Connecting the Dots: A Collaborative USGS–NPS Effort to Expand the Utility of Monitoring Data

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Introduction

The Natural Resource Challenge (National Park Service 1999) was a call to action. It constituted a mandate for monitoring based on the twin premises that (1) natural resources in national parks require active management and stewardship if we are to protect them from gradual degradation, and (2) we cannot protect what we do not understand. The intent of the challenge was embodied in its original description:

> We must expand existing inventory programs and develop efficient ways to monitor the vital signs of natural systems. We must enlist others in the scientific community to help, and also facilitate their inquiry. Managers must have and apply this information to preserve our natural resources.

In this article, we report on ongoing collaborative work between the National Park Service (NPS) and the US Geological Survey (USGS) that seeks to add to our scientific understanding of the ecological processes operating behind vital signs monitoring data. The ultimate goal of this work is to provide insights that can facilitate an understanding of the systems and identify potential opportunities for active stewardship by NPS managers (Bennetts et al. 2007; Mitchell et al. 2014). The bulk of the work thus far has involved Acadia and Rocky Mountain national parks, but there are plans for extending the work to additional parks.

Our story starts with work designed to consider ways of assessing the status and condition of natural resources and the potential for historical or ongoing influences of human activities. In the 1990s, the concept of "biotic integrity" began to take hold as an aspiration for developing quantitative indices describing how closely the conditions at a site resemble those found at pristine, unimpacted sites. Quantitative methods for developing indices of biotic integrity (IBIs) and elaborations of that idea (e.g., ecological integrity) have received considerable attention and application of these methods to natural resources has become widespread (Karr 1991; Barbour et al. 1999; Stoddard et al. 2008). Despite widespread use,

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many questions remain about how metrics are combined to form effective indices and about how to interpret both.

Scientists and natural resource specialists within NPS and USGS have joined forces to critique the current analysis methods, with the collaboration involving the Rocky Mountain and Northeast Temperate NPS Inventory and Monitoring (I&M) networks, along with others, and USGS scientists from the National Wetlands Research Center and Patuxent Wildlife Research Center. Funding that initiated the project was from a joint-partnership fund managed by the USGS Ecosystems Program for National Park Monitoring research and the work was focused at Acadia National Park and Rocky Mountain National Park. Here we present synopses of two major issues addressed by the group.

Problem 1: Developing an interpretive framework for assembling multimetric indices

Multimetric indices such as the IBI are constructed by combining measures of biological characteristics that correlate with human alterations of ecosystems into a single integrative measure. Combining measures into a single index seems like a simple matter, but the process is complicated by (1) the fact that both human activities and natural system characteristics can covary across environmental gradients, (2) the necessity to choose from many available metrics to create an effective index, and (3) the fact that one has to decide how to mathematically assemble the final index.

The issue of natural gradients (e.g., variations in elevation) is particularly problematic. Historic human use in parklands typically varied along such environmental gradients. For example, there have been fewer historical uses and there are now usually far fewer visitors at high elevations. Natural ecosystems also change along these gradients (high-elevation wetlands are naturally much different from those at low elevation) and thus false or spurious correlations between human disturbance and ecosystem condition can occur. Because of these complications, we are left to disentangle effects of natural gradients from those of human effects. While this problem is well understood, we feel that traditional solutions, which rely on "statistical control," not only obscure the logic behind adjustment procedures, they also risk biasing estimated effects. Scientists wish to make adjustments based on scientific interpretations of a situation, not on a purely automatic process with questionable assumptions. So, we decided on a different approach.

In our work, we decided to apply graphical analysis and causal modeling to tackle these problems (Schoolmaster et al. 2013). These somewhat advanced methods pose hypotheses about *why* variables are correlated, and use causal diagrams for analyses. Figure 1 shows a set of hypothetical scenarios we evaluated. In this example, there is a common suite of variables included, but the causal relations between them are different in each case. Standard methods of adjusting for the effects of the natural gradients treat all these situations as if they are the same, but we showed that such an approach leads to serious mistakes. We went on to provide a documented process for preparing indices that is appropriate for different situations (Schoolmaster et al. 2012a). Most importantly, by showing the presumed causal connections visually in a graph, the approach permits investigators and managers to consider *how* the coupled human–natural system works, while guiding the process of quantifying conditions.

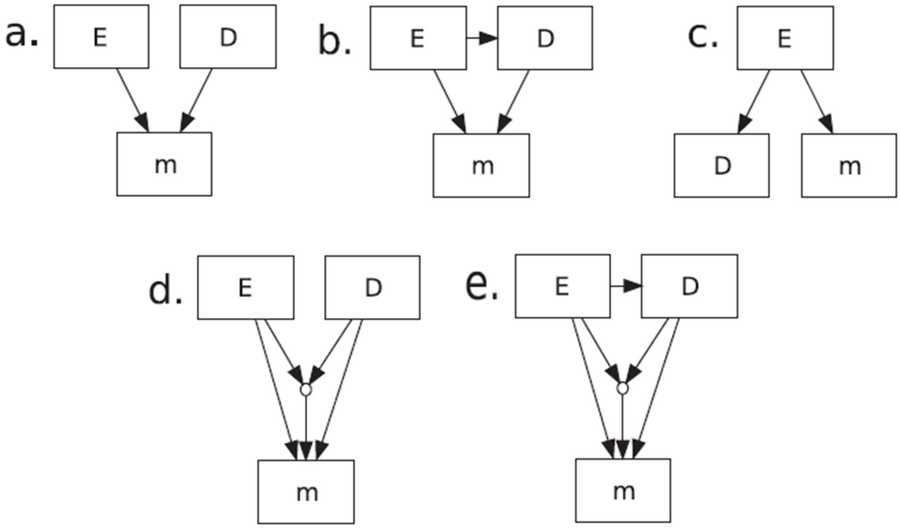


Figure 1. Range of scenarios used to consider how different causal situations would influence automatic approaches to statistical control in index of biotic integrity (IBI) construction (from Schoolmaster et al. 2013). "E" represents an environmental factor, "D" a human disturbance factor, and "m" a biological metric.

Building on these ideas, we re-evaluated the fundamental principles behind indices generally (Schoolmaster et al. 2012a). Here we again used causal graphical diagrams to lay out the problem, going on to develop a protocol for index assembly when the goal is to build an index in the most efficient and effective manner (Schoolmaster et al. 2012b).

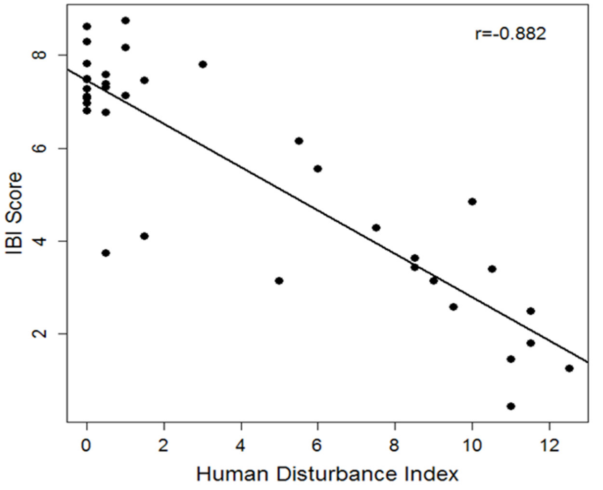
Problem 2: Figuring out the pathways whereby human activities connect to biological conditions

The process of building an index for assessing biotic integrity involves combining many pieces of information into a single, integrative index. When calibrated against a quantified range of human disturbance, such indices become reflective descriptions that can be used to diagnose altered conditions in the landscape (Figure 2).

In addition to meeting the primary objective of assessing and tracking conditions (bioassessment), the data collected along the way can serve an additional, important purpose: providing insights into how human activities may have altered biotic conditions, and therefore, perhaps, what park managers might do about changes that are undesired. Describing our work on this second problem requires us to get a bit more specific about the systems being examined.

Acadia National Park is one of the most visited NPS units in the eastern US. Among its many outstanding features is a large collection of wetland communities scattered across its terrain. Prior collaborative studies of 37 nonforested wetlands involving NPS, USGS, and

Figure 2. Bioassessment results for Acadia National Park wetlands (Schoolmaster et al. 2012a), expressed as a plot of scores for the IBI against estimates of the human disturbance index (HDI). The practical goal of the structural equation model (SEM) example presented in this paper is to elucidate the causal connections between human activities (disturbances) and the biotic responses identified in the IBI analysis.



university partners (Little et al. 2010) had described many of the ecological relationships between wetland types and environmental conditions. Measured were (a) landscape conditions for each wetland, (b) water pH and conductivity, (c) hydrologic fluctuations, and (d) plant community characteristics. Building on that, we added additional data describing the degree and types of human activities around the studied wetlands, permitting us to develop an IBI for the system (Figure 2). Then we went about the business of posing and evaluating hypotheses about how human activities might impact natural conditions in the wetlands. We tackled the problem using a methodology known as structural equation modeling. This method is built around the idea of causal networks, and specifically how hypotheses about cause–effect connections in systems can be evaluated against data. The details of our study and of the methods used are given in Grace et al. 2012; here we describe generally what was examined and found in that analysis.

Of all the activities in our study, the business of proposing and evaluating hypotheses about how wetlands might be impacted by human activities required the most teamwork. Here, both researchers and park natural resource managers had plenty of ideas. Figure 3 shows the major ways that humans typically impact wetlands: through alterations to nutrient inputs and changes in hydrology. Following a consideration of the measured variables and using our knowledge about the system, we constructed an initial causal network model for evaluation (Figure 4).

Lots of thinking and discussion went into constructing the initial hypothesis/model. First, as shown in the top part of Figure 4, the model considered how the different measures of human activities fit together. Patterned after prior work developing IBIs for wetlands (Mack 2001), an evaluative system appropriate for quantifying human activities in the local area was developed and information on human activities were aggregated into measures of (a) intensity of land use, (b) the degree to which hydrology had been altered, (c) how close to the edge of a wetland human activities had occurred (also known as "buffer intrusion"), and

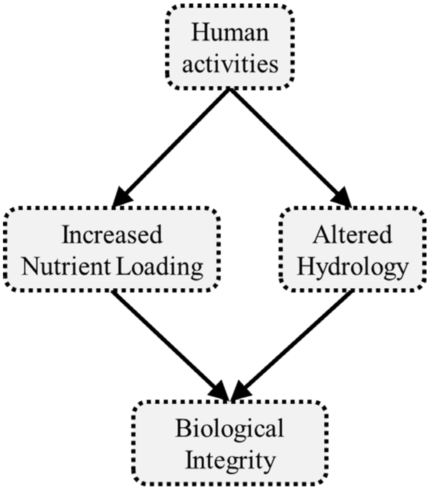
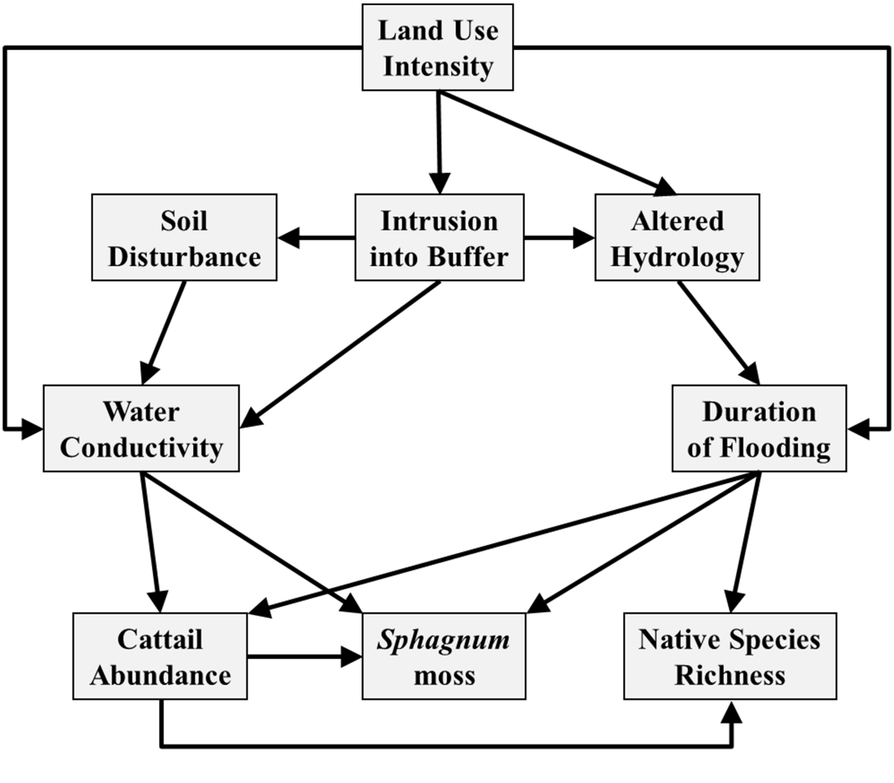


Figure 3 (left). Conceptual model representing general *a priori* expectations for how human activities most commonly affect wetland communities.

Figure 4 (below). Initial SEM representing a complex hypothesis developed for how biological conditions in wetlands (at bottom of diagram) might connect with human activities in the landscape (at the top of the diagram). From Grace et al. 2012.



(d) where there was obvious soil disturbance adjacent to or in the wetland. A logical set of hypothetical relations between elements of the model was developed.

The bottom of the model in Figure 4 includes three major system attributes selected to represent wetland condition or characteristics apparently sensitive to human alterations of the habitat. Such characteristics were revealed in the process of screening a long list of possible metrics against an overall index of human disturbance (constructed from the above-mentioned measures of human activities). First, we saw a prominent negative relationship between human disturbance and native species diversity (specifically, species richness). Second, *Sphagnum* moss, an indicator of higher-quality bog habitats, was also lower where human activities were greatest. Third, cattails (*Typha* taxa) were observed to dominate in heavily disturbed areas, a common phenomenon in wetlands worldwide (Newman et al. 1996). While other wetland features were also found to vary with human disturbance, modeling is partly about simplification, and we felt the three characteristics included in the model were the most interpretable and most meaningful to management.

The final thing we considered when developing the initial model was whether any measured variables might capture the environmental changes linking human activities to the biotic responses (these are often referred to as mediator variables). Measurements of water conductivity and pH showed clear relationships to human activities. While nutrient inputs into the wetlands were not measured directly, we felt that water conductivity, which is strongly influenced by total mineral solutes in the water, might serve as an indicator of nutrient loading (Biggs 1995). Finally, data from water level recorders allowed us to calculate a number of summary measures of water level and its fluctuation. Most importantly, the number of days each year when the soil was flooded at the monitoring site was most clearly related to wetland condition. The general hypothesis represented by our model was that human influences on water conductivity and duration of flooding could explain the major effects of land use intensity on wetland characteristics (Figure 4).

In structural equation modeling, the evaluation of the initial hypothesis with actual data is a matter of seeing "if things add up." If a model accurately reflects important properties of a system then the raw correlations between system properties (as represented by the variables in the model) will all add up to those implied by the model. For example, we would expect the observed correlation between land use intensity and native plant richness would equal the sum of all path strengths connecting the two variables. Proceeding from this basic premise, an evaluation of alternative models was conducted.

Once the initial model was evaluated with data, some of the ideas incorporated in the model had to be revised. Perhaps most importantly, the analyses showed that some additional connections beyond those initially suspected needed to be included (Figure 5). It seems that land use intensity is negatively associated with native plant richness (shown as a direct arrow from land use intensity and plant richness in the model) for some reason beyond those captured by the mediator variables in the model. We must be careful to rule out influences of land use planning before concluding there is some additional influence of actual land use on native plant richness, but both possibilities remain for future consideration. Also unanticipated were small, but detectable, impacts on *Sphagnum* from hydrologic alterations and soil disturbance, which were added to the model, again for future investigation.

Perhaps as important as the links that had to be added to the model are those whose impacts were undetectable in the data (Figure 5 versus Figure 4). Surprisingly, the intrusion of human construction activities into the immediate buffer around a wetland is not required for

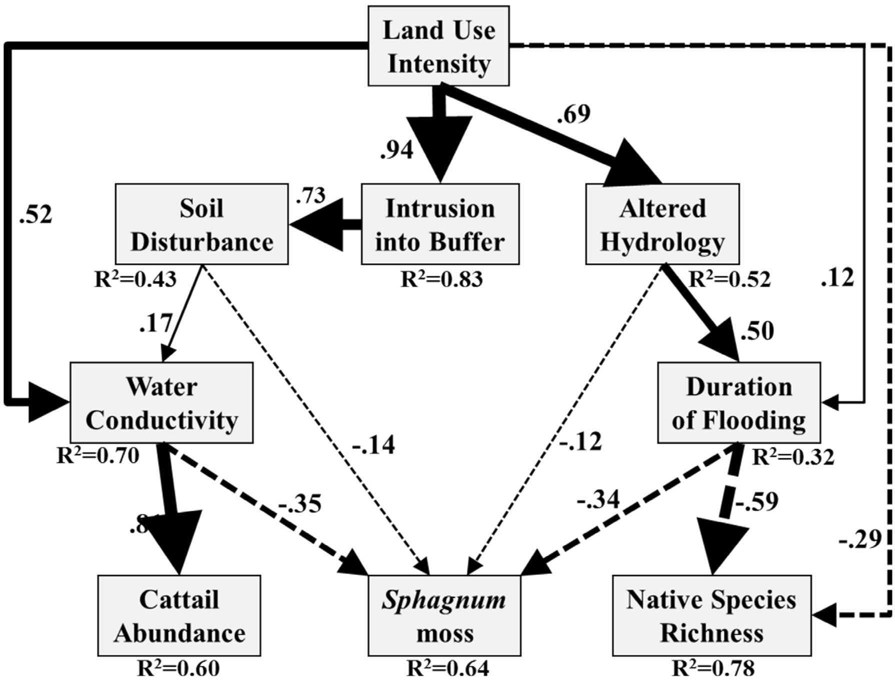


Figure 5. Representation of SEM results (from Grace et al. 2012). Solid lines represent predicted positive effects while dashed lines represent negative effects. Widths of lines are proportional to predicted sensitivities. Variance explained for each response variable is given as R-squares. Coefficients presented are standardized values.

hydrologic alterations to be important. Our revised view is that damming of outflows, either purposely or in concert with roadways, works in combination with the natural topography to stabilize water levels in many of the wetlands. Also, buffer intrusion does not seem to automatically enhance nutrient runoff and elevated water conductivities as expected. Results reveal the direct path in the model from land use intensity to conductivity was quite strong, suggesting nutrient inputs to wetlands primarily involve established routes for water movement. Expected but not detected was an influence of flooding duration on cattails, as has been found in other locations (Grace 1989). Finally, once joint influences were considered, we did not detect direct impacts of cattails on *Sphagnum* or native species diversity. It is believed that this lack of relationship occurred because cattail abundances have not yet reached critical levels (and hopefully will not).

Overall, the results from Acadia (especially focusing on the thickest arrows that show the strongest relationships in Figure 5) provide a general confirmation of the idea that human influences on biotic conditions are through nutrient inputs and altered hydrology, though with some additional processes operating as described in the preceding paragraph. Aside from providing a concrete and quantified representation of the coupled human–natural system, details of the model results suggest some opportunities to prevent further degradation, as explored in Grace et al. 2012. For example, we can ask how blocking any particular path in the model might influence this particular suite of wetlands (those sampled). It must be noted that modeling enterprises such as the one demonstrated here depend on assumptions that require further evaluation. Nonetheless, it is notable that nearly all the data necessary for this analysis were already collected in the previous studies through the natural intuitions of the scientists and natural resource personnel involved.

A joint effort—Using modeling to motivate monitoring

High-quality monitoring efforts such as the NPS Vital Signs program are challenging to develop and expensive to maintain. Sustaining year-after-year measurement protocols depends on the long-term value of the effort being sufficiently appreciated to maintain support for the effort. We believe that the example described above represents a proof of concept that additional analyses can produce insights from monitoring data that are intuitive, useful, and may aid management decisions. At Rocky Mountain National Park, where similar wetland bioassessment modeling was developed (Schweiger et al., in press), the initial effort to develop IBIs is being extended to include structural equation modeling studies of how human and natural disturbance agents may be affecting ecosystem conditions. At Acadia National Park, the wetland focus has been replaced by an effort to develop general models for forest health, with the ultimate intention of extending this effort to additional parks in the eastern forest biome. The partnership between NPS and USGS in this endeavor results in a combination of talents, skills, and knowledge that generates an important synergism with many potential benefits. It is our hope that the modeling effort will help maintain awareness of the many values of the monitoring effort, which is ultimately vital to management.

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