MONITORING ECOSYSTEM INTEGRITY

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Abstract In ecosystem preservation, restoration, and management, plan development and implementation is based on both policy and scientific considerations, which are not mutually exclusive. Decision and policy makers, scientists, and practitioners must meet a consensus regarding what, where, and how to monitor these initiatives. The results, of which, are synthesized into an end product utilized by managers to make a decision. We review a theoretical approach to developing metrics for monitoring restoration projects which is based on fundamentals of decision analysis and the overarching goal of enhancing ecosystem integrity. We then test the application of this framework to a stream restoration case study in Georgia. Through this example, we seek to clarify the roles of technical personnel and decision makers in identification and application of metrics for monitoring ecosystem benefits, goods, and services.

INTRODUCTION

A review of 37,000 stream restoration projects revealed that by 2007 funding had reached over $1B annually and was increasing rapidly. Although public interest and scientific investigation were increasing analogously, reported monitoring of these efforts was associated with a mere 10% of projects (Bernhardt et al. 2007; Palmer et al. 2007). Although not reported, comparable trends are expected for restoration initiatives in other aquatic ecosystems. Monitoring is well recognized as not only a significant source of scientific advancement, but also a tool for informing decision making (Bernhardt et al. 2007).

Successful design and implementation of monitoring programs is dependent on reliable time and funding resources, well-defined monitoring objectives, robust metrics measuring objectives, and application of results to inform decisions (Caughlan and Oakley 2001), each of which relies heavily on the interaction of scientists, policy and decision makers, and other stakeholders.

The objective of this paper is to highlight the interaction of science and policy in the development of metrics to monitor ecosystem restoration. We present techniques for metric development that are based on decision analytic processes and center on the overarching objective of enhancing ecosystem integrity. We then contrast this scientific framework with the reality of how monitoring metrics are developed and applied across a science-decision making gradient. We present collaborative metric development as seen on the Soque River. Finally, in an effort to clarify roles of scientists and non-scientists, we present issues that often arise in metric development and application and recommend simple actions technical personnel may use to appropriately engage the decision process.

METRIC DEVELOPMENT: THE SCIENCE

Identification of metrics for monitoring outcomes of decisions is well-founded in decision science (Keeney and Gregory 2005; Keeney 2007), and physical and life scientists increasingly apply metric development techniques to restoration projects (e.g. Harwell et al. 1999; Reichert et al. 2007). We follow a recent definition of metrics as measurable system properties used to quantify the degree of achieving objectives (Reichert et al. 2007) and use the term metric synonymously with attribute, indicator, performance measure, criterion, and assessment endpoint.

By definition, metrics provide a translation between objectives and measurement of that objective (Keeney and Gregory 2005). Therefore, without clear and complete objectives, it is impossible to develop metrics that appropriately measure the degree to which the objectives are achieved (Gregory and Keeney 2002). A complete list of objectives includes all primary and secondary objectives relevant for making a decision. Clear objectives state exactly what is meant by the objective and thus cannot be misinterpreted. Gregory and Keeney (2002) provide objective setting guidance and present a systematic process for developing complete and clear objectives based on: 1) writing down concerns to address, 2) converting general concerns into succinct objectives, 3) separating ends from means, and 4) clarifying what is meant by each objective.

Because restoration success is almost never solely defined by ecological success, it is essential to have objectives that encompass the broader coupled natural and social systems (Reichert et al. 2007; Turnhout et al. 2007). To address this issue, McKay et al. (2009) and Covich et al. (unpublished) propose an overarching goal for ecosystem restoration and management initiatives as enhancing ecosystem integrity. They define an ecosystem possessing integrity as “a dynamic and resilient unit inclusive of the biotic, abiotic, and social systems in which it is situated”. To clarify what is meant by ecosystem integrity, they present significant ecological and human components of integrity, namely: hydrogeomorphology; biogeochemistry; biotic systems; socioeconomics; cultural, demographic, and political systems; and landscape character. These components serve as sources of discussion for generation of more refined, project-specific objectives and metrics.

Following development of a robust set of objectives centered on enhancing ecosystem integrity, metrics may be developed to monitor the degree of achievement of objectives and inform decisions. Based on the work of Keeney and Gregory (2005), McKay et al. (2009) present an iterative process to guide metric development and application which consists of selection, evaluation, and documentation of metrics (Figure 1). Metrics are selected using a logical hierarchy of: 1) natural metrics in general use that represent the common unit of measure of a given variable, 2) constructed metrics developed to directly measure an objective when no obvious or single natural attribute exists, and 3) proxy metrics that serve as indirect measures of a given variable or process and are often used because of the relative ease of measurement or understanding. Following selection, metrics are evaluated based on six properties characterizing robust metrics: relevant, unambiguous, comprehensive, direct, operational, and understandable (Keeney and Gregory 2005; McKay et al. 2009). The metric development process is concluded with two often overlooked issues: situation-appropriate documentation and archival in common repositories (e.g. libraries, internet databases) for future use.

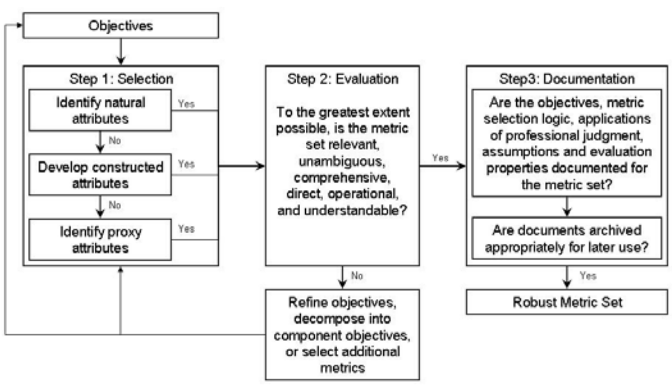

Figure 1. Metric development (McKay et al. 2009)

METRIC DEVELOPMENT: THE REALITY

Although this metric development process is intended to identify appropriate monitoring metrics for a given situation inclusive of policy, decision making, resource, and other constraints, often tension exists between technical personnel and stakeholders/decision makers over metric selection. The success of a monitoring plan is highly dependent upon scientific and non-scientific support; thus, gaining buy-in from both groups is critical. We believe two significant factors impact the success of communication between scientists and non-scientists: 1) rigidity in roles of scientists and decision makers and 2) differing objectives for monitoring metrics.

Scientists often view their role in the decision process as a clear dichotomy of acting as policy advocates for a particular issue or shunning the policy realm and focusing solely on science; however, they may also serve as providers of scientific information or scientific reviewers of policy options (Scott et al. 2008). This range of options emphasizes the lack of distinct roles and instead encourages a gradient of interaction between the two communities centered on knowledge transfer and use (Figure 2; Turnhout et al. 2007). In particular, metric development and application serves as a beacon for this fuzzy interface and should not be considered an issue of one-way communication only. In fact, effective metrics should serve as tools to connect the two domains and pass information back and forth between them (Turnhout et al. 2007).

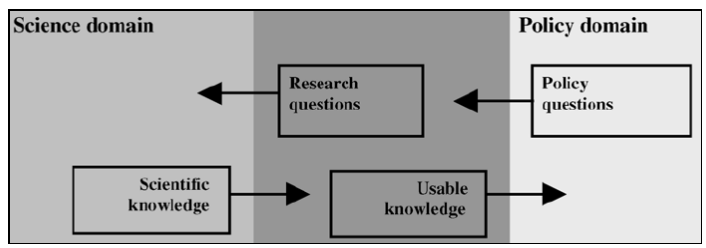

Figure 2. Science-policy fuzzy interface (from Turnhout et al. 2007)

Additionally, in an effort to overcome communication challenges, scientists often seek to improve the metrics themselves rather than working with non-scientists to understand why the indicators are ineffective (Turnhout et al. 2007). As such, we believe that communication between technical and decision-making personnel is further hampered by different objectives for the metrics themselves. Scientists often prefer the most relevant, comprehensive, and direct metrics to adequately measure complex environmental processes; however, the stakeholder/decision-making community is often more concerned with ambiguity, operationality, and understandability of metrics (Schiller et al. 2001). The decision making community may even prefer some ambiguity in metrics to leave room for negotiation of controversial environmental issues (Turnhout et al. 2007). Scientists may further impede understandability of metrics by how they present them. Schiller et al. (2001) demonstrated that the generalized process and message a metric communicated was more important to non-scientists than the measurement technique or supporting science. We believe these different paradigms and approaches to metric development may be hindering communication between these groups.

APPLICATION: LEFT FORK OF THE SOQUE RIVER

In 1996 with partners from the Environmental Protection Agency, Savage-Roberts Farms, U.S. Fish and Wildlife Service, Soque River Watershed Association, and Southeast Water Americorps, the Upper Chattahoochee Riverkeeper (UCR) initiated the Chattahoochee River Headwaters Riparian Restoration and Education Project. The overall goals of the project were two-fold: 1) demonstrate the value of functioning riparian zones in protecting stream health; and 2) assist interested communities with protection and restoration of stream and riparian ecosystems (UCR 1996). A 1250-foot stream reach on the Left Fork of the Soque River in Habersham County, Georgia, was selected as a demonstration project. Scientists representing the aforementioned project partners interacted with UCR to ensure that project objectives successfully met the overarching goals and mission of UCR. The scientific and administrative teams agreed upon the following project objectives (UCR 1996; Baer et al. 1999):

- Prevent future accelerated bank erosion and loss of property;
- Utilize natural channel design technology;
- Enhance fish habitat and stream condition; and
- Demonstrate the ease and cost-efffectiveness of problem prevention over repair.

The scientific portion of the team synthesized these objectives into technically oriented metrics for monitoring the project. These metrics were then presented to stakeholder groups and modified to more understandably communicate outcomes to decision makers. For instance, natural (1-3) and proxy (4-6) metrics were identified to measure the first objective (bank erosion) and included: 1) installation of bankpins to monitor channel stability; 2) establishment of permanent cross-sections to monitor cross-sectional geometry; 3) measurement of bed material by conducting pebble counts (Wolman 1954); 4) evaluation of channel stability (Pfankuch 1975); 5) calculation of bank erodibility hazard index (Rosgen 1996); and 6) evaluation of bank stress (Rosgen 1996). Pre- and post-project monitoring was conducted and metrics were used to communicate project outcomes to stakeholders and decision makers. Not only did metric communication inform the project team (technical and non-technical) of the success or failure of the project, but it also served to create knowledge applicable to other UCR projects. The pre-, during-, and post-project interaction between all interested parties fostered communication between scientific and stakeholder communities and ultimately led to robust objectives and metrics for monitoring restoration outcomes and informing decisions regarding this and other projects.

CONCLUSIONS

In order to facilitate meaningful support to the decision process, scientists and decision makers must establish, foster and maintain lines of communication during the formulation of project objectives as well as design, implementation, and selection of metrics. We prescribe the formation of a project team composed of policy and decision makers, scientists and practitioners, and other stakeholders affected by the project (e.g., property owners).

Multiple roles for scientists exist within the science-policy gradient from the professional society influence on a particular national policy or monitoring program (Scott et al. 2008) to the local project team monitoring a specific restoration action. To overcome communication barriers between technical and decision making communities, we present a partial listing of some of the issues that scientists can emphasize in communication with decision makers.

- Upfront, clear communication and involvement from all relevant science and decision making parties are critical. These groups need to interact at early stages of a given effort to ensure that science and societal viewpoints are adequately expressed in problem and objective statements. This may be most important in areas of high socio-political controversy such as urban environments (Ingram 2008; Lauber et al. 2008).
- A clear and concise set of objectives is critical to structure the problem and identify metrics; thus, bringing both parties to the table to develop objectives is vital (Lauber et al. 2008). For ecosystem restoration projects, we encourage the development of objectives centered on enhancing ecosystem integrity.
- Products and deliverables should be identified. If a connection between an objective and a product is not clear, the product should be revised to be more supportive of the decision making process.
- Selection of robust metrics directly related to overarching goals and specific objectives is paramount to a successful project. Metrics are ineffective if they cannot be utilized by managers and decision makers to inform decisions and successfully coordinate, plan, and implement a project.
- Quality control and standard operating procedures related to collection, chain-of-custody, transport, and analysis of metrics must be established and adhered to. However, in developing and communicating metrics, emphasis should be placed on the conceptual motivation for each metric and the

general process or function it measures, not what data collection and statistical techniques will be applied (Schiller et al. 2001).

- Data should be reduced and interpreted in a timely manner so that outcomes can be adaptively managed for maintenance, contingencies, and future monitoring.

In general, science can serve as a source of debate if problems are not framed appropriately. Decision makers need to understand that ecosystems are highly complex systems and significant uncertainty exists. Well-designed metrics minimize complexity and uncertainty, but this issue cannot be completely overcome (Turnhout et al. 2007). Robust metrics are monitored to evaluate, inform, and adaptively manage environmental policy, management, and restoration initiatives; thus, they should be viewed as a source of efficiency in ecosystem management and restoration efforts, not an unwarranted cost.

REFERENCES

Able, T., K. Baer, M. Flexner, B. Pruitt, J. Derby, and P. Kalla. 2001. Stream channel post-restoration monitoring of the Soque River, Georgia. Georgia Water Resources Conference, March 26-27, 2001, Ed. Kathryn J. Hatcher, Athens, GA.

Baer, K., J. Derby, T. Able, M. Flexner, B. Pruitt, and P. Kalla. 1999. Fluvial restoration in the Chattahoochee headwaters. Georgia Water Resources Conference, March 30-31, 1999, Ed. Kathryn J. Hatcher, Athens, GA.

Bernhardt, E.S., et al. 2007. Restoring Rivers One Reach at a Time: Results from a Survey of U.S. River Restoration Practitioners. Restoration Ecology. 15 (3): 482-493.

Caughlan, L. and K.L. Oakley. 2001. Cost consideration for long term ecological monitoring. Ecological Indicators. 1: 123-134.

Covich, A.P., S.K. McKay, M.A. Kenney, B.A. Pruitt, M. Harberg, J.C. Fischenich, and J.J. Boland. Enhancing Aquatic Ecosystem Integrity with Effective Objectives and Metrics for Restoration. Unpublished manuscript.

Gregory, R.S. and R.L. Keeney. 2002. Making smarter environmental management decisions. JAWRA. 38 (6): 1601-1612.

Harwell, M.A. et al. 1999. A Framework for an Ecosystem Integrity Report Card. Bioscience. 49 (7): 543-556.

Ingram, M. 2008. Urban ecological restoration. Ecological Restoration. 26 (3): 175-177.

Keeney, R.L. 2007. Developing Objectives and Attributes. Advances in Decision Analysis: From Foundations to Applications. Eds. Edwards, Miles, and von Winterfeldt. Cambridge University Press, New York, NY.

Keeney, R.L. and R.S. Gregory. 2005. Selecting attributes to measure the achievement of objectives. Operations Research. 53 (1): 1-11.

Lauber, T.B., D.J. Decker, and B.A. Knuth. 2008. Social Networks and Community-Based Natural Resource Management. Environmental Management. 42: 677-687.

McKay, S.K., B. Pruitt, M. Harberg, A.P. Covich, M. Kenney, S.A. Miller, and J.C. Fischenich. 2009. Metric development and application for environmental benefits analysis. ERDC TN-EMRRP-EBA. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Palmer, M.A., J.D. Allan, J. Meyer, and E.S. Bernhardt. 2007. River Restoration in the Twenty-First Century: Data and Experiential Knowledge to Inform Future Efforts. Restoration Ecology. 15 (3): 472-481.

Pfankuch, D.J. 1975. Stream reach inventory and channel stability evaluation. US Forest Service. R1-75-002. Government Printing Office #696-260/200. Washington, D.C.

Reichert, P., et al.. 2007. Concepts of Decision Support for River Rehabilitation. Environmental Modeling and Software. 22: 188-201.

Rosgen, D.L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, CO.

Schiller, A., et al. 2001. Communicating ecological indicators to decision-makers and the public. Conservation Ecology. 5 (1).

Scott, J.M., J.L. Rachlow, and R.T. Lackey. 2008. The science-policy interface: What is an appropriate role for professional societies? Bioscience. 58 (9): 865-869.

Turnhout, E., M. Hisschemoller, and H. Eijsackers. 2007. Ecological indicators: between the two fires of science and policy. Ecological Indicators. 7: 215-228.

UCR. 1996. Upper Chattahoochee Riverkeeper web page http://www.ucriverkeeper.org/programs4c.html

Wolman, M.G. 1954. A method of sampling coarse riverbed material. Transactions of AGU, 35: 951-956.