Adaptive management is a systematic approach for improving resource management by learning from management outcomes (1). Its origin can be traced back to ideas of scientific management pioneered by Frederick Taylor in the early 1900s (2,3). Various perspectives on adaptive management are rooted in parallel concepts found in business (total quality management and learning organizations [4]), experimental science (hypothesis testing [5]), systems theory (feedback control [6]), and industrial ecology (7). The concept has attracted attention as a means of linking learning with policy and implementation (8,9). Although the idea of learning from experience and modifying subsequent behavior in light of that experience has long been reported in the literature, the specific idea of adaptive management as a strategy for natural resource management can be traced to the seminal work of Holling (10), Walters (11), and Lee (12).

Adaptive management as described here is infrequently implemented, even though many resource planning documents call for it and numerous resource managers refer to it (13). It is thought by many that merely by monitoring activities and occasionally changing them, one is doing adaptive management. Contrary to this commonly held belief, adaptive management is much more than simply tracking and changing management direction in the face of failed policies, and, in fact, such a tactic could actually be maladaptive (14). An adaptive approach involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions (15). Adaptive management focuses on learning and adapting, through partnerships of managers, scientists, and other stakeholders who learn together how to create and maintain sustainable resource systems (3).

The purpose of this technical guide is to present an operational definition of adaptive management, identify the conditions in which adaptive management should be considered, and describe the process of using adaptive management for managing natural resources. The guide is not an exhaustive discussion of adaptive management, nor does it include detailed specifications for individual projects. However, it should aid both U.S. Department of Interior (DOI) managers and practitioners in determining when and how to apply adaptive management.

Examples of decision making in natural resource management include the control of water releases from a dam, direct manipulation of plant or animal populations through harvesting, stocking, or transplanting, and manipulations of ecosystems through chemical or physical changes to habitats.

1.1. Decision Making and Natural Resource Management

A context for resource management involves a decision making environment characterized by multiple (often competing) management objectives, constrained management authorities and capabilities, dynamic ecological and physical systems, and uncertain responses to management actions. Management thus involves not only predicting how ecological or physical systems are likely to respond to interventions, but also identifying what management options are available, what outcomes are desired, how much risk can be tolerated, and how best to choose among a set of alternative actions. The challenge confronting managers is to make "good" decisions in this complex environment, recognizing that the quality of decision making in the face of uncertainty should be judged by the decision making process as well as progress towards desired outcomes.

A common problem in natural resources management involves a temporal sequence of decisions, in which the best action at each decision point depends on the state of the managed system. Because management actions at each point in time can influence change in the resource system from that time forward, the goal of management is to prescribe objective-driven strategies that account for both the current and future impacts of decisions. A key issue is how best to choose management actions, recognizing that the most appropriate management strategy is obscured by limited understanding.

Often the uncertainty about management impacts is expressed as disagreements among stakeholders who have differing views about the direction and magnitude of resource change in response to management. An adaptive approach explicitly articulates these viewpoints, incorporates them into the decision making process, and uses management itself to help identify the most appropriate view about resource dynamics. In this way, understanding of the resource can be enhanced over time, and management can be improved.

Examples of this kind of decision problem include the control of water releases from a dam, direct manipulation of plant or animal populations through harvesting, stocking, or transplanting, and manipulations of ecosystems through chemical or physical changes to habitats.

The following management issues exemplify sequential decision making in natural resources in the face of uncertainty:

• In a newly established meta-population of wolves, how many animals (if any) should be relocated periodically to maximize the probability that the meta-population will persist over the long term?

• What amount and timing of water release from a dam will maintain downstream water quality, water quantity, and living resources, including people and communities?

• How can an area be managed to minimize the impacts of recreational use on flora and fauna?

• When and how much should water levels be raised or lowered in an impoundment to maximize abundance and availability of invertebrates for foraging shorebirds?

• How can plant communities in an area be managed so as to protect and sustain archeological resources in the area at minimum cost?

• How much forest should be cut each year as part of a pine regeneration program to maximize old-growth pine for use by red-cockaded woodpeckers?

• How can fuel loads be decreased while minimizing effects on forested ecosystems?

• Should annual hunting-season regulations be restrictive or moderate to maximize the longterm cumulative harvest of mallards?

• How much and how often should herbicide be applied to minimize the proliferation of the invasive plant hydrilla in a group of southern lakes?

• In what order should patches of isolated bull trout habitat be reconnected in a network of tributaries to maximize the probability of population persistence while minimizing costs?

• When and where should prescribed burns be used in a collection of management units to maximize the probability that Florida scrub-jays will persist at a refuge over the long term?

Management of problems like these increasingly involves a systems approach with explicit and agreed-upon objectives, management alternatives, and analytical approaches that can identify the most appropriate management strategies. Adaptive management exemplifies such an approach; however, its focus is not only on making good decisions in the present, but also on gaining experience and knowledge so that future management decisions can be improved.

Adaptive management as an example of structured decision making

The move toward accountability and explicitness in natural resource management has led to a growing need for a more structured approach to decision making. Improved clarity about key elements in a decision making process can help decision makers focus attention on what, why, and how actions will be taken. Activities in a structured approach to decision making include the following:

• Engaging the relevant stakeholders in the decision making process

• Identifying the problem to be addressed

• Specifying objectives and tradeoffs that capture the values of stakeholders

• Identifying the range of decision alternatives from which actions are to be selected

• Specifying assumptions about resource structures and functions

• Projecting the consequences of alternative actions

• Identifying key uncertainties

• Measuring risk tolerance for potential consequences of decisions

• Accounting for future impacts of present decisions

• Accounting for legal guidelines and constraints

In the ensuing chapters it will be clear that adaptive management is itself a structured approach to decision making, in that it includes the key elements listed above. The distinguishing features of adaptive management are its emphasis on sequential decision making in the face of uncertainty and the opportunity for improved manage-

ment as learning about system processes accumulates over time.

Embracing uncertainty

Making a sequence of good management decisions is more difficult in the presence of uncertainty, an inherent and pervasive feature of managing ecological systems (16,17). Uncertainties arise with incomplete control of management actions, errors in measurement and sampling variation, environmental variability, and an incomplete understanding of system dynamics (see Section 5.2). These uncertainties potentially degrade management performance and contribute to acrimony in the decision making process.

Perhaps not surprisingly, managers have sometimes been reluctant to acknowledge uncertainty in environmental assessments and management strategies (18). Often there is a perception that asserting certainty as to management impacts is more convincing, and acknowledging uncertainty increases the likelihood that recommended actions will be ignored. Acknowledgement of uncertain management outcomes is sometimes seen as an invitation for confrontation among different interest groups, resulting in an inability to reach timely agreement on a proposed action.

Adaptive management forces stakeholders to confront unresolved uncertainties that can significantly influence management performance. An adaptive approach provides a framework for making good decisions in the face of critical uncertainties, and a formal process for reducing uncertainties so that management performance can be improved over time.

1.2. Operational Definition of Adaptive Management

For the U.S. Department of the Interior to effectively implement adaptive management in a consistent and coherent manner across all bureaus, an operational definition is needed that will be applicable for all of DOI. The definition used in this technical guide is adopted from the National Research Council (19):

Adaptive management [is a decision process that] promotes 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. Adaptive management also recognizes the importance of natural var ability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.

This definition gives special emphasis to uncertainty about management impacts, iterative learning to reduce uncertainty, and improved management as a result of learning. Key points in the definition are discussed in more detail below:

Adaptive management openly acknowledges uncertainty about how ecological systems function and how they respond to management actions (20,21). However, adaptive management is not a random trial-and-error process. Instead, it involves formulating the resource problem, developing conceptual models based on specific assumptions about the structure and function of the resource system, and identifying actions that might be used to resolve the problem. Through the monitoring of outcomes following management interventions, adaptive management promotes improved understanding about which actions work, and why.

Adaptive management is designed to improve understanding of how a system works, so as to achieve management objectives (20,21). Models are used in adaptive management to embed hypotheses about system behaviors and enable managers to predict the impacts of their activities. These predictions are the basis for learning later on. Once activities are implemented, the testing of underlying model assumptions against monitoring data provides the foundation for learning and the improvement of management based on what is learned.

Adaptive management is about taking action pursuant to desired outcomes (21). In adaptive management, the outcomes of decisions, assessed through followup monitoring, are compared against explicit predictions of those outcomes (20), with the comparative results fed back into decision making to produce more effective decision making (11,22,23,24). Actual and expected results can differ for many reasons: underlying assumptions are wrong, actions are poorly executed, environmental conditions have changed, monitoring is inadequate, or some combination of these problems. An adaptive approach helps isolate inadequacies in a management application, allowing adjustments to be made and management to be improved.

Adaptive management requires the participation of stakeholders. Stakeholders include people and organizations who use, influence, and have an interest, or "stake," in a given resource (25). Stakeholders should be involved early in the adaptive management cycle, to help assess the problem and design activities to solve it. Stakeholders also can help to implement and monitor those activities, and participate in the evaluation of results. Involvement

of stakeholders from the beginning increases management effectiveness and the likelihood of achieving agreed-upon outcomes (25).

There are many definitions in the literature on adaptive management, but a common theme shared by them all is that adaptive management is a learning-based process (26). The definition used in this guide was chosen because it emphasizes the use of learning to improve management decisions and because it is germane to resource management in DOI.The sequence of activities shown in Fig. 1.1 is often used to characterize adaptive management. Additional structure can be incorporated into this sequence, by recognizing an embedded feedback loop of monitoring, evaluation, and management adjust- ments that focuses specifically on learning about the impacts of management. Multiple iterations of this loop may occur within each iteration of the overall cycle, accelerating learning about ecological process within the more comprehensive cycle that includes learning about the adaptive process itself (through periodic problem reassessment, design, and implementation). Learning at both levels is discussed in more detail in Section 3.1.
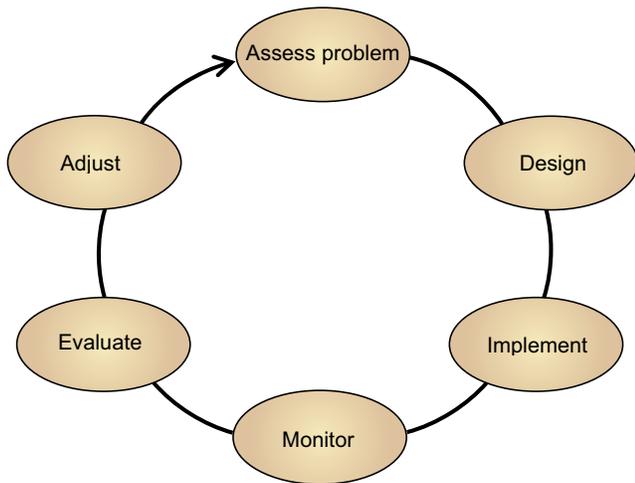
Figure 1.1. Diagram of the adaptive management process.

Other approaches to resource management

Learning from the experience of management is certainly not a new idea, but the purposeful and systematic pursuit of knowledge as an explicit part of management has rarely been practiced. The term "adaptive management" has been used to describe a broad array of approaches that involve learning while doing, but the phrase is not always appropriate. For example, management by trial and error is sometimes described as adaptive management, but at best it is likely to be inefficient, and at worst it can retard the institutionalization of experience and learning. Nor should adaptive management be confused with conflict resolution, which focuses on negotiating tradeoffs among competing interests. Management approaches that primarily depend on expert opinion and advice for decision making are not by themselves adaptive. Finally, in the absence of additional structure in a decision making process, monitoring a managed resource system does not itself make an application adaptive. A great many resource systems are monitored in some manner, but in most cases the resulting data are not used systematically for learning and improvement in a context of objective-driven management.

More formal approaches to decision making can be identified, depending on the amount of uncertainty facing managers and the capacity to influence the system being managed (Fig. 1.2). In an ideal situation in which system controllability is high and management impacts are predictable, formal optimal control approaches can be used to identify optimal management strategies. If one's ability to control the system is limited, hedging strategies or scenario planning can be useful, depending on how well the effects of management can be predicted. As indicated in Fig. 1.2, adaptive management is appropriate if management can strongly influence the system but uncertainty about management impacts is high (27).
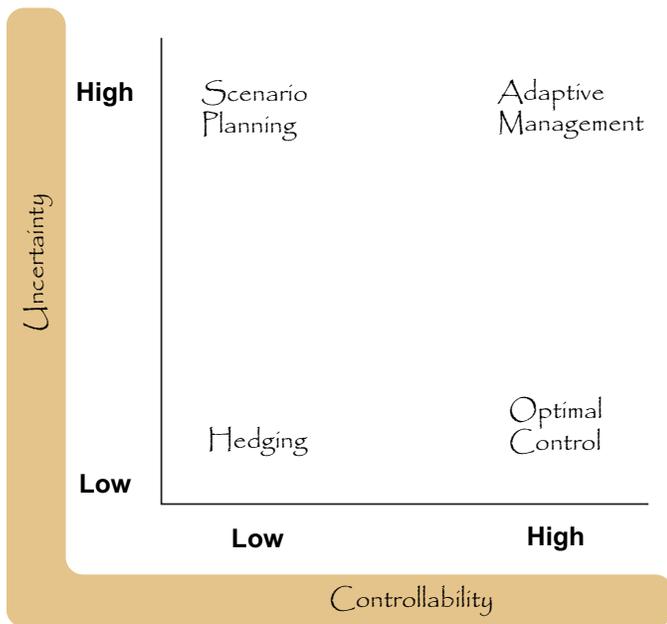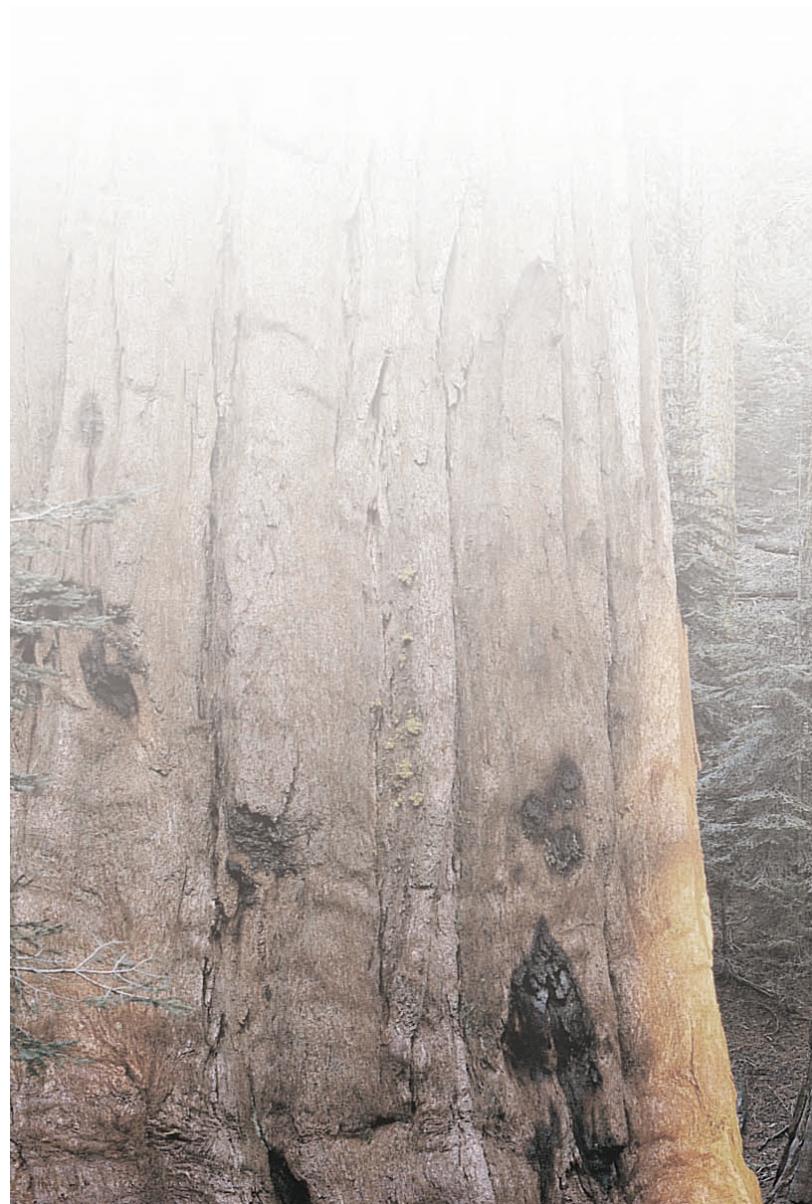
Figure 1.2. Approaches to decision making in a natural resource system. The appropriate approach depends on the influence decisions can have on system behavior and the amount of uncertainty about management impacts (27).

Adaptive management requires stated management objectives to guide decisions about what to try, and explicit assumptions about expected outcomes to compare against actual outcomes. It is important to know what the available management options and alternative assumptions are, in case the action that is tried does not work as expected. The linkages among management objectives, learning about the system, and adjusting direction based on what is learned distinguish adaptive management from a simple trial and error process. In the chapters that follow, we describe adaptive management formally in terms of objectives, management options, and models that embed alternative hypotheses about management responses. But in essence, adaptive management will be seen to be learning by doing, and adapting based on what is learned (28). A comparison of adaptive management with some other approaches to natural resource management is presented in Section 5.1.

Adaptive management requires stated management objectives to guide decisions about what actions to take, and explicit assumptions about expected outcomes to compare against actual outcomes.