Adaptive management for national parks: Considerations for an experimental approach

By Tony Prato

THE CONCEPT OF ADAPTIVE MANAGEMENT WAS DEVELOPED in the mid-1970s as a means to account for uncertainty in the way ecosystems respond to human intervention (Holling 1978; Walters 1996). Adaptive management postulates that "if human understanding of nature is imperfect, then human interactions with nature [e.g., management actions] should be experimental" (Lee 1993). Kohm and Franklin (1997) state that "adaptive management is the only logical approach under the circumstances of uncertainty and the continued accumulation of knowledge." Adaptive management improves understanding of ecosystem responses to human interventions, such as management actions, and promotes shared understanding of ecosystems by stakeholders, scientists, policymakers, and managers. The methods used to apply adaptive management to national parks are often site- and problem-specific (see examples below), which makes it difficult for park managers to use them in other park units. In this article, I propose a generic analytical framework for adaptively managing natural and cultural resources and visitors to national parks and other protected areas.

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Nature of adaptive management

Adaptive management is not management by objective with feedback, trial and error, or prediction and planning, although it can involve these elements. It is a form of integrated learning that acknowledges management outcomes can be surprising and unpredictable. This framework is appropriate when a manager can influence the state of an ecosystem (defined in terms of the attributes of interest) by implementing management actions, but is uncertain about whether those management actions alter the state of an ecosystem. A case in point is a park manager who wants to determine the optimal number of campsites to have or backcountry camping permits to issue in order to sustain desirable levels of plant diversity and backcountry user satisfaction. In this case the manager is able to control the number of campsites and permits, but is uncertain about how varying their number influences plant diversity and user satisfaction.

Adaptive management can be either passive or active. With passive adaptive management, a manager (1) formulates a predictive model of how a coupled natural-human system responds to management actions, (2) selects the best management actions based on model predictions, (3) implements and monitors those management actions, (4) uses monitoring results to revise the model, and (5) adjusts management actions based on the revised model. Advantages of passive adaptive management are that it is relatively simple to use and can be less expensive to apply than active adaptive management, depending on the sophistication of the monitoring applied. Disadvantages are that it does not produce statistically reliable information about the impacts of management actions on ecosystems because of the lack of experimental controls and replication or randomization of management actions.

Active and passive adaptive management embody the notion that managers cannot accurately predict the outcomes of management actions because of scientific, organizational, community, and political uncertainties. Active adaptive management uses experiments to test hypotheses about ecosystem states and maximizes the capacity of managers to learn about ecosystems and achieve their management goals. Because active adaptive management incorporates experimental controls and replication and randomization of management actions, it provides statistically reliable information about ecosystem responses to management actions that can be generalized to other areas. This is usually not the case with passive adaptive management. Active adaptive management requires major investments in research, monitoring, and modeling and has prerequisites that may not be satisfied (Prato and Fagre 2005).

Adaptive management is now employed in Banff National Park in Alberta, Canada, to develop a human use management strategy for the park (Parks Canada 2002). Elk and bison populations in Elk Island National Park in Alberta are managed through an adaptive landscape management approach. Federal and state agencies implementing the Interagency Bison Management Plan in the United States use adaptive management to test and validate ongoing strategies to reduce the risk of brucellosis transmission from bison to cattle outside Yellowstone National Park (Status Review Team 2005). In addition, it is used to manage snowmobile use in Yellowstone and Grand Teton national parks. In the lower Colorado River, which flows through Grand Canyon National Park, adaptive management improves understanding

Figure 1. In 1996, dam operators sharply increased water releases from the Glen Canyon Dam on the lower Colorado River. The adaptive management experiment increased water flows to 45,000 ft^3/s (1,260 m^3/s) for one week in an effort to rebuild sandbars using sand from existing channel eddy deposits. This successful experiment was repeated in 2004, pictured here.

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of how water releases from Glen Canyon Dam influence sediment, vegetation, fish and wildlife habitat, and other resources (fig. 1). All elements of the Comprehensive Everglades Restoration Plan incorporate an adaptive management approach designed to enhance the achievement of the plan's ecosystem restoration goals (fig. 2). The adaptive management applications in Yellowstone National Park are passive, and those in Grand Canyon and Everglades national parks are active.

User capacity example

In order to facilitate comprehension of the proposed adaptive management framework, I describe it using a simple, hypothetical example of user capacity for national parks. The National Park Service defines user capacity as the types and levels of public use that can be accommodated while sustaining desirable resource and social conditions (Rees et al. 2007). The user capacity example considers a national park manager who wants to determine the optimal number of backcountry campsites or camping permits needed to achieve or sustain desirable levels of plant diversity and user satisfaction. These management goals are assumed to be competitive, which means that increasing the number of campsites/permits decreases plant diversity and increases user satisfaction, and vice versa.

Determining the optimal number of campsites/permits requires the park manager to infer ecosystem states based on measurements or assessments of the impact of the number of campsites/permits on plant diversity and user satisfaction. Suppose the manager defines three ecosystem states for user capacity: (1) S_1 is high plant diversity and low user satisfaction; (2) S_2 is moderate plant diversity and moderate user satisfaction; and (3) S_3 is low plant diversity and high user satisfaction, where S_1 and S_3 are deemed undesirable states and S_2 is considered a desirable state. These ecosystem states can be defined based on user capacity standards like those employed in the VERP (Visitor Experience and Resource Protection), LAC (Limits of Acceptable Change), VIM (Visitor Impact Management), and VAMP (Visitor Activities Management Process) methods (Rees et al. 2007). In addition, suppose the manager selects three measurable resource or social conditions for plant diversity and user satisfaction: (1) C_1 is < 40% of potential plant diversity and > 75% of the users satisfied; (2)

Figure 2. Florida Everglades. The goal of the Comprehensive Everglades Restoration Plan is to capture freshwater that now flows unused to the ocean and the Gulf of Mexico and redirect it to natural areas that need it the most.

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C_2 is 40–80% of potential plant diversity and 40–75% of the users satisfied; and (3) C_3 is > 80% of potential plant diversity and < 40% of the users satisfied. These percentages are meant to be illustrative, not definitive. In practice, the manager can choose any number of ecosystem states and resource or social conditions. In general, ecosystem states refer to the status of an ecosystem with respect to certain desirable or undesirable properties (e.g., plant diversity and user satisfaction), and conditions refer to measured values of the properties.

The manager can make two kinds of errors in inferring an ecosystem state from a resource or social condition. First, he or she may decide the ecosystem state is desirable (S_2) when it is actually undesirable (S_1 or S_3), which can create a false sense of security regarding the state of the ecosystem with respect to user capacity. Second, he or she may decide the ecosystem state is undesirable (S_1 or S_3) when it is actually desirable (S_2), which can prompt the manager to implement a new management action when it is not needed, resulting in inefficient use of human and financial resources. Such errors may occur because (1) plant diversity and user satisfaction (and hence ecosystem states) vary over time and space in response to variability in environmental processes and other factors beyond the control of the manager, such as climate change; and (2) plant diversity and user satisfaction are measured with errors, which can mask the true values of these variables. The next two sections describe an analytical framework for implementing active adaptive management under risk and uncertainty.

Adaptive management under risk

In the risk case, the manager does not know for certain how management actions influence the ecosystem and is able to assign subjective prior (or initial) probabilities to ecosystem states. Hypotheses about the most likely ecosystem state are evaluated using the posterior probabilities of ecosystem states estimated by applying Bayes's rule to the prior probabilities of ecosystem states, experiments conducted to determine the ecosystem impacts of management actions, and other information (Prato 2005). In the context of resource management, Bayes's rule is a method of determining posterior probabilities of ecosystem states by updating the prior probabilities of those states using experimental information. This approach minimizes the aforementioned errors. Adaptive management for the risk case involves (1) determining the optimal number of campsites/permits in the first evaluation period (i.e., the number of consecutive years over which the adaptive management experiments are conducted), (2) implementing the optimal number of campsites/permits, and (3) adjusting the optimal number of campsites/permits in subsequent evaluation periods if justified based on monitoring information. The experiments for the user capacity example involve (1) selecting a random sample of backcountry campgrounds and users; (2) randomly assigning different numbers of campsites/permits to subsets of the sample (e.g., five campgrounds have 4 campsites, five campgrounds have 6 campsites, five campgrounds have 8 campsites, and five campgrounds have 10 campsites); (3) measuring plant diversity and user satisfaction for all subsets; and (4) determining posterior probabilities of ecosystem states for all subsets. The optimal number of campsites/permits is the number for the subset of the sample having the highest posterior probability of S_2, which is considered to be a desirable ecosystem state.

Adaptive management under uncertainty

The uncertainty case, in which there is uncertainty about the impacts management actions have on ecosystem states, assumes the

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Table 1. Hypothetical estimated net losses (L) from increasing the number of campsites/permits in backcountry campgrounds under three ecosystem states in the first evaluation period

Increase[a]	Ecosystem state: S_1[b]	S_2[c]	S_3[d]	Maximum net loss[e]
$A_1 = 2$	$L(A_1, S_1) = 8$	$L(A_1, S_2) = -5$	$L(A_1, S_3) = -7$	-7 (S_3)
$A_2 = 4$	$L(A_2, S_1) = 10$	$L(A_2, S_2) = -10$	$L(A_2, S_3) = -9$	-10 (S_2)
$A_3 = 6$	$L(A_3, S_1) = -20$	$L(A_3, S_2) = 5$	$L(A_3, S_3) = -18$	-20 (S_1)

[a]In number of additional campsites above four.
[b]High plant diversity and low user satisfaction.
[c]Moderate plant diversity and moderate user satisfaction.
[d]Low plant diversity and high user satisfaction.
[e]The state with the maximum net loss is shown in parentheses.

manager is unable to assign prior probabilities to ecosystem states, which rules out use of Bayes's rule. Three criteria can be used to determine the optimal number of campsites/permits under uncertainty: the safe minimum standard of conservation, the precautionary principle, and the minimax regret criterion. The safe minimum standard is designed "to preserve some minimum level or safe standard of a renewable resource unless the social costs of doing so are somehow intolerable, unacceptable or excessive" (Berrens et al. 1998). A difficulty with applying the safe minimum standard to park management is defining the minimum levels or safe standards of renewable resources.

The precautionary principle states that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations 1992). This principle is not particularly relevant to user capacity and other park management issues for which the ecological harm done to park resources by human activities can be reversed by limiting such activities. For example, in the case where user capacity is exceeded, the park manager can implement several management actions designed to rectify the problem.

The minimax regret criterion is suitable for assessing user capacity and other park management issues. A simplified, hypothetical example is used to demonstrate the application of the minimax regret criterion. In the example, the park manager determines the optimal number of campsites/permits, which is the number that minimizes the maximum net loss (L). The latter is defined as the costs in terms of losses in plant diversity minus the benefits in terms of gains in user satisfaction from increasing the number of campsites/permits. Net losses can be determined using an index of plant diversity and an index of backcountry user satisfaction. Suppose the manager determines the plant diversity index is 60 with six campsites and 80 with four campsites, and the user satisfaction index is 80 with four campsites and 90 with six campsites under S_3. Then suppose the manager determines that the net loss from adding two campsites (A_1) when the ecosystem state is S_3 is $L(A_1, S_3)$ = (plant diversity index with six campsites − plant diversity index with four campsites) + (user satisfaction index with six campsites − user satisfaction index with four campsites) = 60 − 80 + 90 − 80 = −10. A net loss of 10 and other hypothetical net losses in the first evaluation period are shown in table 1. The last column in the table shows the maximum net losses for the three increases in campsites/permits over the three ecosystem states, namely −1 with A_1, −10 with A_2, and −20 with A_3. Since the maximum net loss is lowest with A_1, the optimal increase in campsites/permits is two.

Adaptive management under uncertainty involves applying the minimax regret criterion to the net losses for consecutive evaluation periods. For example, if A_1 is the optimal increase in campsites/permits in the first evaluation period and A_2 is the optimal increase in campsites/permits in the second evaluation period, the manager should increase the number of campsites/permits from two to four. As with the risk case, the optimal number of campsites can vary over time with the uncertainty case.

Conclusion

I propose a generic analytical framework for implementing active adaptive management for national parks under risk and uncertainty. Implementation of the framework requires the park manager to specify the prior probabilities of ecosystem states and measure the ecosystem impacts of management actions in the risk case or determine the net losses for different management actions and ecosystem states in the uncertainty case. Although the framework is described using a simplified, hypothetical example of managing user capacity in national parks, the generic nature of the framework makes it suitable for adaptive management of a wide range of park management issues, such as protecting the habitats of threatened and endangered species in the vicinity of protected areas (e.g., Prato 2005, 2006) and alleviating multiple external threats to national park ecosystems (Prato 2004).

On the positive side, active adaptive management produces scientifically defensible information about ecosystem responses to management actions, which is often not the case for passive adaptive management. On the negative side, applying active adaptive management requires considerable information. Obtaining that information would require major investments in research, monitoring, and modeling, which may not be feasible for some park units. A park manager's decision to use passive adaptive management, active adaptive management, or neither should be based on a careful comparison of the benefits and costs of the approaches.

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