Article

Networked lake science: how the Global Lake Ecological Observatory Network (GLEON) works to understand, predict, and communicate lake ecosystem response to global change

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Abstract

The Global Lake Ecological Observatory Network (GLEON) has built an international, grassroots network of scientists and citizens, data, and lake observatories to advance understanding of lake ecosystems. Through careful attention to the professional needs and aspirations of a community, GLEON has formed as its foundation the trust and respect essential to product-based network science. As a consequence, GLEON is making significant advancements in lake ecosystem understanding through all "five legs of the table that support scientific understanding"—natural history, multiscale data, experiments, theory, and comparative studies—with particular emphasis on multiscale data and comparative studies. Technical products, such as cyberinfrastructure in support of network data and operations, software tools for calculating lake physical metrics (e.g., thermocline depth, buoyancy frequency, Schmidt stability), and lake metabolism, as well as ecosystem-scale numerical simulation software, have derived from GLEON collaborations and have become community resources catalyzing interdisciplinary science. Education and outreach initiatives have served to engage citizens from outside the traditional boundaries of academia directly in research. Moreover, these cross-boundary collaborations have provided essential links to lake and reservoir stakeholders who have informed how science is prioritized and communicated within GLEON. As a grassroots network, GLEON derives its momentum, flexibility, and impact from its talented members, who are committed to the future sustainability of lakes and reservoirs and the services they provide.

Key words: cyberinfrastructure, data, lake, network, reservoir, team science

Introduction

Earth systems are changing at unprecedented rates (IPCC 2014, Melillo et al. 2014). Climate, land-use change, and spread of invasive species are causing large-scale disruptions in ecosystem services. To respond to the grand scientific challenge of understanding these changes, our science has become increasingly large-scale and multidisciplinary (Uriarte et al. 2007, Heffernan et al. 2014, Weathers et al. 2016). Here, we suggest that a networked global approach, both geographically and intellectually, will be increasingly important to perceive and predict widespread environmental change, as well as to communicate its importance and imagine creative suites of management and policy solutions.

Quality of life is intimately linked to the quality, quantity, and distribution of freshwater resources (Gleick 2014). Although they cover only <5% of the planet's surface (Downing et al. 2006), lakes and reservoirs provide crucial ecosystem services such as drinking water, power generation, habitat for organisms, and aesthetics and recreation. They are also crucial to sustaining food production (Foley et al. 2011). Further, lake and reservoir systems have long been the focus and passion of organized

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citizen groups interested in protecting the beauty and ecosystem services freshwaters provide (e.g., Weathers 2011, 2014, McGowan et al. 2014). However, these crucial freshwater resources are threatened worldwide because of climate, land-use change, and invasive species (UN 2006, NAE 2008, Carpenter et al. 2011). We currently lack the ability to predict how lakes will respond to complex changes in local, regional, and global scales; our current empirical and process models for predicting consequences of these changes are nascent and often single-place–based. Nor do we have adequate, harmonized, globally diverse, long-term or short-term, high temporal frequency datasets needed to parameterize models or detect changes over short or long time scales. Thus, understanding and interpreting the causes and consequences of change in lake ecosystems, and how they do or do not vary across the globe, are difficult challenges; multiple factors operate over a variety of temporal and spatial scales to influence lake dynamics. In particular, directional change is often punctuated or altered completely by events such as floods, droughts, heat waves, and severe storms, which are expected to increase in frequency and severity (IPCC 2014). Such events can lead to large changes in lake water quality and environmental function (Jennings et al. 2012, Klug et al. 2012) and can accentuate complex internal feedbacks among lake food webs and biogeochemical processes with surprising outcomes, such as toxic algal blooms (Qin et al. 2010), which are on the rise worldwide (e.g., Brookes and Carey 2011, Cottingham et al. 2015) and pose an increasingly serious threat to humans and animals (Dodds et al. 2009).

Responding to the grand challenge of understanding global change requires diverse approaches and a global perspective, one that harnesses new capabilities of diverse (including citizen scientists) collaborative teams (Uriarte et al. 2007, Cheruvelil et al. 2014, Cooke and Hilton 2015, Read et al. 2016a), novel data synthesis, and the development of open-source integrated models coupled with new environmental observations (Hamilton et al. 2015). In particular, one way the science community has responded to unprecedented change is to utilize developments in technology that allow near real-time

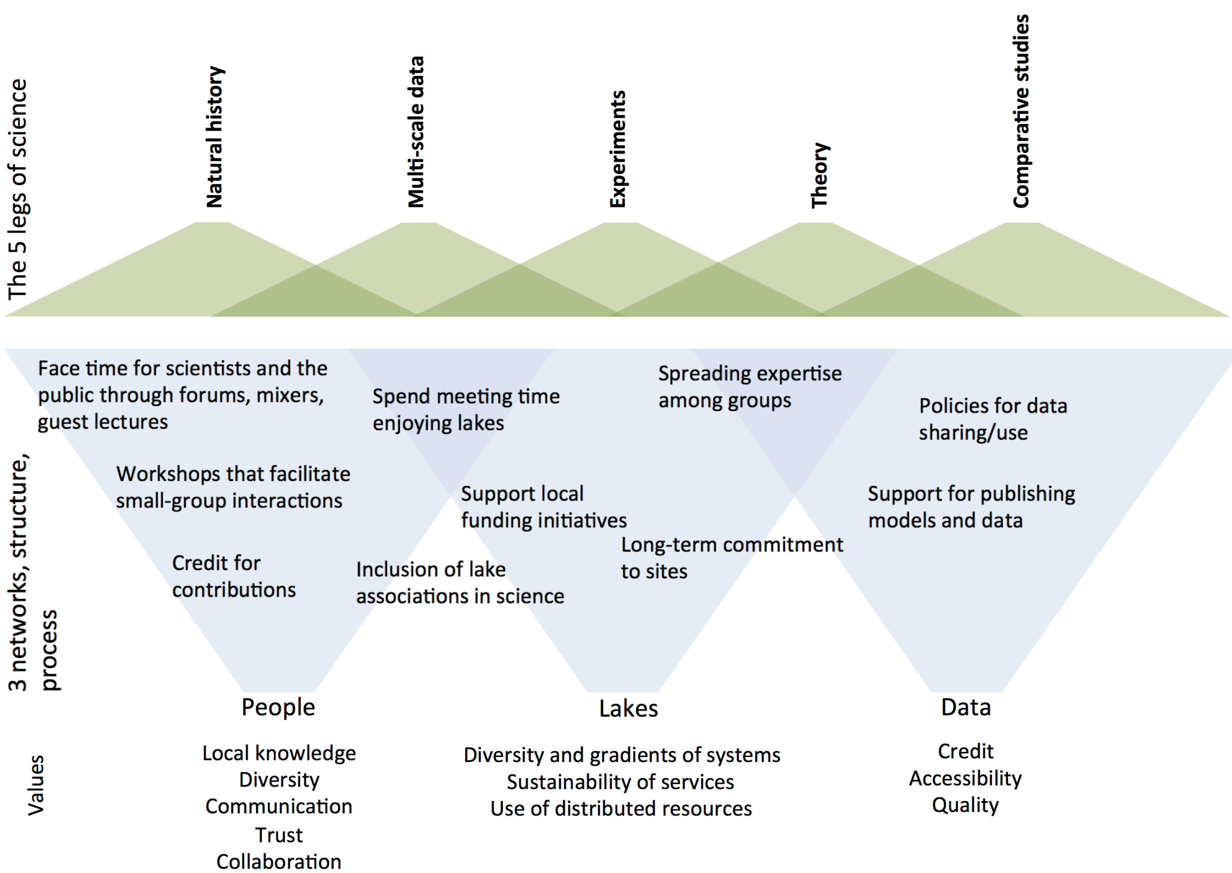

Fig. 1. GLEON supports the 5 legs of science with a network structure and function based on a core set of values. Network components more social in nature are listed on the left, and components more technical in nature are toward the right.

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environmental sensing and to organize sensing networks within and across ecosystems. A number of Observatory Networks or Observation Systems (e.g., National Ecological Observatory Network [NEON], the Great Rivers Ecological Observatory Network [GREON], Integrated Ocean Observing System [IOOS], and the Hudson River Environmental Conditions Observing System [HRECOS]) have emerged to provide the underlying data necessary to understand and forecast change (NAS 2004, Carpenter 2008, Weathers et al. 2013a) across regions, continents, and the globe. Over the next decade, we will begin to see how these networks and a collaborative team science approach will meet the challenge.

In this paper, we demonstrate how the Global Lake Ecological Observatory Network (GLEON)—utilizing different "legs of the table" of knowing (Fig. 1)—is building understanding of lake responses to environmental change at local, regional, and global scales and across networks of people, from scientists to citizen scientists. Although this work focuses primarily on GLEON science, we emphasize that careful attention to the collaborative environment (people) leads to a flexible, creative, and productive science network (e.g., Cheruvelil et al. 2014). The outcome (illustrated in Fig. 1) is that effective networks are really 3 networks—people, data, and ecosystems (Weathers et al. 2013a, Cooke et al. 2015)—and that these networks are at the base of scientific advances. We also stress that some of the biggest challenges, as well as opportunities with conducting network science, are to catalyze, guide, and effectively harness the resources distributed in the network and deliver a concerted effort toward addressing relevant science questions. We identify scientific advances made in the first decade of GLEON's existence, primarily through analysis of multiscale data and comparative studies built on a foundation of significant natural history knowledge.

Building robust scientific understanding of lake structure and function

Some of the most robust and powerful understanding of ecosystems is based on effective measurement and monitoring, synthesis, and research conducted from several different perspectives and paradigms. These approaches include natural history, theory, multiscale observation, comparative studies, and experiments, and they form the support system—the legs of the table of understanding (Fig. 1; Weathers et al. 2013b, as modified from Carpenter 1998). Robust scientific conclusions of important consensus documents, such as the Intergovernmental Panel on Climate Change (IPCC), are based on conclusions derived from all of these approaches. Although use of these scientific approaches is not unique to network science (Carpenter 1998), they do provide a framework for describing how networks can contribute to science in unique and useful ways and indicate where a particular network's science is most represented. For each approach, we describe its use within GLEON and identify the principles, structure, and processes of the network meant to enable the approach, building from the 3 networks (people, data, ecosystems) up (Fig. 1). The legs of the table support GLEON's current mission, which is to "conduct innovative science by sharing and interpreting high-resolution sensor data to understand, predict and communicate the role and response of lakes in a changing global environment" (www.gleon.org).

Natural history observations

Natural historians, citizens as well as scientists, have long noticed, recorded, and reflected on observations of ecosystems. Natural history is "the oldest continuous human tradition" (Fleischner 2011). There is no substitute for experiencing an ecosystem, using our senses to observe, record, and take part in the biophysical interactions that define ecosystems; this experience is essential to the "sense of place" that draws scientists and nonscientists to lakes (Hogan and Weathers 2003, Stedman et al. 2007). Through experience and the documentation of what and who is present and in what numbers, we describe and begin to catalog the structure or "state" of an ecosystem as a basis for understanding its ecology, or "process." For example, GLEON scientists have documented the distribution and morphometry of lakes in Argentina (Bohn et al. 2011) and water clarity across altitudinal gradients (Rose et al. 2009). The paucity of descriptive studies within GLEON does not relegate the importance of natural history to the past, but rather reflects the emphasis on process-based studies more consistent with the technological origins of GLEON. Many of the data that exist and, increasingly, research within GLEON draw on natural history databases and inventories collected by students, scientists, and citizen scientists, often over decades.

Natural history observations and data play another role in GLEON. They serve to bind scientists and nonscientists through sharing a lens on the natural world—their common observation of and appreciation for lakes; they serve as a launch point for understanding how ecosystems work and how the methods of science enable the study of ecosystems. Sometimes our citizen scientist partners first bring interesting, and often troubling, observations to our attention. For example, members of the Lake Sunapee Protective Association (LSPA; Box 1) noticed a novel cyanobacteria bloom and alerted a GLEON scientist to this scientific conundrum. Discussions among research colleagues subsequently led them to engage a student and regional faculty to study *Gloeotrichia echinulata* (Carey et al. 2012a, McGowan et al. 2014). Observational and descriptive understanding of ecosystems can catalyze and underpin research programs, but, perhaps more important, it tends to evoke the human emotion manifest in poetry, song, and art (Ecological Reflections 2013) about ecosystems. The importance of connecting what we as scientists do in a largely abstract/theoretical way with the values people place on lake ecosystems presents a remarkable opportunity. Thus, GLEON activities increasingly have included local citizens, managers, and experiences of the ecosystems we study in designing research questions and creating outreach and education products (Box 2).

Multiscale observations

The initial motivation for forming GLEON was the use of sensors and sensor networks to provide new scales of lake observations (Weathers et al. 2013a). Sensor data, together with long-term data from traditional sampling paradigms, "book end" the time scales that can be observed directly. From high-frequency data, we have learned about temporal dynamics (Sadro et al. 2011, Laas et al. 2012, Solomon et al. 2013) and spatial heterogeneity in lake dynamics; metabolism (Staehr et al. 2012, Van de Bogert et al. 2012) and how lake metabolism responds to management actions (Dunalska et al. 2014); and how and over what time period natural disturbances, such as typhoons (Tsai et al. 2008) and hurricanes (Klug et al. 2012), affect lake ecosystem function. High-frequency data have also improved our understanding of lake energy budgets, mixing regimes, and the processes that govern gas flux between lakes and the atmosphere (Read et al. 2012, Dugan et al. 2016). Finally, a more synoptic understanding of ecosystem biophysical interactions has been studied through the use of numerical simulation for lake phytoplankton dynamics (Kara et al. 2012) and organic carbon cycling (Hanson et al. 2011), allowing scientists to explore how lake ecosystems might respond to exogenous drivers, such as changing climate. This *in silico* approach to studying lakes and reservoirs has been taken to the classroom as part of the Environmental

Box 1. How might ecosystem science underpin the outreach and education programs of a lake association? The Lake Sunapee Protective Association (LSPA) example.

The LSPA is the oldest environmental not-for-profit in New Hampshire, with a more than 110-year history of preserving and enhancing the environmental quality of the Lake Sunapee watershed and beyond. LSPA relies on volunteers supported by 5 staff and an annual budget derived from membership and donations to conduct watershed restoration activities and deliver education and outreach programs to 4000–5000 people per year. LSPA was the first GLEON site member and also served as a model for other GLEON citizen-researcher-initiated buoy sites (e.g., Lake Annie, FL; Lake Lillihonah, CT; Iowa Lakeside Lab, IA). In 2004–2005, they supported the sabbatical leave of a scientist (Weathers) to explore how rigorous ecosystem science might underpin their outreach and education programs. That was the beginning of LSPA's leadership in GLEON, including co-hosting a GLEON all hands' meeting, and the initiation of productive associations with regional lake ecosystem, information, and computer scientists to advance research, education, and outreach.

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As with many such groups around the country and the world, citizen science volunteers have gathered more than 20 years of water quality monitoring data, and their critical observations have contributed to a better understanding of the ecosystem. The LSPA research and education programs also involve the use of high-frequency data.

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Data-Driven Inquiry and Exploration Project (Project EDDIE; www.projecteddie.org), which teaches students how to use both high-frequency data and simulation software as a basis of inquiry and understanding (Carey et al. 2015).

Analysis of high-frequency data has inspired the development of novel analytical tools, several of which have become important products of GLEON. An in-depth description of the state-of-the art in measuring and computing lake metabolism, based on high-frequency free-water gas measurements (Staehr et al. 2010), helped catalyze researchers to improve measurements as well as the software commonly used in metabolism calculations (Winslow et al. 2016). The use of lake physics indices has become more accessible to ecologists through the development of software (LakeMetabolizer; Read et al. 2011) that calculates common metrics of lake physical state, such as the depth of the thermocline, Schmidt stability, and buoyancy frequency. The biophysical dynamics of lakes and reservoirs are difficult to model due to ecosystem complexity; however, through leadership of GLEON members with expertise in numerical simulation, an open-source numerical simulation (GLM -AED2) has been developed as a community initiative in support of community needs (Hipsey et al. 2013). Numerical simulation uses commonly measured exogenous drivers such as wind speed, irradiance, and precipitation, along with local knowledge of the lake morphometry, landscape setting, hydrology, and ecology, to model lake dynamics. Common to all of these technological developments is a commitment to sharing tools with the broader community through repositories such as GitHub (https://github.com/gleon). These technologies and the supporting cyberinfrastructure have been described (Porter et al. 2012) and are addressed in much more detail in a separate article (Read et al. 2016b). We note as well that these modeling tools are currently being modified for use in creating watershed models that can be used by citizen scientists as well as research scientists for scenario building and predicting lake response to global change (http://www.organicdatascience.org/cnh).

While sensor network data have been central to many of the activities of GLEON, at least in its first decade of scientific inquiry, the inclusion of long-term and spatially

Box 2. GLEON at the interface: experiments in expanding the network, shaping the dialog. Since 2009, GLEON all hands' meetings have included engagement with stakeholder communities from around the world.

Local-to-Global

- G8: New Zealand; Lake Association (field trip)
- G9: WI; Society of Environmental Journalists (dinner meeting, talks, discussion)
- G10: Brazil; local mayors (public presentation and social)
- G11: China (cross disciplinary interaction-75th anniversary of Nanjing Institute of Geography and Limnology)
- G13: NH; Lake Sunapee community (student workshop; public events)
- G14: Ireland (state agency–scientist public forum)
- G15: Argentina (public presentation, media, visits to local communities)
- G16: Quebec, Canada (public forum with lake associations and managers)

By providing a forum for discussion of management issues and concerns of citizens, and by including citizens in science-based discussions, GLEON helps form the understanding that bridges the citizen-science divide and that leads to trusting relationships—an essential component of effective collaborations.

extensive data in analyses has increased. This use of diverse types of data has occurred, in part, because sensor data alone are rarely sufficient to convert data to knowledge, but also because of aquatic scientists' interest in questions that span multiple spatiotemporal scales. An analysis of nearly 6 million lakes within the contiguous United States has quantified the length of shoreline of inland lakes at ~1.8 million km (~50 times the perimeter of the Laurentian Great Lakes; Winslow et al. 2014) and informed conditions in which smaller lakes might contribute more to continental scale processing than larger lakes, such as carbon mass accumulation rates in sediments (Winslow et al. 2015). Further, GLEON students, as part of an NSF-funded GLEON Fellowship training program, have analyzed and synthesized data from the US Environmental Protection Agency's National Lake Assessment to understand controls over lake water quality at the continental scale and found that lake-specific characteristics, such as depth, sediment, and area:volume ratio explained much of the variance (54–60%), whereas regional factors were much less important (28–39% of variance explained; Read et al. 2015). Finally, in the time domain, scientists in Florida linked water transparency to 30-year oscillations in the Atlantic Multidecadal Oscillation (Gaiser et al. 2009), and scientists who developed their collaboration through GLEON characterized long-term variability in phytoplankton seasonal succession in a north temperate lake (Carey et al. 2016).

Comparative studies

GLEON is particularly well suited to study phenomena and processes across broad environmental gradients because of the available data and local knowledge brought to the network from ecosystems in 50 different countries. Analyses of lakes spanning a broad size gradient have shown how control over gas exchange between lakes and the atmosphere switches between internal (advective) control to external (wind-driven) control as lake size increases above ~10 ha (Read et al. 2012). Predictions of the timing of ice-on and ice-off for lakes have improved (Pierson et al. 2011, Bruesewitz et al. 2015), and the responses of lakes and reservoirs to major disturbances has been shown to depend on lake morphometry as well as surrounding catchment characteristics (Klug et al. 2012). Ecosystem respiration depends primarily on the rate of gross primary production in lakes, but also on catchment characteristics correlated with allochthonous carbon loads (Solomon et al. 2013). Further, GLEON science has demonstrated that the choice of physical model can have a large and significant influence on estimates of gas exchange across lakes spanning a productivity gradient (Dugan et al. 2016), in some cases resulting in a switch from a lake being considered net autotrophic versus heterotrophic. Regarding the important role of lakes and reservoirs in the global carbon cycle, variation in dissolved organic carbon among lakes can help explain their thermal responses to external energy inputs (Read and Rose 2013) and has important implications for how lakes respond as sentinels of climate change (Williamson et al. 2014, O'Reilly et al. 2015). While dozens of papers using more than one lake can be cited within the GLEON context, the aforementioned studies exemplify the collaborative nature of GLEON through data sharing (http://gleon.org/data).

Data sharing within GLEON is explicitly considered an opportunity for collaboration by tying the 3 networks together and expanding collaboration. The studies mentioned earlier represent use of time series data of multiple variables from each system, and the data required considerable time and expertise to assemble, curate, analyze, and synthesize. As a culture of data sharing continues to grow, along with the technologies needed to support that sharing and the skills needed to analyze those data, we expect more comparative studies with many more ecosystems representing important gradients (Soranno et al. 2014).

Ecosystem experiments

GLEON science to date has made the most progress in 3 of the 5 legs of science (natural history, multiscale data, comparative studies), and GLEON scientists are well positioned to make advances in the remaining 2 (ecosystem experiments and theory). GLEON has been opportunistic about "natural experiments," such as quantifying the response of lakes to typhoons and tropical storms (Jones et al. 2008, Tsai et al. 2011, Klug et al. 2012). Recognition of the importance of such events on lake ecosystems has inspired new sampling campaigns, such as "Blitzs." GLEON Spring Blitzes and Storm Blitzes, both associated with mixing events, are underway and are the result of networking the network of scientists to sample across events around the globe. Experimental manipulations across GLEON sites are a frontier area for exploration. GLEON has the people network in place to do a planned, distributed set of manipulative experiments in the future.

Theory and synthesis

Theory provides the intellectual framework for explaining ecosystem observations and formulating the hypotheses and questions that structure the research process (Pickett et al. 2007). Synthesis provides an

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opportunity for confronting theoretical frameworks with a body of knowledge and inspiring new directions for research. This notion of synthesis toward innovation better describes GLEON productivity. High-frequency monitoring is needed to advance microbial ecology (Shade et al. 2009). Resolving the roles that lakes play in landscape carbon cycling will best be advanced with improved models of organic carbon (OC) cycling (Hanson et al. 2014). Understanding OC dynamics in bog lakes, where much of the OC in northern hemispheres is stored, requires a much better understanding of how their hydrology differs from almost all other lake ecosystems (Watras et al. 2013). The future of water quality in lakes and reservoirs will require a better understanding of both the climatic and the nutrient effects on cyanobacteria (Brookes and Carey 2011, Carey et al. 2012b, Cottingham et al. 2015, O'Reilly et al. 2015, Schaeffer et al. 2015) as well as how invasive species affect biodiversity and ecosystem function. Macroscale science questions will require high-performing collaborative research teams (Cheruvelil et al. 2014) and scientists with skills in managing and analyzing big data (Porter et al. 2012).

Although GLEON science has yet to be synthesized to formulate new theory, research to date represents pragmatic and tangible advances toward answering big science questions. Indeed, much of the work to date could be loosely classified within a suite of over-arching questions. How do the relative contributions of allochthonous and autochthonous carbon sources shape lake ecosystem function and the roles lakes play in the landscape? How do lakes integrate and respond to exogenous drivers, and in what ways do lakes act as sentinels of change? How resilient to disturbances are lakes, and under what conditions do lakes cease to provide critical ecosystem services? What controls the observed diversity of aquatic communities, and how will communities change under altered physicochemical environments and food webs? What are the ecosystem services most important to stakeholders, and how do value systems interact with services to determine the fate of lake water quality and availability? Given the diversity of systems, the large natural gradients represented, and the multidisciplinary talent embodied in its membership, GLEON—all 3 of GLEON's networks in concert—is well suited to address big questions. In the decade to come, we envision continual progress toward addressing these and similar questions.

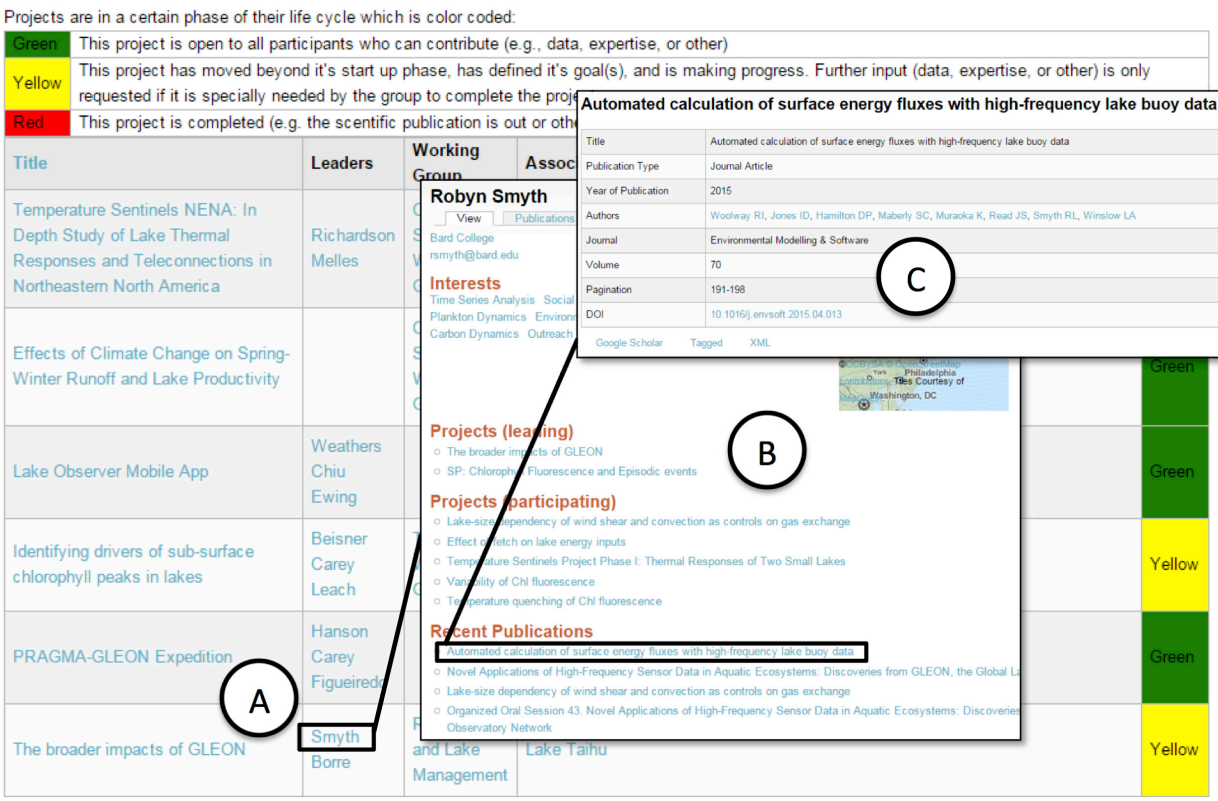
Integrating networks of people, ecosystems, and data to advance science, education, and outreach

Founding principles that have guided GLEON in its first decade explicitly emphasize the importance and value of the people in the network (Weathers et al. 2013a). Principles of diversity, credit, and trust have led to a naturally organizational, representative structure that is transparent and has multiple leadership opportunities. The principles are manifest in network process, as well (Fig. 1). To remain productive and engaged, it is important for members to meet face-to-face on a regular basis and have shared experiences that include science as well as education, outreach, and social interactions, such as opportunities to experience local culture (Cheruvelil et al. 2014). The unit of productivity in GLEON meetings is the working group, which tends to be a group of 10–20 members who have an interest in the same topic and who work toward the creation of products, ranging from scientific manuscripts, to analytical models, to educational and communication materials. Working group facilitators and moderators within GLEON are trained to emphasize active engagement of people in all career stages, disciplines, and cultures to help ensure the broadest participation possible and to ensure credit for contributions.

GLEON is a network of lake ecosystems. With representation from >100 sites from 50 different countries, the ecosystems of GLEON are diverse. The network includes lakes with instrumented sites ranging from <1 ha (Trout Bog, WI) to thousands of hectares (Lake Rotorua, NZ); eutrophic lakes (Lake Mendota, WI), oligotrophic lakes (Lake Sunapee, NH), and brown-stained lakes (Lac Feagh, Ireland); large shallow lakes (Taihu, China) and deep lakes (Lake Tanganika, Africa); and alpine lakes (Alpine Lake Observatory, France), subtropical lakes (Yuan Yang Lake, Taiwan), and lakes from Antarctica (Bonnie Lake). This diversity provides opportunities to develop generalized understanding across large ecosystem gradients (e.g., Read et al. 2012, Solomon et al. 2013, O'Reilly et al. 2015) and potentially develop globally relevant relationships (Hanson et al. 2014).

This lake ecosystem diversity has influenced how GLEON operates. With each lake and its associated community comes a set of resources of substantial value to the broader scientific community. The bulk of GLEON research is funded at the local level (i.e., by member sites); GLEON provides leveraging opportunities for sites. Sites, in turn, contribute resources, such as data and human expertise, to network synthesis activities. The expertise from each site provides critical local knowledge for interpreting data and a diversity of skills and viewpoints needed for effective science teams.

Box 3. GLEON Project Tracker (http://gleon.org/research/projects): the myriad of projects that evolve from a network are difficult to track because of varying time scales of progress, the diversity of resources involved, and the broadly distributed group of researchers who collaborate over long distances.



GLEON developed Project Tracker for communication. Its specific purposes are to identify projects underway, inform scientists of collaboration opportunities in these projects, give credit for the diverse set of contributions required of projects, and report on the progress of projects. Projects may be considered for inclusion in the list when: the idea was generated by a GLEON working group; the project uses GLEON data/tools; the idea came out of discussions at a GLEON meeting; the idea came out of discussions in a GLEON forum (or, for example, the GLEON tech list or session at another professional meeting); the idea was presented at a GLEON meeting with an open invitation for additional participants; GLEON is acknowledged in the publication; GLEON was leveraged to get funding for the work. Important components of the GLEON information system are linked: (A) Project Tracker, (B) member page, (C) associated recent publications. There are also metadata and links to lake web sites (not shown for simplicity). Collectively, these "linked data" are managed using Drupal content management software (Drupal.org), which supports semantic technologies.

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Finally, sites host meetings. Hosting is a point of pride for a site and an opportunity for the host to rally local stakeholders within a forum (i.e., a GLEON meeting) to discuss local issues within a global context (Box 2). This balance between the value of GLEON to a site (local value) and the value of the site within the broader community (global value) engenders long-term commitment of site members to the organization.

GLEON is a network of data. With data come a suite of social and technical opportunities and challenges, many of which define how GLEON has evolved in its first decade (Box 3). Individuals and institutions have invested tremendous resources in gathering observational data, and in some cases data are the primary asset brought to collaboration. The ethos in GLEON has evolved from “can we use your data?” to “would you like to collaborate?,” based on the notion that the people who provide data often have important and deep knowledge of the data, as well as the system from whence those data came, and thus can be can be invaluable to research.

Although providing data may not justify authorship in many cases, the spirit of inclusion has stimulated multiple ways to recognize contributions beyond being listed in acknowledgements. For example, GLEON is beginning to assist in publication of datasets and models (Read et al. 2016b). Through Project Tracker (Box 3), GLEON attempts to provide a transparent means to identify data sources and track the progress of the projects using data, and perhaps most important, the collaborative status of a project (i.e., whether new collaborators are invited [green], specific skills sets are needed [yellow], or the project is near completion and “closed” [red]; Box 3). Project Tracker also provides a mechanism for data providers to demonstrate how their data are being used. The spirit of data sharing has also catalyzed the development of polices for data use and sharing and has elevated the discussion of these topics to the network level.

One of the lessons learned in the first decade of GLEON is that scientists and citizens are eager to join a grassroots network and dedicate time and local resources to collaborate. GLEON has grown primarily through the human network and exposure of collaborative opportunities through presentations at national and international meetings and the scientific literature. We believe this largely volunteer model works when the network is open, inclusive, transparent, diverse, and participants are willing to learn and evolve. Explicitly recognizing the importance of members by providing an easy path for members to engage in the network helps foster the sense of community and trust necessary for successful team science. Ultimately, scientific research does not conduct itself; people do. Thus enhancing trust and collegiality, indeed friendship—and enjoying the work—can tap into the shared deep appreciation of the natural world and lead to creativity, excitement, and advances in scientific understanding (Weathers et al. 2013a, Chevurelil et al. 2014).

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