The Principle and Value of the European Multi Lake Survey

MANTZOUKI, Evanthia, IBELINGS, Bastiaan Willem

Abstract

On-going global warming and eutrophication are expected to promote cyanobacterial dominance worldwide. Although increased lake temperature and nutrients are well-established drivers of blooms, the mechanisms that determine cyanobacterial biomass are complex, with potentially direct, indirect, and interactive effects. Cyanobacteria can produce toxins that constitute a considerable risk for animal and human health and thus a substantial economic cost if we are to ensure safe drinking water. Such global range phenomena should be studied at a wide spatial scale, to directly compare phytoplankton response in different lake types across contrasting climatic zones. The European Multi Lake Survey (EMLS) sought to harness the power of group science in order to sample lakes across Europe and disentangle the effect of environmental stressors on potentially toxic cyanobacterial blooms. The first EMLS results showed that the distribution of cyanobacterial toxins and the toxic potential in lakes will be highly dependent on direct and indirect effects of temperature. If nutrients are not regulated, then they may interact synergistically [...]
The Principle and Value of the European Multi Lake Survey

Evanthia Mantzouki and Bas W. Ibelings

Abstract
On-going global warming and eutrophication are expected to promote cyanobacterial dominance worldwide. Although increased lake temperature and nutrients are well-established drivers of blooms, the mechanisms that determine cyanobacterial biomass are complex, with potentially direct, indirect, and interactive effects. Cyanobacteria can produce toxins that constitute a considerable risk for animal and human health and thus a substantial economic cost if we are to ensure safe drinking water. Such global range phenomena should be studied at a wide spatial scale, to directly compare phytoplankton response in different lake types across contrasting climatic zones. The European Multi Lake Survey (EMLS) sought to harness the power of group science in order to sample lakes across Europe and disentangle the effect of environmental stressors on potentially toxic cyanobacterial blooms. The first EMLS results showed that the distribution of cyanobacterial toxins and the toxic potential in lakes will be highly dependent on direct and indirect effects of temperature. If nutrients are not regulated, then they may interact synergistically with increased lake temperatures to promote cyanobacterial growth more than that of other phytoplankton taxa. Providing continental scale evidence is highly significant for the development of robust models that could predict cyanobacterial or algal response to environmental change.

Introduction
Cyanobacteria, the blue-green superstars of the aquatic world, have been around for a long time; ever since they pioneered the use of sunlight to make food and produce oxygen as a fortunate waste product. This so-called “Great Oxygenation Event” or “Oxygen Catastrophe,” brought with it mass extinction, as excess oxygen was toxic for anaerobic bacteria (Young 2012). Life eventually adapted, and aerobic bacteria started to appear, taking up oxygen from the atmosphere and playing their part in regulating oxygen to levels that we have today. The evolution of photosynthetic organisms enabled life to diversify, and led to the biological world as we know it from fossil records and modern-day observations. Nowadays, cyanobacteria are again the culprits of ecosystem imbalance, this time by promoting anoxia and biodiversity loss, supporting a notion of “Cyanobacteria giveth, and cyanobacteria taketh away.”

Canny scientific articles, such as “Blooms like it hot” (Paerl and Huisman 2008), “Blooms bite the hand that feeds them” (Paerl and Otten 2013), “Is the future blue-green?” (Elliott 2012), along with the controversial issue “It takes two to Tango” (Paerl et al. 2016) in relation to which nutrient—N + P or N-only? (also see Schindler et al. 2016)—to control, and the prominent “Allied attack” (Moss et al. 2011) of climate warming and eutrophication, spotlight their notoriety. Anticipated climatic changes along with on-going eutrophication are expected to promote cyanobacterial dominance worldwide either directly or indirectly. The direct effects of these stressors mainly address the physiological properties of organisms, for example, by facilitating growth through nutrient availability and warmer temperatures. The indirect effects of such stressors modify the physical environment, like enhancing the stability of the water column, which can support the growth of buoyant cyanobacterial species. Climate warming and eutrophication may also interact synergistically and thus intensify cyanobacterial blooms. Answers to what drives cyanobacterial blooms or cyanobacterial toxin production, and how can we deal with them, are rather complicated and typically system specific.

Consensus among scientists may be hard to achieve since often there are valid arguments from either side, excluding a single solution to ecological problems. The scientific community needs to take a step forward in changing the way we assume responsibility...
towards nature. “It takes a village to raise a child.” Even if we cannot predict with point accuracy the status of the ecosystems in a few years, we do know for a fact that climate is changing, temperature is rising, and environmental catastrophes are becoming more frequent. Previous studies have demonstrated that cyanobacteria have the capacity to outcompete other primary producers as they proliferate from environmental disturbances (review in Carey et al. 2012). Gathering more information at a global scale, to demonstrate how patterns are consistently repeated, can help reduce uncertainty and eventually push for stricter regulation to ensure freshwater quality.

What makes cyanobacteria so capable? Cyanobacteria have many ecological (functional) traits that may allow them to thrive under various scenarios of environmental change. These traits can vary predictably along environmental gradients like buoyancy regulation during periods of enhanced stratification, or nitrogen fixation during nitrogen limitation. Another trait that many cyanobacterial taxa possess is the production of various types of toxins, such as hepatotoxins, neurotoxins, and cytoxins. These toxins constitute a considerable risk and a substantial economic cost in achieving safe drinking or recreational water (Codd et al. 2017). Experiments have shown that increased water temperatures and nutrients can interact synergistically to boost the production of toxic strains (Lurling et al. 2017). Understanding how and when those functional traits come into play and facilitate the dominance of cyanobacterial species could aid lake managers to disrupt the conditions that favor cyanobacterial blooms and control them (Mantzouki et al. 2016). Since cyanobacterial blooms are a typical response of aquatic systems to environmental perturbation worldwide, it is urgent to draw the patterns of cyanobacterial occurrence at regional, continental, and global scale.

Scientific responsibility

How can we move forward, without waiting for political activities to solve the world’s unbalanced distribution of wealth? By reinforcing grassroots initiatives where the power of the scientific outcome lies in the number of participants, regardless of their geographic origin. The European Multi Lake Survey (EMLS) was such an initiative. The EMLS took place in summer 2015 and consisted of 26 European countries, each with their own legislation and culture around the management of national water resources. The EMLS was inspired by the National Lakes Assessment of the Environmental Protection Agency in the U.S.A. (Pollard et al. 2018), that showed how to adequately sample numerous lakes over a short period. In Europe, although the Water Framework Directive stipulates guidelines to achieve good ecological condition, it neither covers costs for transnational surveys nor ensures the participation of both European Union (EU) and non-EU member states. For this reason, the organization of EMLS as a self-funded initiative was important. With this action, we showed that high-standard collaborative research could be carried through following the motto of “If you want to go fast, go alone; if you want to go far, go together.”

Understanding the impact of global scale phenomena requires information from many lakes of similar—and different—characteristics (e.g., morphometry, trophic status) across a large geographic scale to demonstrate if they respond in a consistent manner to similar—and different—environmental forcing. To do so, the EMLS followed a space-for-time substitution approach where current spatial phenomena are studied instead of long-term biotic records (Pickett 1989). Snapshot sampling, where lakes are sampled only once, is commonly used in multilake comparisons. A predefined time-period is chosen, based on when the studied phenomenon is expected to happen, to avoid seasonality. Such sampling efforts produce comparable datasets, with uniform, synchronic data. Thus, we can obtain a valuable synoptic picture of the relationship between environmental predictors and biological responses that drive the structure of the phytoplankton communities at spatial scale. Space-for-time substitution can explain temporal patterns (Blois et al. 2013), but supporting studies are needed to fully understand the complex cause-effect relationships that aids cyanobacterial bloom occurrence and to predict future lake statuses.

To turn the EMLS into a truly robust survey, we brought together lake experts, of different related disciplines, from two European COST Actions, CyanoCOST (http://cyano-cost.com/) and NETLAKE (https://www.dkit.ie/networking-lake-observatories-europe). Collaboration and assistance was also achieved at a global level through participation in Global Lake Ecological Observatory Network (http://www.gleon.org/). To ensure comparable datasets among data collectors, we established standardized sampling, sample processing, and analyses protocols among lakes. During a 3-day training school in Evian-Les-Bains, France (May 2015), we designed straightforward sampling protocols to accommodate the capacity in funding, available time, personnel and equipment of all participants, without compromising quality. Finally, we agreed on complete inclusiveness of all participants in three initial peer-reviewed publications.
To achieve a large number of lakes for adequate spatial coverage, the representatives of each country reached out for more collaborations in their respective countries. As a result, 369 lakes spread across the continent (Fig. 1) were sampled for chemical, physical, and biological parameters. In this way, environmental gradients across wide geographic scales were covered with relatively little effort and with high-cost efficiency. We sampled in summer as cyanobacterial blooms are a distinct feature of summer phytoplankton, during the locally warmest period, in order to test for temperature effects on cyanobacteria.

The shipping and storage of samples was centralized at University of Wageningen, The Netherlands. Lake samples for nutrients, algal pigments, and cyanobacterial toxins were analyzed in dedicated laboratories, by one person on one machine, to minimize variation in analytical errors. Quality control and integration of the different datasets did not require more than a month. The integrated dataset was then made available online using the GeoNode platform (http://geon.grid.unep.ch/). The EMLS dataset has already benefitted several countries individually (Poland, Spain, Turkey), through national reports on cyanobacterial toxin profiles, national assemblies about water quality, and applications for national research funding, for example.

**Research questions**

The first scientific outcome of the EMLS was a paper on toxin distribution across the European continent (Mantzouki et al. 2018). Insight into how environmental change determines the production and distribution of cyanobacterial toxins (hepatotoxins, neurotoxins, cytotoxins) is necessary for risk assessment and management (Ibelings et al. 2014). Nevertheless, experimental studies are not yet conclusive in attributing toxin production to specific cyanobacterial species under specific environmental conditions (Neilan et al. 2013). Hence, the lack of consistency in experimental findings and in standardization of monitoring and sampling campaigns impedes understanding of how environmental stressors are linked to cyanobacterial toxin production and toxin quota (toxin concentration per unit algal biomass). In Mantzouki et al. (2018), we used community ecology approaches to examine toxins as a “community” of potentially coexisting toxin types, instead of focusing on each toxin separately.

Ordination analysis showed that direct and indirect effects of temperature were mostly responsible for the distribution of the different toxins at the continental scale. Toxin diversity increased with latitude demonstrating more diverse toxin mixtures in the Boreal region (Fig. 2). Higher toxin diversity would potentially lead to higher stability in overall toxicity within a bloom, since if one toxin declines, another may increase, leading to persistence in overall toxicity. As global warming continues, increased lake temperature and water stability will drive changes in cyanobacterial toxin distribution across Europe, and potentially promote a few highly toxic species or strains.

The second product of the EMLS (in preparation) focuses on the importance of direct and indirect effects of global warming and eutrophication and the mode of interaction between them. Although experiments and modeling studies clearly hint at a possible synergistic interaction between increased nutrients and temperature in promoting cyanobacterial blooms (Rigosi et al. 2014) and their toxin production (Lurling et al. 2017), convincing evidence from field observations is barely present. Water column stability (stratification) is also expected...
to increase as an indirect effect of increased temperature (Gerten and Adrian 2002). Enhanced stratification may establish a shallow near surface mixed layer restricting light availability within this narrow zone. The light availability will only favor phytoplankton that can maintain their position, such as buoyant cyanobacterial species (Reynolds 2006), within this narrow zone. Thus, modified light climate (indirect effect of high nutrients) might also interact synergistically with enhanced stratification, accentuating cyanobacterial blooms at the continental scale.

The EMLS aimed to address this question by sampling mostly (hyper-)eutrophic lakes. Data analysis focusing on interactive terms of nutrients and temperature can be helpful to determine if and how (synergistically, additively, or antagonistically) this interaction will determine total algal and cyanobacterial biomass across the continent.

The complete EMLS dataset and methodology are currently under peer review in Nature Scientific Data. The rest of the data can be incorporated with the EMLS dataset in the online database of the Environmental Data Initiative (https://portal.edirepository.org/nis/mapbrowse?scope=edi&identifier=176&revision=4). We hope that the first EMLS products might inspire similar initiatives to study across large geographic areas and gather more evidence on how lakes respond in a changing environment. We highly encourage scientists to make the best use of the publicly available EMLS dataset and explore other interesting hypotheses that we have not yet addressed. Good water quality is vital for everyone, and if we are to better understand the threats to aquatic ecosystems in a changing world, we must make it our responsibility to use all the data that are out there and generate all possible ideas using our scientific expertise.

Acknowledgments

The authors acknowledge COST Action ES 1105 “CYANOCOST—Cyanobacterial blooms and toxins in water resources: Occurrence impacts and management” and COST Action ES 1201 “NETLAKE—Networking Lake Observatories in Europe” for contributing to the realization of the EMLS. Evangelia Mantzouki was supported by a grant from the Swiss State Secretariat for Education, Research and Innovation (SERI) to Bas Ibelings and by supplementary funding from University of Geneva. We would like to thank University of Geneva, University of Amsterdam, University of Wageningen, and the German Environmental Protection Agency for providing financial and technical support for the analysis of nutrients, pigments, and toxins.

References


Carey, C.C., B. W. Ibelings, E. P. Hoffmann, D. P. Hamilton, and J. D. Brookes. 2012. Eco-physiological adaptations that favour...
Paerl, H. W., and others. 2016. It takes two to tango: When and where dual nutrient (N & P) reductions are needed to protect lakes and downstream ecosystems. Environ. Sci. Technol. 50: 10805–10813. doi:10.1021/acs.est.6b02575
Young, G. M. 2012. Precambrian supercontinents, glaciations, atmospheric oxygenation, metazoan evolution and an impact that may have changed the second half of Earth history. Geosci. Front. 4: 247–261. doi:10.1016/j.gsfb.2012.07.003
Evanthia Mantzouki, Department F.-A. Forel for Environmental and Aquatic Sciences, University of Geneva, Geneva, Switzerland; Evanthia. Mantzouki@unige.ch
Bas W. Ibelings, Department F.-A. Forel for Environmental and Aquatic Sciences, University of Geneva, Geneva, Switzerland.