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The effect of cyanobacterial blooms on lake ecosystems may be determined by trophic status

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One of the most common paradigms in limnology is that cyanobacterial blooms reduce the species richness and biomass of non-blooming phytoplankton and, by being poor quality food, decrease zooplankton grazing. Modeling and experimental work have indicated that the diversity of non-blooming phytoplankton during cyanobacterial blooms is low because cyanobacteria produce surface scums that limit light penetration, excrete allelopathic chemicals, and fix their own nitrogen; all mechanisms that allow cyanobacteria to outcompete other phytoplankton. However, recent research has indicated that the effects of cyanobacterial blooms are more complex and context-dependent than previously realized. For example, allelopathic screenings of cyanobacteria have demonstrated both inhibitory *and* stimulatory effects on other phytoplankton. Furthermore, a growing number of studies indicate that cyanobacteria *can* stimulate the growth and division of other, more edible phytoplankton in both laboratory and field settings. These findings have major implications for our understanding of food webs and nutrient cycles during cyanobacterial blooms. Why do some systems exhibit inhibitory and other systems exhibit stimulatory effects of cyanobacterial blooms? The majority of the studies of inhibitory blooms were conducted in eutrophic and hypertrophic systems, while the studies of stimulatory blooms were primarily performed in more nutrient-limited systems, indicating that nutrient limitation may be an important determinant of how cyanobacterial blooms affect a lake. Here, I present experimental data indicating that the effects of cyanobacterial blooms on lake ecosystems may be driven by trophic status.

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Midges from space?! Massive aquatic insect emergence from Lake Mývatn, the Icelandic “midge lake”

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Aquatic insects, such as midges (Diptera: Chironomidae), are capable of linking processes that occur within lakes to those that occur in the adjacent terrestrial ecosystem. The naturally eutrophic Lake Mývatn in northeast Iceland has long been famous for its periodic massive emergences of midges during the summer months, the result of the unique geomorphology of the lake basin. The total midge biomass that emerged from the lake

exceeded 30 metric tons dry weight annually during the years 2008-2010. The midges form dense mating columns at the lake edge where some are consumed by predatory arthropods but many more eventually die and deposit their carcasses onto the ground. The midges of Lake Mývatn are approximately 10% N and 1% P by mass, and thus represent a massive flux of lake-derived nutrients onto land, matching or exceeding background rates of N deposition (5kg ha^{-1} yr^{-1}) over a large area (25 km^2). This fertilization effect in turn greatly increases rates of primary productivity along the lakeshore, a phenomenon that can be remotely sensed from space using satellites. We are using these remote sensing data to refine our estimates of midge emergence from the lake, as well as to predict other lakes in the region that may show similar patterns of terrestrial fertilization via midges. In contrast to the prevailing paradigm our work emphasizes the potential importance of intra-lake ecology to that taking place in the surrounding landscape.

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Summer high frequency monitoring in Sauce Grande shallow lake (Argentina)

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Sauce Grande shallow lake (38°57' S - 61°24'W) is located in the Southwest of Buenos Aires province (Argentina). The location and morphometry of this natural water body is controlled by a coastal dunes system. The Sauce Grande river discharges into the shallow lake and then continues its flow to the sea. Due to the lack of water in the region the sluices connecting to the water reservoir were closed. Monthly physical (water temperature, electrical conductivity, suspended sediment, pH, dissolved oxygen) and meteorological parameters (air temperature, relative humidity and wind) were measured from September 2008 to December 2010. On February 2011, a buoy was installed in the Sauce Grande shallow lake. Water temperature, conductivity, suspended sediment, water level and meteorological parameters are measured with a time interval of 5 minutes. Data is available at a website (emac.criba.edu.ar). An analysis of the measured parameters is presented. Electrical conductivity values ranged between 9.5 and 7.5 mS/cm. Suspended sediment concentration varied between 200 and 550 mg/l and those values were correlated with wind speed. The evaporation on the shallow lake was significant during February 2011 due to the high summer temperatures.

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Linking climate change, lake ecosystem health, and better watershed management in New York State, USA

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Our research focuses on understanding climatic impacts on lake ecosystems as they will affect fisheries, recreation, wastewater discharge, and other aspects of aquatic ecosystem health. The overall goals are to evaluate the impacts of climate change on lake temperature profiles, oxygen availability, and associated ecosystem health and recommend watershed management practices for mitigating these impacts. Field-based monitoring, modeling and extension are used to accomplish these objectives. This study is conducted within 207 km^2 Oneida Lake and its 3,500 km^2 watershed located in Central N.Y., USA. Field data are collected on stream and groundwater temperature loading, weather, and lake temperatures at varying depths. Lake temperature profiles under historic and anticipated climatic conditions are modeled using DYRESM, a one-dimensional thermodynamics model, coupled with CAEDYM, an aquatic ecological model. Solar radiation is a major contributor in this large, shallow lake; however, initial modeling suggests cooler temperatures of tributary and groundwater inflow may exert a significant regulating effect on lake temperatures and stratification in the presence of increasing air temperatures. In a future phase, SWAT, a land management model, will be used to evaluate how changes in land use, including streamside vegetation preservation, snowpack retention, and agricultural best management practices, can reduce temperatures of inflowing waters. The three models will be integrated to test different scenarios using anticipated climate changes and watershed management practices and assess the likely impacts of climate change on lake ecosystems and provide insights into how proper watershed management can mitigate the impacts of climate change and buffer temperature increases.

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A Commercial Machine-To-Machine (M2M) Service based Smart Real-Time Lake Monitoring

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Real time lake monitoring is the technique to monitor the ecological and environmental state of the lake *immediately and constantly* and allows us to examine the status at any time. Real time monitoring requires both sensors for monitoring and communication systems for data transmission to operate all the time. However such constant operation is a serious challenge for scientists because sensors are often exposed to harsh natural environments and scientists have to build their own communication facilities for them.

In order to address the real time lake monitoring effectively, we propose reliable and smart monitoring techniques and present a prototype system for Lake Soyang in Korea. This system is based on a commercial machine-to-machine (M2M) service. M2M is a technique to allow devices and instruments to communicate with a central server or one another, to provide online services, and to allow remote control. In this project, we use a commercial M2M service provided by SKT® (the mobile telecommunications operator with the largest market share in Korea) which is available almost everywhere in Korea and is known to be very reliable. We also use a commercial terminal device (MPT-800 CDMA/GPS Terminal from MELPER®)to provide the CDMA communication service, the data logging service, the SKT M2M service, and the embedded programming service. Therefore, scientists do not have to worry about the communication service at all.

We present a lake monitoring data distribution system by integrating the M2M service into the Data Turbine system. It allows us to distribute monitoring data to a number of data management and service systems. Our real time lake monitoring system is designed to support the smart maintenance which can minimize the human maintenance overhead. For example, abnormal sensor values are detected and the remaining battery charge is always examined. Scientists can be notified of failures on sensors and the shortage of batter charge by SMS (CDMA Short Messaging Service), a part of the M2M service.

Finally, the system allows the user to access the current state data of the lake via Google Map in real time manner and to examine sensor data for a given period of time by a chart service.

We plan to build the KLEON (Korea Lake Observatory Network) infrastructure by extending this system. KLEON will include a number of lakes in Korea.

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Time-scale dependence in numerical simulations: Assessment of physical, chemical, and biological predictions in a stratified lake at temporal from scales of hours to months

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We evaluated the predictive ability of a one-dimensional coupled hydrodynamic-biogeochemical model across multiple temporal scales using wavelet analysis and traditional goodness-of-fit metrics. High-frequency in situ automated sensor data and long-term manual observational data from Lake Mendota, Wisconsin, USA, were used to parameterize, calibrate, and evaluate model predictions. We focused specifically on short-term (< 1 month) predictions of phytoplankton biomass over one season. Traditional goodness-of-fit metrics indicated more accurate prediction of physics than chemical or biological variables in the time domain. This was confirmed by wavelet analysis in both the time and frequency domains. For temperature, predicted and observed global wavelet spectra were closely related, while observed dissolved oxygen and chlorophyll-*a* fluorescence spectral characteristics were not reproduced by the model for key time scales, indicating that processes not modelled may be important drivers of the observed signal. To determine the influence of exogenous drivers and starting conditions on system dynamics, we simulated the response of dominant phytoplankton groups to different nutrient and water temperature scenarios. We found that the initial conditions of water column phosphorus concentration was more important to the timing and magnitude phytoplankton response than nitrogen concentration or initial water column temperature. Dynamics of simulated variables did not change with starting conditions or changes in temperature or phosphorus loading. Although the magnitude and timing of physical and biological changes can be simulated adequately through calibration, time-scale specific dynamics, for example short-term cycles, are difficult to reproduce. Wavelet transforms and diverse observational data provide for model evaluation techniques that are complementary to traditional goodness-of-fit metrics, and are particularly well suited for assessment of temporal and spatial heterogeneity when coupled to high-frequency data from automated in situ or remote sensing platforms.

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First high frequency metabolism studies in large shallow Lake Võrtsjärv, Estonia

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Large and shallow (area 270 km^2; mean depth 2.8 m, catchment area 3100 km^2) Lake Võrtsjärv was intensively studied for more than 50 years before the monitoring buoy was deployed for high frequency measurements of lake physical and chemical parameters. Phytoplankton primary production (PP) in Võrtsjärv has been measured *in situ* with ^{14}C-

assimilation technique already since 1982. PP has been measured mainly during ice-free periods from April to October with weekly to monthly intervals.

This study presents the first results of high frequency measurements in Lake Võrtsjärv that started with multisensor in year 2009 (May to late- July) and followed with buoy in 2010 (mid-April to late-October). We estimated the net ecosystem production (NEP), lake respiration (R) and gross primary production (GPP) by continuous measurements of oxygen, irradiance, wind, temperature and chlorophyll a. There were three to five distinct peaks in gross primary production (GPP) and community respiration (R) during the summer season and lows from fall to spring after broad-scale changes in irradiance and temperature.

Mean pelagic NEP was 28 mmol O_2 m^{-3} d^{-1} (range of –46 to 112) in 2009 and -5 mmol O_2 m^{-3} d^{-1} (range of –131 to 120) in 2010. Calculated rates of metabolism varied also strongly: mean pelagic GPP was 90 mmol O_2 m^{-3} d^{-1} (range of 18 to 230) in 2009 and 75 mmol O_2 m^{-3} d^{-1} (range of 0.8 to 319) in 2010; mean pelagic R was 63 mmol O_2 m^{-3} d^{-1} (range of 8.7 to 249) in 2009 and 80 mmol O_2 m^{-3} d^{-1} (range of 7.2 to 412) in 2010. GPP was positively correlated with photosynthetically active radiation (PAR) and negatively with wind speed. Lake metabolism was annually balanced (mean GPP:R was1.81 in 2009 and 1.17 in 2010), with net autotrophy occurring mainly from mid-April to late-July (mean GPP:R 1.81 in 2009 and 1.61 in 2010), and net heterotrophy from August to late October (mean GPP:R 0.62 in 2010).

The studies of last two years confirm that the metabolism of Lake Võrtsjärv may switch between autotrophic and heterotrophic types twice per year. In the summer period lake is acting prevalently as a net autotrophic system while in the autumn and spring net heterotrophy prevails.

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Patterns and Processes that Shape the Ecological Stoichiometry of Lake Kinneret

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It is well established that nutrient cycling in the pelagic zone of aquatic ecosystems is generally controlled by microorganisms, primarily the interactions between zooplankton, phytoplankton and bacteria. However, very little is known about how the microbial interactions that govern nutrient recycling manifest in the overall patterns of stoichiometry between different trophic levels within freshwater ecosystems. In this study, we examine the patterns and processes that shape the ecological stoichiometry of Lake Kinneret, and in particular study the effect of the microbial loop in regulating nutrient exchange between phytoplankton, bacteria and micro-zooplankton. A one-dimensional coupled hydrodynamic-ecosystem model (DYRESM-CAEDYM) has been applied to investigate the physical-biogeochemical-ecological interactions within the Lake Kinneret ecosystem and validated over a five year period (1997-2001). To unravel the significance of different pathways, three microbial loop configurations are compared: (1) static bacteria with constant mineralization rates, (2) bacteria with dynamic mineralization rates unable to take up dissolved inorganic N & P, and (3) bacteria with both dynamic mineralization rates and ability for dissolved inorganic nutrient supplementation. Through comparison of different simulation results, insights into the stoichiometry of nutrient recycling pathways illustrate that the ability of bacteria to regulate their stoichiometry is a significant factor that has ecosystem wide implications. In particular, the analysis of N and P limitation functions for the five simulated phytoplankton groups indicate that competition by bacteria for nutrients can contribute to shaping the pattern of algal succession within the lake. These results highlight the dynamic shifts in stoichiometry within different pools within the lake and the importance of the microbial loop in regulating the stoichiometry of nutrient flows. Careful consideration should therefore be given to parameterization of the microbial loop as an important component of aquatic ecosystem models.

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Modeling trophic interactions within lake ecosystems: potential use of complex ecological models

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Lake Kinneret is an example of aquatic ecosystem food web that contains intraguild predation (IGP). The predatory invertebrate (cyclopoid copepods) and the lavnun (*Acanthobrama terraesanctae*) feed on herbivorous zooplankton and form a trophic triangle that includes intraguild predation by fish on the Cyclopoid copepods. Thus fish affect zooplankton both directly and indirectly.

A complex mechanistic hydrodynamic-ecological model (DYCD) coupled to a bioenergetics-based fish population model (DYCD-FISH) was employed in the aim of revealing the IGP dynamics in Lake Kinneret in the years 1997-2003. The simulation results indicate that the predation pressure of the predatory zooplankton on herbivorous zooplankton varies widely with season, exerting predation pressure 10-20 times higher than fish predation pressure at the time of its annual peak. The model was further used to explore IGP dynamics when the number of the fish was significantly higher, as occurred in the lake after atypical meteorological years. Similarly to observed data, the model indicates that an increase in the number of the fish 8-fold higher than the initial base level, is able to turn the ecosystem to be top-down controlled by the planktivorous fish. The predation pressure on the predatory and herbivorous zooplankton populations reduces their average biomass significantly ($p < 0.05$). However, seasonally, the decrease in predatory-zooplankton biomass is followed with a decrease in their predation pressure, allowing for the increase of the herbivorous zooplankton biomass to extents similar to the base level. These results demonstrate the use of complex ecological models in revealing the trophic interaction dynamics within lake ecosystems.

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Processes Controlling the Horizontal Distribution of Phytoplankton in Lake Kinneret

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Phytoplankton spatial heterogeneity, a ubiquitous feature in oceans and lakes, has been studied for decades as the patterns observed often provides insight into the underlying controlling mechanisms. A major constraint in the advancement of this research subject is the lack of spatial coverage using conventional in-situ point sampling methods but is being overcome with the development of remote sensing technology in the recent years. A comprehensive study to investigate the physical and biological processes governing the horizontal spatial patterns of phytoplankton was carried out using a combination of remote sensing information, in-situ measurements, numerical and analytical modeling, and geo-statistical methods, for Lake Kinneret (Israel). The first part of this study found that physical processes play an important role in determining the large scale features of phytoplankton patches. More specifically, satellite images showed phytoplankton concentration emerged as narrow bands adjacent to the shoreline at the start of the bloom, but progressively towards the centre of the lake as the bloom proceeded; and this phenomenon is attributed to the change in structure of internal waves and increase in wind magnitude. The second part of this study found that while phytoplankton growth is responsible for initiation of patches, its influence in shaping the horizontal structure is minimal. Vertical migration behaviour, on the other hand, was found to be dominant in producing fine-scale features in the spatial distribution. The study demonstrates an integrated approach for understanding the temporal and spatially variability of environmental variables in aquatic systems.

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Physical variability in temperate lakes: A global analysis of high-frequency instrumented buoy data from 25 lakes

Thermal stratification in lake ecosystems exerts an important control on the in-lake vertical fluxes of dissolved and particulate material but is extremely variable across climate and lake types. We present data from 25 lakes in temperate latitudes with a wide range of depths (1 to 254 m) and surface areas (0.46 ha to 2,250 km^2), where each unique water body contributes to an improved description of the tremendous variability in lakes across regional as well as continental scales. We specifically present patterns in stratification dynamics related to lake properties and location, as well as estimate the thermal influence of each lake on local climate.

Kevin C. ROSE[1]

Insights from Chlorophyll and CDOM Fluorescence Sensors: Understanding Signals Across Lakes and Temporal Gradients

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Novel optical sensors, including chlorophyll and CDOM (chromophoric dissolved organic matter) fluorometers, can provide unique insights into the structure and function of aquatic ecosystems. Yet these sensors are sensitive to processes which subject them to particular biases. For example, chlorophyll and CDOM sensors exhibit strong diel fluctuations which may not related to actual changes in chlorophyll concentration or dissolved absorbance. Thus, high frequency observations from these sensors may provide signals distinctly different than longer term studies and profiling applications. Here I highlight short-term phenomenon that affect these sensor measurements; I show how diel changes in non-photochemical quenching affect *in situ* chlorophyll fluorescence and how diel changes in pH affect CDOM fluorescence. In contrast to high frequency observations, data from profiling and long-term applications show the utility of these instruments to generate novel ecological insights. I show how the depth of the deep chlorophyll maximum (DCM), as inferred from chlorophyll fluorescence, is closely related to the 1% PAR across a broad gradient of lakes, demonstrating that light limitation regulates the vertical structure of chlorophyll. Additionally, I show how CDOM fluorescence is closely related to dissolved absorption coefficients and seasonal changes dissolved absorption may be driven by photobleaching and, in some lakes, autochthonous generation of CDOM near the DCM.

K.C. Rose, L. WINSLOW, J. Read, E. Kara, and C. Solomon

Towards better open water metabolism estimation: Metabolic model parameter uncertainty explained by Lake Number and PAR

Since Odum's 1956 paper and the advent of automated Dissolved Oxygen (DO) measurement, free-water estimates of primary productivity and respiration have been a commonly used method for estimating metabolism in aquatic systems. This model of primary productivity and respiration is often confounded by physical and other non-modeled processes occurring in aquatic systems which can result in large uncertainty in estimating open-water Gross Primary Productivity (GPP) and Respiration (R). We present work showing correlation for many lakes of model parameter uncertainty with physical drivers and indices of lake physics, specifically PAR and Lake Number. We show that using simple rules based on PAR and Lake Number, days on which parameter uncertainty is high can be predicted, improving overall ecosystem parameter certainty while additionally offering a potential mechanistic explanation for DO dynamics observed.

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Investigating the contribution of autotrophic production to carbon availability in a west of Ireland lake chlorophyll *a* fluorescence

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While allochthonous sources of carbon generally dominate in humic lakes, autochthonous carbon will also contribute. The seasonal patterns in the availability of these two sources will vary. The project is using a combination of high resolution fluorescence data to estimate the phytoplankton and DOC pools, together with lower frequency sampling of the carbon pools in additional biological components in Lough Feeagh, a humic lake on the west coast of Ireland. The site is of importance in salmon research and the contribution of these two carbon sources to consumers, including zooplankton and fish species is of particular interest. The initial stages of the project involve calibration of in-situ instrumentation to measure Chl *a* fluorescence, including correction for drift due to fouling, an assessment of the impact of temperature mediated quenching on fluorescence levels and light photo-inhibition. This work will contribute to the development of a more accurate carbon budget for Lough Feeagh and the Burrishoole Catchment.

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Interaction between internal waves, a sloping bathymetry and mixing patterns on a shallow shelf connected to a deep lake

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Cayuga Lake, located in the Finger Lakes region of NY state, USA, is a long (60 km), narrow (4 km) and deep (120m) lake with a shallow southern shelf. 40% of the total inflow to the lake is discharged onto the southern shelf via tributaries that carry high nutrient and sediment loads. Two municipal wastewater treatment plants also discharge their treated effluent into this part of the lake.

The geometry of the lake, including the alignment of its long axis with the prevailing winds in the region lends itself to the generation of large amplitude internal waves (order 20m internal seiche amplitude). The interaction of the internal seiche with the shelf controls the mixing and transport of nutrients on the shelf, and leads to strong gradients in water quality on the shelf.

Following strong wind events which cause runup of the thermocline onto the shelf, exchange between the shelf and the deep basin is constrained, leading to localized spikes in nutrient levels. Under normal conditions while the lake is stratified there is exchange between the water on the shelf and the main basin's hypolimnion due to bottom shear generated turbulence as the internal seiche propagates up and down the shelf slope. This mixing is increased in some areas relative to others, due to bathymetry and effects of the earth's rotation. This leads to dilution of surface water with hypolimnetic water, decreasing turbidity and concentrations of chlorophyll-a. We will present the results of several field campaigns that observed primarily the physical properties of this system.

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Sediment or bloom, who is the major nutrient player in Taihu?

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Sediment cores were sampled at 22 sites in Lake Taihu and incubated in laboratory to reveal the influence of mass accumulation of algal bloom on the increase of nitrogen and phosphorus in the lake water. The column experiment involved three treatments with: (i) water and sediment, (ii) water and algae and (iii) water, sediment and algae, respectively. Concentration of dissolved oxygen (DO), total nitrogen (TN) and phosphorus (TP), ammonium (NH_4^+-N), phosphate (PO_4^{3-}-P) and other parameters were determined during cultivation in water and some of them in sediment. Bloom addition caused significant increase of nutrients in both water column and water-sediment column. However, the concentrations of nutrients are not too much different among the columns from different

regions, especially in the water-algae treatments. In column without algae, nutrients increased slightly with the release from the sediment, and showed the greatest increment in the region of river mouth, where the sediment was highly polluted. Meanwhile, the rate of increase of nutrients in river mouse was generally greater than other regions, which were also blamed for the polluted sediment. The study indicated that the concentrations of nutrients were mostly influenced by the mass accumulation of algal bloom, while the differences in sediments caused the different response times in different regions.