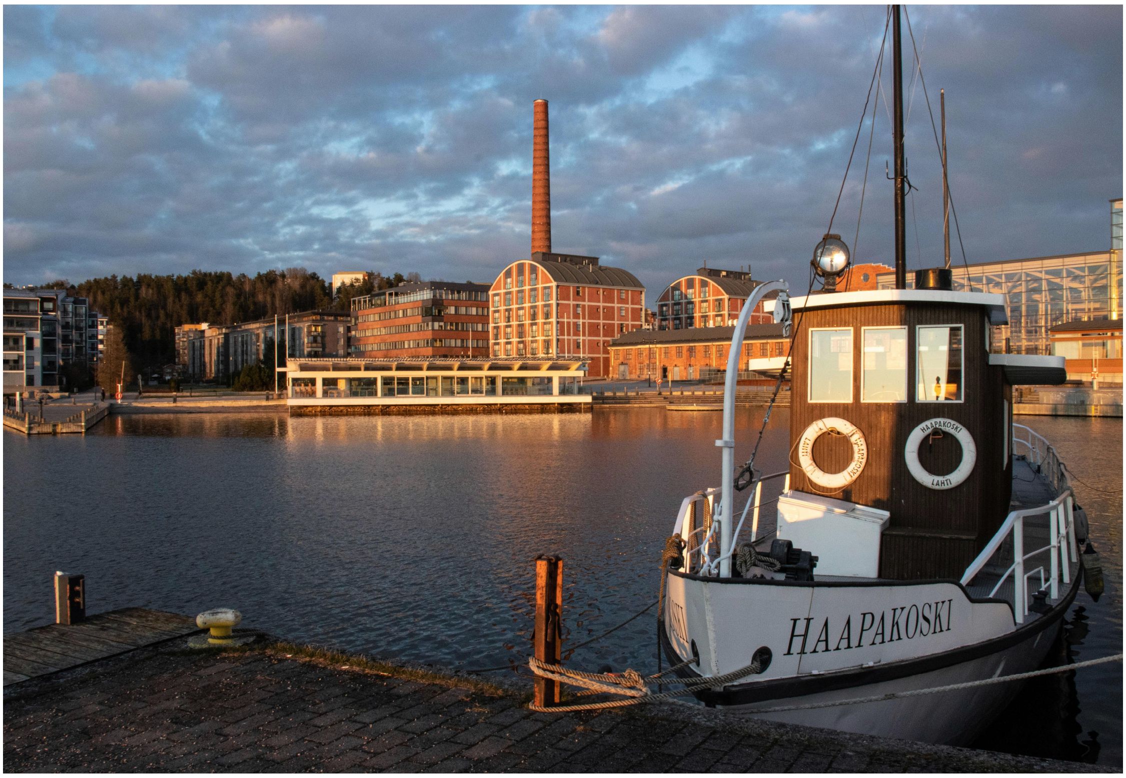

LAHTI LAKES 2021

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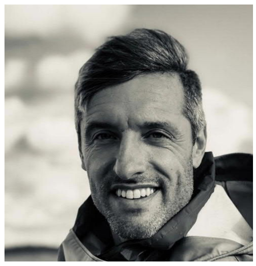

Dear participants,

A lot has happened since June 2018, when we held the first Lahti Lakes symposium in the Sibelius Hall on the shores of Lake Vesijärvi (pictured on the previous page). It is of course a great shame that we cannot meet in person as we did back then, but on the other hand we are excited to host this year's event in a hybrid format including a majority of presentations online. We are also very happy to connect our meeting to the official Lahti European Green Capital 2021 program, and to join forces with the SIL Working Group on Lake Restoration.

The COVID-19 situation has affected all of us in various ways. We are grateful that despite the difficulties of the last year, our symposium continues to be of interest to a wide audience around the world. This year's event will be attended virtually by over 100 participants from 15 countries, giving us some great opportunities for sharing our experiences of tackling lake restoration problems worldwide.

We have put together the program along similar lines to the 2018 symposium, grouping the oral presentations into 7 themed sessions. There are also two poster sessions, with a dedicated set of presenters in each, to maximize the chance for interaction. The symposium is hosted from Lahti, where I will be standing in front of the camera introducing the sessions (☺), but most of you will be following online through the platform hosted by our partner Liveto. In the platform we will have group video chats at the end of each session, so that we can debate the topics raised by the speakers, as well as plentiful opportunities for 1-to-1 discussions.

We are very excited by the range of presentations in the program this year. Key themes emerging in our field right now include the need to understand how to account for climate change in lake restoration planning, and how to integrate lake restoration into sustainability and circular economy strategies. Many of the presentations touch on these themes, and we are sure that the community will have plenty to discuss over the three days. We are especially grateful to our plenary speakers Erik Jeppesen, Anne-Mari Ventelä and Bryan Spears, each of whom will give extended talks embedded into the oral sessions. But thank you already to all presenters of the oral and poster sessions for working with us to make the online meeting a reality. We are very much looking forward to hearing about your work!

Best wishes on behalf of the organizing committee,

Tom Jilbert

University of Helsinki, Finland

UNIVERSITY OF HELSINKI · SIL Working Group on Lake Restoration · LAHTI Winner 2021 EUROPEAN GREEN CAPITAL An initiative of the European Commission · I Vesijärvi Lake Vesijärvi Foundation, Lahti, Finland

Contents

Abstracts have been edited for language by the organizing committee

MONDAY 7 JUNE

ORAL SESSION 1: FOODWEBS AND BIOMANIPULATION

PLENARY 1: Biomanipulation as a tool to counteract negative climate warming effects in lakes in different climate zones

Erik Jeppesen (1, 2), Martin Søndergaard (1), Zhengwen Liu (3, 4)

(1) Department of Bioscience, Aarhus University, Denmark (2) Department of Biology, Middle East Technical University, Turkey (3) Nanjing Institute of Geography and Limnology, Nanjing, China (4) Department of Ecology and Institute of Hydrobiology, Jinan University, Guangzhou, China

Lakes around the globe are under severe pressure, due to an increasing anthropogenic impact from a growing population in a more developed world. Accordingly, many lakes are highly eutrophic and suffer from severe blooms of, often, toxic cyanobacteria. Recent research has further shown that global warming and subsequent changes in water use will further exacerbate the eutrophication process in lakes. There is therefore a growing demand for lake restoration and insight into sustainable lake management. While external loading reduction is of key importance for all type of lakes to combat eutrophication and help mitigating the effect of climate warming, the in-lake measures that can be used to speed up recovery, depend on the climate the lakes are facing. In this talk, I will show restoration examples from different climate zones, with special emphasis on biomanipulation. While fish removal can lead to both top-down and bottom-up effects in temperate lakes, we cannot expect a comprehensive shift in top-down control via fish and grazers in warm lakes. So focus should here be on bottom-up control, and combined physico-chemical and biological methods have proven particularly efficient in warm lakes.

Biomanipulation of lakes: implications for waterfowl

Laura H. Härkönen (1), Ilkka Sammalkorpi, Jukka Ruuhijärvi (2), Markku Mikkola-Roos (3), Ilpo Huolman (4)

(1) Finnish Environment Institute, Freshwater Centre, Helsinki, Finland (2) Natural Resources Institute Finland, Helsinki, Finland (3) Finnish Environment Institute, Biodiversity Centre, Helsinki, Finland (4) Centre for Economic Development, Transport and the Environment, Uusimaa, Helsinki, Finland

The conservation status of Finnish inland waterfowl populations has dramatically decreased. According to the latest review, populations of the most abundant, inland nesting species have declined significantly during a 33-year monitoring period especially in eutrophied lakes. Changes in water quality, food resources and vegetation are all relevant to waterfowl abundance. Eutrophication often steeply increases the biomass and proportion of benthivorous cyprinids. Shared food resources with benthivorous cyprinids subject aquatic birds to food competition. Many benthivorous, aquatic bird species such as Tufted duck (*Aythya fuligula; EN*) and Common Pochard (*A. ferina*; CR) have become endangered in the 2010´s.

Biomanipulation has long been identified as a potential way to diminish algal blooms in eutrophied lakes. In the management of waterfowl lakes however, biomanipulation has been less implemented despite its potential, and evidence, to reduce competition between waterfowl and fish for invertebrate prey.

The national Helmi habitats programme [1] aims to strengthen Finland's biodiversity by 2030. In waterfowl habitats, biomanipulation will be systematically implemented among other restoration measures. There are dozens of lakes in which prerequisites for biomanipulation will be assessed within the framework of Helmi programme. Biomanipulation will be launched in 2021 in at least 17 lakes with a high fish CPUE in standard gillnets, abundant cyprinid fish stock and declined waterfowl populations. During the programme, these target lakes will be monitored for numbers of waterfowl, fish stock, water quality, zoobenthos/aquatic insects and vegetation. Expectations are that biomanipulation will increase the numbers of waterfowl, especially diving ducks, at the treated lakes. Efficient biomanipulation can also reduce turbidity, thus leading to wider occurrence of submerged macrophytes offering food sources to declined herbivorous bird species as well.

[1] https://ym.fi/en/helmi-habitats-programme

Spread of non-indigenous moss animal Pectinatella magnifica in Finland - impacts and management

Kristiina Vuorio

Finnish Environment Institute SYKE, Latokartanonkaari 11, FI-00790 Helsinki, Finland

Deliberate or unintentional introductions of new species to aquatic environments are generally unwanted. In underwater environments, non-indigenous species may proliferate long before their existence is registered. Many such species spread intensively and have irreversible and uncontrollable adverse impacts on biodiversity and ecosystem functions. Not only can they displace native species by predation or competition, but they can also transmit (parasitic) diseases harmful to native species and cause environmental, health-related or economic impacts, or have negative effects on recreational use of waters. The moss animal Pectinatella magnifica (Leidy 1851) originates from Northern America, but it has recently spread by human all over the northern hemisphere. The most probable vector for the invasion is ship ballast water. The species was first recorded in Finland from Lake Saimaa around 2006. Since then, it has spread to the vicinity of ports of international and national shipping around the Vuoksi watercourse in Southeast Finland. For now, the only other confirmed observations in Finland are from Lakes Kirkkojärvi and Pyhäjärvi in Pirkanmaa Southern Finland, at some 250 km distance from Vuoksi, without water connection. The most apparent environmental harm of Pectinatella is biofouling. However, it may pose a potential risk for salmonid fish as it may be a host for a myxozoan parasite, potentially transmitting proliferate kidney decease (PKD), lethal to salmonid fish. Climate change is expected to enhance the geographic range of Pectinatella and other non-indigenous species. Eradication or even prevention of further spread of these species is usually extremely difficult or impossible due to their high spread potential. At the moment, there are no efficient measures to manage the species. Moreover, funding opportunities for non-indigenous species management are often limited, unless the species is accepted to the national or EU list of harmful non-indigenous species.

The potential of long term fish removal in eutrophic lakes

Ilkka Sammalkorpi (1), Anne-Mari Ventelä (2), Mikko Olin (3), Jukka Ruuhijärvi (3), Jaana Hietala (4), Arto Hautala (5), Helene Annadotter (6), Jouko Sarvala (7)

(1) ilkkasam@gmail.com (2) Pyhäjärvi Institute, Finland (3) Natural Resource Centre LUKE, Finland (4) Keski-Uusimaa Environment Centre, Finland (5) Arto Hautala Environment Services (6) Regito AB (7) University of Turku, Finland

Eutrophic lakes are often characterized by high cyprinid biomass. Thus, effective fishing represents a potential sink to remove phosphorus from the lake ecosystem. Cost effective fish removal methods have been developed in biomanipulation of Finnish lakes. We estimated the role of the phosphorus pool in fish biomass removed in long management of eight North European lakes (area 145 – 15500 ha, retention time 0,2 – 4,9 years, external phosphorus load <0,1 – 0,6 g P m-2a-1, fish removal 0 – 240 kg ha-1a-1 and duration of fish removal from five to 20+ years). Long term development of lake water quality benefitted from fish removal and vice versa. The phosphorus pool removed in fish biomass (FPout) was compared with parameters of nutrient balances. It was up to 25 % of the mean annual external total phosphorus (TP) loading, it could exceed 50 % of the mean TP concentration of the lake water, mean sedimentation of TP and TP of outflow. The relative importance of FPout depended on the efficiency of fishing and retention time. By shorter retention time and high external loading, even high catches in kg ha-1a-1 were lower compared with the external load, but their percentage of retention and annual outflow of phosphorus increased. Our results suggest that biomanipulation can, in addition to the positive short term impacts, also support long term nutrient removal in the river basin scale. However, it does not compensate the necessary long term measures reducing diffuse external loading which are tackled e.g. in agricultural policy.

ORAL SESSION 2: CHEMICAL METHODS IN LAKE RESTORATION

Managing eutrophication through chemical inactivation of phosphate- an overview of materials available

Maíra Mucci (1,2), Guido Waajen (3), Li Kang (1), Said Yasseri (2), and Miquel Lürling (1)

(1) Wageningen University and Research, P.O. Box 47, 6700, AA, Wageningen, the Netherlands (2) Limnological solution International, Level 6, 57 Esplanade, Cotton Tree 4558, Queensland, Australia (3) Water Authority Brabantse Delta, P.O. Box 5520, 4801 DZ Breda, the Netherlands.

Managing eutrophication, and in particular diffuse loading and internal nutrient loading, remain a challenge to water managers. Currently, the manipulation of biogeochemical processes (i.e., geo-engineering) by using phosphorus-adsorptive techniques has been recognized as an appropriate tool to manage the internal load problems and has been used in several restoration plans worldwide. There are numerous (more than 100) materials able to chemically inactivate phosphorus (P) described in the scientific literature. However, most of these cannot be used on a large scale due to a lower efficiency under realistic conditions, unknown toxicology effects, lack of long-term studies, or unavailability of commercial quantities. Compounds with nitrogen (N) binding capacities are even rarer. There are currently four principal groups of materials that are being used at the whole lake scale to inactivate P (aluminium, calcium, iron and lanthanum-based materials). Here, we will discuss the differences between these four groups of materials focusing on their primary modes of action, P-binding capacity, and their cons and pros. In addition, an example of a whole lake intervention will be shown where an aluminium salt - polyaluminium chloride (PAC) (primarily as a coagulant) and lanthanum modified bentonite - Phoslock® (primarily as sediment P fixative) were used in combination. The treatment aimed to target both dissolved and particulate phosphate and to block P-release from the sediment. After application of 6 tons of PAC and 32.5 tons of Phoslock®, total phosphate, turbidity, and chlorophyll-a were reduced in Lake de Kuil (the Netherlands). Secchi depth increased and microcystin concentration was reduced. Monitoring results will be presented in detail shedding light on the efficacy and durability of the treatment.

Aluminium treatment for internal load phosphorus reduction and lake restoration: what works, what doesn't, and why

Brian J. Huser

Dept. of Aquatic Sciences and Assessment Swedish University of Agricultural Sciences Box 7050 75007 Uppsala Sweden

Aluminum addition has been used for over five decades in hundreds of lakes around the world to reduce the release of legacy phosphorus in sediment and improve water quality in lakes. However, results have varied greatly, leading to contention and uncertainty as to when and where this restoration method should be applied. A large portion of this is due to advancements in dosing, but other factors are also important and can affect treatment effectiveness greatly. In this talk I will cover historical treatments (going back to the late 1960s) and present results showing varying levels of treatment effectiveness and why we see this variability. I will also discuss current research covering the role different factors, including lake type, benthic feeding fish, binding efficiency, etc. play in treatment effectiveness and longevity. Finally, methods to ensure cost-effective and sustainable treatments in the future will be discussed.

Assessing the potential of iron byproducts from water purification in the prevention of phosphorus-release from lake sediments

Karel S. As (1), Melanie A. Münch (2), Thilo Behrends (2), Stefan Peiffer (1)

(1) Chair of Hydrology, University of Bayreuth, Universitätsstraße 30, 95447 Bayreuth, Germany (2) Utrecht University, Princetonlaan 8A, 3584CB Utrecht, the Netherlands

According to the European Environment Agency (EEA), about 60% of the European surface waters are failing good ecological status. Lakes exhibiting significant remobilization from the sediment are likely to require restoration measures to reach management goals. Conventionally, lake restoration measures are performed using iron or aluminum salts. Although effective, these salts potentially cause problems in badly buffered lakes. This limits the scope of usage. In this study we investigate and compare the efficacy of iron byproduct, a waste product from water purification, in preventing sedimentary phosphorus release. Sediment was taken from the internally loaded lake Kleiner Brombachsee near Nuremburg, Germany. The sediment was mixed and incubated with an amendment of Al(SO4)2 · 12 H2O, Fe(II)Cl¬2· 4 H2O and the iron byproduct at 70 g Me*m-2. The sediment cores were subsequently exposed to weekly oscillating redox conditions. Each day samples were taken from the overlying water. Each week the sediment was analyzed using micro-sensors and sequential extraction of iron and phosphorus. From these analyses we found that all treatments were able to prevent release of phosphorus. However, upon addition of organic matter and under anaerobic conditions the iron byproduct was less capable than iron salts to prevent release of phosphorus from the sediment. The sequential extraction results indicated that the iron salt was able to bind phosphorus more effectively and in a larger variety of ways. The precise nature of the iron species associated with these fractions should be investigated further. Although the iron byproduct was slightly less effective, multiple advantages were found: 1) pH of the overlying water was not altered, 2) no effects compared to reference on pH and pE of the sediment and 3) prevention of sulfide build-up at sediment-water-interface. Iron byproduct can be an interesting alternative to conventional salts treatments, especially for sensitive lake systems.

Sedimentary pools and dynamics of P and Fe in a eutrophic peat lake after Fe-amendment

Melanie A. Münch (1), Rianne van Kaam (1), Karel As (2), Stefan Peiffer (2), Gerard ter Heerdt (3), Caroline P. Slomp (1), Thilo Behrends (1)

(1) Utrecht University, Princetonlaan 8A, 3584CB Utrecht, the Netherlands (2) University of Bayreuth, 95440 Bayreuth, Germany (3) Waternet, Korte Oudekerkerdijk 7, 1096 AC Amsterdam, the Netherland

Excess P input is a global challenge for surface water quality. In lakes internal loading with legacy P stored in the sediments has been shown to grow in importance when external loading is reduced. Sustainable methods to prevent P mobilization from lake sediments include addition of Fe(III) salts. Field scale treatments show diverse effects and the governing factors are not fully understood yet. In this study the impact of Fe addition on the Fe and P dynamics in peaty lake sediments is investigated. Terra Nova is a eutrophic shallow peat lake. It was treated with FeCl3 in 2010, effectively reducing surface water P concentrations, but since 2016 the P loading of the water column has been increasing steadily to higher levels than before the treatment. Sediment cores were collected in May 2020. Porewater and sediment were analyzed for chemical composition and sequential extractions of P and Fe were performed on the solid phase. Undisturbed sediment cores where incubated under oxic and anoxic conditions. The results show that the dynamics of Fe and P are coupled in the sediment. But the increased availability of Fe does not lead to increased burial of P. According to the incubation experiments, more P than Fe escapes into the water column during anoxic periods, preventing the quantitative trapping of P by Fe upon reoxygenation of the water column. The sequential extraction results provide an explanation for this phenomenon as they suggest that significant amounts of Fe in the sediment is associated with organic matter. This Fe pool is more redox sensitive than Fe (oxyhydr)oxides but also less mobile as the organic matter stabilizes the Fe cations. Further research will focus on the nature and biogeochemical properties of Fe – organic matter associations and their reactivity towards P. This data will then be used for reactive transport modelling with the aim to identify the key factors for successful lake restoration using Fe byproducts from drinking water production.

Geochemical mechanisms controlling internal phosphorus loading in a lanthanum-remediated eutrophic lake

Wessam Neweshy (1), Marie Demers (1), Dolors Planas (2), Elisabeth Tellier (3), Raoul-Marie Couture (1,4)

(1) Chaire de recherche Sentinelle Nord en géochimique des milieux aquatiques, Département de chimie, Université Laval, Québec, Canada (2) Université du Québec à Montréal et Groupe de recherche interuniversitaire en limnologie (3) Action de Conservation du Bassin Versant du Lac Bromont (4) Takuvik Joint International Laboratory ULaval-CNRS

Sustained eutrophication of aquatic environments by remobilization of legacy P stored in the sediment is a worldwide issue. In that context, abatement measures via bottom water treatment or sediment remediation have been shown to successfully complement catchment management approaches [1]. Here, we present a case study of the eutrophied Lac Bromont, which underwent remediation treatment using lanthanum-modified bentonite (LMB). We investigated the effectiveness of LMB in decreasing soluble reactive phosphorus (SRP) availability in sediments and in reducing dissolved fluxes of P across the sediment-water interface. Sediment cores were retrieved before and after LMB treatment, to measure P speciation using sequential extractions. Porewater P, Fe, dissolved organic matter (DOC) and La profiles were obtained after treatment at three sites. Results indicate that SRP extracted from the sediments decreased at all sites, while total P bound to redox-sensitive Fe oxides increased. Results further show that P mobility is coupled to La or Fe depending on the site. Modeling confirms that a $LaPO_4(s)$ mineral phases are likely forming (i.e., rhabdophane and/or monazite [2], but suggest that La^{3+} binding by DOC hinders its precipitation [3]. Finally, ^{31}P NMR reveal that 30-50% of total solid-phase P is in an organic form, susceptible to be released via microbial degradation.

[1] Jilbert, T., et al., Hydrobiologia, 2020. 847(21): p. 4343-4357.

[2] Dithmer, L., et al., Environmental Science & Technology, 2015. 49(7): p. 4559-4566.

[3] Marsac, R., et al., Geology, 2021. 567: p. 120099.

ORAL SESSION 3: PHYSICAL METHODS IN LAKE RESTORATION

The potential of hypolimnetic withdrawal and treatment in the restoration of eutrophic lakes

Soila Silvonen (1), Juha Niemistö (2), Adrián Csibrán (3), Tamás Krámer (3), Péter Torma (3), Leena Nurminen (1), Tom Jilbert (1), Jukka Horppila (1)

(1) University of Helsinki, Viikinkaari 1, 00790 Helsinki, Finland (2) AFRY Finland Oy, Jaakonkatu 3, 01620 Vantaa, Finland (3) Budapest University of Technology and Economics, Műegyetem rkp. 3, 1111 Budapest, Hungary

Internal phosphorus (P) loading can maintain the eutrophic state of a lake long after the external loading has been reduced to a sustainable level. The removal of this circulating P through e.g. hypolimnetic withdrawal (HW) may accelerate the recovery of the lake considerably, but careful planning and optimization of the technique are required to maximize the benefit and minimize any potential disturbances caused to the lake and its surroundings. We studied how the effectiveness and proper scaling of HW may be assessed through a biogeochemical and hydrodynamic approach, and how conventional HW can be applied into a closed-circuit water treatment system to tackle some of the limitations of the method. We monitored the seasonal cycles of the sediment and water chemistry as well as the thermal conditions of our study lake (Lake Kymijärvi, southern Finland), and conducted test runs of an onshore hypolimnetic withdrawal and treatment system (HWTS) pilot. We found that adjusting P removal via HW to the diffusive flux of sedimentary P into the water is an optimal approach as it removes large amounts of P and still may not disturb the lake's thermal stratification significantly. The test runs of HWTS showed that a simple water treatment and filtration system can effectively capture most of the P, enabling a closed-circuit system that prevents the pollution of the waters downstream and allows the recycling of the captured P.

Prevention of cyanobacteria proliferation in two connected drinking water reservoirs

Gertrud K. Nurnberg

Freshwater Research 3421 Muskoka Rd 117 P0B 1A0 Baysville, Ontario Canada

The drinking water of the City of Moncton, New Brunswick, Canada depends on two reservoirs. One of these reservoirs was built upstream and put on line in 2014 to prevent possible future water shortages. This upstream reservoir experienced a potentially toxic cyanobacteria bloom in the fall of 2017, and limnological monitoring by staff of the City of Moncton of both reservoirs has since provided an abundance of data to address potential causes and future prevention of cyanobacteria.

Both reservoirs are relatively unproductive according to Secchi Disk, nutrients, and chlorophyll growing period values with the upstream reservoir being borderline meso-eutrophic (e.g., 0.017 mg/L total phosphorus, TP) and the downstream reservoir, with the outlet into the water treatment plant, oligotrophic (0.008 mg/L TP). However, both reservoirs experience oxygen depletion (< 3.0 mg/L DO) with a maximum anoxic factor of 21 d/yr in the upstream and 9 d/yr in the downstream reservoir, depending on climate-related stratification status.

Phosphorus, iron, and manganese depth profiles, their seasonal concentration changes, and sediment P fractionation indicate internal P release from anoxic sediment in 3 of the 4 study years. Since 2017, internal load was up to 28% of total TP load in the upstream and up to 12% in the downstream reservoir. Phosphate released from bottom sediments can present a nutrient source for cyanobacteria growth in late summer and fall. Therefore, a lake treatment based on a phosphorus binding material with lanthanum, Phoslock, was recommended. However, a Phoslock treatment may not be licensed in Canada in the near future and other possible treatment options are needed.

A physical management approach was considered most promising according to theoretical limnological considerations and TP mass balance modeling. Physical management involves the increase of the upstream dam height, which is planned in the future to accommodate increases in population. The heightening of the water level in conjunction with the management of deep-water outlets (suggested are 2 additional depth outlets) would create conditions less favorable to cyanobacteria. The beneficial effect on the phytoplankton where a larger epilimnion would discourage surface blooming cyanobacteria, especially Dolichospermum, in favour of more beneficial algae genera, outweighs concerns respective increased hypoxia, metalimnetic cyanobacteria proliferation, and increased P export to the downstream reservoir.

Flexibility of adjusting the outflow depth would assist in management, if necessary. For example, an elevated outflow depth could decrease the outflow of redox-related substances (P, Fe, and Mn) and provide control of the export of potentially toxic Planktothrix species from the metalimnion. Benefits to the upstream reservoir from the decrease in TP concentration by dilution and from the decrease in the probability of toxic surface blooms because of the dependence of cyanobacteria on shallow, stratified, well-lit conditions are expected to outweigh any adverse effects to the downstream drinking water reservoir.

Preliminary assessment of hypolimnetic oxygenation to improve water quality in Hodges Reservoir, California, USA

Marc Beutel (1), Naivy Rodal (1) Byran Fuhrmann (1,2)

(1) Environmental Systems Graduate Group, University of California, Merced, California, 9343, USA (2) SePro Corporation, Whitakers, North Carolina, 27891, USA

This presentation provides an update to Dr. Beutel's presentation on Hodges Reservoir water quality at the first Lahti Lakes Conference in 2018. Data is provided in coordination and consultation with the City of San Diego Public Utilities Department. The reservoir is a hypereutrophic water supply reservoir in northern San Diego, USA with a typical maximum depth of around 22 m, mean depth of 8 m and surface area of 6 km2. Poor water quality has limited use of the reservoir to serve as a regional source of potable water. In the fall of 2020, the City of San Diego Public Utilities Department installed a 6-metric-ton-per-day hypolimnetic oxygenation system using pure oxygen gas to enhance bottom water dissolved oxygen and water quality in Hodges Reservoir. Intensive water quality monitoring from 2017-2019 revealed extreme hypolimnetic accumulation of ammonia and phosphate, which fueled summertime algal productivity in this modestly deep reservoir. Bottom waters also accumulated high levels of manganese (Mn), which was also found to increase in surface waters, indicating active internal loading of dissolved compounds from the hypolimnion to surface waters. Iron (Fe) accumulation in bottom waters appeared to be limited due to the precipitation of Fe-sulfide. The COVID-19 outbreak impeded recent water quality monitoring and resulted in a downsizing of water quality monitoring efforts. But recent water quality data after oxygenation shows a dramatic decrease in bottom water ammonia and Mn. Fe in bottom waters increased slightly while turbidity decreased substantially, which was attributed to a lack of sulfide and associated Fe-sulfide precipitation. Pre-oxygenation data showed that bottom waters accumulated toxic methylmercury (MeHg) coincidental with manganese accumulation. There appeared to be a hot moment of MeHg bioaccumulation in the spring when mildly reduced conditions prevailed. MeHg levels were lower later in the season coincidental with elevated sulfide levels in bottom waters. Continued monitoring of mercury in the reservoir is planned for 2021 to assess how oxygenation affected the cycling of this toxic and bioaccumulative compound.

TUESDAY 8 JUNE

ORAL SESSION 4: NEW PERSPECTIVES IN LAKE RESTORATION

PLENARY 2: Lake restoration as an integral component of circular economy and sustainable food production

Anne-Mari Ventelä

Pyhäjärvi Institute, Finland

As the effects of climate change on our environment become more concrete and visible, our possibilities of achieving the objectives of lake restoration are declining. Flooding and other extreme weather events create serious problems in reducing external nutrient load. Many of our current restoration methods are becoming insufficient. However, in many areas the emphasis of work in lake catchments has already been changed from trying to trap nutrients and eroded soil after they leave the field (wetlands, sedimentation ponds etc.) to an effort to retain nutrients and water in the field soil by improving the growth capacity of the soil. In Finnish lake catchments there exist areas in which most of the farms have a contract with large, national scale food companies. These companies are currently facing lot of pressure from retail chains and customers (environmental certificates, foot prints etc.) and are willing to invest in sustainable production, to the benefit of lake restoration. Furthermore, in the world of circular economy, nutrients and biomass (fish, algae and plants) are seen as a valuable resource. In Lake Pyhäjärvi the long term biomanipulation has been linked to commercial fishery, and a local food company has recently developed a very popular product derived from earlier underutilized fish biomass. Therefore, the whole biomanipulation is now self-funded from the lake management perspective. This commercially driven biomanipulation is very powerful tool to decrease internal nutrient loading even in a changing environment. These kind of win-win solutions may motivate private companies to participate in lake restoration actions as a long-term partner. In Finland today there are several successful cases where the public-private-partnership model has been used in long term lake restoration. This model has many benefits to all actors.

Remote sensing as useful tool to establish the presence and density of cyanobacterial blooms and their temporal and spatial distribution at continental water bodies

Rebeca Pérez (1), Xavier Sòria-Perpinyà (1), Eduardo Vicente (2), Juan M. Soria (2), Jesús Delegido (1)

(1) Image Processing Laboratory (IPL), Universitat de València. Paterna University Campus, 46980, Paterna (València), Spain (2) Cavanilles Institute of Biodiversity and Evolutionary Biology (ICBiBE), Universitat de València. Paterna University Campus, 46980, Paterna (València), Spain

Remote sensing is an appropriate tool for water management, which allows studying some of the main consequences of pollution, such as Cyanobacterial Harmful Algal Blooms. These species are increasing due to eutrophication and all the adverse effects that climate change entails. This leads to water quality loss, generating great environmental impact, causing a problem for human water supply, having to be subjected to more expensive purification processes. The application of satellite remote sensing images as bio-optical tools is a promising way to monitor and control phycocyanin (PC) concentrations, which indicates the presence of cyanobacteria. For this study, 90 geo-referenced in situ phycocyanin measurements were made, using Turner C3 Submersible Fluorometer calibrated with phycocyanin standard, at water bodies of Eastern Iberian Peninsula. These samples were synchronized with Sentinel-2 satellite orbit. Their images were processed using SNAP software, being first resampled and corrected with the C2RCC atmospheric correction programme. To get algorithms that allow obtaining phycocyanin concentration from corrected remote sensing images, the following band combinations were tested: R705/R665, R705-R665, R740/R665 and R740-R665. Samples were equally divided, half of them were used for the algorithm calibration, and the other half for validation. With the best adjustment, the algorithm was recalculated using all the data to obtain a more robust and accurate algorithm. The best correlation was obtained with R705/R665 band ratio with the equation [PC](µg/l)=25.6338(R705/R665)^3.502, obtaining R2=0.7, RMSE=8.1µg/l and NRMSE=3.5%. We have observed alarming phycocyanin concentrations in several reservoirs, which may trigger many environmental health problems, as established by the World Health Organization. Remote sensing provides a new monitoring method for temporal and spatial distribution of these cyanobacteria blooms to make good management, control and inland waters improvement.

Microplastics pollution in Vesijärvi lake and PikkuVesijärvi pond

Costanza Scopetani (1), David Chelazzi (2, 3), Alessandra Cincinelli (2, 3), Maranda Esterhuizen-Londt (1, 4, 5)

(1) Faculty of Biological and Environmental Sciences, Ecosystems and Environment Research Programme, University of Helsinki, Niemenkatu 73, FI-15140 Lahti, Finland (2) Consorzio Interuniversitario per lo Sviluppo dei Sistemi a Grande Interfase (CSGI), Sesto Fiorentino, 50019 Florence, Italy (3) Department of Chemistry Ugo Schiff, University of Florence, Sesto Fiorentino, 50019 Florence, Italy (4) Helsinki Institute of Sustainability (HELSUS), Fabianinkatu 33, 00014 Helsinki, Finland (5) Environmental Safety Group, Joint Laboratory of Applied Ecotoxicology Campus E 7.1, Korean Institute of Science & Technology (KIST Europe), 66123 Saarbrücken, Germany

In the last decade, several studies have been conducted and published on the occurrence of microplastics (MPs) in marine environments, but data on freshwater ecosystems are still lacking. This work aims to start filling this knowledge gap by studying the occurrence and the chemical composition of microplastics in Vesijärvi lake and Pikku Vesijärvi pond, situated close to the city of Lahti (Finland). The sampling campaign was carried out in winter, and sediment, snow, and ice core samples were collected near the shore of the two sampling sites. A Fourier transform infrared spectroscopy (FTIR) microscope was used to detect and identify microplastics, a technique that allowed the analysis of the samples without the need for any potentially invasive treatment. The microscope FTIR spectroscopy technique has successfully been applied in several microplastics studies, and it is considered one of the most powerful techniques currently available for microplastics identification in environmental samples. The FTIR results showed the occurrence of both natural and synthetic polymers, including polyamides (up to 53.3%), cellulose (up to 45.8%), wool (up to 18.8%), polypropylene/polyethylene (up to 17.1%), and polyacrylates (up to 9.8%). Microplastics were detected in all sample matrices in the shape of fibers (≥99%) and fragments (≤ 1%) with a mean concentration of 395.5 ± 90.7 MPs/kg, 117.1 ± 18.4 MPs/L, and 7.8 ± 1.2 MPs/L, in sediment, snow, and ice samples, respectively. The potential local sources of the microplastic pollution were considered to include stormwater and lacustrine sports activities.

Citizen science in lake restoration: experiences on wood addition activities in the Lake Saimaa

Kari-Matti Vuori, Laura Blombqvist

The Association of Environmental and Science Education of Saimaa

Finland is officially marketed as a land of a thousand clean lakes, but concerns about negative trends in lake water quality are widespread. Significant discrepancies often appear between official lake status classifications and people's experiences. Feedback on people's concerns on brownification and eutrophication of lakes has been collated in hearings of the River Basin Management Plans (RBMPs) and in a number of projects. A general tendency is that official classification considers a majority of larger lakes to be in high or good ecological status, whereas both paleolimnological evidence and long-term observations of local people detect clear weakening of the lake quality. Hence, it is not a surprise that local people have a high willingness to participate in active water protection and lake restoration measures also in the water bodies where the RBMPs do not identify any immediate protection needs. Our association co-operates actively with NGOs and private owners of the water areas to develop new cost-effective, nature-based solutions for lake protection and restoration. Recent efforts include immersion of wood in the ditches, wetlands and littoral zones of eutrophied lakes. Citizen participation in these activities has been very enthusiastic. We give examples of sinking used Christmas trees in the Lake Pien-Saimaa, establishment of a wood treatment construction in forest ditches and building a wooden cassette construction on ice to be sunk on soft bottoms of a lake. We are also seeking a membership in a global Living Lakes network and discuss how such networking would help in translating scientific results into action via public participation and citizen science.

POSTER SESSION 1

Remote sensing tools to estimate organic and inorganic suspended solids in different types of inland waters

Bárbara Alvado Arranz (1), Jesús Delegido (1), Xavi Sòria-Perpinyà (1), Eduardo Vicente (2)

(1) Image Processing Laboratory, C/Catedrático José Beltrán, 2, 46890 Paterna (Valencia), Spain (2) Cavanilles Institute of Biodiversity and Evolutionary Biology, C/Catedrático José Beltrán, 2, 46890 Paterna (Valencia), Spain

Inland waters are very sensitive ecosystems mainly affected by pressures and impacts in their watershed. Suspended particulate matter, one of the dominant water constituents, can carry heavy metals, pollutants or nutrients and therefore lead to poor water quality. It is important to know the composition of suspended materials since the ecological consequences they have on lakes depends whether they are mostly organic compounds (phytoplankton, decomposition of plant matter, etc.) or inorganic (silt, clay, etc.). The presence of substances at the water surface can significantly change a water body's backscattering characteristics. This is the basic principle of remote sensing, used from the 1980s to study surface water quality. Nowadays, the European Space Agency (ESA) Sentinel-2 mission has exceptional characteristics for measuring inland waters' biophysical variables. This work has led to the development of a series of algorithms that can estimate the total concentration of suspended solids (TSS), differentiating organic from inorganic fractions, through the combined use of Sentinel-2 images with an extensive database from reservoirs, lakes and marshes at the eastern zone of Spain. For this, information from 121 georeferenced samples collected throughout 40 field campaigns over a 4-year period has been used. All possible two-band combinations were obtained and correlated with the biophysical variables by fitting linear regression between the field data and bands combination. The results determined that only with band 705 or combining bands 443 and 783 allows to obtain the amount of total suspended solids with errors of 10.28% and 13.56% respectively. On the other hand, only with band 783 or combining bands 665 and 560 make it possible to obtain the amount of suspended organic fraction with errors of 14.75% and 15.03% respectively. Thereby, remote sensing provides information on TSS dynamics and characteristics as well as its spatial and temporal variation, which would help to study its causes.

Insights on the phosphorus fluxes in a drained agricultural catchment

Victoria Barcala (1), Joachim Rozemeijer (1), Leonard Osté (1), Bas Van der Grift (2), Laurens Gerner (3), Thilo Behrends (4)

(1) Inland Water Systems, Deltares, Utrecht, the Netherlands (2) KWR Water Research Institute, Nieuwegein, the Netherlands (3) Water Board Rijn and IJssel, Doetinchem, the Netherlands (4) Department of Earth Sciences, Faculty of Geosciences, Utrecht University, the Netherlands

Phosphorus (P) leaching from agriculture is a major driver of water eutrophication in downstream rivers and lakes. In NW Europe, agriculture intensified in the decades after the second world war and in recent years P surplus is close to zero (Bol et al. 2018; McDonald et al. 2019). In drained lowland areas with intensive agriculture, a reduction in the fertilizer applications may be insufficient to improve the water quality in the short term (Melland et al.2018), as the P accumulated in the soil during decades of high fertilization may continue leaching for many years. A complementary approach to reduce P exports from agriculture is to implement edge-of-field mitigation measures. The selection of effective measures requires a detailed insight into the chemical and hydrological transport mechanisms. Here, we determined the main P sources, processes, and transport routes to quantify the legacy P and relate it to the yearly P export downstream. To do this, we combined high-resolution monitoring data from the soil, groundwater, surface water, and ditch sediments. The legacy P in the topsoil was high, about 2,500 kg/ha. The predominant subsurface flow and the subsoils' P sorption capacity retained the P mobilized from the topsoil and explained the relative moderate flux of P to surface waters (0.04 kg/ha during the 2018-2019 drainage season). The dissolved P entering the drainage ditch via groundwater discharge was bound to iron-containing particles formed due to the oxidation of dissolved ferrous iron. Once leached from the soil to the drainage ditch, resuspension of P-rich sediment particles during flow peaks was the most important P transport mechanism (78%). Therefore, hydraulic constructions that reduce flow velocities and promote sedimentation of P-containing particles could reduce the export of P further downstream to rivers and lakes.

Submerged macrophytes mitigate the stimulating effect of hot summer on cyanobacterial blooms in a shallow reservoir under restoration

Agnieszka Budzyńska, Renata Dondajewska-Pielka, Katarzyna Kowalczewska-Madura, Ryszard Gołdyn

A. Mickiewicz University of Poznań, Faculty of Biology, Department of Water Protection, Uniwersytetu Poznańskiego 6, 61-614, Poznań, Poland

Hot weather periods, increasing in duration and frequency in the temperate zone due to climate change, may hamper the success of restoration actions and stimulate cyanobacterial blooms. The aim of the present study was to identify which factors shaped the phytoplankton community, including cyanobacteria, in a shallow reservoir under restoration. Factors crucial for the phytoplankton development were included, ie. phosphorus concentration, directly shaped by the restoration, and factors indirectly influenced by restoration or independent from it (water temperature, euphotic depth and mixing depth, concentration of ammonium and nitrates, submerged macrophytes, the zooplankton). Hot weather and typical weather periods were also considered. The study was performed before the restoration (2005), during its first phase (2006-2007), consisting of phosphorus precipitation with low doses of iron coagulant several times per year, and during the second phase (2015-2019), with more frequent phosphorus precipitation, and nutrient control at the inflows. Data were analysed using Statistica and multidimensional analyses in Canoco. Our results showed that before submerged macrophytes appeared, hot weather conditions steered the phytoplankton community, and in hot summer restoration efforts were not sufficient to prevent cyanobacterial blooms. After submerged macrophytes overgrew the reservoir, they became the primary driving factor of the phytoplankton community, and no significant difference in the cyanobacterial biomass was noted between hot and typical summer months when macrophytes were present. We conclude that submerged macrophytes may diminish the hindering role of hot weather on restoration actions.

Decades needed for ecosystem components to respond to a sharp and drastic phosphorus load reduction

Ingrid Chorus (1), Antje Köhler (2), Camilla Beulker (3), Jutta Fastner (4), Klaus van de Weyer (5), Tilo Hegewald (6), Michael Hupfer (7)

(1) Ingrid Chorus, Deidesheimerstr. 24, 14197, Berlin, Germany (2) Berlin Senate Department for the Environment, Transport and Climate Protection, Am Köllnischen Park 3, 10179, Berlin, Germany (3) Landeslabor Berlin Brandenburg; presently Federal Environment Agency, Schichauweg 58, 12307 Berlin, Germany (4) Federal Environment Agency, Schichauweg 58, 12307 Berlin, Germany (5) Lanaplan, Lobbericher Str. 5, 41334 Nettetal, Germany (6) Department Water Quality, State Reservoir Administration of Saxony, Bahnhofstraße 14, 01796 Pirna, Germany (7) Department of Chemical Analytics and Biogeochemistry, Leibnitz Institute for Freshwater Ecology and Inland Fisheries, Müggelseedamm 301, 12587 Berlin, Germany

Lake Tegel is an extreme case of restoration: inflow treatment reduced its main external phosphorus (TP) load 40-fold, sharply focused in time, and low-P water flushed the lake volume about 4 times per year. We analysed 35 years of data for the time TP concentrations took to decline from ca. 700 to 20–30 µg/l, biota to respond and cyanobacteria to become negligible. The internal load proved of minor relevance. After 10 years, TP reached 35–40 lg/l, phytoplankton biomass abruptly declined by 50% and cyanobacteria no longer dominated; yet 10 years later at TP\20–30 lg/l they were below quantifiable levels. 20–25 years after load reduction, the lake was stably mesotrophic, macrophytes had returned down to 6–8 m, and vivianite now forms, binding P insolubly in the sediment. Bottom-up control of phytoplankton through TP proved decisive. Five intermittent years with a higher external P load caused some 're-eutrophication', delaying recovery by 5 years. While some restoration responses required undercutting thresholds, particularly that of phytoplankton biomass to TP, resilience and hysteresis proved irrelevant. Future research needs to focus on the littoral zone, and for predicting time spans for recovery more generally, meta-analyses should address P load reduction in combination with flushing rates.

Effectiveness of innovative nitrate treatment in a small Uzarzewskie lake (Western Poland)

Renata Dondajewska-Pielka (1), Katarzyna Kowalczewska-Madura (1), Anna Kozak (1), Agnieszka Budzyńska (1), Ryszard Gołdyn (1), Stanisław Podsiadłowski (2)

(1) Adam Mickiewicz University, Faculty of Biology, Department of Water Protection, Uniwersytetu Poznanskiego 6, 61-614 Poznan, Poland (2) Poznań University of Life Sciences, Faculty of Agronomy and Bioengineering, Institute of Agricultural Engineering, Wojska Polskiego 50, 60-627 Poznań, Poland

Hypertrophic Uzarzewskie Lake (10.6 ha, max depth 7.3 m), situated in Western Poland had suffered from intense cyanobacterial blooms, resulting in low water transparency and high chlorophyll-a content for many years. Restoration treatment aiming at the improvement of water quality was conducted in three stages: (I) P inactivation with iron sulfate, dosed by mobile aerator in 2006-2007; (II) nitrate treatment in hypolimnion to increase the redox potential since 2008 and (III) magnesium chloride dosing to a small watercourse feeding the lake since 2017. Water analyses were conducted in 2005-2020, with special attention to nutrients, chlorophyll-a concentrations, and plankton structure, to assess the effectiveness of restoration treatment. Prior to the restoration, mean TP concentration near the bottom reached over 1.0 mgP L-1, decreasing to 0.5 mgP L-1 in the first stage of treatment. Further reduction was observed in the phase II – to 0.1 mgP L-1 in 2018. Water transparency increased from 0.7 m in 2005 to 1.4 m 2017 as the result of diminishing chlorophyll-a content from max. 160 mg m-3 in 2005 to <70 mg m-3 in 2017-2018. It was related to changes in phytoplankton structure manifested as cyanobacteria biomass reduction in favor of i.a. cryptophytes. A distinct reduction of ammonium nitrogen was also observed, both in the surface water (from 1.6 mg N-NH4 L-1 in 2005 to 0.52 mgN-NH4 L-1 in 2017) and near the bottom waters (from 5.1 mgN-NH4 L-1 to 2.1 mgN-NH4 L-1, respectively). The obtained results proved the efficiency of multistage lake restoration, however a deterioration of water quality in the peak of summer in 2019 and 2020 was observed, manifested by higher content of chlorophyll-a and nutrients, as well as by reduction in water transparency. It was related to changes in weather conditions (dry years with warm winters and hot summers) and periodical malfunction of pipes delivering nitrate-rich spring waters. Therefore, restoration treatment shall be continued and intensified in the manner of sustainable approach.

Larval and juvenile perch feeding in some Estonian and Latvian study lakes

Katrit Karus (1,2), Matiss Žagars (1), Helen Agasild (2), Tõnu Feldmann (2), Arvo Tuvikene (2), Madara Medne-Peipere (2), Linda Puncule (2), Priit Zingel (1)

(1) Institute for Environmental Solutions: „Lidlauks", LV-4126, Priekuļu parish, Priekuļu county, Latvia (2) Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences, Chair of Hydrobiology and Fishery, Centre for Limnology,51006 Kreutzwaldi 5-D119, Tartu, Estonia

Larval and juvenile perch (0+) first year diet was studied in 6 different study lakes located throughout Latvia (Lake Auciema, Lake Riebinu, Lake Laukezers) and Estonia (Lake Kaiavere, Lake Prossa, Lake Akste). The main aim of the research was to study and compare larval perch feeding in littoral and open-water sites of the lakes during their first year of feeding – in spring, summer and autumn, 2019. Larval and juvenile perch samples were collected by specifically targeted nets: beach-seines and scoopnets in littoral of the lakes and a bongonet in open-water sites. Larval and juvenile fish diet was estimated by a gut segmentaion methodology using epifluorescence microscopy. Also whole planktonic components (bacterio-, protozoo- (heterotrophic nanoflaggellates, ciliates), phyto- and metazooplankton) were collected to estimate planktonic community structure, abundance and biomass for estimating the presence of suitable food objects for young fish (0+). In addition, we also studied macrophytes, their community structure and species parameters three times a year and adult fish community once a year in summer to assess their influence on the development of young fish communities. A more detailed overview about the feeding conditions of perch larvae in open-water and littoral sites of the lakes in spring, summer and autumn will be presented during the Lahti Lakes online symposium.

Plankton reaction to long-term restoration treatments in the dimictic Lake Durowskie (Poland)

Beata Messyasz (1), Slawomir Cerbin (1), Katarzyna Kowalczewska-Madura (2),Renata Dondajewska-Pielka (2), Ryszard Gołdyn (2)

(1) Department of Hydrobiology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland (2) Department of Water Protection, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland

The aim of the 12-year study was to compare the structure of phytoplankton and zooplankton assemblages resulting from conducted restoration treatments. Prior to the restoration of the lake, its phytoplankton structure was dominated mainly by filamentous cyanobacteria: Limnothrix redekei, Planktothrix agardhii, Pseudanabaena limnetica. This arrangement of species from the S1 functional group found in phytoplankton of Lake Durowskie confirmed its fixed eutrophic nature. At the same time zooplankton was dominated by bacterivorous rotifers, typical for high trophy of water. Species which have achieved large numbers in this period were: Keratella cochlearis var. tecta, Anuraeopsis fissa and Pompholyx sulcata. Cladocerans from the genus Daphnia were represented only by small D. cucullata, and were not frequent. Large-bodied cladocerans that are most effective in controlling phytoplankton were absent. Due to restoration measures only about 30% of the pre-restoration phytoplankton species survived to 2020. Most of them were replaced by taxa adapted to the new environmental conditions, specimens of a larger ecological scale or indicators of better water quality. The phytoplankton species composition changed from the dominant cyanobacteria to green algae (Coelastrum reticulatum, C. astroideum, Cosmarium abreviatum, Phacotus lenitcularis, Closterium acutum var. variabile), diatoms (Fragilaria crotonensis, Cyclotella radiosa, C. ocellata), dinoflagellates and chrysophytes. The long-term restoration of Lake Durowskie had a distinct impact on phytoplankton, whose communities in 2020 were more diverse compared with 2009, but these changes were mainly due to the lake treatment with a substance coagulating and precipitating phosphorus. Regular restocking of the lake with pike was unsuccessful in relation to zooplankton, which caused grazing pressure on algae only in 2011. The low abundance of crustacean zooplankton continued to be observed.

Nitrogen and its trends in Estonian lakes and rivers – expected impacts and knowledge gaps

Tiina Nõges

Estonian University of Life Sciences, Kreutzwaldi 5D, 51006, Tartu, Estonia

The relative role of nitrogen (N) and phosphorus (P) reduction to control eutrophication in lakes continues to be debated. A strong statement by Schindler et al. [1] about the irrefutable leading role of P provoked immediate criticism from other leading scientists [2] arguing that diminishing only P inputs has not been effective for eutrophication reduction in estuarine and coastal ecosystems, and both N and P control is needed. The debate that has lasted over 10 years by now, and has not discredited the importance of P control but has displayed plentiful evidence on the wide-ranging significance of N reduction to recover lake ecosystems. So far Estonian limnologists have been generally P-believers and N manipulation as a tool for lake water quality management has been largely neglected. The faith into P management has been based mainly on the post-socialist experience – sharp reduction of N loading brought back cyanobacterial blooms to Lake Peipsi [3,4]. Moreover, in the N-rich alkalitrophic lakes (e.g. Lake Äntu Sinijärv), P concentration is low due to binding with Ca and water is exceptionally clear without any eutrophication symptoms [5]. It is now the time to revise our P-centred opinion as recent piling information is suggesting the critical need to consider also N in lake management plans. In Lahti Lakes we will present N and P trends in some Estonian lakes and inflowing rivers, analyse the connections with phytoplankton community and evaluate the potential scenarios of eutrophication management. This study was funded by the European Union H2020 WIDESPREAD grant 951963 TREICLAKE and Estonian Research Council grant PRG709.

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Use of water residence time manipulation to control internal phosphorus loading

Freya E. Olsson (1,2), Ellie Mackay (1), Phil Barker (2), Sian Davies (3), Ruth Hall (4), Bryan Spears (5), Ian Jones (6)

(1) UK Centre For Ecology & Hydrology, Bailrigg, LA1 4AP, Lancaster, UK (2) Lancaster Environment Centre, Lancaster University, Bailrigg, LA1 4YQ, Lancaster, UK (3) Environment Agency, Red Kite House, Howbery Park, OX10 8BD, Wallingford, UK (4) Natural England, Worcester County Hall, Spetchley Road, WR5 2NP, Worcester, UK (5) UK Centre For Ecology & Hydrology, Bush Estate, Penicuik, EH26 0QB, Midlothian, UK (6) Biological and Environmental Sciences, University of Stirling, FK9 4LA, Stirling, UK

Anthropogenic eutrophication degrades lake water quality. Nutrients accumulated in sediments can provide an internal source of nutrients. Internal loading from the sediments is particularly problematic, in stratifying lakes, when anoxia develops in the hypolimnion during the summer stratified period. Increasingly in-lake methods are required to meet legislative targets on water quality. Using natural processes, a restoration technique, targeting lake residence time, attempted to inhibit internal loading. Water was diverted from a nearby river to reduce lake water residence times, increasing the cooling effect of the inflow, with the aim of limiting the length of the stratified period, and reducing internal loading. We used multi-year field data in a Before-After-Control-Impact study alongside hydrodynamic modelling, to understand the intervention effects on stratification and lake water quality. Annual water residence time was reduced by 40% in response to the intervention, but this reduction was less than the natural variability in residence times experienced in the system and the restoration did not achieve its aims. The lake continues to stratify strongly and develops anoxia at depth. As a result, there was little significant change in phosphorus or chlorophyll a concentrations and only minor changes in stratification dynamics. Results showed that the change in water residence time was not sufficient to impact stratification and improve water quality in the lake. Our results show that taking account of natural variability when designing restoration schemes using this approach is important. Furthermore, lake modelling and multi-year observation studies enable the isolation inflow effects on in-lake physical processes. This more process-based approach can provide improved understanding of what change in residence time would be required to affect subsequent impacts on hypolimnetic oxygen and internal loading potential.

Some important factors to consider in lake restoration

Olga Tammeorg (1,2), Gertrud Nürnberg (3), Juha Niemistö (1), Jukka Horppila (1)

(1)Ecosystems and Environment Research Programme, University of Helsinki, P.O. Box 65, FI-00014, Helsinki, Finland (2)Chair of Hydrobiology and Fishery, Estonian University of Life Sciences, 61117 Rannu, Tartumaa, Estonia (3) Freshwater Research, 3421 Hwy 117, Baysville, Ontario, Canada, P0B 1A0

Internal phosphorus (P) loading has often been related to oxygen deficits, and reduction of iron. Thus, aeration is among the most common methods of lake restoration. However, our recent studies showed some limitations for this approach. We showed that anoxia in the stratifying lake areas is of minor importance in water quality regulation. As the shallow areas were found to control lake water quality, it is interesting to know what mechanisms specifically are responsible for this? To answer this question, we quantified internal P load due to anoxia of deep stratifying areas (IPobs) for numerous lakes worldwide. Also we quantified internal P load accounted for by the anoxic sediment surfaces of shallow areas (IPpred). Additionally, we carried out studies of internal P load in a large, polymictic lake (Lake Peipsi) by long-term data analysis and short-term measurements. Finally, we studied P mobility in four small Finnish lakes. According to our results, only the contribution of IPpred to water quality was high. This correlated with both TP concentration in surface water layers and Chl a. The relationships were even more pronounced for a group of aerated lakes, suggesting that aeration enhances P supply for algal growth. In polymictic Lake Peipsi, our measurements did not reveal any anoxia in the uppermost sediments. Nevertheless, the anoxia in surface sediments is likely to occur. Mineralization of organic material promotes a decrease in redox potential at sediment surface. Furthermore, internal P load increases at low water level, as it enhances the transport of P from deeper sediments via resuspension. Finally, studies of P mobility in four eutrophic lakes of Finland revealed an importance of humic substances in sediment P recycling. We observed lowest release rates of P in highly coloured lakes that had highest proportion of organic P in their sediments. In conclusion, lake restoration may rely only on the solid understanding of the mechanisms behind eutrophication.

Added wood in water protection structures benefits multiple ecosystem services: experiences from sedimentation basins of peatland forestry

Kari-Matti Vuori, Saija Koljonen, Johanna Järvistö

Finnish Environment Institute, Mustialankatu 3, 00790 Helsinki, Finland

Large woody debris (LWD) is known to benefit multiple ecosystem services in aquatic ecosystems. LWD enhance water purification and diversity and secondary production of macroinvertebrates, crayfish and fish. In addition, LWD in lakes and wetlands constitute a significant long-term carbon sink. By the same token, we hypothesized that wood addition may benefit ecosystem services in sedimentation basins constructed for diffuse pollution abatement purposes. We studied three pairs of sedimentation basins of peatland drainage catchment areas. For each basin pair wood was added in one basin while the other basin was left as a control. Water quality samples of inflow and outflow waters were taken five times in 2018-2020. Species richness and abundance of macroinvertebrates were assessed with standard kick net sampling in two basin pairs six months after the wood addition. Further, in one treatment basin additional zoobenthos samples were taken 18 months after wood addition. The wood treatments reduced significantly total suspended solids, COD, nutrient (TotN and TotP) and organic carbon (TOC, DOC) concentrations of the outflow water in comparison to inflow. The most positive results were high reduction rates of nutrients and organic carbon (over 40%) and TSS (up to 80%) during floods. Significant reduction was observed also for iron concentrations. Treatment did not affect oxygen levels, whereas pH of the outflow water increased slightly. Control basins had much lower reduction capacity, which was even unsubstantial during the peak flow periods. Diversity of the benthic invertebrate community benefitted significantly from the wood treatment. Number of taxa varied between 5 to 12 in treatment basins, while the abundance ranged between 16 to 292 individuals per sample. In the control basins diversity was considerably lower, the taxa richness ranging between 3 to 5 and abundance between 10 to 57 per sample. Both the average species richness and abundance values were significantly higher in the wood treatments compared to control basins in both wood treatment basins. Furthermore, taxon diversity and species abundance increased significantly in 2019 samples, indicating overall habitat diversity enhancement over time. Control basins had a poor fauna with distinct dominance of midge larvae. Treatment basins had more diverse fauna with the most common and abundant groups consisting of chironomids, mayflies, asellids and dragonflies. Our results imply that LWD greatly improves water purification processes of peatland drainage waters. Wood addition also contributes to significant increase of zoobenthos diversity and production in sedimentation basins. While wood also persists for centuries-millennia in wet conditions, wood addition has a great potential as a tool to increase long-term carbon sinks.

Modelling the environmental response to enhanced legacy phosphorus retention in a eutrophic bay

Zhihao Xu, Bo G. Gustafsson, Emil Rydin, Linda Kumblad, Erik Gustafsson

Baltic Sea Centre, Stockholm University, 10691 Stockholm, Sweden

Eutrophication is a global environmental issue that often promotes oxygen consumption in bottom water and thereby weakens phosphorus (P) binding capacity of sediment. As increasing efforts are taken globally for external P load reduction, legacy P stored in sediment acts as an internal pollution source and hinders water quality improvement. To enhance sediment P retention, dissolved aluminum (Al) was injected into the anoxic sediment of a eutrophic bay in the Baltic Sea, serving as a P-binding agent. However, the environmental response to Al-treatment has been rarely studied in existing modelling research. This study develops a coupled biogeochemical and sediment model that is capable of simulating Al-treatment. We account for three stages in simulating P bound to Al. All phosphate generated by sediment mineralization and a certain percent of phosphate in water is bound during the Al-treatment period (i.e., first stage). Most phosphate generated by mineralization is bound in the first year following Al-treatment (i.e., second stage). Thereafter, the effectiveness of Al treatment gradually decreases (i.e., third stage), due to the decrease of Al availability and the sedimentation of organic matter on the top of the Al-layer. The model is applied in the treated bay of the Baltic Sea as a case study. Calibration results show that the model performs well in simulating P, nitrogen, oxygen, phytoplankton and Secchi depth in the water as well as P binding and Al consumption at the sediment. The validated model is then used to evaluate the restoration performance of Al-treatment through comparing scenarios with and without considering Al-treatment. Besides significant effect on water P concentration reduction, Al-treatment contributes to mitigating phytoplankton production in spring and bottom oxygen deficiency in summer. This study offers a modelling tool for supporting legacy P management decision-making and investigating the environmental response.

POSTER SESSION 2

A 25-year retrospective analysis of factors influencing success of aluminum treatment for lake restoration

Oskar Agstam-Norlin (1) Emma E. Lannergård (1) Emil Rydin (2) Martyn N. Futter (1) Brian J. Huser (1)

(1) Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, P.O Box 7050, 750 07 Uppsala, Sweden (2) Stockholm University, Baltic Sea Centre, 10691 Stockholm, Sweden

Internal phosphorus loading in lakes is a result of historical P accumulation from external sources such as leaching from agricultural soils and municipal/industrial wastewater inputs. Even if external input of P is limited, however, recovery can be delayed by decades or more due to the release of legacy (or mobile) P in lake sediment. Aluminum (Al)-salts have been used to permanently inactivate excess mobile P in sediment and restore lake water quality for more than 50 years, with varying effect on eutrophication. In this study we analyzed the effectiveness and longevity of Al treatments performed in six Swedish lakes over the past 25 years. Historical trends of nutrient related water quality data (Total phosphorus (TP), Chlorophyll a (Chl a), Secchi disc depth (SD) and internal P loading rates (Li)) were analyzed and compared to pretreatment conditions. Most water quality parameters available for each lake improved significantly during the first 4 years, but with varying magnitude. SD improvement ranged from 7 to 121%, Chl from 50 to 78%, TP from 29 to 80% and Li from 68 to 94%. Treatment longevity varied substantially from 8 to 47 years. In lakes where data availability allowed for historical Li trend analysis, determination of the direct effect of Al treatment on sediment P release was possible, but only for 3 lakes. Our findings support that adequate lake monitoring programs are crucial to be able to determine the effect of Al-treatment on sediment P release.

Ecosystem services as a management tool for Lake Ladoga

Natalia L. Bolotova, Ivan A. Mukhin, Olga G. Lopicheva

Vologda State University, Russia

The observed degradation of the ecosystem of Lake Ladoga is to be considered as a problem of national and global scale given its status as the largest waterbody in Europe and its transboundary catchment. The need for taking measures towards lake restoration in Ladoga is determined by its natural value, including the strategic freshwater resource and the unique biodiversity. It is shown that the intake of toxic substances in the lake can be reduced by adequate rationing of discharges from industrial enterprises. Management of eutrophication as an ecosystem process is a more complex and expensive task, complicated by the administrative division of the lake between Leningrad Oblast and Karelia. Switchover to the Ecological Economics strategy in implementation of the ecosystem services concept will allow to overcome the contradictions between users of natural resources. The cost evaluation of ecosystem services will create mechanisms for self-financing of environmental projects and eco-compensation programs. The proposed algorithm of the eutrophication strategic management for Lake Ladoga includes: ecosystem services identification, their economical evaluation by means of appropriate complex methods, determination of the beneficiaries of these services, and compensatory payment system introduction for the sake of ecosystem functions' preservation. Description of the composition and distribution of ecosystem services, and their investment attractiveness was carried out using GIS technologies. Models to predict growth of the value of ecosystem services are built. The transportation cost share is evaluated to be the largest, with 16 bn dollars per annum due to Lake Ladoga belonging to the Volga-Baltic Waterway. The influence of a vast catchment area on coastal zones with eutrophic status and the role of protected areas in reducing the supply of nutrients as a compensation mechanism (non-use value) are analyzed. The expediency of various types of use of Lake Ladoga are considered.

Effects of aluminum sulfate treatment on nutrient dynamics and a Planktothrix bloom in a shallow, semi-enclosed lake area

Joseph L. Davidson (1), Stephen J. Jacquemin (2), Silvia E. Newell (1), Justin A. Myers (1) Mark J. McCarthy (1)

(1) Wright State University, 3460 Colonel Glenn Hwy, 45435, Dayton, OH, United States (2) Wright State University-Lake Campus, 7600 Lake Campus Dr., 45822, Celina, OH, United States

Grand Lake St. Marys is the largest (52 km2) inland lake in Ohio, USA, and receives high nutrient loadings (90th percentile for total nitrogen (N) and phosphorus (P) concentrations in the USA) from a watershed dominated by agricultural row-crops and livestock production. Eutrophication and cyanobacterial harmful algal blooms, dominated by non-N2 fixing Planktothrix, persist year-round, including in winter months. An aluminum sulfate (alum) treatment was conducted within a three-acre swimming enclosure on June 9th, 2020, to remove excess dissolved P from the water column. The objective of this study was to examine pre- and post-treatment biogeochemical and physicochemical conditions in contrast to the surrounding lake. Weekly sampling recorded chlorophyll-a and microcystin toxin concentrations ranging from 48-368 and 5.7-68.2 µg/L, respectively, persisting from April into November 2020 within the treatment area, indicating a failure of the alum treatment to reduce bloom conditions. Persistently high algal biomass contributed to a hypoxia/fish kill event in July 2020, with sediment oxygen demand (SOD) reaching >10000 µmol O2 m-2 h-1. A transition from net denitrification (N removal) to net N fixation (N source) in sediments during summer, coinciding with dissolved inorganic N depletion, suggested that internal N regeneration and recycling pathways were required to support Planktothrix biomass both within and outside the enclosure. N cycling and SOD rates in sediments suggested no difference between water column conditions inside and outside of the enclosure, as well as between pre- and post-treatment with alum. TP concentrations did not decrease after alum treatment.

First, we had to accept that we could not control the external load. And then what? A synthesis of an ongoing multilake rehabilitation project in southern Uruguay

Guillermo Goyenola

Centro Universitario Regional del Este, Universidad de la República. Tacuarembó entre Saravia y Bvar. Artigas. ZIP 20000, Maldonado, Uruguay.

In the urban matrix of Ciudad de la Costa and Paso Carrasco (Uruguay) there are more than twenty artificial deep lakes, as result of sand extraction in the 20thcentury. Almost all of them were formed by infiltration from the water table and lack permanent surface connectivity. Like similar urban sandpit lakes around the world, these became subject to strong anthropogenic pressures. The first fish kill was reported in 1986, and a few years later the area began a quick transformation from vacation to residential use, resulting in an explosive population growth and exacerbating pressure. Systematic monitoring of lakes started in 2008, in collaboration between local government and the Universidad de la República. A generally eutrophic state was observed, with specific local conditions influencing each lake. For 2013, a decision to use the lakes for flood control was taken. Harmful phytoplanktonic blooms, foul-smelling events and fish kills occur sporadically. The high number of filtering septic tanks, the low rate of connection to the new sanitation system, and the increased connectivity to the storm drain system, make the control of the external load unfeasible in the short/medium term. The increased frequency and intensity of negative interactions with the urban surrounding, have promoted the implementation of management actions. By 2021, macrophyte harvest, phosphate immobilization, and hypolimnetic oxygenation were applied in a few lakes, and results are still under monitoring. Automatized monitoring buoys with telemetry are allowing us to recognize the intra and inter-lake variability. This strategy will be complemented with hydro-numerical modeling. The next step will be strongly associated to geo-engineering. Success depends on find effective alternatives with reduced costs.

Case study of Athalassa Lake, Cyprus: Fish kills, cyanobacterial blooming, and treatment with hydrogen peroxide

Eleni C. Keliri (1), Dariuzs Dzinga (2), Hanna Mazur-Marzec (3), Maria G. Antoniou (1)

(1) Cyprus University of Technology, 3036, Lemesos, Cyprus (2) Jagiellonian University, Gronostajowa 7, 30387 Krakow, Poland (3) University of Gdańsk, Marszałka Piłsudskiego 46, 81-378 Gdynia, Poland

Cyanobacteria (blue-green algae) are phototrophic microorganisms which can be found in almost every terrestrial and aquatic environment such as surface waters, oceans, soil and muds, lagoons, rocks, and snow. Their growth is favored in warm stagnant waters such as ponds, dams and lakes. In combination with high loads of organic matter and nutrients, cyanobacteria can excessively grow (bloom) and form surface mats that block oxygen and light. They can also be harmful to humans, animals and other living organisms since they have the ability to produce bioactive metabolites, known as cyanotoxins. Cyanotoxins differ structurally, hence exhibit different bioactivity: neurotoxicity, hepatotoxicity, cytotoxicity, and endotoxicity. During Fall Season (September) 2020, Athalassa Lake which is located at the National Forest Park of Athalassa in Cyprus, faced a massive fish kill event which raised many questions regarding the source of toxicity in the Lake. Our research group requested and was granted access to monitor and sample from the lake to characterize the bloom and conduct bench-scale treatments. Water samples collected from the scum were analyzed for cyanobacteria and toxic genes presence as potential cyanotoxins producers. Bloom species composition was found to be mainly Planktothrix and Euglenophyta species that are microcystins and euglenophycin producers, respectively. Water samples' fluorescence was measured in two excitation wavelengths, λ= 450, 620 nm, and showed that cyanobacterial species had high photosynthetic activity and quantum yield meaning that the bloom was dense and active. When such blooming events occur, it is imperative to find effective, cost efficient, and environmentally friendly mitigation techniques to apply for early restoration of the site. For this purpose, liquid hydrogen peroxide was utilized in three bench-scale application methods: (a) single low dose HP, (b) single high dose HP, and (c) multiple low HP concentration doses. Multiple dosing proved to be more efficient and have long-lasting effects without harming the rest of the lake's ecosystem in contrast with the direct application of high concentration liquid HP.

Lake restoration by excavating sediment and recycling of sediment phosphorus to close P cycle

Mina Kiani (1), Priit. Tammeorg (1), Asko Simojoki (1), Olga Tammeorg (2,3)

(1) Department of Agricultural Sciences, University of Helsinki, Helsinki, Finland (2) Ecosystems and Environment Research Programme, University of Helsinki, Helsinki, Finland (3) Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences, Tartu, Estonia

Phosphorus (P) is one of the critical non-renewable natural resources ensuring food production. Inefficient use of P fertilizers leads to the transfer of P into water bodies, causing their eutrophication. Sediment removal is one of the most promising restoration strategies that permanently removes P accumulated in lake sediments and opens the opportunity to close the P cycle by re-using P in a sustainable manner. Although lake sediments are known to be rich in nutrients including P, there is a paucity of information regarding the P availability for crop growth. In the present study, we aimed to identify the status of the lake after sediment removal and examine the effect of sediment application on P availability of growing medium. The sediment was excavated from the 1-ha eutrophic Lake Mustijärv in 2016. The spatial and seasonal changes in the sediment internal P loading were monitored during 2017–2018. Also, in a nine-month indoor lysimeter experiment, the effect of sediment application on ryegrass growth was examined by measuring the aboveground biomass, root mass distribution, P uptake as well as easily soluble nutrients and concentration of different P fractions in growing medium. Indeed, removing 7 500 m3 of nutrient-rich sediment removed 6 400 kg of P, including the potential source of P for algae. However, a large pool of releasable P was rebuilt up soon after the removal of sediment due to high external P loading, resulting in renewed high internal P loading. Applying excavated sediment improved plant growth conditions as the yield and P uptake of ryegrass almost doubled in treatments containing sediment compared to control soil. Of the main components of total P, the iron bond P fraction was the most important contributor to plant P uptake. Furthermore, applying a thick layer of sediment on topsoil did not increase the risk of phosphate and mineral nitrogen leaching and their average concentrations in leachate were below the minimum threshold values of European Union. With the aim of closing the P cycle, our small case study can be upscaled to larger lakes with similar sediment properties. However, there should be an adequate control on external loading to the lake. In addition, environmental impacts (e.g., nutrient leaching, greenhouse gas emissions, changes in soil biota community structure, and risk of erosion) of recycling sediment into crop production needs to be assessed in the real field condition.

Why, despite over 60 years of experience, the restoration of lakes still does not bring the expected results? – Polish case study

Joanna Rosińska (1), Michał Rybak (2)

(1) Department of Environmental Medicine, Poznań University of Medical Sciences, Rokietnicka 8, 60-806 Poznań, Poland, rosinska.asia@gmail.com (2) Department of Water Protection, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland

In the 1950s the first attempts to improve the quality of water lakes in Poland were made. Lake Kortowskie was the first lake where restoration was applied to – the hypolimnetic withdrawal (the Olszewski's pipeline). Over the years various methods have been used: technical – dredging, oxygenation of bottom waters with various types of aerators, chemical – phosphorus inactivation using coagulants (iron, aluminium) or other chemicals, biological – catching benthivorous fish, restocking predatory fish, mowing macrophytes, effective microorganisms and mixed – the most popular are simultaneous oxygenation of bottom waters, phosphorus inactivation and biomanipulation. During nearly 70 years, 83 lakes and water reservoirs in Poland have been subjected to restoration treatments, often with varying degrees of success. The difficulty in achieving the expected results has been related to several aspects. Most of the lakes (43 lakes) that have been subject to restoration treatments are shallow (up to 10 m deep), flow-through (54 lakes), and their catchment area is agricultural (30 lakes). These lakes are often located in cities. Thus many of them were receivers of municipal or industrial sewage (36 lakes). In such cases it is challenging to effectively eliminate sources of pollution, both external and internal. Therefore, these lakes are characterized by a high trophy and degree of degradation. We analyzed 4 main parameters: water transparency, concentrations of chlorophyll, total nitrogen and total phosphorus in restored lakes. Then we compared those parameters with the benchmark lakes (based 20 years of data) to observe the progress of eutrophication. It has been often difficult to assess the effectiveness of the carried out activities due to the lack of or difficult access to monitoring data before or during restoration treatments. However, the main reason for the lack of permanent improvement effects is still the failure to eliminate the causes of reservoir degradation.

Changes in phytoplankton of Lake Vesijärvi during the recovery from eutrophication

Kalevi Salonen (1), Juha Keto (2), Ismo Malin (2), Kristiina Vuorio (3)

(1) Lammi Biological Station, University of Helsinki, Pääjärventie 320, FI-16900 Lammi (2) Lahti Environmental Services, 15100, Lahti, Finland (3) Finnish Environment Institute, Latokartanonkaari 11, 00790 Helsinki, Finland

The Enonselkä basin of Lake Vesijärvi was eutrophied by the discharge of untreated waste waters from the city of Lahti. In the middle of the 1970s the waste waters were diverted elsewhere, but heavy cyanobacterial blooms continued still 10 years later. To accelerate the recovery of the lake, a mass removal of fish was organized in 1989–1994 and fish removal continued later in a smaller scale. The aim was to increase the abundance of large zooplankton, to decrease phytoplankton biomass, and in order to limit nutrient release from the sediment, reduce the abundance of benthivorous fish. After the beginning of the mass removal of fish, phytoplankton biomass and cyanobacterial blooms decreased in the Enonselkä basin, but it was probably due to several factors, including weather conditions. At the end of the 1990s theoretical dilution of the past waste waters was less than 5% of original, but chlorophyll a concentration remained roughly at the same level. However, phytoplankton biomass, both in the Enonselkä basin and in the downstream reference basin, Kajaanselkä, continued to decrease slowly. The discrepancy between chlorophyll a and phytoplankton biomass can likely be explained by the decreases in the biomass of mixotrophic phytoplankton groups (cryptophytes and dinoflagellates) corresponding the decrease in the total phytoplankton biomass. In 2010-2019 oxygen rich epilimnetic water was pumped into the deeps of the Enonselkä basin in order to reduce the internal load of nutrients. The decrease in the phytoplankton biomass was associated with oxygenation, but because the same happened in the reference basin, it was unlikely due to the oxygenation. The preliminary results suggest that the interpretation of phytoplankton data requires long time series including diverse biological, chemical and physical data.

Successful restoration of Lake Littoistenjärvi with chemical precipitation of phosphorus: the first four years after treatment with polyaluminium chloride

Jouko Sarvala (1), Harri Helminen (2), Jukka Heikkilä (3)

(1) Department of Biology, FI-20014 University of Turku, Finland (2) Luostarinkatu 3, FI-20700 Turku, Finland (3) Department of Management and Entrepreneurship, Turku School of Economics, FI-20014 University of Turku, Finland

The ecological state of the shallow lake Littoistenjärvi in SW Finland deteriorated during the 2000s and 2010s, rendering the lake unusable for any human purposes. Intense blooms of toxic cyanobacteria persisted throughout the summer season. Internal loading of phosphorus had become high, and a reduction of external loading by diversion of inputs from parts of the drainage area did not improve the situation. Fish removal and intensified winter aeration were attempted with little success. As the last option, precipitation of phosphorus with polyaluminium chloride was performed in early May 2017. The chemical treatment had an immediate effect. Water became clear in 24 hours, and for some weeks horizontal visibility was up to 30 m. Later transparency varied between 1 and 2.8 m. Phytoplankton recovered in four weeks and crustacean zooplankton in two months. Five tons (33 kg ha^{-1}) of dead or dying big, 1-4-kg bream were removed from the lake during the first weeks after treatment when pH temporarily went below 5.5, but otherwise the fish were not affected. The average summertime total phosphorus level dropped from 79-95 µgP l^{-1} in 2014-2016 to 22-38 µgP l^{-1} in 2017-2020, and chlorophyll from 26-86 to 4-15 µg l^{-1}, and transparency increased from 0.6-0.7 to 1.7-2.2 m. Most importantly, July-August biomass of cyanobacteria declined from 11-24 to 0.01-1.5 mg l^{-l} (the 2017-2020 median 0.23 mg l^{-l}). In 2019 and 2020 there were short-term increases of total phosphorus and chlorophyll during hot weather spells, but low levels were soon re-established, indicating efficient phosphorus sinks in the system. Accordingly, internal loading of phosphorus declined from 170 mg m^{-2} a^{-1} in 2004-2016 to 27 mg m^{-2} a^{-1} in 2017-2020. The greatest threat in the new clear-water situation was thought to be the return of the mass occurrences of the submerged macrophyte *Elodea canadensis*, similar to those in the 1980s and 1990s. So far, however, *Elodea* has increased only moderately, possibly partly due to the feeding by the high numbers of herbivorous waterfowl aggregating to Littoistenjärvi in the autumn months. In 2018-2020, zooplankton was scarce and small-sized, indicating a high predation pressure from fish. In this situation no top-down control of phytoplankton is expected, but the good water quality depends on the maintenance of low phosphorus levels. This suggests good phosphorus binding capacity of the sediment, but phosphorus uptake by the submerged macrophytes and the microscopic epiphytic and epibenthic algae may be even more significant. Experimental harvesting of *Elodea* was planned for 2020 to explore the possibility to remove phosphorus from the lake in the plant biomass, but due to the COVID-19 pandemic, only one experiment could be arranged. So far the chemical restoration of Littoistenjärvi can be considered a success, but the coming years will show how long-lasting the improvements will be. Comprehensive ecological monitoring of the lake continues, with readiness to new management interventions if required.

From headwater lakes towards downstream – a multi-approach restoration project of Siuntionjoki river system

Anu Suonpää-Espinola, Katja Pellikka, Jussi Vesterinen

The Association of Water and Environment of Western Uusimaa (LUVY), Länsi-Louhenkatu 31, 08100, Lohja, Finland

The River Siuntionjoki is a sea trout river flowing to the Gulf of Finland. It is 48 km long, begins from Lake Enäjärvi and has a catchment area of 483 km2. There is lots of permanent residence, vacational houses and agricultural activity in the catchment area, and many water bodies are used for recreation and tourism. Parts of Siuntionjoki belong to the Natura 2000 network, and an endangered thick-shelled river mussel (Unio crassus) is also found in the river. Lakes and ponds cover 5.3 % of the catchment area and most of them are highly eutrophic. Siuntionjoki is almost exclusively responsible for the nutrient loading in the Baltic Sea estuary of Pikkalanlahti Bay. The headwater lake Enäjärvi accounts for almost half of the nutrient load in the lakes downstream. Thus, targeting extensive restoration actions on headwaters can improve the water quality all the way to Baltic Sea. We have updated the restoration plan for the two headwater lakes, Enäjärvi and Poikkipuoliainen, and put together a working group to raise funding for a nine-year project (approx. EUR 6.5 million). With the large budget, we will combine both biomanipulation and catchment management (using soil improver products and constructing buffer strips, wetlands and two-stage channels) on both lakes and their catchments prior to AlCl3-treatment, which will be conducted in Lake Enäjärvi. Additionally, we plan to raise the water level in Lake Poikkipuoliainen and restore streams in the catchment area. Water quality and biological monitoring will be carried out during the project combining both sampling and water quality instruments. To succeed in obtaining the funding and implementing the project, a large-scale collaboration is important. The project provides great opportunities for researchers across disciplines to conduct a wide range of research. We welcome researchers and research groups to collaborate, network and join us to plan and brainstorm research opportunities – and hopefully also to implement them.

Complex studies of lakes in Kenozersky national park, Russia

Taisiya Y. Vorobieva (1), Liudmila S. Shirokova (1,2), Svetlana A. Zabelina (1), Oleg S. Pokrovsky (1,2), Sergey I. Klimov (1), Olga Yu. Moreva (1), Elena I. Sobko (1), Anna A. Chupakova (1), Artem V. Chupakov (1), Natalya V. Neverova (1)

(1) N. Laverov Federal Center for Integrated Arctic Research of the Ural Branch of the Russian Academy of Sciences, Russia, 163000, Arkhangelsk, Naberezhnaya Severnoy Dviny, d. 23 (2) Geoscience and Environment Toulouse, UMR 5563 CNRS, University of Toulouse, IRD, 14, avenue Edouard Belin, Toulouse, France

Small lakes of the boreal zone are highly sensitive indicators of both global environmental change and local anthropogenic pressure. This work presents the results of multidisciplinary study of 3 small, seasonally stratified lakes of NW Russia, conducted since 2002 to the present time. These lakes were subjected to various degree of impact by rural population and agricultural activity since the beginning of the 20th century but the population and anthropogenic pressure have decreased since the 1990s. To monitor the recovery of these lakes from human impact and to relate the evolution of their hydrochemical parameters to short-term weather events and global climatic trends, we measured the lake water temperature and chemical composition (carbon, macro- and micronutrients, trace elements) in summer and winter over the full depth of the water column. The pH and concentration of DIC, SO4 and H2S decreased over the past decade. Concentrations of Si and nitrite increased over the past 15 years, probably linked to progressive replacement of diatoms by cyanobacteria. We also recorded an increase in concentration of Cl and major cations in all lakes, likely linked to increasing connection to groundwater reservoirs. Some trace elements (Fe, Mn, Al, Zn, As, Pb) can serve as suitable indicators of on-going natural processes controlling lake response to external factors. Contrary to the widely reported global trend of DOC and Fe concentration increase in boreal surface waters of Europe and Northern America, such a trend was not discernable in the studied Fe-rich humic lakes. We conclude on the necessity of complex, multidisciplinary studies of small humic lakes in the boreal zone, because these “model” lakes can serve as important proxies of on-going environmental changes in highly abundant aquatic ecosystems of poorly characterized regions of NW Russia.

Recent sedimentary phosphorus dynamics in a small groundwater-fed lake influenced by catchment erosion: A case study of Vähä-Tiilijärvi, Southern Finland

Siqi Zhao (1), Mirva Ketola (2), Tom Jilbert (1,2)

(1) Aquatic Biogeochemistry Research Unit, Ecosystems and Environment Research Program, Faculty of Biological and Environmental Sciences, University of Helsinki, Viikinkaari 1, 00014, Helsinki, Finland (2) Lake Vesijärvi Foundation, Askonkatu 9C, 15100, Lahti, Finland

Internal phosphorus (P) loading is widely recognized as a vital cause for retarding the effects of lake restoration. However, sediment phosphorus dynamics may vary widely between lake types, depending on sediment composition, bathymetry, and physical and chemical constraints. In this study, using biogeochemical analysis of sediment solid-phase and pore waters, we investigate the dynamics controlling internal P release and permanent burial, as well as the role of internal P loading in sustaining eutrophication of a small groundwater-fed boreal lake in a forested catchment (Vähä-Tiilijärvi, Hollola, Finland). Although the catchment contains no agricultural areas, small-scale deforestation and urbanization have altered the fluxes of sediment materials into the lake during the 20th century. The organic matter contents of sediments reach up to the range of 80%-90% in the bottom of the sediment cores but show a decreasing trend upwards, indicating an increase of inorganic matter inputs from the catchment because of human-induced erosion. Furthermore, upwards increasing ratios of phytoplankton and terrestrial sources of organic matter indicate concurrent eutrophication in recent decades, likely driven by external P inputs entering the lake together with eroded inorganic material. By comparing to current annual external loading of 3.35kg P/yr, we show that the mobile-P (NaOH- extractable P) inventory of the uppermost reactive layers of sediment is in decline, with permanent burial rate estimated at 4.12kg P /yr, suggesting that the lake has entered a long-term recovery phase since its initial eutrophication. However, the average upward diffusion flux rate in the sampling year (2.05kg P/yr) is equivalent to 60% of external P loading, implying an ongoing important role for internal P loading in this system. The inputs of material from catchment erosion have thus caused a legacy of internal loading, but have likely also increased sedimentation rates in the lake. The latter could theoretically accelerate the recovery from eutrophication through accelerating P burial, provided that external P inputs are controlled.

WEDNESDAY JUNE 9

ORAL SESSION 5: THEMED SESSION ON LAKE VESIJÄRVI

Restoration and management of Lake Vesijärvi in six decades: A joint long-term venture of limnological research and stakeholder activity

Juha Keto (1), Ilkka Sammalkorpi (2), Ismo Malin (3), Heikki Mäkinen (4), Jukka Ruuhijärvi (5)

(1) Lake Vesijärvi Project, Lahti, Finland (2) Finnish Environment Institute, Helsinki, Finland (3) City of Lahti, P.O.B.202, 15101, Lahti, Finland (4) Lake Vesijärvi Foundation, Lahti, Finland (5) Natural Resources Institute Finland, Latokartanonkaari 9, 00790, Helsinki, Finland

Due the sewage of the City of Lahti L. Vesijärvi (total area 109 km2) was one of the most polluted lakes in Finland in the 1970´s. Since sewage diversion in 1976 the lake has been rehabilitated by working both in the catchment and in the lake ecosystem to combat harmful cyanobacterial blooms and restore the lake´s fisheries value. The measures have been implemented through joint efforts of local and national authorities, researchers, professionals and local stakeholders, mainly hundreds of voluntary workers. Biomanipulation was added in the arsenal when cyanobacterial blooms had continued for 12 years after the sewage diversion. The cyprinid related internal loading was mitigated by intensive fishing in 1989-1993 and afterwards by maintaining management fishing. Active local participation was facilitated by reinforcement of predatory fish stocks and acceptance of shoreline management demanded by local residents in the management measures. The anti-pollution and biomanipulation measures led to an increase in water clarity and natural reproduction of pike-perch was repatriated. Blooms of cyanobacteria decreased in two stages in the early 1980s and between 1990 and 1994 but intensified again in the early 2000s. Long term management was firmly established in 2007 when municipalities and local enterprises committed in the funding of Vesijärvi Foundation. A central lesson of the long time-span of the management of L. Vesijärvi was finding opportunities for sustainable local development by reinforcing the ecosystem tolerance and resilience to internal and external loading, reviving both recreational and commercial fisheries, raising the lake to the top of Finnish pike-perch lakes and promoting ways of livelihood linked to the sound water quality. Popularizing lake research results and raising the local societal awareness of the importance and benefits of protecting lakes have secured commitment of local stakeholders in the responsible voluntary work for L. Vesijärvi.

Possibilities to control the abundance of planktivorous smelt by management of piscivore populations

Jukka Ruuhijärvi (1), Mikko Olin (1), Tommi Malinen (2), Matti Kotakorpi (3)

(1) Natural Resources Institute Finland, Latokartanonkaari 9, 00790, Helsinki, Finland, (2) KVVY,Patamäenkatu 24, 33900, Tampere, Finland, (3) City of Lahti, P.O.B.202, 15101, Lahti, Finland

Constant biomanipulation is applied in Lake Vesijärvi to reduce the stocks of planktivorous cyprinids. Smelt, the main planktivore species in the pelagial of Lake Vesijärvi, has been extremely abundant since 2014. Increased predation on zooplankton has resulted in smaller size and lower grazing capacity of herbivorous Cladocera. The majority of smelt population is small 0+ fish, too small to be effectively caught with fishing gear. Abundant stocks of piscivorous fish is thought to be the most feasible way to control small planktivores. Perch and pikeperch are the most abundant predators of smelt in Lake Vesijärvi, yet they have not been able to control the high abundance of 0+ smelt in summer. We studied the diet of predatory fish and estimated the consumption of predators on smelt. The potential increase in predator abundance to control smelt abundance was estimated. We also assessed the fisheries management options that would enable sufficient abundance and biomass of piscivore populations.

Biotracers and metatranscriptomics in modelling seston composition and nutrition

Jaakko J. Litmanen (1), Cyril Rigaud (1), Kristiina Vuorio (2), Marja Tiirola (1), Tommi A. Perälä (1), Sami J. Taipale (1)

(1) Department of Biological and Environmental Science, University of Jyväskylä, P.O. Box 35 (YA), FI-40014, Jyväskylä, Finland (2) Finnish Environment Institute (SYKE), P.O. Box 140, FI-00251, Helsinki, Finland

Understanding the interactions between seston and zooplankton helps comprehending the dynamics of aquatic food webs at the primary consumer level. We evaluate the nutritional quality and composition of seston available for herbivorous zooplankton in a freshwater lake. This information may be a crucial component in the assessment of climate change effects on lake ecosystems and the effectiveness of lake restoration methods. We collected seston samples from Lake Vesijärvi, Lahti in years 2018 and 2020. Fatty acid, sterol and metatranscriptomics analyses were performed on the samples. We created a new seston composition model that combines fatty acid profiles and metatranscriptomics data. The new method was also validated with microscopy. The usability of metatranscriptomics data in the assessment of seston composition and nutritional quality will be discussed. Also, the possibilities these methods present in lake monitoring will be explored. Further use of the seston model will be explored, for example in the estimation of herbivorous zooplankton diets, in the future.

ORAL SESSION 6: CASE STUDIES OF LAKE RESTORATION

Effective restoration of Lake Groote Melanen: from diagnosis to multiple measures

Miquel Lürling (1), Guido Waajen (2)

(1) Wageningen University, Droevendaalsesteeg 3a, 6708 PB, Wageningen, The Netherlands (2) Water Authority Brabantse Delta, Bouvignelaan 5, 4836 AA, Breda, the Netherlands

Lake Groote Melanen is a shallow eutrophic urban lake (4.8 ha, The Netherlands), characterized by regular cyanobacterial blooms. The poor water quality hampers the recreational and natural values of the lake. The mean summer (Apr-Sep; 2012-2014) concentration of cyanobacterial chlorophyll-a is 58 µg L-1, total phosphorus (P) is 0.62 mg P L-1 and the mean summer Secchi depth is 0.55 m. Submerged macrophytes are lacking, while the fish biomass is 268 kg ha-1 (78% carp). Water management focusses on the structural realization of the clear water state dominated by submerged macrophytes, the reduction of cyanobacterial blooms and the establishment of a diverse fish community. A diagnosis (water system analysis) of the causes of the poor water quality showed that the external P-load is 3.8 mg P m-2 d-1, exceeding the critical P-load. The major P-input is caused by the drainage into the lake of two water courses contributing 68% to the external P-load. Sediment P release is 1.9 mg P m-2 d-1. To restore the water quality, a package of measures was based on the diagnosis and executed from Febr. 2015 until Apr. 2016. The measures included the reduction of the external P-loading below the critical P-load, reduction of the internal P-load (by dredging, sediment capping with sand and capping with the P-fixative Phoslock), increase of the critical P-load (by reconstruction of lake shores) and the transition of the turbid state to the clear state (by removal of carp and bream, introduction of macrophytes and geo-engineering with Phoslock and polyaluminium chloride). After the restoration measures (2016-2020) the mean summer concentration cyanobacterial chlorophyll-a is 5 µg L-1, total P is 0.04 mg P L-1 and mean summer Secchi depth 0.65 m. Coverage of submerged macrophytes gradually increased to 15% in 2020. Fish biomass is reduced, while uncontrolled introduction of carp needs constant attention and management if necessary. The case provides an example of a diagnosis-driven rehabilitation comprised of multiple measures to maximize the chance of success.

Cross-border cooperation on environmental monitoring of Lake Peipsi: main results and perspectives

Lea Tuvikene

Department of Hydrobiology and Fishery, Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Limnoloogia tee 1, 61117, Tartu County, Estonia

The 47 814 km2 catchment area of Lake Peipsi-Pskov (lake area 3555 km2, mean depth 7.1 m) is shared between Russia (58%), Estonia (34%), and Latvia (8%). An agreement between the Republic of Estonia and the Russian Federation on the use and protection of the natural resources of was signed in 1991. Since 1997, a working group on water management, monitoring and scientific research of the Joint Commission for the Protection and Sustainable Use of Estonian-Russian Transboundary Waters has met annually. Continuous joint or simultaneous monitoring expeditions, data exchange and common assessment of the ecological status of the lake form a good basis for planning improvement measures. Despite differences in the two countries' monitoring and status assessment methodologies, there is a general consensus on trends. In addition to the monitoring results, I will present some results of recent research publications. The most powerful driver of the ecological status of Peipsi is the annually (by 1.5 m) fluctuating water level. Due to climate change, the lake surface water temperature has increased by more than 0.4 °C per decade during the last 50 years, and the ice cover duration has shortened by approximately 35 days. High phosphorus (P) concentration, especially in low-water years, is the main anthropogenic problem. Due to heavy point source and diffuse pollution, nutrient loading increased rapidly in the 1980s followed by a drop in the early 1990s, but began to grow again since the 2000s, due to increased use of fertilizers. The role of internal loading in the P cycle is continuously large. Climate change with shorter ice cover will increase algal biomass and the share of toxic cyanobacteria among phytoplankton. More efforts are needed to reduce the nutrient loads to the lake, including strict control on the use of fertilizers in the whole catchment area. The study was supported by the EU H2020 WIDESPREAD grant 951963 TREICLAKE and Estonian Research Council grant PRG709.

Lake Ormstrup, Denmark: biomanipulation, sediment removal and phosphorus recycling

Martin Søndergaard (1), Kasper Reitzel (2), Christian Skov (3)

(1) Aarhus University, Vejlsøvej 25, DK-8600 Silkeborg, Denmark (2) University of Southern Denmark, Campusvej 55, DK-5230, Odense M, Denmark (3) Technical University of Denmark, Vejlsøvej 39, DK-8600 Silkeborg, Denmark

Lake Ormstrup is a 12 ha, shallow (mean depth = 2.3 m and maximum depth = 5.5 m) lake located in the central part of Jutland, Denmark. The lake is highly eutrophic; in particular, phosphorus concentrations are high, reaching 0.4-0.8 mg/l during summer. Mean summer Secchi depth is 1.2-1.7 m and chlorophyll a concentrations range between 40 and 80 µg/l. Submerged macrophytes are almost completely absent. The external phosphorus loading is low and the high lake water concentrations of phosphorus are due to a high internal loading and release from the sediment where a large phosphorus pool has been accumulated (up to 9 mg P/g dry weight in the surface sediment). Paleoecological studies show that the lake used to be low alkaline and nutrient poor and characterized by isoetid vegetation. To improve the lake water quality in the short term, the lake was biomanipulated in autumn 2020 by removing 4 tons of roach (Rutilus rutilus). In the long term, the plan is to remove the upper layer of the sediment and reuse its phosphorus for agricultural purposes. Prior to its biomanipulation, the lake was characterized and studied very intensively, including nutrient cycling from the sediment, temporary stratification events, greenhouse gas emissions, undertaking of high frequency buoy measurement (every 15 min.) and biological interactions, including fish population characteristics (species, density, recruitment and behaviour measured by telemetry). In this study, we present some of the preliminary results. In the coming years, the effects of the biomanipulation will be studied intensively in order to investigate the effects on chemical and biological processes when a shift occurs from turbid to clear water conditions. The data obtained will be used for optimizing lake restoration measures, including the development of a mechanistic model of the lake (digital twin). Furthermore, research into the possibility for removing and reusing phosphorus from the sediment will be strengthened in order to establish sustainable reuse of phosphorus in combination with the restoration of lakes to improve the water quality.

Sustainable restoration of an urban lake - changes in water quality and bottom sediments during 12 years of treatments

Katarzyna Kowalczewska-Madura (1), Beata Messyasz (2), Renata Dondajewska-Pielka (1), Sławek Cerbin (2), Ryszard Gołdyn (1)

(1) Department of Water Protection, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland (2) Department of Hydrobiology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland

Sustainable restoration is the simultaneous use of several complementary methods to improve water quality. These are pro-ecological treatments called "nature-based solutions", the aim of which is to gradually rebuild the structure and functioning of the aquatic ecosystem. The Lake Durowskie is an urban lake situated in the city of Wągrowiec (Poland). This dimictic, flow-through lake, is located in the course of Struga Gołaniecka River. The lake area is 143 ha, maximum depth 14.6 m and mean depth 4.6 m. As a result of deteriorating water quality, three methods of sustainable restoration measures were taken in 2009, i.e. hypolimnetic water aeration with the use of two wind-driven aerators; phosphorus inactivation in the water column using low doses of iron sulphate and magnesium chloride, and biomanipulation based on pike and pikeperch fry stocking to increase the contribution of predatory fish in the lake ichthyofauna. Studies on water quality and internal phosphorus loading from bottom sediments in the lake were carried out between 2009 and 2020. They showed that as a result of sustainable restoration treatments there have been changes in the functioning of the lake and an improvement in its water quality. First of all, the average transparency has increased from 1.3 m in 2009 to 2.8 m in the last years of the study. The mean concentration of chlorophyll-a showed a clear downward trend in successive years and did not exceed 10 µgL-1 in 2020. Similar variability was observed in the case of ammonium nitrogen, whose mean concentration decreased from 1.91 mgN-NH4L-1 in 2009 to 0.7 mgN-NH4L-1 in 2020. In the case of total phosphorus, its concentration fluctuated in subsequent years and in recent years it has not exceeded the value of 0.06 mgPL-1. Ex situ experiments carried out with regard to the internal phosphorus loading showed that in the initial years of sustainable restoration, the process of phosphorus release from bottom sediments dominated, reaching an average of 4.5 mgP m-2d-1, whereas in recent years phosphorus accumulation in bottom sediments was predominant.

ORAL SESSION 7: BIOGEOCHEMISTRY

PLENARY 3: Do the benefits of lake restoration outweigh the costs?

Bryan M. Spears (1), Will Brownlie (1,2), Laurence Carvalho (1), Linda May (1), Amy Pickard (1)

(1) UK Centre of Ecology & Hydrology, Bush Estate, Penicuik, Midlothian, UK (2) The University of Edinburgh, School of GeoSciences, The King's Buildings, Alexander Crum Brown Road, Edinburgh, UK

Restoring lakes by reducing nutrient pollution can bring multiple benefits. Some are obvious, such as cleaner and safer water, the return of locally extinct plants and animals, and an increase in recreational and tourist visitors. Others are less so. These include a reduction in greenhouse gas emissions, the generation of jobs, and enhancement of social wellbeing and health. Indeed, the UK Treasury Dasgupta Review (2021) uses the concept of regime shifts in shallow lakes due to changes in phosphorus loading to exemplify interactions between biodiversity and economic recovery/growth, more generally. However, our lakes are under stress caused by increasing and diverse pressures. For example, the combined effects of climate change and nutrient pollution make implementing effective restoration measures to meet sustainability ambitions a more challenging task. We will review recent advances that offer hope in meeting this challenge. We will provide an overview of recent work that unpicks the impacts of multiple stressors on lakes, providing increasing confidence to support costly management interventions. At the pan-European scale, nutrient pollution continues to be the dominant stressor that affects our lakes, but for individual lakes, more complex interactions between climate sensitive stressors and nutrients can emerge. These must be managed carefully to avoid 'toxic investments'. We will draw on the experiences of practitioners who are tasked with delivering lake management plans to meet multiple sustainability ambitions, from enhancing biodiversity, to social and economic recovery, to contributing to Net Zero. Finally, we will provide a perspective on the need to share experiences and will make the case for lake restoration to be embedded within the wider global sustainability agenda, with a particular focus on sustainable nutrient management.

Hidden Nitrogen: the key to modeling cyanoHAB toxin concentrations

D.K. Hoffman (1), M.J. McCarthy (1), T.W. Davis (2), and Silvia E. Newell (1)

(1) Wright State University, Dayton, OH, USA (2) Bowling Green State University, Bowling Green, OH, USA

Microcystis-dominated cyanobacterial harmful algal blooms (cyanoHABs) in western Lake Erie (WLE) have increased in severity since the mid-1990s. Microcystis produces the cyanotoxin microcystin, which has 10 N atoms per molecule, and production is initiated by nitrogen availability. However, no strong relationships between concentration of microcystins and any environmental parameter have been reported, making it difficult to model bloom toxins. This is likely due to the high bioreactivity of NH_4^+, which leads to rapid recycling and makes it difficult to accurately characterize in situ NH_4^+ concentrations and availability with snapshot sampling and monitoring efforts. Here, we used NH_4^+ assimilation and turnover/recycling rates and typical water quality monitoring parameters to develop a preliminary model for concentration of microcystins based on three field seasons of sampling in western Lake Erie with the NOAA Great Lakes Environmental Research Lab (GLERL). The model uses NH_4^+ turnover rates along with common monitoring metrics to predict concentration of particulate microcystins, and the relationship between actual and predicted concentrations is very strong ($R^2 = 0.84$, $p < 0.0001$). Likewise, we are able to model NH_4^+ turnover ($R^2 = 0.79$, $p < 0.0001$) from only common environmental parameters.

The impact of eutrophication and climate change on accumulated sediment properties: Results from a long-term lake mesocosm experim

Peeter Nõges (1), Katrin Saar (1), Martin Søndergaard (2), Maria Jensen (3), Charlotte Jørgensen (3), Kasper Reitzel, (3) Erik Jeppesen (2), Torben Lauridsen (2), Henning S. Jensen (3)

(1) Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Kreutzwaldi 5, 51006 Tartu, Estonia (2) Department of Bioscience - Lake Ecology, Aarhus University, Vejlsøvej 25 building M2.07, 8600 Silkeborg, Denmark (3) Institute of Biology, University of Southern Denmark, Campusvej 55, 5230, Odense M, Denmark

Although much progress has been made to reduce the external phosphorus (P) loading from lake catchments, it is expected that climate change can exacerbate the eutrophication problem by increasing both the external and internal loads. Deposited bottom sediments in water bodies, depending on their physical and chemical properties, and environmental conditions may become an internal source of P loading having a strong feedback on the actual water body status. Sediment accumulation rate, its P content and fractional composition depend on climatic conditions and nutrient loading history, but as these factors are interrelated, it is often hard to disentangle their individual roles on sediment properties in natural lakes. We studied the sediments accumulated in a long-term mesocosm experiment in Denmark since 2003. The experiment was run in 24 outdoor flow-through mesocosms in four replicates with three different temperature treatments (ambient, low and strong heating), and two nutrient treatments (low and high). We analysed the thickness of the accumulated sediments, the physical and chemical properties of the surface and a deeper organic sediment layer, and the dominant type of primary producers. K-means clustering of the samples and Principal Component Analysis (PCA) was applied to test the effects of different treatments. Both analyses showed a strong and clear effect of nutrient enrichment on sediment accumulation rate, total P and its fractional composition. Vegetation was a covariant of nutrients and did not emerge as an independent factor. Most of the enriched mesocosms were phytoplankton dominated and non-enriched ones macrophyte dominated. The effect of temperature treatment was weak and was manifested only in nutrient-enriched mesocosms showing a synergistic interaction between nutrient loading and temperature.

A future tale of two winters? Sediment-water interface nitrogen dynamics in Lake Võrtsjärv (Estonia) during the ice-free winter 2019/2020

Mark J. McCarthy (1), Silvia E. Newell (1), Lea Tuvikene (2), Margot Sepp (2), Marju Tamm (2), Priit Zingel (2), Tõnu Feldmann (2), Kalle Olli (2), and Tiina Nõges (2)

(1) Wright State University, 3640 Colonel Glenn Highway, Dayton, OH 45435 USA (2) Estonian University of Life Sciences, Kreutzwaldi 64, 51014 Tartu, Estonia

Aquatic systems are susceptible to the effects of climate change, such as altered temperature and precipitation, as well as the timing and intensity of episodic climate events. For aquatic systems at temperate toward polar latitudes, these changes include the timing and duration of ice cover. Historically, many aquatic scientists have assumed that little or no microbial activity occurs in winter or under ice in these systems, but research within the last few decades has shown that assumption to be false. A mechanistic understanding of microbial transformation rates and pathways, even during winter and under ice, is critical for determining the actual availability of various nitrogen (N) forms to primary producers in aquatic systems. We measured sediment-water interface nutrient dynamics, including net inorganic nutrient (N and P) fluxes, sediment oxygen demand, denitrification (and anammox), and dissimilatory nitrate reduction to ammonium in Lake Võrtsjärv, a eutrophic lake in southern Estonia. Intact sediment cores were collected in December and late February during the exceptional, ice-free winter of 2019/2020 and incubated in a continuous-flow system at 1.0 °C. Denitrification was active in sediments from both the southern, shallow area of the lake and the central, open area of the lake. However, this microbial N sink was counteracted to varying degrees by heterotrophic N fixation occurring simultaneously, as well as ammonium releases. Addition of 15N-labelled nitrate stimulated total N2 production, suggesting an enhanced capacity for microbial N removal during discharge events. Sampling and incubations scheduled for winter 2020/2021 were not possible due to the COVID-19 pandemic, but additional sampling is planned for winter 2021/2022.

Where do we go from here? Mitigating harmful cyanobacterial blooms in a world facing human nutrient over-enrichment and climate change

Hans W. Paerl, Malcolm A. Barnard, Nathan S. Hall, Haley E. Plaas, Karen L. Rossignol

Institute of Marine Sciences, The University of North Carolina at Chapel Hill, 3431 Arendell Street, Morehead City, NC 28557, USA

Harmful (toxic, hypoxia-generating, food web altering) cyanobacterial blooms (CyanoHABs) pose a serious environmental and human health problem that is expanding globally and threatening sustainability of our aquatic resources. Human nutrient enrichment and hydrologic modifications, including dam and reservoir construction and diversions, are a major driver of bloom expansion. However, climatic changes taking place, including warming, more extreme rainfall and drought events, act synergistically with man-made drivers to exacerbate the problem. Bloom mitigation steps must incorporate these dynamic interactive factors in order to be successful in the short- and long-term. To be most effective, these steps must be applicable along the freshwater to marine continuum spanning lakes, rivers, estuarine and coastal waters. Nutrient input reductions are an essential component of virtually all CyanoHAB mitigation strategies. Traditionally, phosphorus (P) reductions were prescribed for freshwater systems, while (N) reductions were stressed in brackish and coastal waters. However, these systems are hydrologically connected and on the watershed scale single nutrient (e.g., P) management steps taken upstream may not reduce CyanoHAB problems and sometimes exacerbate them downstream. To ensure long term, sustainable success, these strategies should include both nitrogen (N) and phosphorus (P) input reductions. Flexibility in nutrient reductions needed to mitigate along the continuum should be an integral component of nutrient management strategies because as climatic influences change, and internal nutrient loading decreases over time, new nutrient-bloom thresholds will likely emerge.