greater variations. The relationship with zooplankton (existing data for the same period), which can also influence fish behaviour, needs to be also tested.

Dempster, T., Taquet, M. Fish aggregation device (FAD) research: gaps in current knowledge and future directions for ecological studies. Rev Fish Biol Fisheries 14, 21–42 (2004). https://doi.org/10.1007/s11160-004-3151-x

Lee, W., Mayorga, E., Setiawan, L., Majeed, I., Nguyen, K., & Staneva, V. (2021). Echopype: A Python library for interoperable and scalable processing of water column sonar data for biological information. arXiv preprint arXiv:2111.00187 MacLennan, D. N., P. G. Fernandes, and J. Dalen. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES J. Mar. Sci. 59, 365–369.

Girard M., Goulon C., Tessier A., Vonlanthen P., Guillard J., 2020. Comparisons of day-time and night-time hydroacoustic surveys in temperate lakes. Aquatic Living Resources, 33, 9., https://doi.org/10.1051/alr/2020011

LéXPLORE

Godlewska M., Colon M., Jóźwik A., Guillard J., 2011. How pulse lengths impact fish stock estimations during hydroacoustic measurements at 70 kHz. Aquatic Living Resources, 24, 71–78. 10.1051/alr/2011104

**Publications**

…

**Conferences**

LéXPLORE Day 2023

**Collected data**

**Data Source:**
https://lexplore.info/current-projects/lexfish/

**Data Used:**
https://drive.switch.ch/index.php/s/uLIYXTCMDqJs2tT?path=%2Fdata%2F2d_data

Data are planned to be deposited in www.datalakes-eawag.ch with available codes for the analysis.

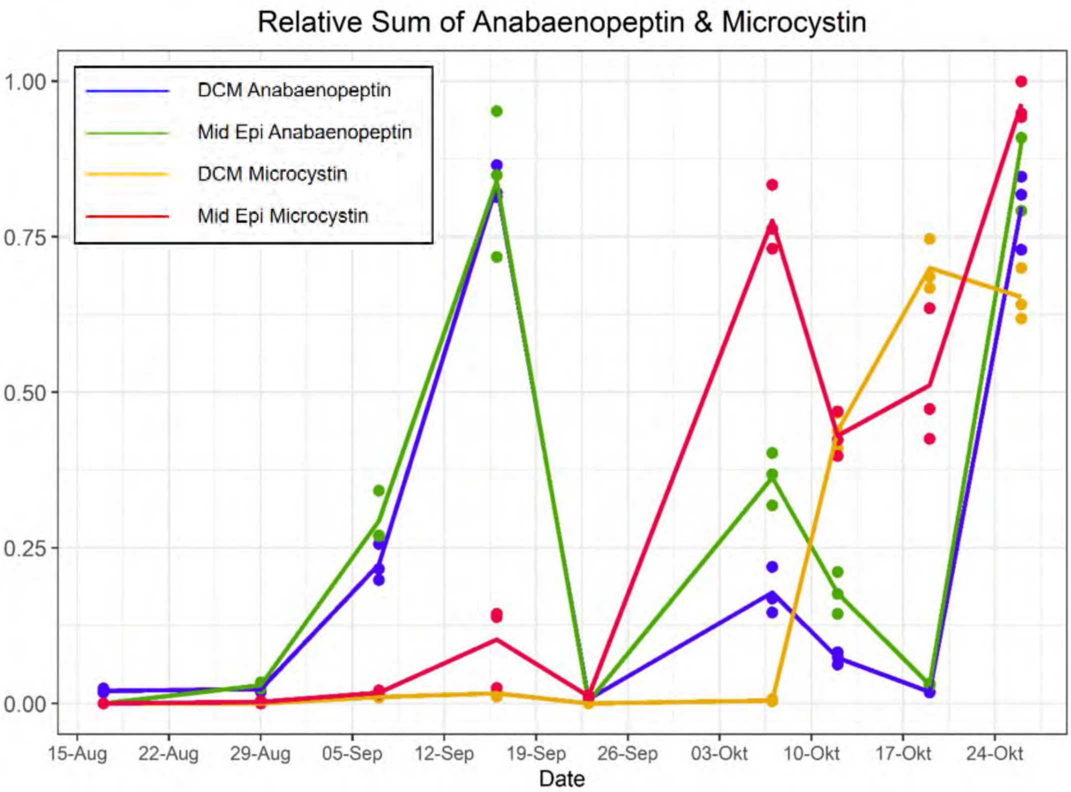
LéXPLORE

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

Anna Carratalà, Elisabeth Janssen, Bas Ibelings, Loé Maire, Daniel Odermatt

**Abstract**

The objectives of the project were to: (i) identify the diversity of both planktonic and benthic cyanobacterial populations by metagenomics and characterize the production of cytotoxins throughout the year, (ii) develop new protocols for the early detection of cyanobacterial blooms and mats by remote sensing, and (iii) to incorporate our findings into risk assessment protocols. To this end, we developed 2 campaigns of weekly samplings from the beginning of July until November 2022. We aimed to determine the dynamics of two main Cyanobacteria that are abundant in Lake Geneva: *Cyanobium* (which is abundant in late summer and early autumn) and *Planktothrix* (mostly dominant in winter). Our results showed that the Cyanobacteria community followed a general seasonal trend, but the relative abundance of the 3 main genera (i.e., Cyanobium, Plantkothrix and Pseudanabaena) was variable. The three were found at every depth, with Cyanobium showing a preference for the surface water when the water column started to stabilize, while Planktothrix and Pseudanabaena favored deeper layers. The succession of Pseudanabaena and Planktothrix followed the evolution of the stratification of the water column, with Pseudanabaena appearing to be advantaged by the light conditions generated by the stabilization of the water column, thus dominating Plantkothrix during the summer season. Similar cyanometabolites were detected in 2022 as compared to 2021 data (CYANOFUN). However, the concentrations from DCM 2022 were overall lower (approx. 10 to 20-fold). In 2021 we observed peak concentrations in September with 1550 ng/L for anabaenopeptins and 147 ng/L for microcystins. Further research is needed to improve the measurements of $a_{ph}$ and to identify spectral features indicative of certain phytoplankton species. The former could be achieved by measuring filtered and unfiltered spectral absorption in a flow-through system rather than on the Thetis profiler. The latter could be investigated using phytoplankton camera classifications rather than metagenomic analyses, or, ideally, by specifying species-specific absorption features from controlled samples. Overall, Cyanobacteria communities are dynamic and widely present in Lake Geneva across all depths and throughout the year. However, protocols to use remote sensing to predict Cyanobacteria proliferation will require further work. Low concentrations of cyanotoxins including microcystins are detected in lake samples, but they are recurrently below guideline recommendations. Overall, health risk driven by Cyanobacteria in Lake Geneva are low, but the existence of toxic species is concerning in a context of climatic changes, and warrants further investigations.




DCM = Deep chlorophyll maximum; Mid Epi = Middle of the Epilimnion.

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## Main results

The objectives of the project were to: (i) identify the diversity of both planktonic and benthic cyanobacterial populations by metagenomics and characterize the production of cyanotoxins throughout the year, (ii) develop new protocols for the early detection of cyanobacterial blooms and mats by remote sensing, and (iii) to incorporate our findings into risk assessment protocols.

To achieve these goals, we conducted sampling campaigns during from July to November 2022. I total, we collected water samples at different depths (2.5, 10, 15, 20, 30 and 50 m) on a weekly basis. During the sampling period, occurrence of heavy storms was repeatedly identified, and we used the opportunity to include more intensive sampling campaign before and after storms, to assess the role of meteorological factors on Cyanobacteria composition.

***Cyanobacteria community dynamics.*** The obtained samples were used to extract nucleic acids and the composition of Cyanobacteria communities was determined by Illumina high-throughput sequencing. In addition, cyanotoxin concentrations were determined by Dr. Janssen using mass spectrometry. Our results showed that the Cyanobacteria community followed a general seasonal trend, but the relative abundance of the 3 main genera (i.e., Cyanobium, Plantkothrix and Pseudanabaena) is variable. The three genera were found at every depth (0-100 m), with Cyanobium showing a preference for the surface water when the water column started to stabilize, while Planktothrix and Pseudanabaena favored deeper layers. The succession of Pseudanabaena and Plantkothrix has followed the evolution of the stratification of the water column, with Pseudanabaena appearing to be advantaged by the light conditions generated by the stabilization of the water column, thus dominating Plantkothrix during the summer season.

In summer, the environmental conditions of the epilimnion (i.e., high light intensity, low nutrients, and elevated temperature) greatly promoted the development of Cyanobium. Nevertheless, its increase during the warm season does not necessarily exclude the development of Planktothrix and Pseudanabaena in the deeper layers of the lake. It appears that the summer assemblage is mainly determined by the environmental conditions at the beginning of the season, and that the composition remains relatively stable until the beginning of the mixing of the waters. The intensity of the stability of the water column at the beginning of the summer thus seems to be a determining factor in the distribution of these three species. This suggests that the increase in temperature and the re-oligotrophication of the lake will promote the development of Cyanobium in the upper layers of the water, but this does not necessarily extend to the entire water column, since stratification establishes niches in which Pseudanabaena and Planktothrix can cohabit with the picocyanobacteria.

The study also highlighted that, under stratified conditions, a meteorological disturbance (i.e., wind and rain) can modify the cyanobacterial community distribution in the short term. The relative abundance of Cyanobium did indeed decrease at certain depths (3.5 m / 8 m), accompanied by an increase in Planktothrix. The latter could be the result of several factors, such as a displacement of water mass generated by the wind, the creation of a suitable niche for the species with a decrease in light intensity and the increase in surface nutrients caused by rain. After a few days of calm, however, Cyanobium regained the upper layers of the water column, indicating a certain resilience of the genus under stratified conditions. Further studies on additional weather events would be required to statistically validate these observation-based hypotheses.

***Detection of Cyanobacteria by remote sensing.*** We compared metagenomics data and in-situ bio-optical measurements by the Thetis profiler, in order to find common patterns that allow for an indication of cyanobacteria using bio-optical measurements. The 2021 metagenomics database (obtained in the context of Cyanofun project) consists of the abundance of phytoplankton species over several months, and in depths between 3 and 80 meters. The Thetis profiler at LéXPLORE measured bulk spectral absorption at high vertical resolution (0.5 to 50 m) at several times a day. This project used Thetis data from 2018 to 2020.

*Planktothrix* and *Cyanobium*, two toxic species commonly found in Lake Geneva have particular pigments that can potentially affect the shape of the spectral absorption. *Planktothrix* contains phycoerythrin (PE) and is mostly dominant in winter and at great depths and colder water in summer. *Cyanobium* contains phycocyanin (PC) pigment and is abundant in summer. The bio-optical data was prepared for analysis by deriving the phytoplankton absorption ($a_{ph}$) from the measured bulk absorption. $a_{ph}$ was computed with an inversion algorithm [Zheng, 2023]. The fourth spectral derivative of $a_{ph}$was then calculated in order to find two distinct features of PE (around 500 and 590 nm) and one feature related to PC (625 nm). In principle, all of these features could be detected, although the 4$^{th}$ derivative $a_{ph}$ spectrum of our measurements showed a high noise level in many spectral intervals. In particular in winter time, the noise level was too high to use the spectral features of PE to indicate the increased abundance of *Planktothrix*. The features appeared much more prominently in summer time, but they did not systematically correlate with *Cyanobium* abundance. Further research is needed to improve the measurements of $a_{ph}$ and to identify spectral features indicative of certain phytoplankton species. The former could be achieved by measuring filtered and unfiltered spectral absorption in a flow-through system rather than on the Thetis profiler. The latter could be investigated using phytoplankton camera classifications rather than metagenomic analyses, or, ideally, by specifying species-specific absorption features from controlled samples.

***Cyanotoxin analysis.*** Of the 18 tested cyanopeptides, we identified 3 microcystins and 3 anabaenopeptins. One of the classi-cal microcystins was detected (MC-LR) and 2 other variants, [D-Asp3,E Dhb7]-MC-RR as well as a minor contribution of [D-Asp3] MC-LR. The maximum concentrations of total microcystins reached 16.5 ng/L in October. This concentration is below the WHO guideline values for recrea-tional as well as drinking water (24 µg/L and 1 µg/L, respectively). In addition to microcystins, three anabaenopeptins were detected throughout the seasons: Anabaenopeptin A, anabaeno-peptin B and oscillamide Y. The maximum concentrations of total anabaenopeptins peaked at 75.2 ng/L in September and again at 79.0 ng/L in October.

The concentrations for DCM samples (deep chlorophyll maximum) and for Mid Epi samples (middle of the epilimnion, always sampled at 7.5m) followed largely the same trend for total anabaenopeptins. The exceptions were samples from October 07th and 12th. Here, the Mid Epi samples showed significantly higher concentrations than the DCM. For total microcystins, the Mid Epi generally showed higher concentrations, best visible for samples from September 16th, October 07th and October 26th. The data demonstrate that the ratio of microcystins to ana-baenopeptins is different between the DCM and the Mid Epi samples and at times microcystins even dominated (October 07-19). Assuming that the producing organisms is the same (Planktothrix), this difference suggests that the production dynamics in the different depths dif-fers.

In October, the maximum chlorophyll occurred in more shallow waters, moving up from 10-15.5m in August and September to 2-6.2m in October. The depth of the DCM samples taken at the chlorophyll max varied accordingly. In August and September the DCM samples were taking below the Mid Epi, i.e., below 7.5 m, and in October above the Mid Epi, i.e., above 7.5 m. Only when the DCM was above the Mid-Epi, the anabaenopeptins were more concentrated in the Mid Epi than in the DCM. One hypothesis can be that the cyanobacterial biomass resided below the layer of periphyton that contributes mostly to the DCM signal. Planktothrix, as main produc-er of anabaenopeptins, harbors phycoerythrin, which allows them to harvest a larger light spectrum and it is observed that they can then thrive in deeper water layers or underneath photo-synthetically active biomass.

Compared to DCM data from the previous year 2021, the same metabolites were detected, however, the concentrations from DCM 2022 are overall lower (approx. 10 to 20-fold). In 2021 we observed peak concentrations in September with 1550 ng/L for anabaenopeptins and 147 ng/L for microcystins. In 2021 we analysed monthly samples from February until December, while in 2022 samples were taken more frequently bi/weekly between mid-August and No-vember. In 2021 the concentrations of microcystins and anabaenopeptin tracked each other more closely, however, the lower time resolution of the samples does not allow to judge what happened on a weekly time scale.

**Publications**

Publications are under development.

**Conferences**

An abstract will be submitted to Swiss Geosciences meeting.

**Collected data**

- Next generation sequencing data of the bacteria communities in 170 samples collected from Lake Geneva from July 2022 until November 2022.
- qPCR data on the abundance of total Cyanobacteria in 170 samples collected from Lake Geneva from July 2022 until November 2022.
- qPCR data on the abundance of microcystin A genes in 170 samples collected from Lake Geneva from July 2022 until November 2022.
- Environmental dataset of CTD profile information for to each sampling date.
- Cyanotoxin dataset for DCM samples collected from July 2022 until November 2022.

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

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# Carbon Cycle in Lake Geneva (CARBOGEN)

Marie-Elodie Perga, Nicolas Escoffier, Thibault Lambert, Gael Many, Marttiina Rantala et Pascal Perolo

**Abstract**

The role of lakes and other inland waters as significant $CO_2$ emitters has been repeatedly demonstrated over the last three decades. Global evasion of $CO_2$ from inland waters, which magnitude is comparable to the atmospheric ocean sink, is now accounted for in global carbon models. However, major uncertainties remain on the ultimate causes and drivers of $CO_2$ supersaturation, notably in lakes, limiting our ability to assess and forecast their variability in space and time.

The metabolic theory has long been the core paradigm for lakes' carbon cycle; i.e., lake metabolism, the balance between inorganic fixation by primary production and release by organic matter mineralization (respiration at large), is the primary mechanism controlling C cycling in lakes. However, the metabolic theory fails to explain how clearwater, autotrophic lakes, such as large Swiss peri-alpine lakes could be $CO_2$ supersaturated, as well as the magnitude and directions of the changes we observed for the last 150 years. More generally, the reality check from the few available time series on lake surface $CO_2$ has revealed that the metabolic theory could not be verified on the ground. We hypothesized that the general discrepancy between observations and theory arises from (i) limited coverage of spatial and temporal variability of processes and (ii) overlooked critical mechanisms by which alkalinity, brought by the catchment 's hydrological inputs, gets converted into $CO_2$.

We, therefore, opted for an in-depth survey of the carbon processes in lake Geneva. We are unaware of any previous study tying up the whole carbon processes in a lake year-round, and Lake Geneva appeared as an ideal pilot site. First, Lake Geneva is one of the most surveyed lakes in the World. Nevertheless, an attempted heuristic carbon budget based on the wealth of available lake data and its catchment is remarkably unbalanced. Second, Lake Geneva, whereby 95% of the carbon stocks are inorganic, receives alkalinity from its catchment. Regular observations of whiting events (sudden but regular events of massive calcium carbonate precipitation) attests that the lake alkalinity is reactive and might contribute to overall lake C fluxes, offering a unique opportunity to finally deal with the insofar unaccounted inorganic geochemistry in lake carbon cycles. LéXPLORE enabled the deployment of new approaches to monitor carbon processes at high-frequency ($CO_2$ fluxes at the lake surface from forced-diffusion flux chambers_**Fig .1a & b**, Dissolved organic carbon by in-situ absorbance, Dissolved inorganic carbon from conductivity and pH, and calcite precipitation. Spatial field samplings and remote-sensing approaches were instrumental also to quantify the spatial and temporal variability of the lake's carbon processes.

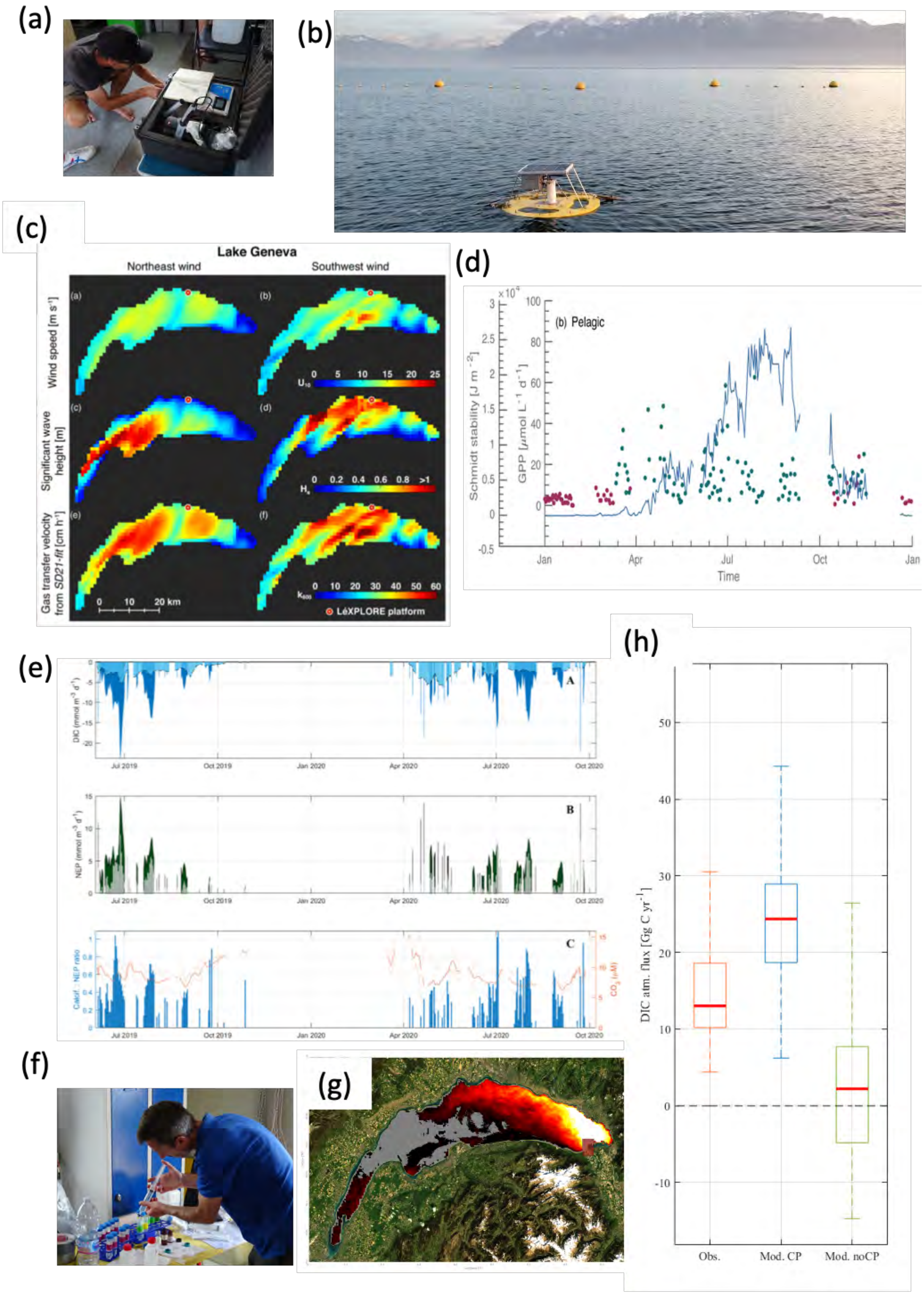


*Fig. 1: Field work and Instrumentation for the CARBOGEN project and illustration of selected results: a) Water CO2 measurements onboard LéXPLORE, b) the forced-diffusion $CO_2$ flux chamber deployed at LéXPLORE, c)*

*spatially resolved modelled gas transfer velocities accounting for wave action on Lake Geneva, d) origin of inorganic carbon sustaining daily gross primary production over a full year in Lake Geneva with $CO_2$ uptake in purple and alkalinity consumption in green, e) finely time-resolved DIC loss, net ecosystem productivity and calcite precipitation over two consecutive summers, f) filtration onboard for sensors calibration, g) map of the occurrence of whiting events in Lake Geneva, 1958-2021. Clearer colors indicate more frequent locations of whitings, as reconstructed from remote sensing storage and transfer in Lake Geneva, h) annual $CO_2$ fluxes at the surface of lake Geneva computed from field observation in orange, and simulated with _blue_ or absence of _green_ calcite precipitation.*

## Main results

Published results have addressed carbon processes' time and space variability. Perolo et al. (2021) showed, for instance, that episodic extreme events with surface waves (6% occurrence) can generate more than 25% of annual net $CO_2$ fluxes in Lake Geneva. The paper also provides a method to estimate gas-piston velocity, accounting for the surface variability in the wind and wave fields (**.**). Perolo (2022) also showed that littoral habitats, despite representing <9% of the surface area, can contribute 35-50% of the total lake $CO_2$ emissions. Combining spatial samplings with bioassays (Lambert & Perga, 2019) demonstrated the high biogeochemical reactivity at the Rhône (the largest inflow) estuary, where the lake and river waters mix, leading to non-conservative behaviors of organic carbon processes. Using remote sensing and machine learning, Many et al (2022) showed that whitings could occur from 0 up to 48 days per year between 1958 and 2021 (mean=18 days), and mostly (95%) in the Western area of the lake where the Rhône influence is maximal (**Fig. 1g**). The annual frequency of whitings tended to increase for years with greater precipitations, and the timing has shifted to earlier whitings with climate change (Many et al, 2022).

A second phase of the work focused on inorganic carbon geochemistry. While alkalinity is assumed as the primary driver of the $CO_2$ supersaturation of hard-water lakes, the mechanisms by which alkalinity converts into $CO_2$ supersaturation remain unexplained. Briefly, alkalinity to $CO_2$ conversion can involve two dominant pathways; (i) the carbonate equilibrium, which is mathematically well constrained and does not affect the total alkalinity, (ii) an alkalinity sink mediated by primary production, primarily through calcite precipitation, which is basically unconstrained. Our purpose here was then to constrain the conditions and C fluxes generated by daily calcite precipitation so that we could create a calcite dynamics module to be implemented in the deterministic water quality model AED2. Combining isotope tracing, geochemical modeling, and remote sensing, Escoffier et al., (2022) could delineate the reasons underlying the specific spatial and temporal distribution of whiting events and address the mechanisms by which high Rhone inflows, rather than phytoplankton blooms trigger those whiting events. However, we found out that whiting events contribute <10% of annually precipitated calcite in the lake and that their contribution to the lake calcite dynamics could be neglected for the final lake C model (Perga et al, 2022).

The continuous calcite precipitation during stratification is the dominant alkalinity sink. Finely time-resolved measures from LéXPLORE showed that alkalinity consumption supported daily primary production for 75% of the year (Perolo et al, 2023, **Fig.1d**) and that calcite precipitation provided enough $CO_2$ to support, on average, half of the daily primary production (up to 100% in the most productive days) (Escoffier et al, 2023, **Fig. 1e**).

The modeling step relied on a coupled 1D physical (SIMSTRAT) and water quality (AED2) model to which we added a calcite module parametrized from the results of Perolo et al (2022, 2023) and Escoffier et al (2023). Once parametrized, the model was used to quantify the role of alkalinity and calcite precipitation in the net positive emissions of lake Geneva. Simulations showed that without calcite precipitation, lake Geneva would be neutral (nor a source, neither a sink of atmospheric C). Calcite precipitation explained why the lake is a net C-source (**Fig. 1h**).

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## Publications

Perolo, P., Castro, B.F., Escoffier, N., Lambert, T., Bouffard, D., Perga, M.E. (2021) Accounting for surface waves improves gas flux estimation at high wind speed in a large lake. Earth System Dynamics 12, 1169-1189.

Escoffier, N., Perolo, P., Lambert, T., Rüegg, J., Odermatt, D., Adatte, T., Vennemann, T., Perga, M.-E. (2022) Whiting Events in a Large Peri-Alpine Lake: Evidence of a Catchment-Scale Process. Journal of Geophysical Research: Biogeosciences 127, e2022JG006823.

Lambert, T., Perolo, P., Escoffier, N., Perga, M.E. (2022) Enhanced bioavailability of dissolved organic matter (DOM) in human-disturbed streams in Alpine fluvial networks. Biogeosciences 19, 187-200.

Many, G., Escoffier, N., Ferrari, M., Jacquet, P., Odermatt, D., Mariethoz, G., Perolo, P., Perga, M.-E. (2022) Long-Term Spatiotemporal Variability of Whitings in Lake Geneva from Multispectral Remote Sensing and Machine Learning. Remote Sensing 14, 6175.

Escoffier, N., Perolo, P., Many, G., Pasche, N.T., Perga, M.-E. (2023) Fine-scale dynamics of calcite precipitation in a large hardwater lake. Science of the Total Environment 864, 160699.

Perolo, P., Escoffier, N., Chmiel, H.E., Many, G., Bouffard, D. and Perga, M.-E. (2023), Alkalinity contributes at least a third of annual gross primary production in a deep stratified hardwater lake. Limnol. Oceanogr. Lett. https://doi.org/10.1002/lol2.10311

Lambert, T., Perga, M.-E. (2019) Non-conservative patterns of dissolved organic matter degradation when and where lake water mixes. Aquatic Sciences 81, 64.

Rantala, M.V., Bruel, R., Marchetto, A., Lami, A., Spangenberg, J.E., Perga, M.-E. (2021) Heterogeneous responses of lake CO2 to nutrients and warming in perialpine lakes imprinted in subfossil cladoceran δ13C values. Science of the Total Environment 782, 146923.

Fernández Castro, B., Chmiel, H. E., Minaudo, C., Krishna, S., Perolo, P., Rasconi, S., & Wüest, A. (2021). Primary and net ecosystem production in a large lake diagnosed from high-resolution oxygen measurements. Water Resources Research, 57, e2020WR029283.

Publications under review

Many, G. Escoffier, N; Perolo, P, Bouffard D. and Perga M-E. The role of the alkalinity-primary production counter pump in CO2 emissions of lake Geneva. Limnol. Oceanogr. Lett.

## Conferences & public communications

Over 10 oral communications in international conferences (AGU, EGU, ASLO and SGM) and 2 invited seminars.

## Filling in the gaps of Lake Geneva's carbon cycle research

LéXPLORE

https://www.openaccessgovernment.org/lake-genevas-carbon-cycle-snsf-funded-project-carbogen/132658/

**Carbon cycle in Lake Geneva**

https://issuu.com/euresearcher/docs/digital_magazine_eur28/s/13629489

## Collected data

Perolo, P. $CO_2$ flux measurements in Lake Geneva (2021). https://zenodo.org/record/5679883#.Y7VsJ-zMJTY

Perolo, P. CO2, O2, and Alkalinity in Lake Geneva (2022) https://doi.org/10.5281/zenodo.7442327

Escoffier, N. Sampling campaign data - Lake Geneva. (2022) https://doi.org/10.5281/zenodo.6421494

Escoffier, N. HF data - Lake Geneva. (2023). https://doi.org/10.5281/zenodo.7463768

LéXPLORE

# Biodegradability assessment of PBX, a sustainable bio-polyester developed at EPFL

Maxime Hedou, Lorenz Manker, Jeremy S. Luterbacher (Laboratory of Sustainable and Catalytic Processing, EPFL)

## Abstract

The Laboratory of Sustainable and Catalytic Processing (LPDC) at EPFL developed and patented a new polyester (PBX) derived from non-edible biomass. A novel diacid can be produced in only two steps from the hemicellulosic sugars contained in the non-edible biomass and can be copolymerized with a diol to form a polyester with properties analogous to PET, with the main difference being bio-sourcing and potential biodegradability. Preliminary data demonstrated that the material is degradable in water with complete dissolution depending on pH and temperature[1]. In order to demonstrate « marine degradability in fresh water », the project aims to perform degradability tests in Lake Geneva. Three PBX samples of 1x1 $cm^2$ were trapped in a zooplankton net (100 microns mesh) to prevent any materials release and secured in a drilled plastic container (Fig. 1). The samples were immersed next to Léxplore on 31.05.2021 with the help of Sébastien Lavanchy and Guillaume Cunillera (Fig. 1). The three pieces of PBX were collected after 1 month, 3 months, and more than one year. Residual materials were characterized to determine residual mass and molecular weight. After one year in the lake, the novel polyester was fully degraded but traces of the monomers were found in the net.

Fig. 1. Picture of the set-up and of the installation on LéXPLORE.

EPFL

**Main results**

This project aimed to get a first screening of the degradability of our novel polyester in Lake Geneva. Three PBX samples of 1x1 $cm^2$ were trapped in a zooplankton net (100 microns mesh) and immersed in the lake on 31.05.2021 (Fig. 1). Samples were recovered at four weeks, 12 weeks, and 78 weeks their mass and molecular weight were determined, as reported in Table 1.

| Sample name | Time in the lake | Mass retention (%) | Mn (g/mol) | Polydispersity | Mn retention (%) |
|---|---|---|---|---|---|
| Ls.Pol28 | 0 week | 100 | 20.46[a] | 2.42 | 100 |
| Lac leman 1 | 4 weeks | 100 | 13.01[a] | 1.99 | 63 |
| Lac leman 2 | 12 weeks | 100 | 7.88[a] | 1.86 | 38 |
| Lac leman 3 | 78 weeks | 0 | <1[b] | / | 0 |

Table 1 Polyester degradability over time (a: determined by Gel Permeation Chromatography - GPC, b: determined by Nuclear Magnetic Resonance – NMR)

From these results, it is confirmed that the polyester is degrading in Lake Geneva as the last sample was essentially fully solubilized and the molecular weight decreased with increasing time in the lake (Table 1). The rate of depolymerization in Lake Geneva appears to be more or less in line with the depolymerization rate measured in laboratory conditions[1], despite lower water temperatures (12-20 °C). However, the initial molecular weight of the samples tested here were lower than those measured by *Manker et al.*, making direct comparison difficult.

Finally, although it is possible to conclude that the polymer is degrading, it is not possible to conclude the biodegradability of the depolymerization product. The film was totally degraded after 78 weeks but a $^1$H-NMR on the zooplankton net revealed traces of the sugar-based monomer. This likely means that the kinetic rate of the polymer degradability is faster than the kinetic rate of the monomer degradability. Following this result, further characterization will be done on the sugar-based monomer to know more timeline required to break the acetal monomer in lake conditions and to get more information about the biodegradability and toxicity of the monomer. Preliminary analyses performed on the sugar-based monomer showed that our molecule is not likely to be a carcinogen. In conclusion, these results show that these novel bio-based polyesters are highly degradable in freshwater marine conditions when compared to other polyesters such as PET, and even biodegradable (industrial composting conditions) polyesters such as PLA. This shows that these materials achieve similar degradability to bacterial-based poly(hydroxy alkanoates) but with the thermomechanical properties of PET.

**Publications**

(1) Manker, L. P.; Dick, G. R.; Demongeot, A.; Hedou, M. A.; Rayroud, C.; Rambert, T.; Jones, M. J.; Sulaeva, I.; Vieli, M.; Leterrier, Y.; Potthast, A.; Maréchal, F.; Michaud, V.; Klok, H.-A.; Luterbacher, J. S. Sustainable Polyesters via Direct Functionalization of Lignocellulosic Sugars. Nat. Chem. 2022, 1–9. https://doi.org/10.1038/s41557-022-00974-5.