Adaptive Management of Watersheds and Related Resources

Byron K. Williams

Abstract

The concept of learning about natural resources through the practice of management has been around for several decades and by now is associated with the term adaptive management. The objectives of this paper are to offer a framework for adaptive management that includes an operational definition, a description of conditions in which it can be usefully applied, and a systematic approach to its application. Adaptive decisionmaking is described as iterative, learning-based management in two phases, each with its own mechanisms for feedback and adaptation. The linkages between traditional experimental science and adaptive management are discussed.

Keywords: adaptive management, conservation, decisionmaking, learning, natural resources, uncertainty

Introduction

Adaptive management (AM), a framework for learning about natural resources through management interventions, has been a part of natural resources thinking for several decades under the generic guise of learning-based management (Beverton and Holt 1957). Holling (1978) and Walters and Hilborn (1978) were the first to provide the name and conceptual framework for adaptive management of natural resources, and Walters (1986) gave a more complete technical treatment of adaptive decisionmaking. Lee (1993) then expanded the context for adaptive management in terms of its social and political dimensions. Because of these and other efforts, many in natural resources conservation now claim, often with only limited justification, that AM is the approach they commonly use in meeting their resource management responsibilities (Failing et al. 2004).

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The scientific and management literature documents considerable variation in the definition and framing of AM. However, almost all definitions incorporate the twin ideas of uncertainty as to the consequences of management and decisionmaking in the face of that uncertainty. A simple definition of AM that captures these essential features is "learning through the process of management itself, with adjustment of management actions based on what's learned." Even more succinctly, AM can be described as learning by doing and adapting based on what is learned. The key concepts in these definitions are learning (the improvement in understanding through time) and adaptation (the adjustment of management strategy through time as conditions evolve). The natural consequences of such an approach are to improve understanding of the resource system being managed and to improve resource management based on that improved understanding.

Framework for Adaptive Management

The context for learning-based resource management involves natural resources that respond to changing environmental conditions and management strategy, with management effectiveness constrained by a limited understanding about resource impacts. Uncertainty about management impacts often is tied to specific processes that control resource dynamics (e.g., reproduction, mortality, movement), vital rates that parameterize these processes, or linkages among processes across ecological or geographic scales. One consequence of this uncertainty is a potential for disagreement about the most appropriate management strategy.

Figure 1 shows a dynamic resource system that is subjected to management actions and fluctuating environmental conditions through time. Environmental conditions in the figure might include exogenous factors such as seasonal temperatures, precipitation, cloud cover, and light intensity that fluctuate through

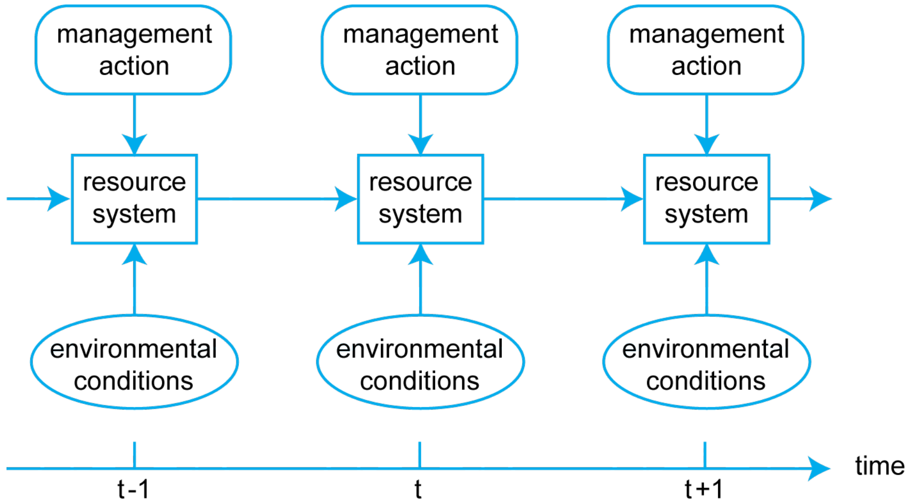

Figure 1. Dynamic resource system, with changes influenced by fluctuating environmental conditions and management actions. Management typically produces short-term returns (costs and (or) benefits) and longer-term changes in resource status.

time, inducing fluctuations in resource status and altering the processes that drive resource dynamics. Potential management actions can be of many different kinds, but they typically focus on resource inputs (e.g., fish stocking), outputs (e.g., water release), or processes (e.g., habitat alterations that affect reproductive success). Finally, resource states are seen as evolving through time, in response to changing environmental conditions and management actions. Management at any point in time is seen as potentially influencing resource dynamics from that time forward. A key feature of AM is uncertainty as to the magnitude and direction of resource changes induced by management actions.

Management interventions in AM are seen as experiments, with the tracking and assessment of resource responses providing experimental results on which to base future management. It is for this reason that AM often is described as "science-based" management. Science and decisionmaking play complementary roles in the overall enterprise, even though science in a context of AM inherits its value from its contribution to improving management. Thus, science supports management by providing information for decisionmaking; but management also supports science with interventions that are designed for scientific investigation. In fact, AM is defined by this bi-directional support with an overall goal of reducing uncertainty and improving management.

A great many (but not all) natural resources under Federal and State jurisdiction are subject to the kind of iterated decisionmaking illustrated in Figure 1. Examples might include agricultural and grazing lands, managed wetlands, ecosystems subjected to fire management, forested wildlife habitat, commercial fisheries, impounded hydrologic systems, and watersheds in a working landscape. The presence of uncertainty about management consequences complicates decisionmaking for these resources and creates the potential for disagreement and controversy among stakeholders.

Conditions That Warrant the Use of Adaptive Management

Not all decisions can or should be adaptive, and in fact several conditions must be met to justify an adaptive approach. First and most fundamentally, management through time is required, even though its effect is uncertain. That is, a problem must be important enough that management actions must be taken, though their consequences cannot be predicted with certainty.

A second condition is that clear and measurable objectives can be identified, by which to guide the decisionmaking process. The articulation of objectives plays a key role in AM, in performance evaluation as well as decisionmaking.

Third, there must be the flexibility to use learning to adjust management. Among other requirements are an acceptable range of management alternatives from which to select actions, and a management environment that is flexible enough to allow adaptations as understanding accumulates through time.

Fourth, there must be a potential to improve management performance by reducing uncertainty. It is the prospect of more efficient and effective decisionmaking that ultimately justifies AM. Conversely, an adaptive approach is not warranted if potential improvements in management are insufficient to justify the costs of acquiring the needed information.

A fifth condition is that monitoring can be used to reduce uncertainty. The analysis and assessment of monitoring data produce an understanding of system processes, and thus an opportunity to improve management. Without periodic monitoring of the appropriate resource attributes, the learning on which to base informed management adjustments is not possible.

Finally, most expositions on AM recognize the importance of a sustained commitment by stakeholders and managers. Stakeholders should be continuously and actively involved in an AM project, from the identification of its objectives and management alternatives to the expression of uncertainty and the collection and analysis of monitoring data (Lee 1999).

It should be clear from the foregoing that there are many problems for which adaptive management may not be a useful approach. On the other hand, there are many problems involving cooperative management of dynamic resources that may be usefully addressed with AM. Included in the latter are management issues involving ecological landscapes, hydrologic systems, and, notably, watersheds. In fact, fisheries, riverine systems, and other aquatic resources have been important focus areas for many years, largely because of the dynamic nature of these resources and the influence of management on them.

The sequence of activities shown in Figure 2 often is used to characterize AM. It is useful to think of the sequence as beginning with problem assessment, followed by planning, implementation, evaluation, and eventual reassessment in an ongoing cycle. Additional structure can be incorporated into this sequence by recognizing an embedded feedback loop of monitoring, evaluation, and management that focuses specifically on technical learning about the effects of management. The overall cycle, which may include multiple iterations of this imbedded loop, incorporates the potential for learning about the adaptive process itself through periodic problem reassessment, design, and implementation.

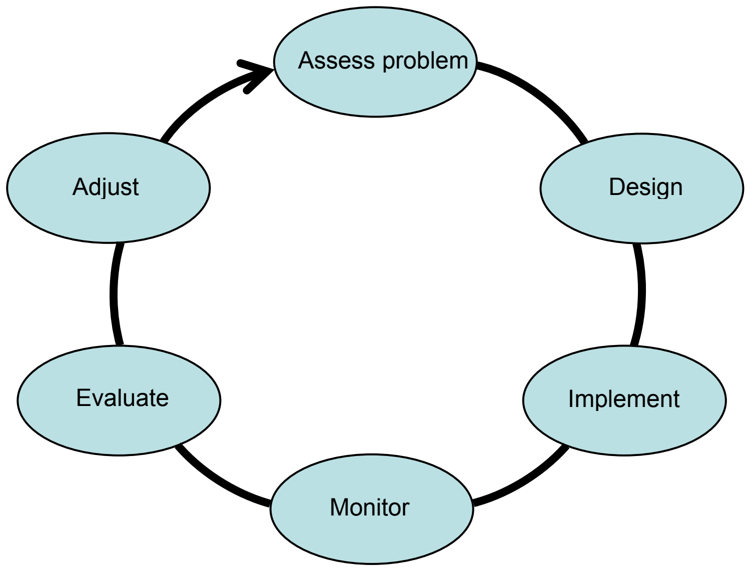

Figure 2. Diagram of the adaptive management process. It is convenient to think of the process as beginning with problem assessment and repeating the cycle as needed to improve resource understanding and management.

Adaptive Management Implementation

One way to describe the implementation of AM is in terms of a deliberative setup phase in which key components are put in place, and an iterative action phase in which they are linked together in a sequential decision process (Norton 2005, Williams et al. 2007). The action phase utilizes the elements of the deliberative phase in an ongoing cycle of learning about system structure and function and managing based on what is learned (Figure 3).

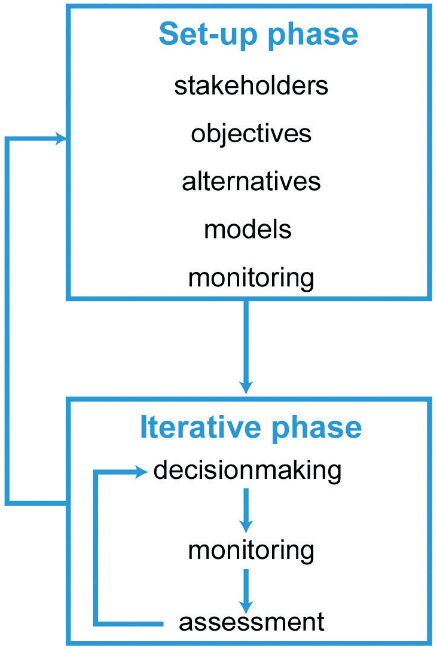

Figure 3. Two-phase implementation of adaptive management. In the deliberative setup phase, key elements of adaptive management are put in place. In the iterative action phase, these elements are folded into an ongoing process of decisionmaking, follow-up monitoring, and assessment of monitoring data. Adaptive management focuses on ecological understanding in the action phase and process learning in the deliberative phase through periodic re-assessment of process elements.

Deliberative phase

In the deliberative setup phase of the AM process, the components of AM are identified and periodically refined as needed. Key process elements include the following.

Stakeholder involvement

A key step in any AM application is to engage the appropriate stakeholders and ensure their ongoing involvement in the process (Wondolleck and Yaffe 2000). Of particular importance is the participation of stakeholders in assessing the resource problem and reaching agreement about its scope, objectives, and potential management actions. By defining the operating environment of an AM project, stakeholders directly influence both decisionmaking and the opportunity to learn.

Objectives

Objectives, resource status, and learning all influence the choice of management interventions in adaptive management. But objectives also play a crucial role in evaluating performance, reducing uncertainty, and improving management through time. Clear, measurable, and agreed-upon objectives are key to guiding decisions and assessing progress in achieving management success.

Management actions

Like any iterative decision process, adaptive decisionmaking involves the selection of an appropriate management action at each decision point, given the status of the resources being managed at that time. Resource managers and stakeholders, typically working with scientists, have the responsibility of identifying the potential actions from which this selection is made.

Predictions

Predictive models play an important role in AM by linking potential management actions to ecological consequences. One example is the use of models to help in the selection of management actions, through the comparison of management alternatives in terms of their anticipated costs, benefits, and resource consequences.

Predictive models also play a key role in representing uncertainty, with contrasting hypotheses about system structure and function imbedded in different models that are used to forecast resource changes through time. At any point, the available evidence will suggest differences in the adequacy of these models to represent resource dynamics. As evidence accumulates over time, the confidence placed in each model (and its associated hypothesis) evolves through a comparison of model predictions against monitoring data.

Monitoring plans

The learning that is at the heart of AM occurs through a comparison of predicted against observed responses. It is by means of these comparisons that one learns about resource dynamics and thus identifies the most appropriate hypotheses about resource processes and their responses to management. Through the tracking of system responses, well designed monitoring programs facilitate evaluation and learning. Monitoring is much more effective when it targets attributes for these purposes (Nichols and Williams 2006).

Action phase

The operational sequence of AM utilizes the elements identified in the deliberative phase to improve understanding and management (Figure 4). Key steps in the iterative process include the following.

Decisionmaking

At each decision point in the timeframe of an AM project, an action is chosen from the set of available management alternatives. Management objectives are used to guide this selection, given the state of the system and the level of understanding when the selection is made. It is the influence of reduced uncertainty (or increased understanding) on decisionmaking that renders the decision process adaptive.

Follow-up monitoring

Monitoring is used to track system behavior, in particular the responses to management through time. In the context of AM, monitoring is seen as an ongoing activity, producing data to evaluate management interventions, update measures of model confidence, and prioritize management options in the next time period.

Assessment

The information produced by monitoring promotes learning through the comparison of model predictions against estimates of actual responses. The comparison highlights the degree of coincidence between predicted and observed changes, which in turn serves as an indicator of model adequacy. Confidence increases for models that accurately predict change, and confidence decreases for models that are poor predictors of change.

Assessment also includes the comparison of management alternatives as to their projected costs, benefits, and resource impacts, for use in identifying management strategy itself. Finally, performance assessment, based on the comparison of desired against actual outcomes, includes the evaluation of management effectiveness and measurement of success in attaining management objectives.

Feedback

At any given time, the gain in understanding from monitoring and assessment is used to inform the selection of management actions. As understanding evolves, so too does the decisionmaking that is influenced by improved understanding. In this way, the iterative cycle of decisionmaking, monitoring, and assessment leads gradually to improved management as a consequence of improved understanding.

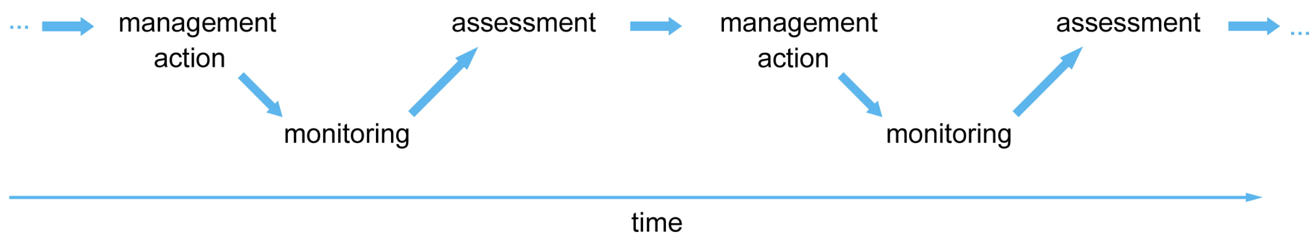

Figure 4. Action phase of adaptive management. Management actions are based on objectives, resource status, and understanding. Data from follow-up monitoring are used to assess impacts and update understanding. Results from assessment guide decisionmaking at the next decision point.

Double-Loop Learning

Adaptive decisionmaking provides an opportunity to learn about the adaptive process itself by periodic but less frequent recycling through the elements in the deliberative phase (Figure 3). The broader context of learning that recognizes process as well as technical learning is sometimes called "double-loop" learning (Argyris and Shon 1978, Salafsky et al. 2001).

The need to address process learning arises from the fact that stakeholder perspectives and values can shift as the adaptive process unfolds, as previously unanticipated patterns in resource dynamics require an adjustment of objectives, alternatives, and other elements of the process. In this sense, learning needs to focus on changes in institutional arrangements and stakeholder values as well as changes in the resource system. Because these process changes can themselves be a result of experience in pursuing objectives, it is useful to account for them as decisionmaking progresses through time. Indeed, understanding and tracking social and institutional relations and stakeholder perspectives can be as important as the resolution of technical issues about system structure and function (Williams 2006).

A well designed AM project provides the opportunity for learning at both the technical and process level, recognizing that technical and process learning often occur on different scales. Technical learning is promoted through the learning cycle in Figures 3 and 4 in a context of relatively short-term stationarity in objectives, alternatives, and uncertainty factors. Non-stationarity in these process factors is addressed over the longer term, through their periodic but less frequent assessment and adaptation.

Discussion

Adaptive management is described above as an iterative process that gradually leads to improved understanding through the use of management "experiments." The cycle begins with an assessment and framing of a management issue in which uncertainty is seen as limiting management effectiveness. It then proceeds through design, implementation, evaluation, and management adaptation, with problem reassessment that starts the cycle again (Figure 2). Beneficial consequences of this approach include the joint improvement of understanding and management through time, recognizing that the primary focus of AM is on long-term management, with science providing the information needed to improve management.

It is useful to contrast the "science-based" approach of AM against traditional scientific investigation, experimental science in particular. Perhaps surprisingly, with some minor renaming of the elements in Figure 2, the cycle of activities shown there also describes experimental science: the scientific process starts with identification of a research question, based on information and understanding accumulated up to the present. An experiment involving experimental treatments and alternative hypotheses about their impacts then is designed to address that question. This is followed by the actual conducting of the experiment in the field or laboratory, during which data are collected and recorded for analysis with, for example, analysis of variance procedures. The analytic results add to our edifice of understanding, but also generate new research questions that must be framed in terms of the new understanding, thereby starting the cycle again.

A few points are worth mentioning. First, the "experimentation" in AM is implemented with experimental treatments that are management interventions. This contrasts with experimental treatments in a context of classical experimental design, which may or may not have anything to do with management interventions.

Second, scientific experimentation and experimental design typically are described in terms of randomization, replication, and experimental controls, which allow for strong inferences based on experimental results (Gauch 2003). In contrast, experimental management often is missing some of these key features; for example, it often is not possible to randomize interventions or replicate them across the landscape. Thus, the inferences from the results often are not as strong as they might otherwise be under more rigorous experimental conditions.

Third, the inferential framework for experimental management differs somewhat from that of classical experiment design, largely because of a difference in focus. Thus, AM ultimately seeks to promote more informed management through learning, whereas traditional experimentation is oriented exclusively to the improvement of understanding. Scientific experimentation is concerned with contrasts among alternative hypotheses, as reflected in such measures as Type I and Type II error rates. In contrast, AM is more amenable to a decision-theoretic basis of inference, in which the inferential questions focus on which hypothesis can lead to the most effective management strategy.

Some in the scientific community might be concerned that AM, with its strong orientation to management, leaves little room for more basic and curiosity driven scientific investigation. But it is important to recognize that scientific investigation, whether basic or applied science, field or laboratory studies, or development of analysis and estimation protocols, contributes to the overall body of understanding on which all human activities, including AM, are based. Some of that large body of scientific investigation fits comfortably in the context of learning-based management and some does not, but AM is nevertheless a beneficiary, not least because of the very important role that basic science can play in helping to assess and frame the problems to be addressed with AM.

Adaptive management can and should utilize experience accumulated up to the present, whatever its source, in structuring a resource problem, identifying feasible management options, and resolving uncertainties about management impacts. The underlying idea is that a process of using management itself to reduce uncertainties can accelerate learning and lead more rapidly to informed management. But nothing in this process excludes the use of information collected through basic and curiosity-driven science. Just as AM can promote the integration of science and management to the benefit of each, so can it promote the integration of basic and applied science to the benefit of each.

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