Journal of Environmental Management 92 (2011) 1346–1353

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Adaptive management of natural resources—framework and issues

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ARTICLE INFO

Article history:
Received 23 September 2010
Accepted 16 October 2010
Available online 13 November 2010

Keywords:
Adaptive management
Decision making
Learning
Modeling
Monitoring
Natural resources
Uncertainty

ABSTRACT

Adaptive management, an approach for simultaneously managing and learning about natural resources, has been around for several decades. Interest in adaptive decision making has grown steadily over that time, and by now many in natural resources conservation claim that adaptive management is the approach they use in meeting their resource management responsibilities. Yet there remains considerable ambiguity about what adaptive management actually is, and how it is to be implemented by practitioners. The objective of this paper is to present a framework and conditions for adaptive decision making, and discuss some important challenges in its application. Adaptive management is described as a two-phase process of deliberative and iterative phases, which are implemented sequentially over the timeframe of an application. Key elements, processes, and issues in adaptive decision making are highlighted in terms of this framework. Special emphasis is given to the question of geographic scale, the difficulties presented by non-stationarity, and organizational challenges in implementing adaptive management.

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1. Introduction

Adaptive management, an approach for simultaneously managing and learning about natural resources, has been around for several decades. One of its earliest articulations in the natural resources literature was by Beverton and Holt (1957), who described adaptive decision making in fisheries without calling it adaptive management. A generation later Holling (1978) and Walters and Hilborn (1978) provided the name and conceptual framework for adaptive resources management, and later still Walters (1986) gave a more complete technical treatment of adaptive decision making. Lee's (1993) book expanded the context for adaptive management by providing a comprehensive exposition of its social and political dimensions. These pioneering efforts sparked an interest in adaptive management that has continued to grow up to the present time. Many in natural resources conservation now claim, sometimes inappropriately, that adaptive management is the approach they commonly use in meeting their resource management responsibilities (Failing et al., 2004).

The objective of this paper is to present a framework and definition for adaptive decision making, and to discuss some important challenges and opportunities for its application. Adaptive decision making is described in terms of a process with deliberative and iterative phases, with their sequential implementation over the timeframe of an application. In what follows the key elements and processes of adaptive decision making are highlighted and discussed in terms of this framework. Other important issues that are discussed include geographic and ecological scale, organizational concerns, and the need to account for non-stationarity.

2. Management situation

The management situation for adaptive management can be framed in terms of resources that are responsive to management interventions but subject to uncertainties about the impacts of those interventions. Applications of adaptive management typically involve the following general features (Fig. 1):

* The natural resource system being managed is dynamic, changing through time in response to environmental conditions and management actions that vary through time. These factors can influence resource status and the ecological processes by which resource changes are realized.
* Environmental variation is only partially predictable, and sometimes is unrecognizable. Variation in environmental conditions induces stochasticity in biological and ecological processes, which leads in turn to unpredictability in system behaviors.
* The resource system is subjected to periodic and potential management interventions that potentially vary over time. Management actions influence system behaviors either directly or indirectly, by altering system states such as resource size, or

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0301-4797/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.jenvman.2010.10.041

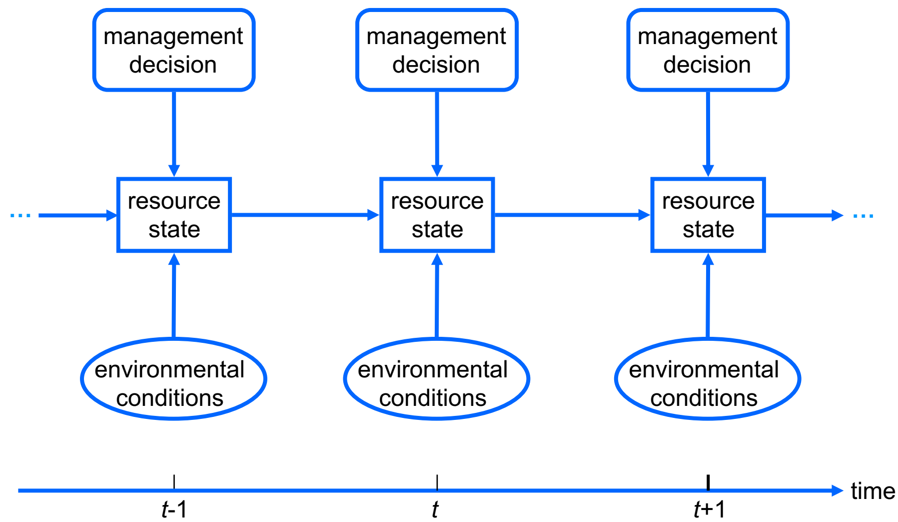

Fig. 1. Dynamic resource system, with changes influenced by fluctuating environmental conditions and management actions. Management typically has both immediate and longer-term consequences.

influencing ecological processes such as mortality and movement, or altering vital rates such as reproduction and recruitment rates.

* Effective management is limited by uncertainty about the nature of resource processes and the influence of management on them. Reducing this uncertainty can lead to improved management actions.

The fact that management, environmental variation, and resource status are expressed through time provides an opportunity to improve management by learning over the course of the management timeframe.

3. Adaptive management defined

The origin of adaptive management draws from many sources, including business (Senge, 1990), experimental science (Popper, 1968), systems theory (Ashworth, 1982), and industrial ecology (Allenby and Richards, 1994). In natural resources adaptive management simply refers to a structured process of learning by doing, and adapting based on what's learned (Walters and Holling, 1990). It is based on a recognition that resource systems typically are only partially understood, and there is value in tracking resource conditions and using what is learned as resources are being managed. Learning in adaptive management occurs through the informative practice of management itself, with management strategy adjusted as understanding improves.

A number of more formal definitions of adaptive management have been advanced. For example, the National Research Council (2004) defines adaptive management as:

> … flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process.

Published treatments of adaptive management variously emphasize experimentation (Lee, 1993), uncertainty (Williams and Johnson, 1995), science (Bormann et al., 2007), complexity (Allen and Gould, 1986; Ludwig et al., 1993), management adjustments (Lessard, 1998; Johnson, 1999; Rauscher, 1999), monitoring (Allen et al., 2001; Bormann et al., 2007), and stakeholder involvement (Norton, 2005). In all cases adaptive management is seen as a learning-based process involving the fundamental features of learning (the accretion of understanding through time) and adaptation (the adjustment of management through time based on this learning). The iterative application of learning and adaptation leads naturally to two salutary consequences: (1) improved understanding of the resource system and (2) improved management based on that understanding.

Adaptive decision making can be distinguished from a trial and error approach of "try something, and if it doesn't work try something else," involving an *ad hoc* revision of strategy through time when it is seen as failing. Adaptive management differs from trial and error by the structure used in adaptive decision making, involving the articulation of objectives, identification of management alternatives, predictions of management consequences, recognition of key uncertainties, and monitoring (National Research Council, 2004). In fact, adaptive management can itself be seen as an application of structured decision making (Williams et al., 2007), with special emphasis on iterative decision making in the face of uncertainty. Thus, learning through *ad hoc* trial and error is replaced with learning by careful design and testing (Walters, 1997).

The feedback between learning and decision making is a defining feature of adaptive management, with learning contributing to management by helping to inform decision making, and management contributing to learning through interventions that are useful for investigating resource processes and impacts. Management interventions in adaptive management can be viewed as experimental "treatments" that are implemented according to a management design, with the resulting learning seen as a means to an end, namely effective management, and not an end in itself (Walters, 1986). That is, the ultimate focus of adaptive decision making is on management, and the value of learning is inherited from its contribution to improved management.

4. Sources of uncertainty in adaptive management

Key concepts in defining adaptive management are how to characterize uncertainty and how to represent and account for it (Bormann and Kiester, 2004; Moore and Conroy, 2006). The published literature documents many sources and types of uncertainty (e.g., Burgman, 2005; Norton, 2005). At a minimum, four kinds of uncertainty can influence the management of natural resource systems:

- **Environmental variation** is often the most prevalent source of uncertainty, and is largely uncontrollable and possibly unrecognized. It often has a dominating influence on natural resource systems, through such factors as random variability in climate.
- **Partial observability** refers to uncertainty about resource status. An obvious expression of partial observability is the sampling variation that arises in resource monitoring.
- **Partial controllability** expresses the difference between the actions targeted by decision makers and the actions that are actually implemented. This uncertainty typically arises when indirect means (for example, regulations) are used to implement a targeted action (for example, setting a harvest or productivity rate), and it can lead to the possible misrepresentation of management interventions and thus to an inadequate accounting of their influence on resource behavior.
- **Structural or process uncertainty** concerns a lack of understanding (or lack of agreement) about the structure of biological and ecological relationships that drive resource dynamics.

Environmental variation, partial observability, partial controllability, and structural uncertainty all limit a decision maker's ability to make informed management decisions. Special emphasis is given in adaptive management to structural or process uncertainty, with adaptive decision making designed to reduce uncertainties about ecological relationships and the effect of management actions on them.

5. Components of adaptive management

A useful way to describe the implementation of adaptive management is in terms of a setup or deliberative phase during which key components are put in place, and an iterative phase in which the components are linked together in a sequential decision process (Williams et al., 2007). The setup phase involves a framing of the resource problem in terms of stakeholders, objectives, management alternatives, models, and monitoring protocols. The iterative phase utilizes these elements in an ongoing cycle of learning about system structures and functions, and managing based on what is learned (Fig. 2).

5.1. Stakeholder involvement

A key step in any adaptive management application is to engage the appropriate stakeholders and ensure their 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 (recognizing that differences of opinion about system responses may exist even with consensus on these issues).

By defining the context and environment of an adaptive management project, stakeholders directly influence both decision making and the opportunity to learn. But adaptive decision making is not prescriptive about the number and identity of stakeholders, or what their perspectives or values are. The breadth and extent of stakeholder involvement can vary greatly among projects, and both are influenced by the scale and complexity of the application.

Recognizing stakeholder interests and ensuring stakeholder involvement generally are required for learning-based management. Frequently, decision making is undertaken in the absence of an agreement even among managers about scope, objectives, and management alternatives. Without this agreement, management strategy is likely to be viewed as reflecting partisan objectives and /or inappropriate or unnecessary constraints on management. The prospects for failure increase dramatically in such a situation.

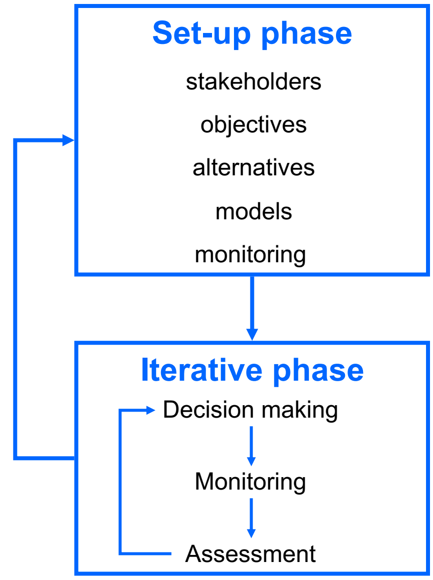

Fig. 2. Two-phase learning in adaptive management. Technical learning involves an iterative sequence of decision making, monitoring, and assessment. Process and institutional learning involves periodic reconsideration of the adaptive management setup elements.

5.2. Objectives

Objectives play a crucial role in evaluating performance, reducing uncertainty, and improving management through time. It is especially important to have clear, measurable, and agreed-upon objectives at the outset, to guide decision making and assess progress in achieving management success.

In resource management there often are multiple objectives. For example, one might seek to sustain species richness in a region while maximizing visitor use, supporting a harvest program for one or more species of wildlife, and allocating resources to these activities so as to minimize costs. In such a situation it is important to weigh different objectives in terms of their perceived importance, so as to facilitate the comparison and prioritization of management alternatives (Burgman, 2005).

5.3. Management actions

Like any iterative decision process, adaptive decision making involves the selection of management actions 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 a set of potential actions from which this selection is made.

The management alternatives in an adaptive management project constitute a key element in its operating environment, in that the strategy choices in an adaptive management project are constrained by the set of available options. If these options fail to span a reasonable range of management activities or fail to produce recognizable and distinct patterns in system responses, adaptive management will be unable to produce effective and informative strategies.

5.4. Models

Models that link potential management actions to resource consequences play an important role in virtually all applications of structured decision making, whether adaptive or otherwise. In order to make informed decisions, it is important to compare and contrast management alternatives in terms of their costs, benefits, and resource consequences. Models typically express benefits and costs in terms of management inputs, outputs, and outcomes through time. Importantly, they allow one to forecast the resource impacts of management.

Models also play a key role in representing uncertainty. In adaptive management, structural or process uncertainty is captured in contrasting hypotheses about system structure and function, with the hypotheses 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.

The challenges in expressing uncertainty with models should not be underestimated (Johnson et al., 2002). If the models fail to incorporate meaningful hypotheses, or fail to produce recognizable differences in projected resource dynamics, an adaptive approach may not produce useful and informative strategies. This argues for engaging managers, resource scientists, and other knowledgeable stakeholders in a thoughtful and deliberate construction of the models to be used in an application.

5.5. Monitoring plans

The learning that is at the heart of adaptive management occurs through a comparison of model-based predictions against observed responses. It is by means of these comparisons that one learns about resource dynamics, and thus confirms the most appropriate hypotheses about resource processes and their responses to management. By tracking useful measures of system response, well-designed monitoring programs facilitate evaluation and learning.

In general, monitoring in adaptive management provides data for four key purposes: (i) to evaluate progress toward achieving objectives; (ii) to determine resource status, in order to identify appropriate management actions; (iii) to increase understanding of resource dynamics via the comparison of predictions against survey data; and (iv) to develop and refine models of resource dynamics as needed and appropriate. Monitoring is much more efficient and effective to the extent that it focuses on these purposes.

Monitoring in adaptive management inherits its focus and design from the larger management context of which it is a part. Simply put, the value of monitoring is derived from its contribution to adaptive decision making, and monitoring efforts should be designed with that goal in mind (Nichols and Williams, 2006).

6. Iterative learning cycle

The operational sequence of adaptive management utilizes the elements discussed above in an iterative decision process to improve understanding and management (Fig. 3). Key steps in the iteration are described below.

6.1. Decision making

At each decision point in the timeframe of an adaptive management 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. The appropriate action is likely to change through time, as understanding evolves and the resource system responds to environmental conditions and management actions. That is, management is adjusted in response to both changing resource status and learning. It is the influence of reduced uncertainty (or increased understanding) that renders the decision process adaptive.

There are many ways to select management actions. For example, formal optimization methods can be used to choose an option that best accounts for current and future consequences (Lubow, 1997; Williams, 1996, 2001, 2009). Alternatively, less computation-intensive procedures can be used to produce suboptimal (but in many cases quite acceptable) management strategies. In many instances decision analysis techniques (Walters and Green, 1997; Peterman and Peters, 1998) can be used to compare and contrast time-specific options. Of course, one sometimes can rely on less formal approaches or common sense to identify acceptable strategies. Irrespective of the approach, however, adaptive decision making is driven by management objectives and informed by resource status and process understanding.

6.2. Follow-up monitoring

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

6.2.1. Assessment

The information produced by monitoring folds into decision making, performance evaluation, and learning. For example, the comparison of model predictions against estimates of actual responses is a key element of learning, with the degree of

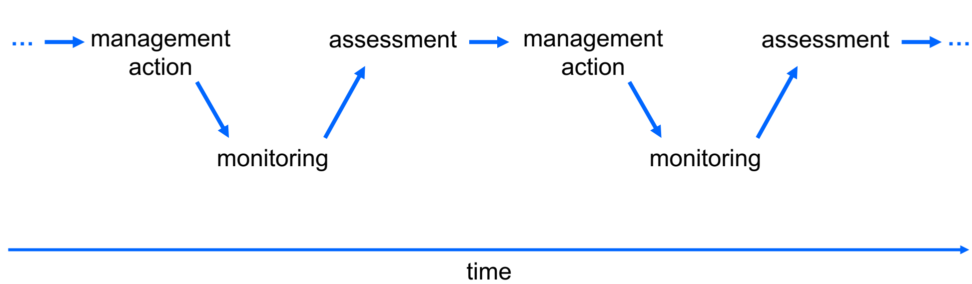

Fig. 3. Iterative phase of adaptive management. Management actions are based on objectives, resource status, and understanding. Data from follow-up monitoring are used to assess impacts and update understanding. Results from assessment guide decision making at the next decision point.

coincidence between predicted and observed changes serving as an indicator of model adequacy. Confidence is increased in models that accurately predict change, and confidence decreases for models that are poor predictors of change. In this way evidence accumulates over time for the most appropriate hypothesis about resource dynamics.

As important as it is, learning is not the only role played by analysis and assessment in adaptive management. Assessment of desired against actual outcomes can be used to evaluate the effectiveness of management and measure its success in attaining management objectives. In addition, comparisons of management alternatives as to their projected costs, benefits, and resource impacts contribute importantly in the identification of management actions.

6.3. 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 decision making that is influenced by improved understanding. In this way, the iterative cycle of decision making, monitoring, and assessment leads gradually to improved management as a consequence of improved understanding.

It is convenient (but not required) to think of the iterative management/learning cycle in Fig. 3 as starting with management, followed by post-decision monitoring, then assessment of monitoring data, and feedback of new knowledge into future decision making. This sequence of activities is repeated over the course of an application, during which management actions are periodically adjusted based on what is learned.

7. Forms of adaptive decision making

Several variants of adaptive management are possible. For example, it may be that a biological community in contiguous space is to be managed over some timeframe, with interventions over the whole community that are designed to influence biological diversity. In such a situation a single action is applied uniformly at each decision point in the timeframe. In the absence of any potential for spatial replication, one can implement different actions through time, with learning-based on a temporal comparison of impacts.

Alternatively, the community might consist of metapopulations at several disjunct sites, with management actions taken at only one location at a time. Under these circumstances, information accrued at a particular site can be used to inform decisions taken at other sites at a later time (Williams et al., 2002).

Yet another variation has different treatments applied simultaneously at different sites, in the spirit of experimental design and management. For example, one might use simultaneous interventions on different management units in different locations. Then it becomes possible to compare the effect of one intervention on a group of management units against a different intervention on other units. Such a comparison is amenable to standard statistical treatments, and thus can contribute to informed management.

A special case of adaptive management considers the management alternatives themselves to be hypotheses. In this instance each alternative is seen as a hypothesis about the effectiveness of the action, much in the way that hypotheses in designed experiments are expressed in terms of responses to experimental treatments. The emphasis here is restricted to system responses to management, in the absence of any additional focus on improved understanding of the ecological processes through which those responses are registered.

These approaches can be illustrated with an example. Consider the alternatives of clear-cutting, thinning, and selective cutting, which can be seen as hypotheses about the appropriate way to manage a forest. A choice of one of the alternatives sets up an "experiment," with evidence that confirms or disconfirms the intervention as an appropriate management action. If the system response is as expected in meeting objectives, the experiment (intervention) is viewed as successful and the result is held to support its continued use. A response differing from what was expected suggests that the intervention should be rejected in favor of another. The problem, of course, is that there always is uncertainty about system responses to management interventions, and predictions about the responses must somehow account for those uncertainties. Absence of a mechanism for learning-based on the comparison of alternative predictions against observed evidence, this approach can easily become little more than trial and error management.

One way to strengthen inferences is to use simultaneous interventions on different management units in the spirit of experimental design, taking advantage of randomization, replication and controls when possible. Another is to frame the opposing hypotheses more generically, so that any particular intervention can be broadly informative about all the hypotheses. Then monitoring data and predictions for each alternative can be used to update one's confidence in the alternatives through time. A natural method is to update the confidence values at each decision point based on a comparison of predicted responses against post-decision monitoring data (Williams et al., 2002). In this way the confidence values can evolve through time, increasing for alternatives that are supported by the data and decreasing for alternatives that are not. The change in the confidence values then becomes a measure of learning over time, leading gradually to a recognition of the most appropriate intervention.

Finally, a key distinction is often made between "passive" and "active" approaches to adaptive management (Salafsky et al., 2001; Bormann et al., 1996; Schreiber et al., 2004). Though there is considerable variability in the use of these terms, in general they are distinguished by the way uncertainty and learning are recognized and treated. As suggested by the wording, active adaptive management actively pursues the reduction of uncertainty through management interventions, whereas passive adaptive management focuses on management objectives, with learning an unintended but useful by-product of decision making (Walters, 1986). In practice the key difference between passive and active adaptive management is the degree to which their objectives emphasize the reduction of uncertainty (Williams, 2011).

8. Double-loop learning

Adaptive decision making provides an opportunity to learn not only about ecological processes, but also about the decision process itself. Learning about non-technical components of the decision making process is promoted by periodic but less frequent recycling through the elements in the setup phase (Fig. 2), with adjustment as needed to account for evolving stakeholder perspectives and institutional arrangements. The broader context of learning that recognizes uncertainty about these elements as well as technical uncertainty is sometimes called "double-loop" learning (Argyris and Shon, 1978; Salafsky et al., 2001).

In many applications of adaptive management, both kinds of learning are of key importance. It sometimes is as important to understand and track social and institutional relations and stakeholder perspectives as it is to resolve technical issues about system structure and process (Williams, 2006a,b). Although a key motivation of an adaptive approach is to improve resource management by reducing structural uncertainty, its success can be impeded by a failure to adapt to social and institutional changes that inevitably occur over time. Because these changes can themselves be a result of early successes in achieving objectives, it is important to recognize and if possible account for them as decision making progresses through time.

The need to better understand and characterize potential changes in the elements of adaptive management often becomes more pressing as adaptive management rolls forward through time. Stakeholder perspectives and values can shift as the adaptive process unfolds and exposes previously unanticipated patterns in resource dynamics and changes in stakeholder values, necessitating an adjustment of objectives, alternatives, and other process. In this sense, learning can focus on changes in institutional arrangements and stakeholder values as well as changes in the resource system.

A well-designed project provides the opportunity for learning at both levels, recognizing that learning often occurs on different time scales. Thus, the technical learning in Fig. 3 occurs in a context of relatively short-term stationarity in objectives, alternatives, and predictive models. On the other hand, learning about the decision process itself occurs through periodic but less frequent assessment of these factors as they evolve in response to management actions and environmental conditions. Learning at both levels can become problematic if the frequency of process adaptation approximates that of technical adaptation.

9. Geographic scale

Adaptive management is most visibly associated with big picture applications with a high degree of complexity. Putative examples that often are described in terms of adaptive management include:

- river management (Columbia, Platte, and Missouri Rivers (Quigley and Arbelbide, 1997; Levine, 2004; Williams, 2006a,b; Wissmar and Bisson, 2003));
- regional forest management (Rapp, 2008; Reeves et al., 2006);
- continental waterfowl harvest management (Williams and Johnson, 1995; Williams, 2006a,b);
- commercial fisheries (Hilborn, 1992; Conover and Munch, 2002);
- broad-scale habitat management (National Ecological Assessment Team, 2006);
- pest management in forested ecosystems (Shea et al., 2002); and
- regional water management (Glen Canyon (Melis et al., 2006; U.S. Geological Survey, 2008), Everglades (Holling et al., 1994; CERP Adaptive Management Steering Committee and Writing Team, 2006)).

Ecosystems at this scale involve economic, institutional, and ecological linkages across large landscapes with high degrees of heterogeneity. One implication is that they are highly likely to respond in unanticipated ways to variable environmental conditions and management practices. Because large ecosystems are so susceptible to surprise, adaptive management seems especially appropriate. The importance and high visibility of such projects have led many to believe that adaptive management only applies to large-scale, highly complex problems.

However, adaptive decision making as described here applies equally well to local issues, as long as the basic conditions are met (see Williams et al. (2007) for examples). There likely are many more potential applications of adaptive management at more localized scales, not only because there is a preponderance of such problems but also because they often can be more easily framed, key uncertainties can be more readily identified, and stakeholder involvement can be more easily facilitated (McConnaha and Paquet, 1996). Irrespective of scale, the key issues in deciding to use adaptive management are whether there is substantial uncertainty about the impacts on management, whether there is a realistic expectation of reducing uncertainty, and whether that reduction can be expected to improve management.

10. Systemic resource changes over time

Most of the theory and application of adaptive management has been framed, often implicitly, on an assumption that the structural features of the resource system and the underlying environment are dynamically stable over the management timeframe. Thus, uncontrolled resource fluctuations are thought to exhibit little or no systematic change in directionality or range of variation. A generic model for adaptive management assumes that resource dynamics at any given time are influenced by the current state of the resource, the current environmental conditions to which it is subjected, and the management action taken at that time (Fig. 1). The assessment of future resource behaviors in response to current actions builds on an assumption of dynamic resource and environmental stability.

A key complication arises with evolving environmental conditions and the ecological processes influenced by them. The most obvious example is climate change, in which the environment is seen as changing directionally over an extended timeframe. Many large-scale issues currently facing resource managers are tied to directional change in the resource environment, as with long-term decreases in average precipitation or increases in the range of ambient temperatures. In addition, shorter-duration directional changes in anthropogenic and other environmental factors also can be important. The net effect of these changes is to induce directionality in resource behaviors, i.e., to generate non-stationary resource dynamics. This presents new complications and challenges in the formulation of forward-looking strategies for natural resources.

The challenges become especially difficult for a learning-based approach like adaptive management, because the targets of learning, namely the ecological processes that determine resource change, are themselves evolving. One way to address this non-stationarity is to carefully track and even model the environmental drivers of change, using trends in environmental conditions to account for inherited changes in temporal resource patterns. Another is to seek limited timeframes over which resource dynamics are largely stationary, so that learning-based management can be effective. Yet another is to develop scenarios of directional change that are based on assumed patterns of directionality, with management strategy identified for each scenario and adaptive decision making accounting for uncertainty about which scenario (and therefore which strategy) is the most appropriate.

The point here is that non-stationarity is a new and serious challenge to adaptive decision making, one that requires new approaches that go beyond the standard ways of framing and addressing learning-based management. At a minimum it is necessary to look for directional trends in environmental conditions and resource dynamics, and consider ways to accommodate them when they are identified.

11. Discussion

At the heart of adaptive decision making is the recognition of competing hypotheses about resource dynamics, along with an assessment of these hypotheses with monitoring data. It is noteworthy that these same features also characterize scientific investigation. Thus, both involve (i) identification of competing hypotheses to explain observed pattern or process; (ii) the use of models imbedding these hypotheses to predict responses to experimental treatments; (iii) monitoring of indictors of actual responses; and (iv) the comparison of actual vs predicted responses to produce improved understanding (Williams, 1997; Nichols and Williams, 2006). This overlap of activities is the primary reason that adaptive management is so often referred to as a science-based approach to managing natural resources. Of course, a key difference between scientific investigation and adaptive decision making is that the treatments in adaptive management are management interventions, chosen to achieve management objectives as well as learning.

Many observers think that the major challenges facing adaptive management are fundamentally institutional rather than technical (Stankey et al., 2005). Institutions are built on major premises and long-held beliefs that are deeply imbedded in educational systems, laws, policies, and norms of professional behavior (Miller, 1999). There is a natural tension between the tendency of large, long-standing organizations to maintain a strong institutional framework for thinking and decision making, and the need in adaptive management for an open, flexible approach that recognizes alternative perspectives, embraces uncertainty, and utilizes participative decision making (Gunderson, 1999).

Structuring a learning-based adaptive organization can be handicapped by a pervasive belief that adaptive management does not constitute a significant departure from the past, and involves little more than occasionally changing management actions (Stankey and Clark, 2006). One consequence is that little attention is given to the institutional barriers to its implementation, and little effort is expended on redesigning organizational structures and processes to accommodate an adaptive style of management. At a minimum, it is necessary to rethink the notions of risk and risk aversion, promote conditions that encourage, reward, and sustain learning by individuals, and build capacity for adaptive planning and management.

It should be recognized that not every natural resource problem is amenable to adaptive management. For example, a non-adaptive management is reasonable if there is little uncertainty about what management actions to take and what outcomes to expect, or there is no way to develop an effective monitoring program, or there is no mechanism for feedback of monitoring and assessment into management strategy. A successful application of adaptive management should be anticipated only when the requirements for its implementation can be met (Williams et al., 2007); otherwise, expert judgment or other approaches can be applied. However, it is worth keeping in mind that resource systems are never fully understood, and there is always the possibility of unanticipated impacts of management strategy. Even if non-adaptive management is used, it is smart to actively engage stakeholders and sustain enough flexibility in management practice to allow for adaptation when the need becomes obvious.

For many important problems, adaptive management holds great promise in reducing the uncertainties that limit effective management of natural resources. Indeed, utilizing management itself in an experimental context may in many instances be the only feasible way to gain the understanding needed to improve management. In concept, adaptive management is neither conceptually complex nor operationally intricate. However, it does require users to acknowledge and account for uncertainty, and sustain an operating environment that allows for its reduction through careful planning, evaluation, and learning. The up-front costs associated with these activities are compensated by more informative and collaborative resource management over the long term.

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