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The Marriage of Science and Management: Eternal Bliss or Misery?

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For many reasons, the analogy of a marriage is well suited to understanding the integration of science and management. Like a marriage, it is all too often that science and management are under the same roof, but fail to interact effectively. Like any marriage, strengthening communication can lead to mutual benefits for both parties. Scientists need to better understand the problems facing managers, and managers need to better understand how and when science can help them achieve their objectives. And, like any marriage, the partners need to invest time and effort to make the relationship work. The marriage of science and management is a partnership, and a lack of communication, interest, devotion, and/or effort will undoubtedly lead to failure.

Are they well suited? One of the first considerations before entering into any partnership is whether or not the partners, in this case science and management, are well suited for each other. Lee (1993) proposed that management can be thought of as a vessel by which we influence natural systems, and that navigation of this vessel can and should be influenced by sociological and economical forces. However, there should also be a mechanism to better learn how to reach our destination using past experiences and knowledge. Lee (1993) describes "navigational aids" for helping us along the journey. Policy, as a guide to management, can help determine our final destination. Science, meanwhile, can help determine the route by which we reach our destination. The success of these processes depends, in part, on where conflict lies. If there is disagreement about the final destination (e.g., the management goals or priorities of management goals), then the best route is likely through negotiation and compromise (Figure 1). Although science can certainly influence our priorities, conflicts regarding the goals may not be the best foundation upon which to develop a partnership between science and management. In such situations, science frequently serves as a displacement behavior that stalls the decision process instead of providing solutions. If, however, the conflict is centered on uncertainty about an expected outcome of management, science offer a valuable solution, and a partnership between science and management can be quite productive.

Embracing uncertainty

In any partnership, unexpected events and outcomes will arise, and an expectation that science will eliminate uncertainly is unrealistic. Rather, planning for unexpected events may aid in "weathering the storm." In planning for uncertainty, we strive to reduce it (through learning) and benefit from it (by taking advantage of the learning opportunities afforded by unexpected events) (Holling 1978). While we certainly can learn from situations without *a priori* planning, preparing for uncertainty through well-designed science will allow for more

Figure 1. Conceptual diagram showing the likely path of conflict resolution depending on whether the conflict centers on the management goals or uncertainly about the response to management (adapted from Lee 1993).

efficient learning than would retrospective assessments (Gould and Lewontin 1979; Nichols 1999).

Tools that help us embrace uncertainty include model building, sampling design, and adaptive management. These tools are not mutually exclusive and I have extracted here just a few salient points from each.

Model building helps to identify and clarify uncertainties (Walters 1986). For example, it is well known that fire, forest insects, and disease have a major impact on whitebark pine communities. However, a simple conceptual model constructed for the Greater Yellowstone Ecosystem illustrated that, in addition, the interaction between these influences and changing climate is an area of great uncertainty.

Adaptive management embraces uncertainty as an inevitable attribute of management and uses management as a tool for reducing uncertainty (Walters 1986; Williams et al. 2002). However, some detractors have suggested that adaptive management implies implementing management and, if it does not produce the desired results, we merely try something else. This perception is substantially different from the concept advanced by Holling (1978) and Walters (1986) and diminishes the usefulness of this approach. Adaptive management considers management actions and policy in a context analogous to experimental treatments and embraces uncertainty by attempting to define a set of possible outcomes (hypothesized predictions) that are consistent with management experience. The relative evidence for the alternatives is then considered in a well-designed monitoring framework, just as one would expect from any research design. Thus, sound sampling designs from the outset can make the difference between effective learning and sloppy management.

Adaptive management contributes to the marriage of science and management because it forces the two disciplines to incorporate parts of the other. When adaptive management is correctly implemented, management continues to focus on objectives, but learning (through sound science) becomes an additional, explicit objective. Likewise, management objectives become a source of scientific inquiry, with the explicit purpose of using past knowledge to improve future management decisions. So, in essence, management takes on a part of science (i.e., learning), and science takes on a part of management (i.e., management objectives).

Setting objectives

There is virtually universal consensus among scientists that setting realistic, clear, specific, and measurable objectives is a critical—but often underdeveloped—first step for monitoring ecosystems (e.g., Spellerberg 1991; Elzinga et al. 1998; Olsen 1999). Given this consensus, I will focus here on attributes of objectives that are less common but play an important role in the ability to integrate science and management.

Management versus monitoring objectives. For the purpose of integrating science and management, it is important to distinguish between management and monitoring (or sampling) objectives. Management objectives should reflect the desired *condition, state,* or *dynamics* of the system. In contrast, monitoring objectives should reflect the *measurement* of the desired condition, state, or dynamics.

Management-oriented science is most efficiently accomplished when clearly defined management objectives exist and are accompanied by clearly defined monitoring objectives. Management objectives, expressed in terms of a desired future condition, provide a reference upon which the success of management actions or policies can be assessed. Monitoring objectives provide the measurement used to make that assessment.

State versus action objectives (ends versus means). Failing and Gregory (2003) identified confusion of the ends with the means as one of the most common mistakes in establishing biodiversity indicators. It is common for agencies and organizations to express objectives in terms of the means to achieve an end, rather than as the end itself. While this approach may be well suited for directing the actions of an organization, it does little for enabling better management decisions through science.

As a hypothetical example of the distinction, imagine having the responsibility of conducting a wildlife burn on 900 hectares of land. First, let's consider the scenario with an action objective such as: *Conduct a prescription burn on 900 hectares in shrub habitat for the purpose of reducing shrub density to improve wildlife habitat.*

In addition, consider that we will conduct our burn in three parts of 300 hectares each. As per standard protocols, a burn prescription will specify the ranges of temperature, wind, fuel moisture, etc. Suppose we complete our three burns and all three were within prescription and successfully reduced shrub cover. However, the burns were accomplished under slightly different conditions (e.g., hotter versus cooler conditions). The question is: which, if any, of these three burns was most successful? If the criterion of success is based merely on the action of conducting a burn within prescription, then all three were equally successful.

Let us reconsider this same example using an objective expressed as the desired state (condition) such as: *Using prescription fire, reduce the shrub cover on 900 hectares of shrub habitat from its current state of 56% cover to a desired state of 25% cover*.

Now let's consider the results in relation to this alternative objective. Based on our monitoring, we have determined that the three burns resulted in an overall shrub cover of 39, 11, and 24%, for burns one, two, and three, respectively. Based on this result, burn number two was clearly the most successful.

The scale and hierarchy of goals and objectives

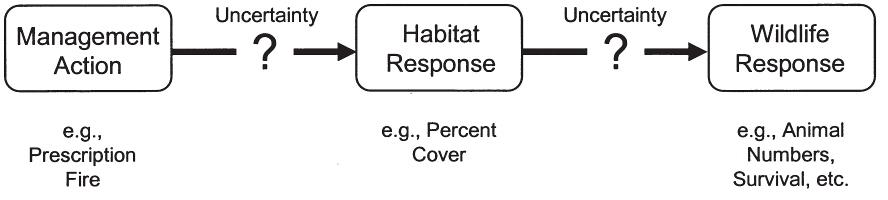
Our management and monitoring objectives are derived from, or are part of, a multitiered framework of NPS goals and objectives stated in the planning documents of each unit (National Park Service 2003). Considering how specific objectives fit within higher-order goals and how objectives themselves can reflect different scales is an important component of planning a partnership between science and management. Consider the example above where prescription fire is being used to improve wildlife habitat. The specific objective is to reduce shrub cover. Thus, in terms of designing a monitoring (science) program, one level of uncertainty is the effectiveness of the management action (prescription fire) on achieving the management objective (25% shrub cover). Yet, there is another level of uncertainty that has been, and is often, overlooked. If the purpose of this prescription fire was to improve wildlife habitat, then it seems that we would also want to know whether or not the targeted wildlife responded favorably to the reduced shrub cover. By not making these relationships explicit, these two different types of uncertainty are confounded. These two components also provide very different information for making decisions. The latter (i.e., wildlife response) is probably the most influential for setting the management objectives in the first place; whereas the former is most likely to influence how management is able to achieve that objective. Here again, a simple conceptual model (Figure 2) can help to identify these sources of uncertainty, and explicit expression of the hierarchy of goals and objectives will help in understanding how the specific objectives in a given context fit with the broader strategy of an organization. Biggs and Rogers (2003) provide an excellent example of such a hierarchy from Kruger National Park.

Management actions and options

In reference to adaptive management, Lee (1993) claimed that it embodies a simple imperative: management "policies are experiments; learn from them." The key element here for the integration of science and management is that management actions are considered analogous to treatments in an experimental context. All too often, research proposals are submitted with claims of being essential to management when the direct link is little more than a statement in a proposal indicating how "critical" the work is to management. While it may not be feasible in most circumstances to treat management actions in a fully experimental context (i.e., with randomized allocation of treatments), we can certainly improve the process of explicitly incorporating management actions into our study designs from the outset.

Thresholds. An additional consideration is whether our science program (e.g., monitoring) is proactive or reactive. For example, we can use science as part of the process to determine whether a management action is warranted by incorporating thresholds into our program. Thresholds can be used to express a condition under which management action is warranted or triggered or, alternatively, they can be used more simply to illuminate points of

Figure 2. A conceptual model for the uncertainties of the direct response of habitat to management and the indirect response of wildlife to the altered habitat.



assessment. Biggs and Rogers (2003) provide another excellent example of what they call "thresholds of potential concern." In the Greater Yellowstone Ecosystem, whitebark pine is considered a "keystone" species with roles ranging from a food source for grizzly bears to having an effect on snow accumulation. In recent decades whitebark pine stands have been decimated in areas of the Cascades and northern Rocky Mountains due to the introduction of an exotic fungus—white pine blister rust—as well as mountain pine beetles. Our specific monitoring objectives are intended to determine if white pine blister rust is increasing within the Greater Yellowstone Ecosystem, and whether or not the resulting mortality of whitebark pine is sufficient to warrant consideration of management intervention (e.g., active restoration)? Thus, we will proactively track the status and trends of blister rust infection. In this context, thresholds can be used to assess whether or not active management is warranted (Figure 3). If a decision is reached to implement active management in all or portions of the network, then reactive management can be initiated to compare alternative management actions toward achieving the management goals for this species.

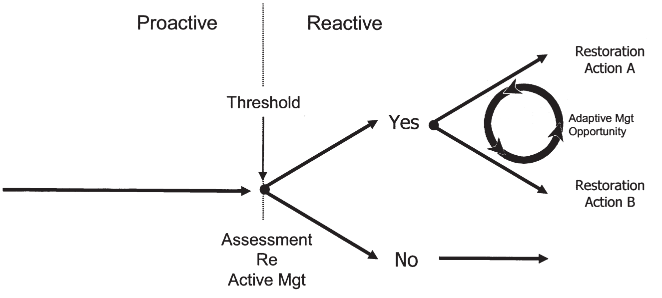


Figure 3. A conceptual model for monitoring whitebark pine health (e.g., infection level of blister rust and survival) in the Greater Yellowstone including a proactive component where a threshold is identified to assess whether or not active management is warranted and a reactive component in should a decision be made to initiate active management.

Incorporating learning into management decisions

The greatest science in the world will do us little good if it does not find its way into the management decision process. Our goal should be providing the right type of information, in the right form, to the right people, at the right time. Much of the discussion thus far has focused on the right type of information. Finding the right form is a different matter altogether. It is naïve to assume that the form in which information is distributed to the scientific community (e.g., technical reports and peer-reviewed journal articles) will be equally useful to managers. Scientific articles and reports may serve to establish the credibility of the information, but not the utility of the information. Effective transfer of information will not likely occur without consideration of the audience and the needs of that audience. It is a rare case that today's managers would have the time or the inclination to wade through myriad detailed statistics, models, and methods needed by the scientific community to establish the validity of the science. Rather, the manager is more likely to need a synthesis of that information that is concise, understandable, and applicable to the management context. An effective synthesis will likely only come from communication between scientists and managers.

Determining the right people and the right time is also a different matter. Providing a manager important new information about the effects of fire on an ecosystem three months after the fire management plan was due is not an effective way to incorporate learning into decisions. In contrast, knowing something about when decisions are made can be a great asset if information delivery is planned from the outset to coincide with when decisions are made. Clearly, communication between scientists and managers will shed some light on this issue, but I also believe another form of conceptual model can help to clarify this information. I believe that it can be helpful to map the decision space (Figure 4). Such a model can include processes or plans for which decisions are expected. It can also include relevant information about who the key players are for a given decision. Unfortunately, it will not likely include all of the decisions for which information would be useful, and so will not replace the need for communication.

Lastly is the process by which information is incorporated into the decision process itself. There are a wide variety of approaches ranging from formal mathematical procedures for deriving an optimal policy using discrete stochastic dynamic optimization (e.g., Kendall 2001) to scientists and managers simply sitting down at the table to discuss the implications of the science to management. What approach works best in a given situation will vary widely, and my argument here is not for one approach over another; however, I do argue that no matter which approach seems suitable for a particular context, it should be explicit and planned. Assuming that information will effectively find its way into the decision process on its own is kind of like assuming that the family vacation you planned on your own without input from your partner will go smoothly.

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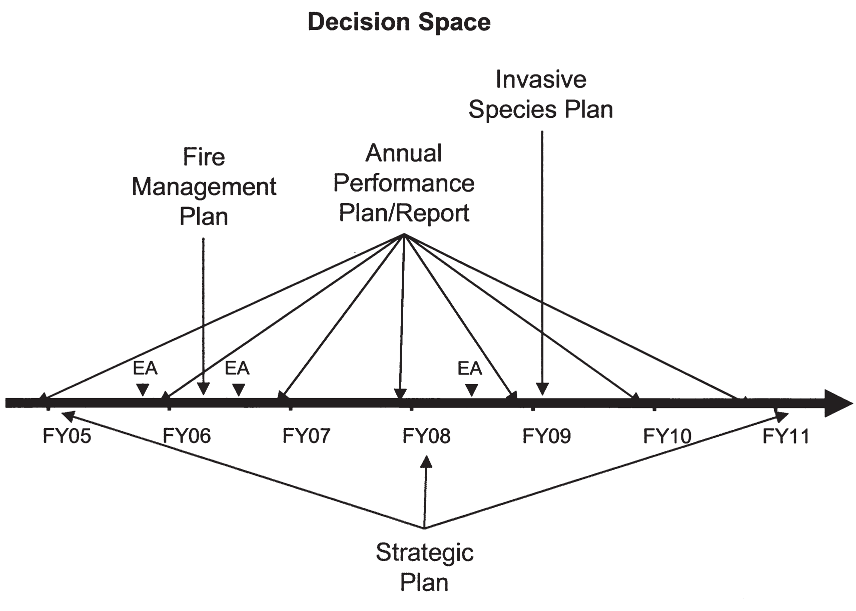
Figure 4. A conceptual model of the decision timing (e.g., plans likely to require decisions) for a national park.



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