GLEON 21.5

Book of Abstracts

GLEON

global lake ecological observatory network

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Poster Abstracts

Macrosystems EDDIE teaching modules significantly increase ecology students' proficiency working with ecosystem models and use of systems thinking

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Aquatic scientists are increasingly using ecosystem simulation models to understand ecological dynamics occurring across multiple spatial and temporal scales. Consequently, integrating simulation modeling and other advanced computational skills into undergraduate curricula is essential to training the next generation of aquatic ecologists. Through the Macrosystems EDDIE (Environmental Data-Driven Inquiry & Exploration) educational program, we developed four hands-on, data-driven modules to introduce simulation modeling to aquatic ecology students in the R statistical environment. Each module combines high-frequency sensor data from GLEON (Global Lake Ecological Observatory Network) and NEON (National Ecological Observatory Network) lakes with whole-lake ecosystem simulation models. We embedded the modules into ecology courses at 17 colleges and universities and assessed student perceptions of models with pre- and post-module assessments. Across all 277 undergraduate and graduate students who participated in our study, completing one Macrosystems EDDIE teaching module significantly increased students' proficiency and likely future use of simulation models. Further, students were significantly more likely to describe that an important benefit of ecosystem models was their "ease of use" after completing a module. Interestingly, students were significantly more likely to provide evidence of systems thinking after completing a module, suggesting that hands-on ecosystem modeling activities may increase students' understanding of how individual components interact to affect system-level dynamics. Overall, Macrosystems EDDIE modules help students gain confidence in their ability to use ecosystem models and provide a useful method for instructors to introduce ecosystem simulation modeling to their undergraduate and graduate students.

Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

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The MONOCLE project is developing a number of in situ observation systems intended to lower operational water quality monitoring and better link in situ and satellite observations of water quality. We will present an update of the latest technological developments ranging from the use of smartphone extensions and non-expert drone flights to automated observation systems to register water colour and atmospheric properties.

Feeding strategy of zooplankton during autumn-winter-spring in a monomictic temperate reservoir

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The biomass and species composition of zooplankton in stratified lakes in winter conditions, when the losses by predation of planktivorous fish are small, is assumed to develop mainly according to the availability and dietary quality of seston. In order to verify this assumption, we monitored the changes in net zooplankton and the composition of seston in the mesotrophic Římov reservoir (max. depth 42 m; TP 30 µg/L; Z-Secchi 3.0 m) during one mixing period (November 2019–April 2020). At the beginning of mixing during autumn, Daphnia and Ceriodaphnia sp. dominated, but then were gradually replaced by Daphnia and Bosmina sp. with a growing proportion of copepods. Phytoplankton biomass and bacterial counts steadily decreased during the whole mixing period until the spring, when they increased with the onset of stratification, while the proportion of detritus in the seston particles increased throughout the mixing period. The phytoplankton assemblage was initially composed of cyanobacteria and diatoms, but the composition gradually changed towards diatoms, cryptophytes and green algae. Using analysis of signature fatty acids and stable isotopes (13C, 15N) in zooplankton and in two different seston size fractions (<40 µm and 40–100 µm), we intend to elucidate what was the main diet of each zooplankton group during the mixing period and whether carnivory occurred in some groups of copepods.

Initial analysis of Essential Climate Variables from ESA's Lake_CCI Satellite Data Package

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Lakes are rapidly responding strategic systems and key sentinels of global change. A globally harmonized observation approach is needed to identify climate signals in lake physical, hydrological and biogeochemical change to support numerical models. One effort in this direction is the ongoing European Space Agency Climate Change Initiative for Lakes (Lakes CCI).

The overarching objective of the project is to produce and validate a consistent data set of Essential Climate Variables (ECVs) for lakes. This includes aiming for the longest period of combined satellite observations by designing and operating processing chains, designed to ultimately feature in a sustainable production system.

Lakes CCI focuses on the following five thematic climate variables:

- Lake Water Level (LWL)
- Lake Water Extent (LWE)
- Lake Surface Water temperature (LSWT)
- Lake Ice Cover (LIC): dynamics of freeze-up in autumn and break-up in spring
- Lake Water-Leaving Reflectance (LWLR): estimates of chlorophyll-a and turbidity

The first Climate Research Data Package (v1, 2020) was recently created for up to 250 globally distributed lakes. It brings together the state-of-the-art in satellite observation using thermal, optical and altimetry missions. The Lakes CCI products are open access presenting an opportunity for lake scientists and climate modellers worldwide to perform studies for which the five lakes variables represent an important dataset. In this conference we will present the project overview and progress with a focus on the preliminary results of the 5 ECVs at global level.

LakeEnsemblR: An R package that facilitates ensemble modelling of lakes

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LakeEnsemblR is a new R package, created by AEMON-J and GLEON members, that facilitates running model ensembles of currently up to five different models (FLake, GLM, GOTM, Simstrat, and MyLake) in a consistent and standardised manner. Using model ensembles has several benefits compared to single-model applications, but is not yet frequently used within the lake modelling community. The LakeEnsemblR R-package can help to overcome this by providing a framework that contains functions for setting up, running, calibrating and post-processing an ensemble simulation of one-dimensional lake models. It uses a standardised format for forcing and output files, and one single configuration file that contains lake-specific information like hypsography as well as model specific settings and parameter values. After running the ensemble, the output from the single models are combined in one file. We showcase the package structure, its most important functions and an example application to two different lakes.

Investigation of littoral zone carbon flux in a humic lake in the west of Ireland.

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Peatlands in Ireland are the largest terrestrial store of carbon. These habitats are, however, particularly vulnerable to carbon mobilisation as a result of human activities which have greatly modified carbon exchange between the atmosphere, land and downstream freshwater bodies. This mobilisation of carbon has been reported as an increase in dissolved organic carbon in multiple aquatic peatland catchments in the Northern Hemisphere. The potential impact of this destabilisation in carbon stores is poorly understood for both terrestrial and aquatic ecosystems, with a greater focus up until now placed on investigating the impact on the pelagic zones of lakes and the inputs from larger streams and rivers. However, the role of the littoral zone, which surrounds the lake edge, in carbon dynamics represents a gap in global literature. This project aims to investigate carbon cycling in the littoral zone of Lough Feeagh, examining its contribution to carbon gas exchange and environmental controls within the lake. In addition, the littoral biological community will be examined with an emphasis on the decay and cycling of organic matter such as leaf litter and the contribution of the littoral zone to energy fluxes through the aquatic food-web.

Testing the impact of micropollutants on aquatic ecosystem functioning, using a mesocosm approach

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Rapidly emerging occurrence of micropollutants in aquatic systems has increased their potential to alter aquatic foodwebs. In addition to direct effects, micropollutants elicit indirect effects in tolerant species that can either be density-mediated or trait-mediated through changes in biomass or behavior of competitors and predators. In environment, aquatic organisms are continuously exposed to a pool of various classes of micropollutants at concentrations ranging between ng/L to µg/L. It is critical to evaluate combined effect these contaminants pose to aquatic ecosystems. In this study, ecological relevance of combined effects caused by pharmaceuticals and microplastics, two ubiquitous micropollutants in Anthropocene are being investigated. Given their ability to cause direct and indirect effects in aquatic organisms individually, we hypothesized a synergistic effect on aquatic organisms and associated trophic interactions. More specifically, decrease in ecosystem functions, such as biomass production and decomposition rate. Considering it prevalence in aquatic systems, fluoxetine hydrochloride -a psychoactive drug was chosen.

Experiments were performed in 9 indoor mesocosms called limnotrons with 845L water and 40L sediment. Microplastics(diameter:10.23µ) were spiked into sediment and water at environmentally relevant concentration of 529 spheres/Kg dry weight and 19 spheres/L respectively. Concentration of fluoxetine in water phase varied from 10 to 500 ng/L. Limnotrons were monitored for 100 days at 20°C with 16:8(L:D) light regime. Parameters such as phytoplankton and zooplankton composition, decomposition rate were monitored along with fluoxetine hydrochloride, dissolved and particulate nutrients and dissolved oxygen (mg/L). Preliminary results indicate fluoxetine hydrochloride to play a crucial role in biomass accumulation and decomposition rate.

Studying global lakes surface temperature variabilities using satellite and in situ observations

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Even though lakes make up a small percentage of the water bodies on the global land surface, lakes provide critically important ecosystem services. Unfortunately, however, several lake surface areas around the globe have been changing with many of them drastically decreasing due to climate variability and local mismanagement at the basin-scale level. Lake Surface Water Temperature (LSWT) is recognized as a critical indicator of climate change in lakes. The changes in water and the surrounding land temperatures may be an indicator of climate variability if there is consistency between changes in both temperatures. This project focuses on the application of remote sensing to investigate the changes in lake surface water temperatures and their relationship with their surrounding land cover type in a bid to identify the main driving factors of these changes. In this study, 507 global major lakes have been investigated. An analysis of temperature variation over these lakes has been conducted using daily observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) from year 2002 to 2018 over the lakes and their surrounding land areas. The rates of change of temperature for both the lakes' water surface and their basins as well as the changes in the lakes' surface areas were calculated. Approximately 43.15% of the studied lakes are warming, and about 51.00% of them are cooling. Furthermore, 62.53% of the lakes are shrinking while 28.35% of them are growing. This study, therefore, provides insights about LSWT variability on a global scale.

Numerical modeling of the role of advective fluxes in the diel oxygen variations for estimating whole-lake metabolism

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Free-water measurements of dissolved oxygen (DO) at high frequency are routinely used to estimate net ecosystem metabolism, gross primary production and ecosystem respiration. In this study, a numerical solution was applied to remove the variability in DO time series caused by horizontal advection and diffusion related to water movement. The experimental dataset consisted in independent DO time series from 3 stations in a water reservoir aligned along the dominant wind direction, together with direct water velocity data from an acoustic Doppler current profiler (ADCP). The water velocity was used to feed a numerical model to estimate horizontal advection and diffusion at the central station and determine their role in DO dynamics. The effect of horizontal advection and diffusion on subsequent estimates of metabolic parameters at the central station was assessed by using standard light-dependent metabolic models in a Bayesian framework. The results of this short experiment showed a minor effect of horizontal advection and diffusion on the metabolic estimates during most of the days considered. The uncertainty associated with the estimation of horizontal advective water movement resulted in lower model fits than without the correction, despite the corrected and uncorrected rates were indistinguishable.

First record of bottom anoxia triggering phosphorus release from the sediment in deep, oligotrophic Lake Lunz

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Lake Lunz has been subject of limnological studies since 1906. Ever since it has been described having an oxic water column throughout summer stratification. Even during periods when the lake received increased nutrient loads from input of untreated domestic waste-water, the oxygen saturation did not drop below 20% in the bottom layer. In recent years oxygen levels were observed for the first time to decline to anoxic conditions in the lower hypolimnion. Simultaneously, we observed that anoxia at the sediment-water interface triggers the release of phosphporus from the sediment, as evident by elevated phosphate concentrations in this layer towards the end of the stratified period.

Results from the ongoing monitoring are presented in context of historical data. Potential reasons for the formation of an anoxic layer and its ecological implications are discussed.

Vulnerability of lakes to climate change along an altitudinal gradient

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Past studies of future 21st century climate effects in lakes along the altitudinal gradient have in the past been limited by unresolved local atmospheric phenomena not being considered in model forcing. Here we resolve this local complexity using 17 locally downscaled climate models, to investigate future climate impact on 29 Swiss lakes with variable size over an altitudinal gradient. Using the physical lake model Simstrat and three Representative Concentration Pathways (RCP8.5, RCP4.5 and RCP2.6), we assess the influence of lake characteristics (bathymetry and altitude) and the now resolved atmospheric complexity on the reaction of lakes to climate change. The projected rate of change of ice-cover duration and winter and summer stratification length are largest at higher altitudes. On the contrary, low and especially mid-altitude lakes where more affected by climate change through physical regime shifts, with dimictic lakes shifting to monomictic and the complete loss of ice cover. Climate effects where most sever with scenario RCP8.5, and could be limited but not completely preventable by stringent greenhouse gas mitigation under scenario RCP2.6.

The importance of considering internal seiche dynamics when designing limnological monitoring campaigns in the nearshore zones of medium-sized lakes.

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In this poster we will highlight the spatial and temporal variability of internal seiches in stratified lakes. Generally stratification is monitored in the centre of lakes, but the ubiquitous rise and fall of internal seiches creates an internal swash zone on the sloping lake bed where temperature and oxygen can rapidly vary.

Global patterns and predictors of microplastic occurrence and abundance in lentic systems

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The majority of microplastic research has focused on seawater, with fewer than 4% of microplastics-related studies occurring on freshwaters. The limited available information suggests that the abundance of microplastics in freshwaters is often as high or even higher than marine environments. However, comprehensive investigations on occurrence and fate of microplastics in freshwaters are scarce and highly fragmented, partly because detection and identification of microplastic particles is rather complex. In addition, up to now, harmonized and standardized protocols for the sampling and analysis of microplastics in freshwaters do not exist, and studies with different research aims and hypotheses often report unstandardized results, making comparison among studies difficult. In the present study, we performed the first global standardized sampling and analysis effort to investigate the occurrence and distribution of microplastics in surface water of lakes and reservoirs with different anthropogenic impacts. Participants aim to collect water samples of freshwater systems with different features (e.g., area, depth, thermal behavior, watershed), following a common protocol. This

establishes the collection of samples by horizontal trawling of a plankton net and, after treatment with hydrogen peroxide, the polymer identification through micro-Raman spectroscopy. This GLEON project will allow obtaining comparable data about microplastic contamination in different freshwater systems around the globe. With this global dataset, our goals are to determine whether a relationship exists between the abundance of microplastics and the waterbody/watershed attributes and understand which factors are likely to influence the occurrence of microplastics in surface water of lentic systems.

Determining actions needed to eliminate metalimnetic hypoxia in Green Lake, Wisconsin

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Green Lake is the deepest natural lake in Wisconsin, USA, with a maximum depth of 72m. In the early 1900's, the lake was oligotrophic, with hypoxia only in the deepest part of the hypolimnion. Increased nutrient (phosphorus) loading, however, has caused the lake to become mesotrophic, with hypoxia also occurring in its metalimnion (metalimnetic oxygen minima). Routine sampling has been conducted since 2004 to document lake water quality and phosphorus loading to the lake, with more comprehensive sampling in the lake (including fall and winter sampling) and tributaries (other nutrients) in 2017–18 to better understand the factors driving the hypoxia. A combination of empirical and hydrodynamic water-quality modeling was used to describe the factors causing the degradation in lake water quality. The General Lake Model coupled to the Aquatic Ecodynamics modeling library (GLM3-AED2) was used to describe short-term changes in lake water quality and to understand the factors causing the formation of metalimnetic oxygen minima. Results from the models indicate lower metalimnetic oxygen concentrations in years with increased productivity (higher chlorophyll-a concentrations) and poorer water clarity, which result from higher external loading. GLM3-AED2 results indicate that external phosphorus load reductions of least 35% are needed to eliminate the occurrence of metalimnetic minima of less than 5 mg/L in over 80% of the years. Results from this study are being used to improve management plans for the lake and guide watershed efforts to improve water quality and reduce the metalimnetic oxygen minima in the lake.

Towards a global understanding of mixing events in lakes

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Short-lived, sudden and intense periods of mixing, known as mixing events, have received growing attention in limnology, due both to their important ecological consequences and the potential link to extreme climatic events. However, as of yet, there is still a lack of clarity on what mixing events are and limited systematic analysis on their occurrence and characteristics. In this project we aim to address some of the important questions relating to mixing events in lakes including; 1) how can mixing events be identified using high-frequency lake buoy data?, 2) Are mixing events in lakes likely to respond linearly to changes in atmospheric mixing drivers?, and, 3) how do mixing events vary between lakes? In this poster we present our previous findings and next steps.

A parameterization strategy for hydrodynamic modelling of a cascade of poorly monitored reservoirs in Brazil

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The scarcity of long time-series of water temperature for tropical reservoirs, usually available at a low frequency of measurements, represents a serious constraint for the understanding of their thermal behavior. Hydrodynamic models become a powerful tool for that understanding through a qualitative approach. In this study, the one dimensional General Lake Model (GLM) was applied to hindcast multiannual temperature profiles of a cascade system of six reservoirs located in southeast Brazil over a period of eight years. The model parameters were calibrated and validated by field data for four reservoirs. To overcome the challenge of exploring hydrodynamics in two reservoirs with a lack of measured temperatures, a parameterization strategy was applied to accomplish a better simulation by the estimation of potential sensitive parameters through regression curves. It is expected that this approach can be extended to other tropical reservoirs whenever field data is not available for the calibration procedure.

Volunteer perspectives on the value of participating in a citizen science lake monitoring project

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Citizen science methods play an important role in generating water quality data at broad scales, and these methods are becoming formally incorporated into environmental policies. As such, citizen science is the focus of an emerging interdisciplinary research field. The growth and expansion of the citizen science concept and its applications corresponds with an interest in understanding and analyzing the sociological dimensions of public participation in science. Extant research suggests volunteers can be motivated by a combination of intrinsic and extrinsic factors like experiential learning of ecological knowledge and principles; building social relationships; care for the environment; a desire to contribute to scientific knowledge; personal interest and enjoyment in the project(s); or distrust in government. Motivations for participation seem to be based on some combination of wanting to learn about the environment and wanting to participate in some direct intervention to help improve it. This poster will present results from a qualitative case study investigating attitudes of participants in the Lake Partner Program, a community-based lake monitoring program in Ontario, Canada that coordinates volunteer measurements of water clarity, phosphorus, and calcium. Forty semi-structured interviews were conducted with Lake Partner Program participants between June and August 2020. Interviews were coded and analyzed using Nvivo Version 12.6.0, based on research questions related to what participants value about citizen science; how participants define citizen science; whether the metrics and measurements correspond with what participants are interested in; and what additional parameters volunteers are interested in measuring that are not captured by existing protocols.

Relating depth distribution of phytoplankton to community structure over time in a small, eutrophic drinking water reservoir

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Does the spatial distribution of an ecological community drive community structure, or does community structure drive spatial distribution? While definite answers may be difficult to find, we consider how the relationship between phytoplankton spatial distribution and community structure in a small reservoir over four years informs our understanding of this question. Phytoplankton frequently exhibit uneven biomass distribution across the water column, with peaks or maxima in biomass occurring at different depths. Because resources such as nutrients and light also vary across depth and phytoplankton taxa exhibit different resource niche preferences, we expect that phytoplankton depth distribution characteristics such as the depth, magnitude, and width of biomass peaks are related to the phytoplankton taxa present. We collected weekly depth profiles of fluorescence-based phytoplankton biomass at Falling Creek Reservoir in southwest Virginia, USA during the thermally stratified period over four years while concurrently collecting phytoplankton grab samples from the depth of chlorophyll maximum. Using linear and time series models, we found biomass peaks at different depths are comprised of different phytoplankton taxa; specifically, shallow biomass peaks contain more cyanobacteria, while deep biomass peaks contain more cryptophytes. Furthermore, preliminary results indicate that the magnitude of the biomass peak exhibits a hump-shaped relationship with genus richness, where richness initially increases with peak magnitude but then decreases as peak magnitude becomes large. Our work suggests that within an ecosystem over time, characteristics of community spatial distribution are linked with community structure, potentially allowing for inference regarding community composition if spatial distribution is known.

Bottom-water temperatures drive changing rates of oxygen depletion in a drinking water reservoir

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Dissolved oxygen is considered to be one of the most fundamental factors that control water quality in lakes and reservoirs. However, our ability to predict future oxygen concentrations is limited by our understanding of which drivers of hypolimnetic oxygen demand are most important on a whole ecosystem scale. In this study, we use near-term iterative forecasting and six years of whole-ecosystem oxygen manipulations to examine the capacity for hypolimnetic temperature and current oxygen availability to predict future changes in oxygen concentrations. We built three process-based models of oxygen demand—one that only includes sensitivity to temperature, one that only includes sensitivity to oxygen concentrations, and a full model that includes both factors. We then used each of these models to generate 14-day forecasts over a six-year time series of oxygen manipulations in Falling Creek Reservoir (FCR; Roanoke, VA, USA) and compared the relative performance of each model. Oxygen concentrations were highly predictable 14 days into the future using the full (temperature and oxygen) model (0.97–1.96 mg/L RMSE), and forecasts can be visualized in an interactive web interface. In general, the temperature-only forecast performed better than the oxygen-only forecast (temperature: 0.92–2.36 mg/L RMSE; oxygen: 1.08–2.79 RMSE), indicating that patterns changing oxygen concentrations may be influenced more by temperature than the baseline concentration of oxygen. Through these forecasts, we simultaneously shed light on a longstanding ecological question and help develop the capacity for preemptive water management.

Usefulness of seasonal forecasting tools of water quality - a stakeholder perspective

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What if we were able to predict next season's climate and its impacts on water quality?

A key aim of the WATExR project is to develop user-friendly tools for seasonal forecasting of surface water quality and ecology, with a particular focus on lakes. The intention is for these tools to be useful to stakeholders to support water management. To develop the tools, seasonal climate model outputs were integrated with freshwater impact models (e.g. catchment hydrology and lake models) at four contrasting case study sites in Europe and Australia. Together with stakeholders, a historic season was chosen when an extreme seasonal climate event resulted in problems within the catchment/lake. Forecasts, along with some confidence metrics, were then produced for this season, and sent to the stakeholders to evaluate their usefulness for management. In a second step, we carried out a more comprehensive assessment of which seasons and variables the forecasting systems had skill in (what we term "windows of opportunity"), and whether these were useful to water managers. Our results show that despite the absence of skills in the seasonal climate forecasts, the impact models show some significant forecasting skills for a non-negligible number of variables and seasons. Whether these skills are a simple legacy of the previous season(s) or a true forecasting ability remains to be investigated.

Evaluation of FABM-PCLake coupled with three different drivers and applied to four lakes

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In lakes, especially shallow lakes, hydrodynamic and biogeochemical processes are highly inter-tangled, however available lake models tender to either focus on hydrodynamics and water quality, or focus on complex biogeochemical dynamics. As publication of FABM-PCLake (2016) marked the step of linking aquatic ecology and hydrodynamics in lake models, which also provided the tool for evaluating the influence of hydrodynamic representations on lake biogeochemical simulations. We hereby present an ensemble model runs for FABM-PCLake, coupled with three difference hydrodynamic representations, i.e. zero dimensional box configuration, vertical one dimensional configuration with stacked pelagic layers and vertically one dimensional configuration with stacked pelagic and benthic layers, to explore the influence of hydrodynamic representations on the lake biogeochemical simulations. The four different lake depths, 2, 5, 10 and 20 meters, was designed for water columns ranging from fully mixed to summer-stratified. Results show that adding vertical water column variation to the basic zero dimensional configuration introduced differences in the biogeochemical model output, increasing with lake depth. Adding both vertical variation and benthic layer to each pelagic layer had bigger impacts on shallower lakes, but the differences decreased with increasing water depths. Meanwhile, the higher the trophic level, the bigger the impact of the hydrodynamic representation was. We emphasize proper evaluation of lake system and modelling purpose before selecting hydrodynamic representation in lake modeling practice, and we propose further improvement of FABM-PCLake model structure, as well as similar ensemble model runs and analysis performed with two dimensional and three dimensional lake model.

Flow cytometric fingerprints reveal temperature-enhanced variability of pioneer phytoplankton communities in a mesocosm system

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A crucial point in current research on plankton ecology is how global warming will change community functioning, which has led to a large number of studies addressing the question with a huge variety of approaches and conclusions. We set up an outdoor mesocosm colonisation experiment to study the effect of temperature on phytoplankton dynamics with the hypothesis that elevated temperature enhances compositional variability, based on our earlier analysis of a long-term data set. Twelve mesocosm tanks were filled with pre-filtered and sterilized lake water with half of the tanks kept at 3°C above the control ones with ambient temperature. Phytoplankton colonisation and subsequent changes in its composition were monitored during a 42-day-long period using traditional microscopic analysis and flow cytometry. Flow cytometric data was evaluated with an automated method using the probability binning algorithm, which allows the assignment of each sample to unique cytometric fingerprints. Despite the fact that all the mesocosms became dominated by chlorophytes, both cytometric and taxonomic data implicated that higher spring temperatures can significantly enhance variability (beta diversity) in phytoplankton composition, presumably reducing the predictability of its annual succession.

Assessing in-situ performance of sensors for automatic high frequency monitoring of algal pigments in Lake Maggiore (Italy)

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Field in-situ sensors to measure algal pigments have become increasingly common worldwide as complementary techniques for lake monitoring and ecological assessment. Fluorometric measurement of in situ chlorophyll and phycocyanin is generally cost-effective and permits frequent observations during sudden events such as floods or short-lived algal blooms, providing warning signals for water managers and local authorities.

However, interpretation of in situ chlorophyll and phycobiliprotein fluorometer data is not a straightforward task. Values generated by these fluorometers need to be effectively calibrated in order to interpret measurements correctly. Because standard pigments might have different fluorescence intensity from in vivo pigments measured in the water, calibration with algal species is highly recommended.

This study presents an experimental assessment of the performance of in situ high frequency sensors of chlorophyll and phycocyanin conducted in the laboratories of CNR Water Research Institute, Italy. The sensors performance has been further tested using field data, comparing data generated by the in situ sensors and the values from pigments extraction techniques. The sensors are part of a High Frequency Monitoring (HFM) system situated on a buoy in Lake Maggiore (Italy).

Non-native fish alter trophic niches of native fishes and amphibians

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We investigated the impact of non-native species, Centrarchidae fishes and American bullfrogs, on native fishes and amphibians in aquatic habitats within the Chehalis River floodplain (Washington, USA). We compared nitrogen and carbon stable isotope ratios from native species in ponds with and without non-native species to observe changes in trophic position and diet. The isotopic niches of non-native fishes overlapped substantially with native fishes and salamanders, indicating potential for competition. As a result, native fishes and salamander larvae reduced their range of food resources and fed lower on the food chain when non-native species were present. In contrast, non-native bullfrogs did not substantially alter the isotopic values of native frog larvae species, suggesting limited competition for food resources. Due to the substantial shifts in salamander and native fish isotopic niches, we recommend future research and conservation efforts focus on these species.

QA/QC procedures for the development of a High Frequency Monitoring system for Lake Maggiore, Italy

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A High Frequency Monitoring (HFM) system has been established within the INTERREG SIMILE project (ID 523544) to assess the water quality of the deep subalpine Lake Maggiore. The present system is composed by a buoy equipped with several sensors collecting data on temperature, conductivity, dissolved oxygen, pH, and photosynthetic pigments (i.e., Chlorophyll-a, Phycocyanin, Phycoerythrin). HFM is used in conjunction with discrete samplings for chemical and biological analyses with the final aim to detect rapid ecological changes and provide early warnings about environmental hazards. The system requires constant Quality Assurance procedures (e.g., maintenance, cleaning, and calibration), and sensor output (raw data) requires Quality Control (QC) procedures. In the present study, we describe the QA and automated QC procedures adopted during the first year of functioning of our HFM system. Such procedures are intended to guarantee and control the quality of data. Some indications on weather retaining, correcting or discarding sensor data are provided. Sample data provide examples of the most common error types in sensor data, therefore representing a valuable reference for the development of a more complex and interconnected HFM system within the INTERREG SIMILE project.

Ensemble warming projections in Germany's largest drinking water reservoir and potential adaptation strategies

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The thermal structure affects the development of aquatic ecosystems, and can be substantially influenced by climate change and management strategies. We applied a two-dimensional hydrodynamic model to explore the response of the thermal structure in Germany's largest drinking water reservoir, Rappbode Reservoir, to future climate projections and different water withdrawal strategies. We used projections for representative concentration pathways (RCP) 2.6, 6.0 and 8.5 from an ensemble of 4 different global climate models. Simulation results showed that epilimnetic water temperatures in the reservoir strongly increased under all three climate scenarios. Hypolimnetic temperatures remained rather constant under RCP 2.6 and RCP 6.0 but increased markedly under RCP 8.5. Under the intense warming in RCP 8.5, hypolimnion temperatures were projected to rise from 5 °C to 8 °C by the end of the century. Stratification in the reservoir was projected to be more stable under RCP 6.0 and RCP 8.5, but did not show significant changes under RCP 2.6. Similar results were found with respect to the light intensity within the mixed-layer. Moreover, the results suggested that surface withdrawal can be an effective adaptation strategy under strong climate warming (RCP 8.5) to reduce surface warming and avoid hypolimnetic warming. This study documents how global scale climate projections can be translated into site-specific climate impacts to derive adaptation strategies for reservoir operation. Moreover, our results illustrate that the most intense warming scenario, i.e. RCP 8.5, demands far-reaching climate adaptation while the mitigation scenario (RCP 2.6) does not require adaptation of reservoir management before 2100.

Are filamentous algae blooms in Lake Tahoe (CA-NV) changing?

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Filamentous algae blooms are occurring in pristine oligotrophic lakes globally, but few lakes have documented increasing biomass through long-term filamentous algae monitoring. For decades, public perception of increasing filamentous algae has caused concern about oligotrophic Lake Tahoe's nearshore water quality. To determine whether filamentous algae blooms are indeed increasing in Lake Tahoe, a monitoring program was established to measure filamentous algae biomass and dominant taxa regularly at nine sites around the shoreline starting in 1982, with up to 54 additional sites monitored annually at peak biomass. Surprisingly, over the last 38 years, filamentous algae biomass has decreased at many sites. Much of the biomass decrease was observed within the cyanobacteria community. We also observed filamentous algae biomass and community composition changed with the lake level variation. Temporally, we observed filamentous algae biomass peaked in March and was low in the summer lake-wide. Spatially, the northern and western lake shores had higher biomass than the eastern and southern shores. As increasing filamentous algae at Lake Tahoe was first cited in the 1960s, it is possible that filamentous algae increased prior to our monitoring program. A dearth of published long-term monitoring data from oligotrophic lakes with reported filamentous algae blooms makes it difficult to determine the extent of this issue worldwide. Long-term monitoring is crucial for tracking and understanding filamentous algae blooms.

Peaks in gross primary production and ecosystem respiration in response to rainfall events in an urban lake

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Large rain events often lead to abrupt changes in lake metabolism due to pulses of carbon and nutrients from the surrounding watershed. Often this contributes to increases in heterotrophy as primary producer biomass is flushed from the system, increases in labile organic carbon contribute to increased ecosystem respiration, or loads of chromophoric dissolved organic carbon reduce light availability for photosynthesis. While there has been a number of studies highlighting these dynamics in alpine, agricultural, and forested lakes, there has yet to be an assessment of the relationship between rain events and metabolism in an urban lake. As carbon and nutrient loading responses may be different due to the impact of impervious surfaces and consistent and abundant human influence, this is a gap in our understanding that deserves attention in order to better categorize ecosystem responses to weather events and climate change. We monitored lake metabolism (gross primary production (GPP) and ecosystem respiration (ER)) in an urban lake in Memphis, TN USA over a growing season to determine the impacts of rainfall events on net ecosystem productivity. We observed strong peaks in GPP and ER owing to rainfall events across the growing season, resulting in generally greater GPP:ER during the events. In some instances, increased frequency of rain events contributed to a shift from consistent heterotrophy to autotrophy. This pattern may be due to increased nutrient loading during this period, but more work needs to be done to better understand mechanisms of metabolic shifts in urban lakes due to weather events.

The interplay of ice cover and extreme events determines dissolved oxygen in a wind-shielded mountain lake

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A decrease in hypolimnetic dissolved oxygen (DO) is a commonly seen effect of climate change. However, in oligotrophic Lake Tovel (Italy), a deep mountain lake, annual mean DO (% saturation) has increased from near anoxia to >20% in the bottom layer (35–39 m). We analyzed long-term patterns of DO (1937–2019) using different methods (correlation and trend analysis, identification of extreme events) to link DO to drivers and indices of mixing. While spring mixing remained temporally limited, later ice-in (5.1 days/decade) and the positive relationship between ice-in and DO the following year evidenced autumn mixing as the main driver for hypolimnetic DO increase. Extreme meteorological events also replenished hypolimnetic DO. Using DO and conductivity (1995–2019), we identified 14 deep mixing events with hypolimnetic DO > 40%. Density-based indices (Schmidt stability, relative thermal resistance, Lake Number, and Wedderburn Number) only partially captured these events that were related to snowmelt, flooding, and cold spells during spring and autumn, with a carryover effect sometimes lasting >1 year. Recently, annual mean DO in the upper layer decreased beyond temperature-dependent solubility. This decrease was not comprehensively confirmed by statistical tests but was possibly linked to atmospheric stilling. We suggest that Lake Tovel's shift from meromixis to dimixis was driven by climate warming (i.e., increasing air temperature 0.6°C/decade) that delayed ice-in and increased autumn mixing. Our work underlines the vulnerability of mountain lakes and their different response to climate change with respect to more studied lowland lakes.

The role of water color in determining mixing pattern in wind-protected tropical lakes

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It is well known that both intrinsic factors, such as lake morphometry, and extrinsic factors, such as seasonality, act together to determine the lake's mixing pattern. However, in this study, we describe two neighboring tropical lakes (5 km away from each other), with similar morphometry, located at the same altitude, and submitted to the same climatic conditions, but with distinct mixing patterns: one warm monomictic and the other warm discontinuous polymictic. Both lakes have fetch around 500m and are well sheltered from the wind. Using a mathematical model (General Lake Model), we show that the distinct mixing pattern is caused mainly by the difference in the vertical light extinction coefficient. This difference leads to a distinct phytoplankton community structure and biomass, where the polymytic lake, although more oligotrophic, has the highest phytoplankton biomass. This result is due to the selection of cyanobacteria adapted to the mixture.

Climate-induced limnological change in shallow lakes during the Little Ice Age

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One of the most important recent challenges is to understand how shallow lakes will respond to global warming, particularly in arid and semiarid regions. Since variations in precipitation can produce significant ecological changes due to changes in water level (WL) and chemical and physical water characteristics of the lake, understanding the effect of changes in climate in the past can help better to address the impact of climate warming in shallow lakes. Thus, we selected four Pampean shallow lakes (Puan, Los Chilenos, Sauce Grande, and La Salada) strategically located in a climatically sensitive transition zone from arid to semiarid to assess the main drivers and mechanisms of long-term ecological change. These lakes originated in the Late Holocene as temporary and clear water lakes, and at around ~910 to 480 cal. yr BP they changed to permanent with turbid waters, except by Puan, the most northern lake, that changed at ~20 cal. yr BP (1930 AD). The primary mechanism inducing the change was an increase in WL and the resuspension of the sediment due to increase in precipitation and wind intensity, most likely associated with the Little Ice Age (LIA). Puan was the exception, it changed only recently, after humid conditions returned after 1930 AD. This suggests that the LIA was not homogeneous in the Pampean Region; it was dry in and the eastern and northern Pampas (where Puan is located) and wet in the southern and western Pampas (where lakes La Salada, Sauce Grande, Los Chilenos are located).

Deepwater oxygen depletion is more severe and related to different drivers in summer compared to winter across 14 Northern Hemisphere lakes

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Deepwater oxygen depletion in lakes has become increasingly prevalent and severe due to a variety of anthropogenic and environmental changes. We analyzed year-round, high-frequency dissolved oxygen data from 14 lakes in North America and Europe to compare the extent of deepwater oxygen depletion across lakes in winter vs. summer and analyzed the phenological, geographic, and morphometric drivers of deepwater oxygen depletion across lakes and seasons. Severe oxygen depletion was common, and was detected more frequently and for longer durations in summer compared to winter in this set of lakes. We found strong relationships between ice cover duration vs. minimum oxygen saturation and duration of hypoxia in winter that increased with elevation. We did not detect a significant relationship between duration of summer stratification and summer oxygen depletion, despite a number of previous studies of individual lakes over time reporting this pattern, but did find that summer deepwater oxygen depletion rate increased with average deepwater temperature. Oxygen metrics during both winter and summer were strongly related to lake morphometry, highlighting the importance of sediment surface area to water volume ratio. Winter oxygen depletion was found to be overall more predictable with broadly generalizable patterns compared to summer oxygen depletion, which is likely due to greater and more variable oxygen inputs and consumption in summer compared to winter. Continued deployments of year-round high-frequency sensors in lakes can improve the spatial and temporal understanding of deepwater oxygen depletion in lakes as well as the potential ecosystem consequences.

A new lake classification system based on thermal profiles to better understand the most dominant lake type on Earth

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Lakes are traditionally classified based on their thermal regime and trophic status. While this classification adequately captures many lakes, it is not sufficient to understand dimictic lakes, the most common lake type. Here, we suggest that an additional classification is needed to differentiate under-ice stratification. When ice forms in smaller and deeper lakes, inverse stratification will set up with a thin buoyant layer of cold water (near 0oC) below the ice, which remains above a deeper 4oC layer. In contrast, the entire water column can cool to ~0oC in larger and shallower lakes. We suggest that these alternative conditions for dimictic lakes be termed “cyrostratified” and “cryomictic.” We describe the inverse stratification in 19 lakes with areas between 0.5 to 82,000 km2 and derive a formula that predicts the temperature as a function of wind stress, area, and depth. This relationship improves our ability to study lake responses to a warming climate.

Understanding lake response to permafrost thaw in the Dehcho region of the Northwest Territories

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Lakes at the southern limit of permafrost are highly sensitive to climate warming. In the southern Northwest Territories (NT), permafrost is typically restricted to forested patches, or peat plateaus, that are elevated above the surrounding wetlands. As mean annual air temperatures approach 0°C, permafrost thaw results in the waterlogging of soil and transition of forested plateaus to wetlands. As the proportion of wetlands in the catchment increases, the routes for the export of terrestrial carbon to enter lakes also increases, which can result in “browning” of the water. Lake browning can impact lakes in many ways, for example, by reducing the amount of light that can penetrate into the water column, which in turn can impact lake food webs. The research presented here focuses on 16 small lakes in the Scotty Creek basin, within the Dehcho region in the southern NT, and aims to answer two questions. First, how have lakes changed in this region and when did these changes begin? To answer this question sediment cores were collected in order to reconstruct environmental histories of a select few lakes in the Scotty Creek basin over the past several hundred years. Second, do current landscape characteristics (e.g. proportion and type of wetlands) impact current lake conditions (e.g. the amount of dissolved organic carbon)? To answer this question landscape characteristics were analyzed using satellite imagery, and lake water samples were collected and analyzed. Here I will present preliminary results that begin to answer these questions.

Ecosystem metabolism dynamics and environmental drivers in Mediterranean confined coastal lagoons

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Aquatic metabolism arises as an important indicator of ecosystem functioning. Although the use of high-frequency data to estimate metabolism has been widely used in some aquatic systems like rivers or lakes , it remains less understood for other ecosystems suchs as lagoons and ponds. In this work we used three years of high-frequency open water oxigen data to study two Mediterranean confined coastal lagoons. These waterbodies are located in La Pletera salt marsh and most part of the time remain isolated from the sea and other freshwater sources. Metabolic rates were calculated applying Bayesian estimations. Our aim was to understand the metabolic dynamics in these particular ecosystems and identify if the main drivers of metabolic variation described in literature resulted significant for these lagoons. We observed seasonal patterns in the metabolic rates, with extremely high oxygen variability during the summer season. Despite the high rates of production registered during the summer, periods of anoxia could prevail for several days during that season. Thus, although the aerobic production and respiration were quite balanced in the lagoons during the study period, these lagoons are probably more heterotrophic since their anaerobic respiration has not been estimated. Because the studied lagoons are rich in nutrients, we expected a low response in the metabolic rates to nutrient increases, since the physiological response of primary producers to nutrient loading is usually low in nutrient-saturated ecosystems; our results supported this hypothesis. The temperature was the primary driver, hightligting the importance os seasonality in there highly productive ecosystems.

Modelling the phytoplankton assemblage response to season and zooplankton grazing in a temperate stratified reservoir

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The ability to simulate the seasonality of phytoplankton and zooplankton dynamics in temperate water bodies is challenging for hydrodynamic-ecological models. In this study, we used the CE-QUAL-W2, a two-dimensional model of hydrodynamics and aquatic ecosystem in lakes and reservoirs, to simulate four major functional groups of phytoplankton (green algae, diatoms, cryptophytes, cyanobacteria) and two zooplankton groups (herbivorous, partly carnivorous) in a meso-eutrophic dimictic reservoir (Římov Reservoir, Czechia). The model was capable, after a trial-and-error calibration, to predict the correct seasonality of these four algal groups using different parametrisations of their growth dependences on temperature, light and nutrients and specific preferences of zooplankton grazing. However, modelling encountered the following challenges: (1) high demands on computing resources; (2) inability to reproduce the occurrence of irregular phytoplankton blooms; (3) seasonally invariant parametrization of algal growth rate and algae/chlorophyll-a ratio (ACHLA); and (4) uncertainty in different parameterization leading to underestimation or overestimation of phytoplankton biomass. To reduce the uncertainty associated with model simulation results, we recommend adjustments to ACHLA according to phytoplankton assemblage, additional mathematical estimation for phytoplankton blooms, and the use of sensitivity analysis in model parametrization. Overall, the model can provide insight to phytoplankton dynamics under the effect of zooplankton grazing and help design a management strategy to reduce phytoplankton growth and improve water quality.

High-frequency temperature and dissolved oxygen monitoring of a discontinuous polymictic reservoir in the Midwestern USA

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Marion Reservoir, Kansas, is a turbid, hypereutrophic, discontinuous polymictic reservoir with a history of cyanobacterial blooms. To evaluate how physical factors relate to near-bottom anoxia and cyanobacterial blooms, high-frequency (10min intervals) temperature and dissolved oxygen sensors were deployed throughout the water column at multiple sites in the summer of 2019 and 2020. Preliminary results show (1) rain events trigger near-bottom thermal stratification and anoxia and (2) relatively low wind days help spur shallow ephemeral layers, which in turn help favor cyanobacteria over other algal groups. Future work aims to use the monitoring data to calibrate a process-based 1D General Lake Model (GLM) and coupled it with Noah-MultiParameterization Land Surface Model (Noah-MP LSM) for hindcasting and forecasting near-bottom anoxia and cyanobacterial blooms.

Simulation of hydrodynamic alterations in a Brazilian reservoir at the 2050s by two climate projections models

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The present study evaluated the likely future changes in thermal stability and water level of a Brazilian multipurpose reservoir for the 2050s using the IPCC representative concentration pathway (RCP) 8.5 for downscaling projections of the HadGEM2-ES (HGE) and MIROC5 (MRC) climatic models. The one-dimensional vertical General Lake Model (GLM) was calibrated and validated to simulate water level (WL), surface water temperature (SWT), and thermal stability based on Schmidt Stability Index (SSI). A period between 2009 and 2018 was considered as being the baseline to the scenarios simulations. The projections data were bias-corrected using the distribution mapping approach for daily precipitation and air temperature; and the linear scaling method for wind speed, shortwave radiation, and air relative humidity time-series. The HGE projections have been shown to be more sensitive to greenhouse gas emissions than the MRC projections. There was a pattern of daily precipitation reduction and average air temperature increase in both models, with higher intensification in the HGE projections. Such changes would directly influence the decrease in the water level and increase the thermal stability of the reservoir (HGE: SSI=+49%, SWT=+1.3 ºC; MRC: SSI=+51%, SWT=+1.7 ºC) in comparison with the baseline scenario. For the MRC projections, the water level would remain similar to the baseline simulation for two scenarios: increase in air temperature and the ensemble of projected variables. On the other hand, for the simulations using the HGE projections, considering the ensemble and each variable individually, the reservoir dead storage would be reached in the mid-2050s.

Can we improve lake water quality by modifying inflow rates?

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Nutrient enrichment is a problem in many lakes globally. High nutrient levels cause blooms of algae and poor oxygen conditions and can be particularly problematic during the summer when higher temperatures and increased solar radiation cause stratification of the water column. During stratification, oxygen depletes in the deeper waters driving internal loading of nutrients. Much research and money has been invested in establishing effective and cost-efficient methods to improve water quality. One novel method is to increase the flow of water into a lake basin in an attempt to disrupt summer stratification. In the summer, the inflowing river has a cooling effect on the lake, so increasing flow could reduce the length and strength of stratification, thus preventing the internal loading of nutrients and associated water quality issues.

To investigate the potential of this method we are using a model system, at Elterwater in the English Lake District, where water has been diverted to increase flow into the lake's first basin. An initial modelling study suggested that increased flow would reduce lake water temperatures and the duration and strength of the summer stratification. Now want to understand how these water temperature changes may affect the water quality.

We use temperature modelling results, field data and historic water quality data in a Before-After-Control-Impact assessment. This methodology enables us to determine what changes have occurred in the test lake (Elterwater), relative to an unchanged control lake nearby. We will be focussing on changes in water temperatures, nutrient concentrations, and algal biomass.

Two-layer Bayesian dissolved oxygen model for ecological process discovery

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Lake oxygen concentrations provide important insights about local lake carbon cycling and global carbon budgets, and low oxygen directly stresses fish and other aquatic organisms. To better understand these fluxes, we developed a two-layer Bayesian model that estimates these oxygen fluxes (and thus carbon) based on dissolved oxygen (DO) concentrations of lakes. The Oxygen DEpletion Model (ODEM) assumes that the lake is either stratified or mixed. In the former case, it calculates the DO concentrations in a completely-mixed epilimnion and a completely-mixed hypolimnion. During mixed conditions, ODEM tracks a DO concentration for the total water column. Flux parameters were estimated using inverse modeling in a Bayesian framework. ODEM was applied to 8 lakes in Wisconsin, USA and achieved excellent modeling results: RMSE = 0.88 g DO m-3 and NSE = 0.93. According to the model results, northern and southern Wisconsin lakes differed distinctly in their temporal DO depletion dynamics. Here, southern lakes experienced a rapid DO depletion at the beginning of the summer stratification period and the general depletion curve followed a convex pattern. In contrast, northern lakes had a slow initial DO depletion. We envision ODEM to be used subsequently for process discovery studies. In the future, we are aiming to apply deep learning methods to visualize the dependency structure between ODEM's fitted flux parameters and available long-term monitoring data. This will support future developments of ODEM to improve the model structure for specific lake setups, as well as augment ecological insights into the dynamics of DO depletion.

Estimating the mixing regime of global lakes from surface water temperature using remote sensing observations

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The process of stratification and mixing is fundamental for understanding the physics, chemistry, and biology of a lake. A lake's mixing regime is defined by the number of times the full water column mixes on average in a year and whether the lake surface freezes in winter or not. For most lakes of the world, the mixing regime is unknown. Yet this information is crucial to understanding the global role of lakes in the functioning of the bio- and hydrosphere and understanding the (projected) changes induced by global environmental change (e.g. warming and cooling lake temperatures, loss of lake ice and less frequent mixing).

As part of my PhD research, I propose to estimate the mixing regime of all lakes of the HydroLAKES dataset (~1.4 million lakes larger than 10 ha.). I am currently collecting Landsat lake surface water temperature (LSWT) observations using the Google Earth Engine processing environment, which will allow me to estimate: (1) the average surface temperature of each lake; (2) whether a lake freezes in winter and; (3) whether and on average how many times a year a lake experiences full water column mixing. For the last point, I will model mixing on- and offset LSWT thresholds depending on climate and lake characteristics. I am looking for researchers that are interested in this project and are willing to collaborate and/or share continuous (full water column) lake temperature observations from field sites, which are needed to train and validate both remote sensing observations and the predictive model.

Understanding and mitigating the subtle effects of psychoactive drugs on aquatic ecosystem functioning

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Use of psychoactive drugs such as antidepressants and antipsychotics is on the rise, with about 270 million consumers worldwide. These pharmaceuticals can end up in water bodies through human excretion or flushing of unused medicines. Since signalling pathways are highly conserved between vertebrate and invertebrate taxa, these psychoactive drugs can affect non-target aquatic organisms. These effects have been observed at very low and environmentally relevant concentrations. There is inadequate information regarding the environmental risks of psychoactive drugs and the standard test protocols currently do not account for subtle effects. Although, psychoactive drugs can contribute to subtle effects by influencing natural communication along the aquatic food chain (infodisruption) or cause other behavioural changes, which could potentially disrupt the ecosystem functioning. To study these impacts, firstly small-scale experiments with chronic low dose exposure will be used, secondly large-scale experiments in near realistic settings with effluent will be used. Along with understanding impacts of psychoactive drugs it is also necessary to implement mitigation strategies. Biological treatment will be used to treat the effluents, post treatment the effluent will be used in the large-scale experiments. The combined results from the experiments will be used to develop bioassays for infodisruption as well as to influence environmental policies by ascertaining the relevance of subtle endpoints in ecosystem functioning.

Oxic methane production: filling gaps in methane lake budgets

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Lakes emit around 20% of natural methane (CH4) emissions, but the contribution of internal sources and sinks that lead to CH4 emissions are not entirely clear. Recent work has shown that oxic methane production (OMP) can be one of the main CH4 sources in lakes, contributing up to 80-90% of atmospheric emissions. Here we analyze sources and sinks of surface water methane in seven lakes across a gradient of trophic state, size and altitude several times during the stratified period. Using a system-wide mass balance analysis and modelling approaches, we show that methane production in well oxygenated surface waters occurs in all of these lakes, but the rates and its contribution to total methane emissions are highly variable over time and across systems. Correlation between oxic methane production and algae concentration and light climate (photic zone/epilimnetic depth) in a nutrient-limited environment could indicate a link between photosynthesis and CH4 production. As these potential methane producers react to changing environmental conditions, eutrophication and climate change could have a strong impact on OMP and its corresponding contribution to atmospheric CH4 emissions from lakes.

Using microbial genomics to inform biogeochemical modelling of anoxic freshwater lakes

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The use of culture-independent techniques in microbiology has led to substantial understanding of the ecology and function of complex aquatic environments over the past decade, yet the genomic era of microbiology has not yet been incorporated in process-based lake models. In anoxic parts of freshwater lakes, where microbes such as Bacteria and Archaea are abundant but oxygen-requiring larger organisms are absent, the roles of microbes in recycling nutrients under oxygen-depleted conditions provides critical feedback into the overall lake's nutrient pool. Here, I present how metagenome-assembled genomes can be used to track complex microbial communities, investigate their metabolic functions, and how this information can be incorporated in lake models. Using five metagenomes collected from Lake Mendota's anoxic hypolimnion, we found that oxidative phosphorylation, complex carbon degradation, fermentation and sulfur cycling dominated the metabolic processes in that ecological zone. By comparing to a multi-year metagenomic time-series of the same lake, we distinguished between microbial processes prominent in the oxygenated epilimnion, and the anoxic hypolimnion. Finally, we present efforts in incorporating the gene-based microbial data in a lake model that aims to estimate the overall lake shift between a harmful blue-green algae-dominated state and not. Overall, the use of microbial genomics can greatly inform our understanding of the biology of anoxic zones of freshwater lakes, and give unprecedented insight in the metabolism of hard-to-observe microbes, which shall prove useful in better estimating lake-level metabolism in anoxic freshwater lakes.

Do years with different ice-out dates influence pelagic and littoral metabolism in a lake?

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The duration of winter ice cover plays a key role in lake metabolism. We analyzed metabolism rates in a littoral (L) and pelagic (P) habitats of a subalpine lake using a metabolism model based on free-water dissolved oxygen during years with early, middle, and late ice-out dates. Gross primary production (GPP) and respiration (R) at L was up to 7.8 and 5.5 times, respectively, higher than at P. GPP and R in both sites was lower during the years with early ice-out (P = 30%, L= 35% decrease) and late ice-out (P = 30%, L= 61% decrease) compared to middle ice-out years. Also, both sites exhibited lower R during the years with early ice-out (P = 26%, L= 41% decrease) and late ice-out (P = 32%, L= 46% decrease). Finally, middle values of net ecosystem production (NEP) were positive during more than 80% of the period analyzed, indicating autotrophic-dominated lake metabolism with one exception in L. In the late ice-out year, L had a negative middle value of NEP during 97% of the analyzed period, showing a shift to heterotrophic metabolism. This study demonstrates how metabolic rates change in different habitats of the lake in years with different ice-out dates. Low heat content on the lake and wash of nutrients and producers late in the ice-free season may have reduced the metabolism during the year with late ice-out. The depletion of nutrients and high grazing rates could have reduced metabolism during the year with early ice-out.

High-resolution hyperspectral water optical properties in a large lake to infer the physical and biogeochemical drivers of primary production

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Measuring primary production (PP) is of major importance to evaluate how lakes are recovering from eutrophication and better constrain their role in global biogeochemical cycles. The classical sampling method involving radio-labelled carbon incubated in bottles at selected depths is associated with heavy logistics and prevents scientists from understanding the short-term dynamics of PP. Therefore, we investigate alternative methods based on optical properties.

Since October 2018, we have deployed a sophisticated autonomous profiler in Lake Geneva, Switzerland. The so-called Thetis profiler measures with a centimeter resolution hyperspectral absorption and attenuation, backscattering and fluorescence at discrete wavelengths, hyperspectral reflectance, along with temperature, dissolved oxygen and conductivity. The profiler was deployed over contrasted seasons and recorded these parameters every three hours over the top 50 m of the water column. Observations of more than 1400 profiles revealed large spatiotemporal heterogeneities of optical properties as a result of seasonal and short-term (weekly to sub-daily) physical and biogeochemical processes. Diel cycles in the inherent optical properties resulted from phytoplankton cells growth-division, grazing, and mixing induced by wind and convection, opening the door to a better understanding of the vertical heterogeneity of PP directly from inherent optical properties. The data also featured advected riverine fluxes and resuspended sediments during storms and periods with dominant snowmelt in the lake catchment. This in-situ data is now being combined with remotely sensed water quality parameters (OLCI products from Sentinel 3) and a three-dimensional hydrodynamic model of Lake Geneva (www.meteolakes.ch) to upscale PP estimates from local to basin scale.

Assessing hydrological responses to river inflow events and their drivers in a New England reservoir

Teresa Sauer[1], Jen Klug[1]

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Climate change is projected to increase the frequency and severity of extreme weather events in Northeastern North America. Both intense precipitation and droughts have serious implications for the health of freshwater ecosystems. Changes in precipitation cause fluctuations of river inflow into lakes, which can alter factors contributing to overall water quality in the lake including temperature, dissolved oxygen and water column stability. Previous research on the impact of storms on lake systems has been limited to severe events such as tropical storms and hurricanes. However, given the projected increase in droughts, it is also important to understand the physical and biological implications of lower magnitude events. The present study examines river inflow events into a temperate reservoir in terms of their deviation from the baseline inflow into the system over a study period of nine summers. I examined changes in the aforementioned factors contributing to water quality as well as potential drivers of those changes. I additionally looked at the potential of river inflow events to alleviate poor water quality conditions within the system. I found that the event caused significant changes in dissolved oxygen at the bottom of the lake as well as temperature throughout the water column. Overall, my results emphasize the importance of high and low magnitude inflow events on the physical and biological processes within the study lake. I propose extending this research by applying the same analyses to a variety of lake systems so that the drivers of change can be better understood.

ZooST – zooplankton over space and time: testing the veracity of space-for-time-substitutions in analyzing and modeling zooplankton community structure and function

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Ecological processes are rapidly being altered in their phenology and magnitude as a result of climate change. Large-scale, multi-lake snapshot surveys are used to evaluate plankton dynamics and their responses to environmental change, especially by substituting environmental gradients over wide geographic areas for time (space-for-time substitutions (SFTS)). SFTS, however, have been critiqued for their assumption that spatial and temporal scales can be coupled. In SFTS lake studies, zooplankton are commonly used as indicators of ecosystem change by modelling how community structure is influenced by environmental variables (e.g., temperature, nutrients, morphometry, chlorophyll-a), or by using processed-based models (e.g., secondary production estimates). We have yet to determine whether these large-scale snapshots are representative of time-integrated patterns in zooplankton community structure and function. In this new GLEON project, we will test whether SFTS survey designs can provide reproducible results that are immune to the potentially confounding factors of space and time. We propose to compile existing long-term time series of zooplankton and associated lake data, empirically re-sample them under different SFTS scenarios, and compare results among the different SFTS scenarios and with the time series data using a suite of typical analyses (e.g., diversity indices, production models based on production:biomass ratios). We hypothesize that results will not be reproducible across different SFTS survey scenarios, and will not capture observed changes and patterns in the long-term time series data. We invite GLEON members to participate in this new project and to contribute applicable long-term time series data.

Modelling the phytoplankton assemblage response to season and zooplankton grazing in a temperate stratified reservoir

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The ability to simulate the seasonality of phytoplankton and zooplankton dynamics in temperate water bodies is challenging for hydrodynamic-ecological models. In this study, we used the CE-QUAL-W2, a two-dimensional model of hydrodynamics and aquatic ecosystem in lakes and reservoirs, to simulate four major functional groups of phytoplankton (green algae, diatoms, cryptophytes, cyanobacteria) and two zooplankton groups (herbivorous, partly carnivorous) in a meso-eutrophic dimictic reservoir (Římov Reservoir, Czechia). The model was capable, after a trial-and-error calibration, to predict the correct seasonality of these four algal groups using different parametrisations of their growth dependences on temperature, light and nutrients and specific preferences of zooplankton grazing. However, modelling encountered the following challenges: (1) high demands on computing resources; (2) inability to reproduce the occurrence of irregular phytoplankton blooms; (3) seasonally invariant parametrisation of algal growth rate and algae/chlorophyll-a ratio (ACHLA); and (4) uncertainty in different parameterization leading to underestimation or overestimation of phytoplankton biomass. To reduce the uncertainty associated with model simulation results, we recommend adjustments to ACHLA according to phytoplankton assemblage, additional mathematical estimation for phytoplankton blooms, and the use of sensitivity analysis in model parametrisation. Overall, the model can provide insight to phytoplankton dynamics under the effect of zooplankton grazing and help design a management strategy to reduce phytoplankton growth and improve water quality.

Cool Things Abstracts

Simulating plankton vertical movement on an hourly time scale with the lake ecosystem model: Water Ecosystems Tool (WET)

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The ability to simulate active vertical movement in phyto- and zooplankton can be important when simulating their vertical distribution on an hourly time scale within a lake. For example, some zooplankton taxa undergo diel vertical migration, staying at deeper depths or near the sediment during the day and closer to the surface during night, or some cyanobacteria taxa can regulate their vertical position by buoyancy to provide access to light at the water surface. We present examples on simulating active vertical movement of plankton in the deep Lake Bryrup, Denmark, with the newly developed lake ecosystem model, Water Ecosystems Tool (WET). The model is a new completely modularized, FABM-compatible model, based on the previously developed FABM-PCLake model. WET allows for a high degree of flexibility in food web configuration and with new options for nitrogen fixation, foraging arena theory and vertical migration.

New Site & Site Update Abstracts

Five Alive! Vermont takes the continuous sensor array plunge on 5 lakes

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In 2011, Vermont began monitoring a set of 13 Sentinel Lakes as reference water bodies. The Vermont Water Quality Standards (VTWQS) defines reference water body as ‘a water that represents the natural condition for a specific water body type against which the condition of waters of similar water body type are evaluated.’ The VTWQS use deviation from the natural condition to determine if the Clean Water Act’s goal of restoring and maintaining the chemical, physical and biological integrity of the Nation’s waters is being met. In 2018, Vermont piloted protocols developed for the Regional Lake Monitoring Network (RLM) by TetraTech with equipment provided by the Environmental Protection Agency at three Sentinel Lakes; Long Pond, High Pond and Holland Pond. Temperature sensors were deployed at every meter with dissolved oxygen and water level sensors deployed 1 m above the bottom. All sensors were set to read every hour and are downloaded, calibrated, serviced, and redeployed twice annually (May/June and October/November). Each lake is sampled at spring turnover and at least once during the summer index period following RLM protocols. In 2020, two more arrays were deployed on Vermont’s Sentinel Lakes; Stannard Pond and Bald Hill Pond. These deployments are part of a grassroots effort by state agency scientists to deploy a network of sensor arrays on least disturbed and representative lakes across the Northeast and upper Midwest of the United States.

US EPA Great Lakes National Program Office: Summary of long-term monitoring program

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The U.S. Environmental Protection Agency Great Lakes National Program Office (GLNPO) long-term monitoring program is the longest-running and most extensive survey of the offshore waters for the Laurentian Great Lakes. The charge to monitor the health of the Great Lakes was initiated by1972 Great Lakes Water Quality Agreement between the United States and Canada (amendments in 1978 and 2012), which required the development of monitoring programs to ensure compliance with the agreement goals. GLNPO initiated its water quality survey (WQS) to track changes in both water quality and the lower food web in offshore waters in 1983 for lakes Erie, Huron, and Michigan, 1986 for Lake Ontario, and 1992 for Lake Superior. Although some changes to the program (mainly additions) have been made since the program began, the GLNPO WQS provides a long-running dataset of water quality and biology variables that have been collected in a consistent way over the decades. Currently, the WQS monitors all five lakes twice per year (spring isothermal period and summer stratified period) with additional intensive efforts in one lake each year on a rotating basis, through the Cooperative Science and Monitoring Initiative (CSMI). Variables measured at all sites include a variety of water quality parameters, as well as phytoplankton, zooplankton, Mysis, and benthic invertebrate communities. This poster summarizes the data that are publicly available from the GLNPO long-term monitoring program.

Localization of EDDIE climate change module with Otsego Lake data

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Project EDDIE is an open educational resource created by GLEON members to provide date-driven inquiry and exploration opportunities for undergraduate and starting graduate students studying environmental sciences. The Climate Change Effects on Lake Temperatures module is packaged to give instructors all the tools needed to guide their students through introduction, hypothesis testing by running their own simulations with the General Lake Model in R, and scaling it up with GRAPLEr package that enables students to run hundreds of simulations in a short time. We envisioned to localize this valuable learning tool with data from Otsego Lake GLEON buoy in upstate NY, USA, so that students in upstate NY and surrounding areas can run another set of simulations with a temperate dimictic lake. General workflow and challenges encountered so far include finding required meteorological data including long and short wave radiation and date/time issues. The original module authors have provided generous support along the way, and we hope that this ongoing project will soon be completed.

Research Update Abstracts

Changing productivity in a sub-alpine lake situated in a pristine catchment

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Lake Lunz is situated in the Northern Calcareous Alps at 600 m a.s. We report rapid changes of productivity in terms of total phosphorus and phytoplankton biomass in the lake within the last ten years. During this time, total phosphorus has almost doubled, from below 5 to 8-10 µg L-1. As the lake is situated in a mostly pristine catchment, point sources and changes in land use can be ruled out as drivers. Nevertheless, we observe overall elevated phosphorus loading from the catchment through the creek Seebach. We discuss potential underlying mechanisms, as the effects of a recent forest dieback in the catchment, and altered climatic conditions.

The chemical diversity of dissolved organic matter

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Dissolved organic matter (DOM) is central to the functioning of freshwaters but its complexity hampers an understanding of its composition and biogeochemical roles. Advances in ultrahigh-resolution mass spectrometry (UHR-MS) are now opening the "black box" of DOM to reveal that each handful of lake water contains thousands of different organic molecules of varying origin, composition, and potential function. Here we update our efforts to predict how chemical diversity influences the functioning of lakes as part of the Ecological and Evolutionary Importance of Molecular Diversity in Dissolved Organic Matter (#sEEIngDOM) project funded by the European Research Council. In 2019, we mapped chemical diversity across 101 lakes spanning the latitudinal extent of Europe using UHR-MS. We have found that diversity promotes ecosystem multifunctionality and is enriched by recalcitrant molecules that can provide novel niches for microbial activity. We will end this update with a call for participants to join a new project from the Lake Metabolism/C-cycling Working Group established at GLEON 21 and affiliated with sEEIngDOM. The DOMseasons project aims to track seasonal changes in the chemical diversity of DOM across the world's lakes using UHR-MS and determine its association with biogeochemical data collected from high-resolution sensors. We are especially interested in welcoming participants that could contribute monthly water samples from pelagic monitoring stations. Delayed by the COVID-19 pandemic, we hope to launch DOMseasons in late-2020 / early-2021.

Swiss Lake temperature monitoring

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Climate change is expected to significantly modify the thermal structure of lakes, with important consequences for their ecosystem services, e.g. drinking water supply, the provision of habitats, or recreational use. In order to better observe these changes, and as a base for developing adaptation and mitigation strategies, the Swiss Federal Office for the Environment (FOEN) intends to develop a lake temperature monitoring network. Water temperature should be observed continuously in a representative set of lakes, including lakes of different sizes and at different altitudes. In 2021, a new research project will be started in collaboration between FOEN and Eawag, where two pilot stations with different technology will be implemented. One station will be located in an oligotrophic mid-altitude lake that will likely shift from dimictic to monomictic due to climate change, and the second station will be in a meso-eutrophic lake where the expected prolongation of summer stratification may increase the occurrence of hypolimnetic anoxia. In addition to the pilot stations, data from already existing stations (e.g. LéXPLORE on Lake Geneva) will be used as a basis for developing the long-term monitoring strategy.

Using multiple Earth observation platforms for monitoring chlorophyll-a concentration in river-connected lakes

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The use of remote sensing techniques for monitoring water quality of lakes has increased, especially with the launch of more powerful sensors and observation platforms (satellites, the international space station, airplanes, and handheld) in recent years. Since chlorophyll-a is a widely used indicator for algae biomass and thus for water quality, several bio-optical algorithms to estimate chlorophyll-a concentration have been developed. The goal of this study is to evaluate the use of multiple Earth observation platforms for chlorophyll-a monitoring in river-connected lakes by ground-truthing through a year-long field campaign in 19 lakes. Data collected from Earth observations sensors were compared to proximal remote sensing measurements and in situ chlorophyll-a concentrations measured on water samples by High Performance Liquid Chromatography in the laboratory. For strongly connected lakes with low retention times (<0.3 year), chlorophyll-a concentrations were accurately estimated by data from sensors collected from different observation platforms (R2 >0.8). However, for weakly connected lakes with higher retention times (>0.3 year), the estimation of chlorophyll-a concentration was acceptable only for shallow and eutrophic lakes (R2 around 0.7), while it was poor for oligotrophic lakes (R2 around 0.4). Our results suggest that although remote sensing tools can be used as a complementary data source for improving current monitoring programs, knowledge of the respective environment is needed to select the most appropriate bio-optical algorithm. Thus, for a universal framework of chlorophyll-a concentration retrieval from remote sensing techniques, a comprehensive validation of bio-optical algorithms for the large variety of global lakes is needed.

Physical and biological drivers of the temperature sensitivity of lake CH4 emissions

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Lake emissions of the climate forcing trace gas methane (CH4) are strongly dependent on thermal energy input due to the compound effects of temperature-sensitive biogeochemical and physical processes. The temperature sensitivity of the flux varies between sites and emission pathways (ebullition and diffusion), but the reasons for this are largely unknown. For improved modeling, a mechanistic understanding of flux temperature sensitivity and its variability is required. We use a multiyear dataset (2009–2017) of ice-free CH4 emissions from three subarctic lakes obtained with bubble traps (n = 14677) and floating chambers (n = 1306) to quantify the temperature sensitivity of the flux. Arrhenius functions closely fit measured fluxes (R2 > 0.93). Ebullition (activation energy 1.36 eV) expressed greater temperature-sensitivity than diffusion (1.00 eV). In this presentation we briefly discuss the physical processes that may contribute to this difference, such as stratification, and highlight key questions that remain.

Effects of consecutive extreme weather events on a temperate dystrophic lake: a detailed insight into physical, chemical and biological responses

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Between May and July 2018, Ireland experienced an exceptional heat wave, which broke long-term temperature and drought records. These calm, stable conditions were abruptly interrupted by a second extreme weather event, Atlantic Storm Hector, in late June. Using high-frequency monitoring data, coupled with fortnightly biological sampling, we show that the storm directly affected the stratification pattern of Lough Feeagh, resulting in an intense mixing event. The lake restabilised quickly after the storm as the heatwave continued. During the storm there was a three-fold reduction in Schmidt stability, with a mixed layer deepening of 9.5 m coinciding with a two-fold reduction in chlorophyll a but a three-fold increase in total zooplankton biomass. Epilimnetic respiration increased and net ecosystem productivity decreased. The ratio of total nitrogen:total phosphorus from in-lake versus inflow rivers was decoupled, leading to a cascade effect on higher trophic levels. A step change in nitrogen:phosphorus imbalances suggested that the zooplankton community shifted from phosphorus to nitrogen nutrient constraints. Such characterisations of both lake thermal and ecological responses to extreme weather events are relatively rare but are crucial to our understanding of how lakes are changing as the impacts of global climate change accelerate.

Effectiveness of phosphorus control under extreme heatwaves: implications for sediment nutrient release and greenhouse gasses emission

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Climate change and eutrophication are identified as key drivers of water quality deterioration worldwide. Extreme climatic events are suggested to exacerbate the effect of nutrient enrichment, through increasing nutrient-run off during extreme precipitation events as well as increasing mineralization rates during heatwaves. In order to prepare managers to future global change scenarios we investigated how the effectivity of a promising nutrient abatement technique is impacted by a heatwave. To this end, we carried out a sediment-incubation experiment, where we tested the effectivity of a solid phase P sorbent, Phoslock® in reducing phosphorus to low enough levels to prevent algal biomass growth with and without exposure to an extreme heatwave event. Our results showed that Phoslock® was able to drastically reduce phosphorus concentrations in the water column, and the heatwave led to permanent higher sediment phosphorus release, with P-elevation lasting to the end of our experimental period. During the heatwaves greenhouse gas emissions also increased temporarily. Our results indicate that the effectivity of Phoslock® might only temporarily be compromised during heatwaves, but the increase in GHG could reinforce climate change.