Article

Insights from the Global Lake Ecological Observatory Network (GLEON)

Kevin C. Rose,[1]*† Kathleen C. Weathers,[2] Amy L. Hetherington,[3] and David P. Hamilton[4]†

[1] *Department of Biological Sciences, Rensselaer Polytechnic Institute, Troy, NY, USA*
[2] *Cary Institute of Ecosystem Studies, Millbrook, NY, USA*
[3] *Departments of Biological Sciences and Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA*
[4] *Environmental Research Institute, University of Waikato, Hamilton, New Zealand*
*Corresponding author: kev.c.rose@gmail.com
† Guest editors for GLEON special issue

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Abstract

The Global Lake Ecological Observatory Network (GLEON) is a grass-roots network of people, data, and observatories. The network represents a unique effort to bring together a diverse community of scientists, engineers, information technology experts, and engaged stakeholders to understand, conserve, and predict the state of lakes and reservoirs globally. Individuals and teams in GLEON have generated a range of scientific, educational, and outreach products, from software tools to scientific publications to education modules and programs. This special issue of Inland Waters brings together a series of papers generated from the network. Here, we discuss the foundations of GLEON that have facilitated these publications and others like them in terms of network structure, research areas, and the threads that tie the network together. GLEON is underpinned by sophisticated analytical tools and a network of high-frequency *in situ* observatories that exploit advanced sensors and associated technologies. This approach expands the space and time domains available to inquiry and analysis of lake processes. Using team science, the network has also established a culture of collaboration, sharing, and trust. This flexible framework allows GLEON members to advance research on a range of topics and has led to an increasing number of collaborative cross-site products. Future success will depend on the network's ability to continue to facilitate the successes of its members while also being responsive to evolving member needs, technologies, and societal priorities.

Key words: buoy, Global Lake Ecological Observatory Network (GLEON), high-frequency, lakes, network science, sensors, team science

Introduction

Environmental research is changing rapidly. Empowered by technological advances in sensors and information technology (Porter et al. 2009, 2012, Benson et al. 2010, Michener and Jones 2012) as well as cultural shifts in data sharing and stewardship (Hampton et al. 2013, Soranno et al. 2015), environmental research is now generating insights into processes previously not measurable at radically expanded temporal and spatial scales. To harness these advances, funding agencies, ecologists, and other researchers are organizing network-based approaches to collaborate and conduct macrosystem-scale research (Hanson 2007, Cheruvelil et al. 2014, Heffernan et al. 2014, Goodman et al. 2015, McDowell 2015). The Global Lake Ecological Observatory Network (GLEON) represents one effort to leverage these analytical tools and build a productive, innovative, and collaborative culture to better understand and manage our natural resources and the ecosystem services they provide (Weathers et al. 2013, Hanson et al. 2016).

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Following its inception in 2005, GLEON has developed a productive, ever-evolving model of networked science. GLEON can be viewed as 3 overlapping and mutually dependent networks—people, data, and lake observatories (Weathers et al. 2013, Hanson et al. 2016)—that provide the foundation for conducting innovative research, education, and outreach. Individual membership in GLEON has grown steadily over the last few years, and at the time of publication of this special issue of Inland Waters exceeds 500 individual members from more than 50 countries. GLEON-affiliated observatories are located on more than 60 lakes across 6 continents and 34 countries (www.gleon.org). GLEON also maintains a repository of data from hundreds of lakes, as well as basic information on millions of lakes around the world (Hanson et al. 2016). Therein lies one of the challenges for the organization: how to better coordinate, synthesize, and enable sharing and dissemination of the data from this diverse network of sites and data types.

The international, grass-roots model of GLEON offers a unique model for conducting science across large spatial extents using heterogeneous data (Hanson 2007). Because GLEON is grass-roots, there is little top-down coordination or standardization of sensors or protocols. This lack of standardization introduces some degree of heterogeneity in data quality and availability, which can complicate data synthesize across systems (Hampton 2013). At the same time, this grassroots approach facilitates member participate and contribution, thereby encompassing a large number of participating sites and researchers from diverse backgrounds.

GLEON research is underpinned by a network of high-frequency *in situ* observatories containing a number of different kinds of sensors (McBride and Rose 2016). Sensors are used to measure *in situ* aquatic characteristics but are also commonly deployed to measure terrestrial and atmospheric processes and characteristics (e.g., meteorology). Sensors to measure abiotic characteristics, such as temperature and light, are common. Many sensors also measure chemical characteristics, such as dissolved oxygen and pH. Sensors to measure biological characteristics are less common, in part because of a lag in their development. Although sensors exist for chlorophyll fluorescence and phycocyanin, the sensing of organisms, particularly at taxon or species level, is still in its infancy (Hussey et al. 2015).

More important than the data within the network, however, is the successful framework for doing collaborative science that GLEON provides. It is grass-roots and people-focused, which enables innovation by all participants. It embraces the diversity of sites, sensors, and the people inherent in the global community (Weathers et al. 2013). It harnesses local infrastructure, funding, and a global outlook with diverse perspectives. Cumulatively, this approach has fostered a healthy, collaborative, and innovative atmosphere among members, which has in turn supported high productivity. In addition to the publications contained within this special issue, at current count, GLEON has more than 100 other attributed peer-reviewed publications.

The nature of GLEON products has evolved over time. Early peer-reviewed outputs of the network included

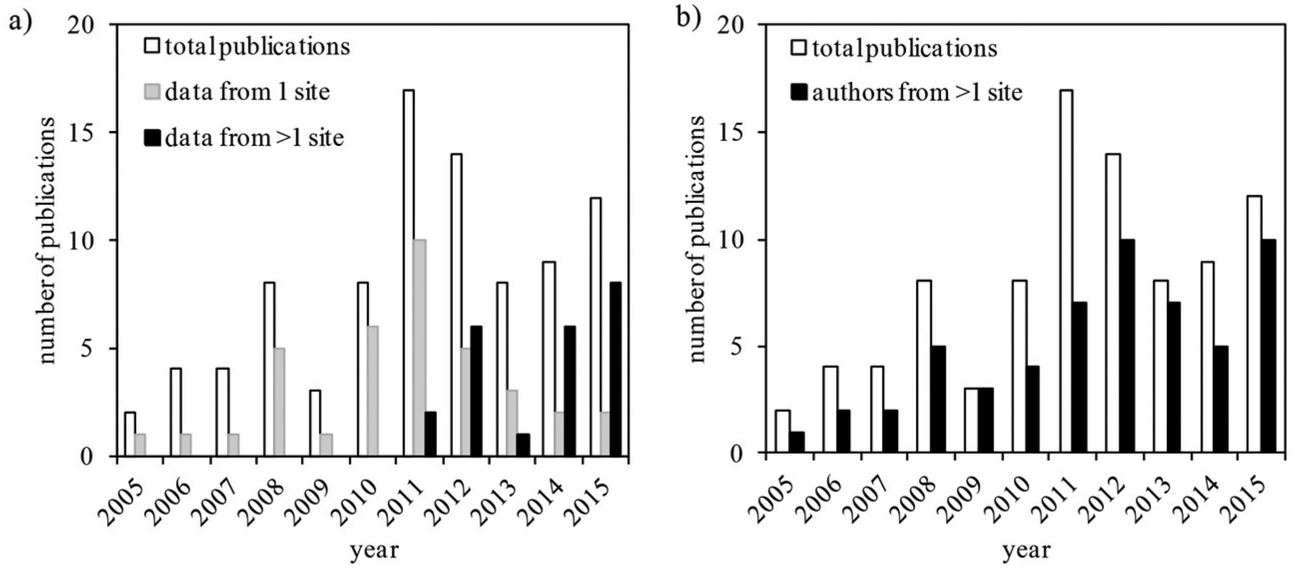

Fig. 1. GLEON-attributed peer-reviewed publications through time. Early network peer-reviewed outputs included many perspective papers, reviews, and research studies based at a single site or region. More recently, publications have increasingly taken advantage of sensor data from (a) many different sites and regions and (b) involved author contributions from many different, often internationally distributed, researchers.

many perspective papers, reviews, and research studies based at a single site or region. These products set the stage for GLEON, articulating the need for network-based environmental research, and providing "proof-of-concept" examples of research that capitalized on observatories outfitted with high-frequency sensors (e.g., Tilak et al. 2007, Benson et al. 2008, Tsai et al. 2008). More recently, GLEON publications have increasingly taken advantage of sensor data from many different sites and regions and have involved author contributions from many different career stages and often internationally distributed researchers (Fig. 1; e.g., papers in this special issue). This evolution is attributed to the maturation of the network. It shows the growing interconnectedness of GLEON collaborations and how teams have been able to capitalize on the strength and diversity of network data and multi-site comparisons. These trends also highlight the importance of the people component of the network (Weathers et al. 2013, Cheverulil et al. 2014, Hanson et al. 2016) and the length of time it takes for highly collaborative, multi-site products to emerge. Although the evolution of the network has taken years, the outcome is an ability to effectively use datasets from across the globe to achieve a diversity of sites required to rigorously test key research themes (Weathers et al. 2013).

Trust between and among individual members is key to building a productive community because some of the biggest challenges in coordinating network science lie in the social dynamics (Hanson 2007, Weathers et al. 2013, Cheverulil et al. 2014, Read et al. 2016). To that end, GLEON has emphasized a team science approach to maintaining and growing an active, vibrant, and diverse community of scholars (Weathers et al. 2013, Read et al. 2016). Team science is a framework designed to understand and enhance the outcomes of large-scale collaborative research and training programs (Stokols et al. 2008, Cheruvelil et al. 2014, Cooke and Hilton 2015). Within GLEON, team science is exemplified by a number of attributes, including the promotion of cross-disciplinary collaborations, leadership and systems thinking, effective project management, cultural sensitivity, emotional engagement, and the assessment of successes, which are applied to facilitate effective team collaborations (e.g., Read et al. 2016).

Networked research is expanding the temporal and spatial domains of environmental research and the products that stem from it (Fig. 2). Typically, traditional environmental approaches have focused on understanding processes that operate on a temporal and spatial scale convenient for human observation and publication. This spatial scale ranges from a single point in space to on the order of about a kilometer or two; the temporal scale typically ranges from about an hour to a year or two. High frequency observatories are expanding the scope of observation to increasingly shorter time steps: sample frequencies on the order of about a minute are now common. At the same time, long-term deployments of these high-frequency observatories are expanding observations to decades or longer. For example, some of the longest operating GLEON-affiliated buoys have now been

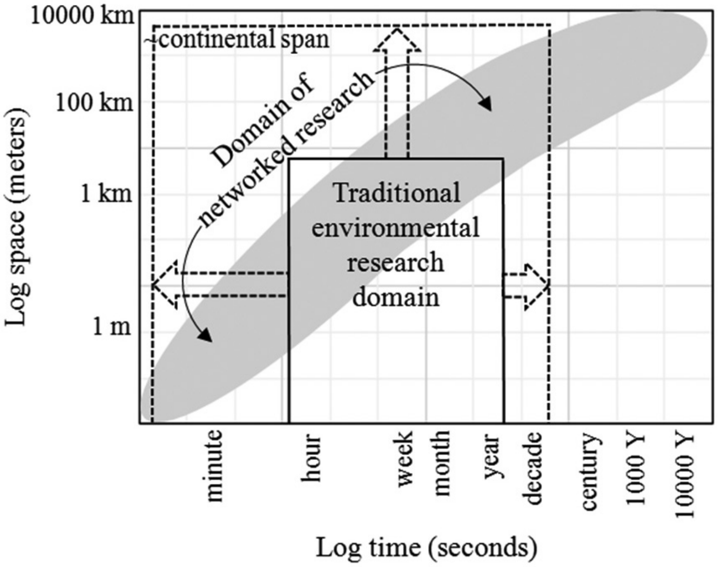

Fig. 2. Environmental processes and interactions (in gray) operate across a series of time and space domains, with processes that operate at broader spatial extents also typically operating at longer temporal frequencies (Stommel 1963, Delcourt and Delcourt 1988). Traditional ecological research (solid box) has been constrained to a space–time domain convenient for human observation. Contemporary networked research (dashed box), which depends in part on high-frequency observatories, expands this observation domain, enabling novel research and insights into environmental processes and interactions at much-expanded spatial and temporal scales.

deployed for more than 25 years, and the US-based National Ecological Observatory Network (NEON) is planning for measurements longer than 30 years. The expanded spatial and temporal observation windows expand the processes and characteristics that can be studied because frequency and spatial extent often co-vary (Stommel 1963, Haury et al. 1978).

Because it is a grassroots network, not every unique combination of lake characteristics is represented in GLEON; however, network research that occurs across many sites is enabling insights into processes, relationships, and trends at the macrosystem scale (Heffernan et al. 2014). Networked research based on high-frequency observatories is only one piece of the technological portfolio enabling this broader world view, however. Other approaches, such as remote sensing, are providing near-comprehensive global spatial coverage (Olmanson et al. 2015). Application of satellite remote sensing to inland waters has been relatively limited to date, but new satellites are enabling shorter return times, broader spectral coverage, and improved algorithms for retrieval of water quality information (Olmanson et al. 2015). Whereas remote sensing expands environmental science research's spatial capability through monitoring, paleo records and process-based simulation models are expanding interpretation of temporal scale far into the past and future, respectively (Williamson et al. 2009, Hamilton et al. 2015). In addition to these emerging technologies, incorporating data available from citizen science groups is also increasing the ability of scientists to ask and answer questions at broad spatial and temporal scales (e.g., Hochachka et al. 2012). Coupling technologies such as high-frequency autonomous *in situ* sensing with process-based simulation models and remotely sensed imagery (e.g., from satellites and/or aerial vehicles) may enable future research to leverage the strengths of each of these methods and override the limitations inherent to any single approach (Hampton 2013, Weathers et al. 2013, Hamilton et al. 2015).

GLEON research is conducted on a number of topics by diverse research teams. While GLEON has a mission (Weathers et al. 2013), the network has no set research agenda. Rather, the network provides the platform and environment through which teams can ask and answer research questions. This process leverages the intellectual and data resources each member brings with them. This special issue highlights just a small fraction of the research, education, and outreach conducted by and with GLEON members. Some GLEON research is still conducted using single lakes but by using tools and techniques that leverage the networks of individuals and sensors, with an emphasis on high frequency sensor measurements. For example, research exploring the relationships between water column stability and phytoplankton (Yang et al. 2016) and among water temperature, chemistry, and a massive fish kill (Kangur et al. 2016) uses high-frequency sensor measurements to yield new insights applicable beyond the shores of these single lakes. Similarly, research on how an Irish lake responded to an extreme precipitation event (de Eyto et al. 2016) leverages network capabilities and extends previous GLEON member research on how extreme episodic weather events such as hurricanes affect lakes (Jennings et al. 2012, Klug et al. 2012).

Beyond research at single sites, GLEON members are increasingly producing research that presents comparative results gleaned from research across many sites. Multi-site research enables a more contextual and hierarchical understanding of ecosystem phenomena. For example, Kuha et al. (2016) used high-frequency sensor data to assess the impacts of weather-induced episodic mixing events on 8 boreal lake ecosystems and found that the effects of episodic events can depend on lake trophic status. In a study using high-frequency data from 15 lakes spread across 3 continents, Staehr et al. (2016) demonstrated that gross primary production is frequently light limited, but similar to Kuha et al. (2016), trophic status is a key predictor of how frequently light limitation occurs. Finally, Brentrup et al. (2016) used data from profiling buoys in 11 lakes to assess the complexity of spatiotemporal patterns in chlorophyll fluorescence, thereby extending the phytoplankton growth model (Sommer et al. 1986) to explicitly include physical controls that regulate the formation of subsurface chlorophyll maxima. The work of Brentrup et al. (2016) also highlights the growing application of profiling instrumentation, which enables researchers to actively monitor dynamics occurring throughout the water column rather than depending on instruments passively collecting data at only a single depth. Sensors placed at a single depth can often miss important phenomena separated from the collecting sensor by spatially heterogeneous conditions, such as thermal (density) stratification. By contrast, profiling systems can produce a much better assessment of "whole lake" dynamics (McBride and Rose 2016). Using a profiler to assess whole-lake characteristics assumes horizontal variability across a system is minimal, which may or not be true, depending on the characteristics of the ecosystem and the parameter being measured. For example, research conducted at GLEON sites shows that ecosystem metabolism can be highly heterogeneous both within the water column as well as horizontally across lakes (Van de Bogert et al. 2012, Rose et al. 2014).

GLEON has frequently been used as a test-bed to compare existing methods as well as develop and test new methods to quantify difficult-to-measure characteristics.

Methods frequently incorporate high-frequency sensor observations, which provide the opportunity to explore relationships across the time domain. For example, Knoll et al. (2016) compared methods to characterize lake phosphorus cycling across 3 GLEON sites using high-frequency measurements of dissolved oxygen. Honti et al. (2016) developed a novel approach to characterize lake ecosystem metabolism by coupling high-frequency dissolved oxygen and chlorophyll fluorescence sensors. Finally, Dugan et al. (2016) used GLEON site data to compare a series of gas flux models and demonstrate how model choice affects estimates of CO_2 flux.

GLEON is also the source of a growing body of software tools, packages, and programs that make large, heterogeneous datasets more accessible and interpretable to a broader array of scientists, educators, and the public. For example, Winslow et al. (2016) present an open-source R package that allows the user to implement multiple models to quantify lake metabolism, which can be used to understand the carbon budgets of lake ecosystems. This new tool joins other successful GLEON software products, including Lake Analyzer (Read et al. 2011) and Lake Heat Flux Analyzer (Woolway et al. 2015). When paired with open data, these software tools present the opportunity to generate large, macrosystem-scale insights into environmental processes and relationships (Read et al. 2016). GLEON is committed to open-source development and maintains a repository on Github. An important software product developed by GLEON members is the General Lake Model (GLM; Hipsey et al. 2013). This process-based simulation model enables users to simulate the hydrodynamics of inland and coastal waterbodies. True to the ethos of GLEON, it is open source and freely available (http://aed.see.uwa.edu.au/research/models/GLM/). GLM's rapid uptake by the modeling community is resulting in new tools to project the possible physical, chemical, and biological futures of our lakes.

Many GLEON members have a strong commitment to outreach and involvement of communities directly with the research or in its outcomes as well as publishing domain science in peer-reviewed journals and creating open-source programs and models. Since early in GLEON's existence, engagement with nongovernmental, not-for-profit, management, and outreach and education groups has been a priority for many individuals. This engagement started with the Lake Sunapee Protective Association (LSPA), an outreach and education organization, and the Lakes Water Quality Society (Rotorua, New Zealand). Both organizations have hosted events associated with GLEON meetings and provided opportunities for direct interactions of GLEON members with their members. The LSPA and a partner researcher realized that publicly available lake buoy data could promote direct and informed dialog between LSPA members and the research community. High-frequency environmental sensor data are also used in various ways by many other citizen and management groups (see Smyth et al. 2016), ranging from monitoring water supplies for major urban areas (Effler et al. 2014) to making predictions about the timing and extent of cyanobacterial blooms and assessing when recreational activities might be best timed (e.g., sailing). Around the world, self-organized citizens groups and management agencies increasingly represent an important component of GLEON's outreach program.

Almost one-third of GLEON members are graduate students. GLEON's Student Association (GSA), which evolved as a grassroots grouping in 2007, is a driving force in GLEON products as well as activities (Weathers et al. 2013). The GSA also leads early career training sessions at every "all-hands' meeting" on topics ranging from leadership to modeling and novel analyses of high frequency data to communication with the public. Further, the GLEON Graduate Student Fellowship Program (Read et al. 2016) is an innovative 1.5-year training program for cohorts of ~12 graduate students, designed to transform the ability of scientists-in-training to lead and operate effectively as members of interdisciplinary teams to tackle complex environmental problems. The goals include hands-on training and development of new tools in complex data analysis and synthesis, as well as modeling, and increasing the skill of students and confidence in international, interdisciplinary, and cross-lab teams through the development of competence in communication and active participation in an existing network of people, data, and technologies (Read et al. 2016). Publications from the first cohort of GLEON Fellows demonstrate the range of topics broached and skills honed by these students (e.g., Read et al. 2015, 2016, Dugan et al. 2016, Winslow et al. 2016) as well as software products (e.g., Winslow et al. 2013). The Fellows program is flexible, modular, and extensible.

The range of GLEON products is a testament to the network's diverse community and the excitement the network has generated. But can this be sustained? Where does the network go from here? Continued evolution is a requirement, but not guarantee, of future relevance and successes. Technologies can become obsolete; priority research and management topics change. Culture, we argue, is the most important feature of the network for maintaining its role leading networked lake science. By facilitating the successes of individual members, GLEON is successful now. By also learning and embracing changes as they emerge, the network is flexible and adaptive, which will enable it to respond to new challenges and opportunities in the years ahead.

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References

Benson BJ, Bond BJ, Hamilton MP, Monson RK, Han R. 2010. Perspectives on next-generation technology for environmental sensor networks. Front Ecol Environ. 8:193–200.

Benson BJ, Winslow L, Arzberger P, Carey CC, Fountain T, Hanson PC, Kratz TK, Tilak S. 2008. Meeting the challenges of an international, grassroots organization of sites deploying sensor networks: The Global Lake Ecological Observatory Network (GLEON). Proceedings of the Environmental Information Management Conference. p. 33–38.

Brentrup JA, Williamson CE, Colom-Montero W, Eckert W, de Eyto E, Grossart H-P, Huot Y, Isles P, Knoll LB, Leach TH, McBride CG, et al. 2016. The potential of high-frequency profiling to assess vertical and seasonal patterns of phytoplankton dynamics in lakes: an extension of the Plankton Ecology Group (PEG) model. Inland Waters. 6:565–580.

Cheruvelil KS, Soranno PA, Weathers KC, Hanson PC, Goring SJ, Filstrup CT, Read EK. 2014. Creating and maintaining high-performing collaborative research teams: the importance of diversity and interpersonal skills. Front Ecol Environ. 12:31–38.

Cooke NJ, Hilton ML. 2015. Enhancing the effectiveness of team science. National Academies Press.

de Eyto E, Jennings E, Ryder E, Sparber K, Dillane M, Dalton C, Poole R. 2016. Response of a humic lake ecosystem to an extreme precipitation event: physical, chemical, and biological implications. Inland Waters. 6:483–498.

Delcourt HR, Delcourt PA. 1988. Quaternary landscape ecology: relevant scales in space and time. Landscape Ecol. 2:23–44.

Dugan HA, Woolway RI, Santoso AB, Corman JR, Jaimes A, Nodine ER, Patil VP, Zwart JA, Brentrup JA, Hetherington AL, et al. 2016. Consequences of gas flux model choice on the interpretation of metabolic balance across 15 lakes. Inland Waters. 6:581–592.

Effler SW, O'Donnell DM, Prestigiacomo AR, Pierson DC, Zion MS, Pyke GW, Weiss WJ. 2014. Robotic monitoring for turbidity management in a multiple reservoir water supply. J Water Resour Plan Manag. 140. doi:10.1061/(ASCE)WR.1943-5452.0000390

Goodman KJ, Parker SM, Edmonds JW, Zeglin LH. 2015. Freshwater science expanding the scale of aquatic science: the role of the National Ecological Observatory Network (NEON). Freshwater Sci. 34:377–385.

Hamilton D, Carey CC, Arvola L, Arzberger P, Brewer C, Cole JJ, Gaiser E, Hanson PC, Ibelings BW, Jennings E, et al. 2015. A Global Lake Ecological Observatory Network (GLEON) for synthesising high-frequency sensor data for validation of deterministic ecological models. Inland Waters. 5:49–56.

Hampton SE. 2013. Understanding lakes near and far. Science. 342:815–816.

Hampton SE, Strasser CA, Tewksbury JJ, Gram WK, Budden AE, Batcheller AL, Duke CS, Porter JH. 2013. Big data and the future of ecology. Front Ecol Environ. 11:156–162.

Hanson PC. 2007. A grassroots approach to sensor and science networks. Front Ecol Environ. 5:343.

Hanson PC, Weathers KC, Kratz TK. 2016. Networked lake science: how the Global Lake Ecological Observatory Network (GLEON) works to understand, predict, and communicate lake ecosystem response to global change. Inland Waters. 6:543–554.

Haury LR, McGowan JA, Wiebe PH. 1978. Patterns and processes in the time-space scales of plankton distributions. In: Steele JH, editor. Spatial pattern in plankton communities. p. 277–327.

Heffernan JB, Soranno PA, Angilletta MJ, Buckley LB, Gruner DS, Keitt TH, Kellner JR, Kominoski JS, Rocha AV, Xiao J, et al. 2014. Macrosystems ecology: understanding ecological patterns and processes at continental scales. Front Ecol Environ. 12:5–14.

Hipsey MR, Bruce LC, Hamilton DP. 2013. GLM general lake model: model overview and user information. Perth (Australia): University of Western Australia Technical Manual.

Hochachka WM, Fink D, Hutchinson RA, Sheldon D, Wong WK, Kelling S. 2012. Data-intensive science applied to broad-scale citizen science. Trends Ecol Evol. 27:130–137.

Honti D, Istvánovics, V, Staehr PA, Brighenti LS, Zhu M, Zhu G. 2016. Robust estimation of lake metabolism by coupling high frequency dissolved oxygen and chlorophyll fluorescence data in a Bayesian framework. Inland Waters. 6:608–621**.**

Hussey NE, Kessel ST, Aarestrup K, Cooke SJ, Cowley PD, Fisk AT, Harcourt RG, Holland KN, Iverson SJ, Kocik JF, et al. 2015. Aquatic animal telemetry: a panoramic window into the underwater world. Science. 348:1–10.

Jennings E, Jones S, Arvola L, Staehr PA, Gasier E, Jones ID, Weathers KC, Weyhenmeyer GA, Chiu C-Y, de Eyto E. 2012. Effects of weather-related episodic events in lakes: an analysis based on high-frequency data. Freshwater Biol. 57:589–601.

Kangur K, Ginter K, Kangur P, Kangur A, Nõges P, Laas A. 2016. Changes in water temperature and chemistry preceding a massive kill of bottom-dwelling fish: an analysis of high-frequency buoy data of shallow Lake Võrtsjärv (Estonia). Inland Waters. 6:535–542.

Klug JL, Richardson DC, Ewing HA, Hargreaves BR, Samal NR, Vachon D, Pierson DC, Lindsey AM, Donnell DMO, Steven WE, Weathers KC. 2012. Ecosystem effects of a tropical cyclone on a network of lakes in northeastern North America. Environ Sci Technol. 46:11693–11701.

Knoll LB, Morgan A, Vanni MJ, Leach TH, Willamson TJ, Brentrup JA. 2016. Quantifying pelagic phosphorus regeneration using three methods in lakes of varying productivity. Inland Waters. 6:509–522.

Kuha J, Arvola L, Hanson PC, Huotari J, Huttula T, Juntunen J, Järvinen M, Kallio K, Ketola M, Kuoppamäki K, et al. 2016. Response of boreal lakes to episodic weather-induced events. Inland Waters. 6:523–534.

McBride CG, Rose KC. 2017. Automated high-frequency monitoring and research. In: Hamilton D, Collier K, Howard-Williams C, Quinn J, editors. Lake restoration handbook: a New Zealand perspective. Springer.

McDowell WH. 2015. NEON and STREON: opportunities and challenges for the aquatic sciences. Freshwater Sci. 34:386–391.

Michener WK, Jones MB. 2012. Ecoinformatics: supporting ecology as a data-intensive science. Trends Ecol Evol. 27:88–93.

Olmanson LG, Brezonik PL, Bauer ME. 2015. Remote sensing for regional lake water quality assessment: capabilities and limitations of current and upcoming satellite systems. In: Younos T, Parece T, editors. Advances in watershed science and assessment. Handbook of environmental chemistry. Switzerland: Springer International Publishing. p. 111–140.

Porter JH, Hanson PC, Lin CC. 2012. Staying afloat in the sensor data deluge. Trends Ecol Evol. 27:121–129.

Porter JH, Nagy E, Kratz TK, Hanson P, Collins SL, Arzberger P. 2009. New eyes on the world: advanced sensors for ecology. Bioscience. 59:385–397.

Read E, O'Rourke M, Hong G, Hanson P, Winslow L, Crowley S, Brewer C, Weathers K. 2016. Building the team for team science. Ecosphere. 7:1–9.

Read JS, Hamilton DP, Jones ID, Muraoka K, Winslow LA, Kroiss R, Wu CH, Gaiser E. 2011. Derivation of lake mixing and stratification indices from high-resolution lake buoy data. Environ Model Softw. 26:1325–1336.

Read JS, Gries C, Read EK, Klug J, Hanson P, Hipsey MR, Jennings E, O'Reilly CM, Winslow LA, Pierson D, et al. 2016. Generating community-built tools for data sharing and analysis in environmental networks. Inland Waters. 6:637–644.

Rose KC, Winslow LA, Read JS, Read EK, Solomon CT, Adrian R, Hanson PC. 2014. Improving the precision of lake ecosystem metabolism estimates by identifying predictors of model uncertainty. Limnol Oceanogr-Meth. 12:303–312.

Smyth RL, Caruso A, Borre L, Zhu G, Zhu M, Hetherington AL, Jennings E, Klug JL, Piccolo MC, Rusak JA, et al. 2016. High-frequency lake data benefit society through broader engagement with stakeholders: a synthesis of GLEON data use survey and member experiences. Inland Waters. 6:555–564.

Sommer U, Gliwicz ZM, Lampert W, Duncan A. 1986. The PEG-model of seasonal succession of planktonic events in fresh waters. Arch Hydrobiol. 106:433–471.

Soranno PA, Cheruvelil KS, Elliott KC, Montgomery GM. 2015. It's good to share: why environmental scientists' ethics are out of date. Bioscience. 65:69–73.

Stokols D, Misra S, Moser RP, Hall KL, Taylor BK. 2008. The ecology of team science: understanding contextual influences on transdisciplinary collaboration. Am J Prevent Med. 35. doi:10.1016/j.amepre.2008.05.003

Staehr PA, Brighenti LS, Honti M, Christensen J, Rose KC. 2016. Global patterns of light saturation and photoinhibition of lake primary production. Inland Waters. 6:593–607.

Stommel H. 1963. Varieties of oceanographic experience. Science. 139:572–576.

Tilak S, Arzberger P, Balsiger D, Benson B, Bhalerao R, Chiu K, Fountain T, Hamilton D, Hanson P, Kratz T. 2007. Conceptual challenges and practical issues in building the Global Lake Ecological Observatory Network. Proceedings of the 2007 International Conference on Intelligent Sensors, Sensor Networks and Information Processing. ISSNIP. p. 721–726.

Tsai JW, Kratz TK, Hanson PC, Wu JT, Chang WYB, Arzberger PW, Lin BS, Lin FP, Chou HM, Chiu CY. 2008. Seasonal dynamics, typhoons and the regulation of lake metabolism in a subtropical humic lake. Freshwater Biol. 53:1929–1941.

Van de Bogert MC, Bade DL, Carpenter SR, Cole JJ, Pace ML, Hanson PC, Langman OC. 2012. Spatial heterogeneity strongly affects estimates of ecosystem metabolism in two north temperate lakes. Limnol Oceanogr. 57:1689–1700.

Weathers KC, Hanson PC, Arzberger P, Brentrup J, Brookes J, Carey CC, Gaiser E, Hamilton DP, Hong GS, Ibelings B, et al. 2013. The Global Lake Ecological Observatory Network (GLEON): the evolution of grassroots network science. Limnol Oceanogr Bull. 22:71–73.

Williamson CE, Saros JE, Vincent WF, Smol JP. 2009. Lakes and reservoirs as sentinels, integrators, and regulators of climate change. Limnol Oceanogr. 54:2273–2282.

Winslow L, Read J, Woolway R, Brentrup J, Leach T, Zwart J. 2013. Package 'rLakeAnalyzer'. The Comprehensive R Archive Network.

Winslow LA, Zwart JA, Batt RD, Dugan HA, Woolway I, Corman JR, Hanson PC, Read JS. 2016. LakeMetabolizer: an R package for estimating lake metabolism from free-water oxygen using diverse statistical models. Inland Waters. 6:622–636.

Woolway RI, Jones ID, Hamilton DP, Maberly SC, Muraoka K, Read JS, Smyth RL, Winslow LA. 2015. Automated calculation of surface energy fluxes with high-frequency lake buoy data. Environ Model Softw. 70:191–198.

Yang Y, Colom W, Pierson D, Pettersson K. 2016. Water column stability and summer phytoplankton dynamics in a temperate lake (Lake Erken, Sweden). Inland Waters. 6:499–508.

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