COLLABORATIVE ACHIEVEMENTS AND CHALLENGES FOR OUR 10-YR RIVER RESEARCH EFFORT

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A majority of the world's rivers have been substantially modified by human activities (Meybeck 2003). A notable example is the Upper Clark Fork River (UCFR) in Western Montana, U.S.A, where historic mining and floods have created the largest U.S. Environmental Protection Agency megafund site. A $200 million dollar ecological restoration of the UCFR was initiated in 2013 and will continue for 20 yrs. Ecological restoration efforts in the UCFR channel and floodplain (Fig. 1) include removal of metal-laden floodplain soils, lowering of the floodplain to reconnect with annual peak flows, and revegetation of over 70 km of the river riparian system. This restoration effort, and funding from the U.S. National Science Foundation (NSF), marked an unparalleled opportunity for our team of researchers to extend long-term process-based insight into the dynamics of a critical river corridor ecosystem during and following a large-scale floodplain restoration. Our story of recently expanded UCFR research, from the project's inception to the execution of new and extended data collection efforts funded by the Long Term Research in Environmental Biology (LTREB) program in the NSF Division of Environmental Biology, was born from a series of conversations around conference venues where we shared ideas in formal and informal settings. Moreover, in implementing the project, we have come to recognize the importance of developing a common language so that we can communicate across disciplinary lines, effectively troubleshoot challenges, and ensure that mistakes are not repeated. Here, we put the spotlight on the emergence of team success from initial conversations and challenges and emphasize our various mechanisms of communication required to ensure broad and lasting impacts.

In the spring of 2014, the Joint Aquatic Sciences Meeting (JASM), in Portland, Oregon, U.S.A, brought Drs. D'Andrilli and Valett together, and by the end of the last social event on the last day of the conference, the two had completed various cocktail napkin graphical interpretations of energy transformations and aquatic resource availabilities with changing ecosystem variables (e.g., temperature, toxins, and time). Six months later, as Valett and colleagues (Drs. DeGrandpre, Payn, and Peipoch) were preparing to resubmit their proposal to the NSF LTREB program, Valett recognized a component missing from their conceptual framework and remembered the interaction with D'Andrilli at the JASM conference. He and the team invited D'Andrilli to participate, providing the missing link needed to address river health from the perspective of organic carbon chemistry and its propensity to bind with toxins. After two proposal cycles from 2015 to 2016, our team was awarded with funding and began our work in April of 2017. Over the initial 4 yrs of implementation, our LTREB program has met ambitious scientific, education, and outreach goals. Scientifically, we re-established a robust monitoring network that will maintain and expand beyond UCFR time series data (Fig. 2), and characterized how water column carbon quantity and composition, stream metabolism, and algal abundance are influenced by the re-establishment of a "flood pulse" promoted by restoring the river's connection to its floodplain.

Some of our greatest successes have come from perseverance and a commitment to ensuring clear communication. Our team represents a multidisciplinary group of researchers who approach understanding the influence of energy subsidies on river processes from different perspectives (Bracken and Oughton 2006). For example, each one of us thinks differently about terms like "energy," requiring semantic conversations to ensure a given word invokes the same meaning for all of us within the project. Ultimately, this may expose ingrained reluctance to put a team first when we have all been trained to be highly independent researchers in our respective domains. Collective perseverance and effective communication are where the power of team science lies, though it can be challenging to harness (Falkenberg and Tubb 2017). Thus, our project

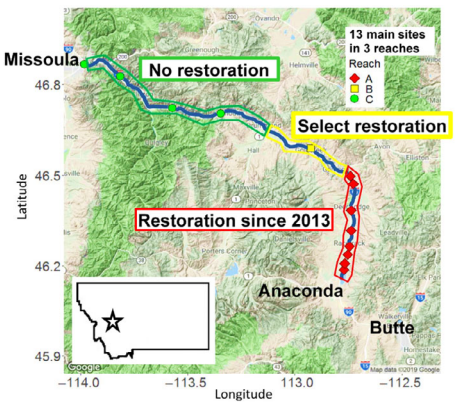

FIG 1. The Upper Clark Fork River, Montana, U.S.A., is now part of the largest Environmental Protection Agency superfund site in the United States, which includes the historic mining towns of Butte and Anaconda. Remediation and restoration efforts, initiated in 2013, were designed to be the most intense at the head of Reach A and decrease with increasing distance downstream across the three reaches (A–C).

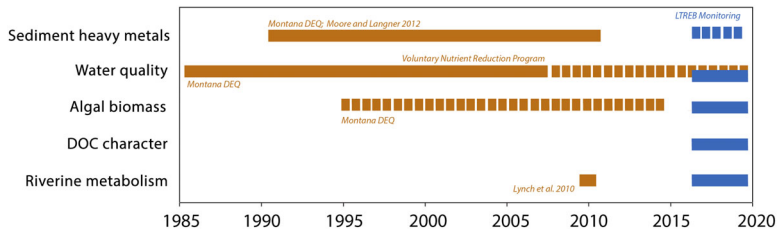

FIG 2. Timeline of historic sampling frequency for various constituents at the Upper Clark Fork River, Montana, U.S.A, over three decades and its continuation and expansion by the LTREB program. Dissolved organic carbon (DOC) character refers to measurements of concentration and absorbance and fluorescence spectroscopy. Solid and dashed bars indicate sampling frequency at monthly or shorter intervals and seasonal or longer intervals.

presents unique advantages and challenges, where combining relatively disparate research interests and language use requires specific focus on addressing complex interdisciplinary problems. Through our team effort, we support each other individually and collectively, creating a mechanism to think broadly about troubleshooting challenges and putting the success of the group effort first.

All data-generating research studies, especially projects of this scale, need a clearly defined and communicated plan for data curation, quality assurance, and sharing policies, ideally before the work starts (Durden et al. 2017; Soranno 2019). Sure, it may appear relatively easy to design an experiment quickly on paper, then rapidly launch into sample collection, but among scientists of diverse disciplines, decisions regarding data generation, metadata use, file management structure, outlier detection, instrument troubleshooting, and data availability do not come simply. Our original strategy did not have the needed extensibility to allow for much growth. Despite numerous attempts to define a central plan, we stored and curated our data individually using five different organizational schemes stored on separate computers. This is a great example of disorganization. After our initial stumbles, we finally realized the need to work backwards from the requirements of community data repositories and consulted an expert in electronic data curation. Data categories, file names, data structure, working data products, quality assurance checks, and publishable products then became essential components of our data workflow. Understanding of data stewardship in public repositories greatly amplifies the value and impact of publicly funded projects and educates current and new researchers in the best practices of data organization (Soranno 2019).

The culture of data sharing and communication in our LTREB program has prompted behavioral change of the principal investigators. Long-held issues of territoriality and competition are being supplanted by the willingness to see data sets themselves as products that belong to both the scientific community and the society that funds these efforts. During the 4th yr of our program, colleagues not directly associated with our LTREB efforts, but studying the same river, asked for our data on water quality and benthic biomass. These data were not yet published and cost the blood, sweat, and tears not atypical of projects with highly ambitious goals relative to the funding provided. Some of us were initially hesitant about the request, yet we made the decision to accept the evolving ethos, driven by the culture of the LTREB program, professional growth, and a more cooperative working model. Even as we worked to move the data sets toward publication on the Environmental Data Initiative DataOne node, funded specifically for LTREB use, we provided data and their metadata brethren; results from over 40 dates, 500 site visits, and thousands of samples were shared in total to the requesting party before publication. The simple concept of using available data is a huge asset for pursuing new questions but requires citable data that appropriately describes how they are to be used and recognizes the people and funding agencies responsible for the work (Soranno 2019). Our goals combine the advantages of leveraging the opportunities and resources to collect more data while maintaining a usable repository for researchers worldwide.

Data sharing is just one example of outreach in our LTREB project. Two other outreach components are centered on effective scientific training of the next generation of researchers with field and laboratory experiences and communication of our results to various target audiences. Connecting with a larger scientific community and incorporating education for the public across multiple states has become a central focus of the project. When we communicate about river ecosystem function, health, pollution, restoration, and material transport, we reiterate how important it is to remember that Earth's biosphere reservoirs are connected, for example, atmospheric, aquatic, and terrestrial. Thus, impacts occurring in the UCFR may affect diverse local and regional biosphere reservoirs by a multitude of transport mechanisms. Therefore, many components of this project are relatable to larger and more diverse audiences and we look forward to future opportunities to communicate these extensive findings.

Throughout our project, we have noted opportunities for more effective communication. That is, after 4 yr, we realized that we do not spend enough time talking about (or writing about) our "failures" and how interdisciplinary teams constructively build from recognizing and responding to them. This article in the *L&O Bulletin* marks our first communication in discussing our LTREB program experiences using a collective narrative voice. We learned that it is important to reflect on the team's growth and communicate what challenges we faced to the community. Beyond regular team meetings, incorporating heuristic discussions of problem-solving practices into regular communication mechanisms is an essential component of team growth. Moreover, extending these findings outward so that other researchers can learn from project challenges is an excellent contribution to the larger community. Therefore, time used for this communication is a worthy investment and creates supportive environments for team education and project success. We hope this article will resonate with many ASLO community members, help keep conversations going, and inspire continued practice in narrative writing for project topics beyond just the project's results in the future.

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