Kanuti National Wildlife Refuge, Alaska

Chapter 2: Framework of Adaptive Management

The origin of adaptive management is rooted in parallel concepts from a variety of perspectives, including business (Senge 1990), experimental science (Popper 1968), systems theory (Ashworth 1982), and industrial ecology (Allenby and Richards 1994). In natural resources, the term simply means learning by doing, and adapting based on what's learned (Walters and Holling 1990). Adaptive management is based on the recognition that resource systems are only partially understood, and there is value in tracking resource conditions and using what is learned as the resources are being managed. Learning in adaptive management occurs through the practice of management itself, with adjustments as understanding improves.

2.1. Learning-based natural resource management

Natural resource managers and policy makers face the challenge of taking actions and making policy despite uncertainty about the consequences of management interventions. One well-known approach to resolving uncertainty is classical experimental science. Investigations using an experimental approach have been extraordinarily effective in analyzing natural resource systems, improving our understanding of ecological relationships, and increasing the accuracy of estimates of parameters in those relationships. An assumption in most applications of experimentation is that learning about the individual components of a system will eventually produce an understanding of how to manage it. In a classical approach to experimentation, science and management functions are usually separate – managers are presumed to know which components of the system need to be investigated, and scientists are presumed to know how to investigate those components. Unfortunately, this separation can present difficulties in attempts to understand and deal with today's large and complex problems. It can also impede the use of experimental learning for management adjustments, which is a critical and even definitive step in adaptive management.

Another approach to resolving uncertainty about the consequences is management by trial and error. Simply put, the idea is to try some management option, and if it doesn't perform as expected or desired, then try something else. The difficulty is that with all but the simplest systems a preferred option may not be obvious. If a selected option does not work as expected, there is no systematic mechanism to use what is learned from that experience as a guide for choosing follow-up options. Finally, there is no clear way to extrapolate site-specific learning to other sites. There are many cases in which trial and error has led to better management. However, the approach tends to be an inefficient way to advance learning and improve management, in large part because the rate of learning is unnecessarily slow. As a result, trial and error management can be costly (especially in terms of opportunity costs) and only marginally effective over unacceptably long periods of time.

In this guide, we describe the learning-based approach of adaptive management and illustrate its features by means of examples of some important problems facing resource managers and conservationists. We emphasize the importance of framing adaptive management problems as a structured process of iterative decision making (see, e.g., Gregory and Keeney 2002 for a discussion of structured decision making). We focus on examples that show how adaptive management can facilitate natural resource decision making and reduce the uncertainties that limit effective management. Because it acknowledges uncertainty and includes procedures to reduce uncertainty through the process of management itself, adaptive management can be applied to many pressing issues that need immediate attention, at local as well as larger scales.

For many resource management problems, the use of management in an experimental, learning-oriented context may be the only feasible way to gain the understanding needed to manage more effectively.

The concept of adaptive decision making has been a part of natural resource management for several decades. One of the earliest discussions in the natural resource literature was by Beverton and Holt (1957), who described fisheries management in the following way:

> It is the changes produced in the fisheries by the regulations themselves … that provide the opportunity of obtaining, by research, just the information that we may have been lacking previously. Thus the approach towards optimum fishing, and the increase in knowledge of where the optimum lies, can be two simultaneous and complementary advances; the benefits to the fisheries of such progress can hardly be exaggerated.

A generation later Holling (1978) and Walters and Hilborn (1978) provided the name and conceptual framework for adaptive management of natural resources, and Walters (1986) gave a more complete technical treatment of adaptive decision making. Lee's (1993) book expanded the context for adaptive management with comprehensive coverage of its social and political dimensions. These pioneering efforts sparked an interest in adaptive management that has grown steadily up to the present time. Many people in the field of natural resource conservation now claim, sometimes wrongly, that adaptive management is the approach they use to manage resources (Failing et al. 2004). The current popularity of adaptive management is somewhat at odds with its rather modest record of documented success, a record based at least in part on an inadequate framing of many management problems, poorly designed monitoring, and incomplete implementation of the adaptive process itself.

This applications guide builds on the framework of DOI Adaptive Management Technical Guide (Williams et al. 2007), which describes adaptive management in terms of the linkage of management with learning about natural resources. Here, we use examples to show how adaptive management can be used for both management and learning. We focus on practical applications in the areas of climate change, water, energy, and human impacts on the landscape.

2.2. Natural resource context for adaptive management

Adaptive management can be useful in cases where natural resources are responsive to management, but uncertainty exists about the impacts of management interventions. Applications usually involve the following general features (Figure 2.1).

- The natural resource system being managed is dynamic, with changes over time that occur in response to environmental conditions and management actions, which themselves vary over time. These factors can influence resource status directly as well as indirectly, through the ecological processes that drive resource changes.

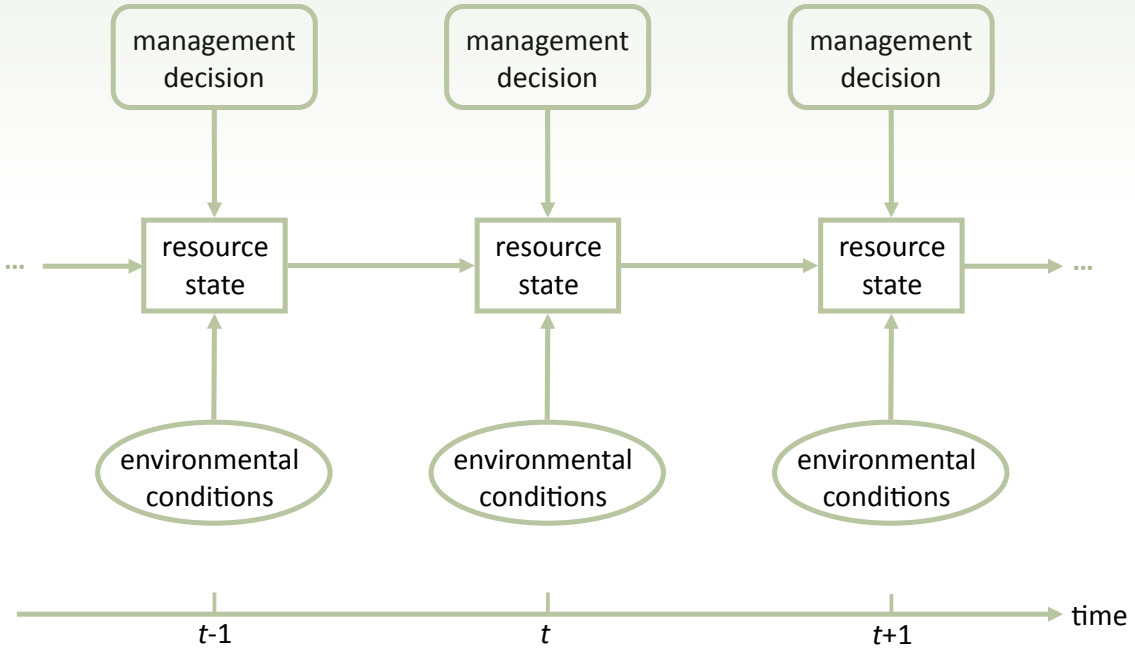


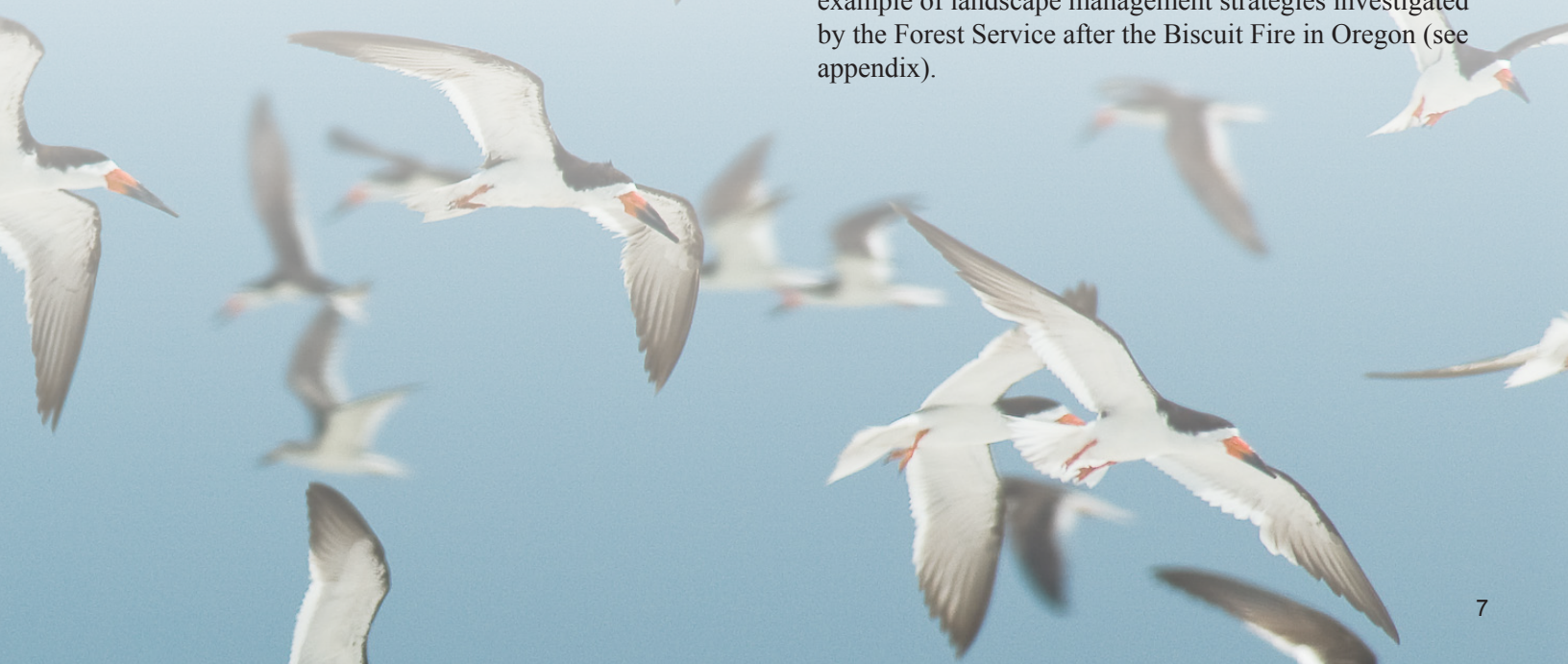
Figure 2.1. Dynamic resource system, with changes influenced by fluctuating environmental conditions and management actions. Management typically produces short-term returns (costs and (or) benefits) and longer-term changes in resource status.

- Environmental variation is only partly predictable, and is sometimes unrecognized. Variation in environmental conditions induces randomness in biological and ecological processes, which in turn leads to unpredictability in system behaviors.

- The resource system is subjected to periodic management interventions that may vary over time. Management actions influence resource system behaviors either directly or indirectly; for example, by altering system states such as resource size, or influencing ecological processes like mortality and movement, or altering vital rates like 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.

Many variations of these conditions are possible. For example, several different sites may be managed with actions taken at one location at a time, with information gained at one site used to inform subsequent decisions at other sites. Our example of solar project permitting illustrates this situation (see appendix). In another variation, different management actions may be taken simultaneously at different sites in the spirit of statistically designed experimentation, as illustrated by our example of landscape management strategies investigated by the Forest Service after the Biscuit Fire in Oregon (see appendix).



The role of time in this context is important. Management, environmental variation, resource status, and uncertainty are all expressed over time, which offers the prospect of management improvement by learning over the course of the management time frame.

Uncertainty and its effects. Uncertainty is always present in natural resource management, and it almost always limits management effectiveness to some degree. Representing and accounting for it in management is generally useful and sometimes critical (Bormann and Kiester 2004, Moore and Conroy 2006).

Many sources and types of uncertainty are documented in the literature (e.g., Regan et al. 2002, Burgman 2005, Norton 2005, Le Treut et al. 2007). At a minimum, four kinds of uncertainty can influence the management of natural resource systems.

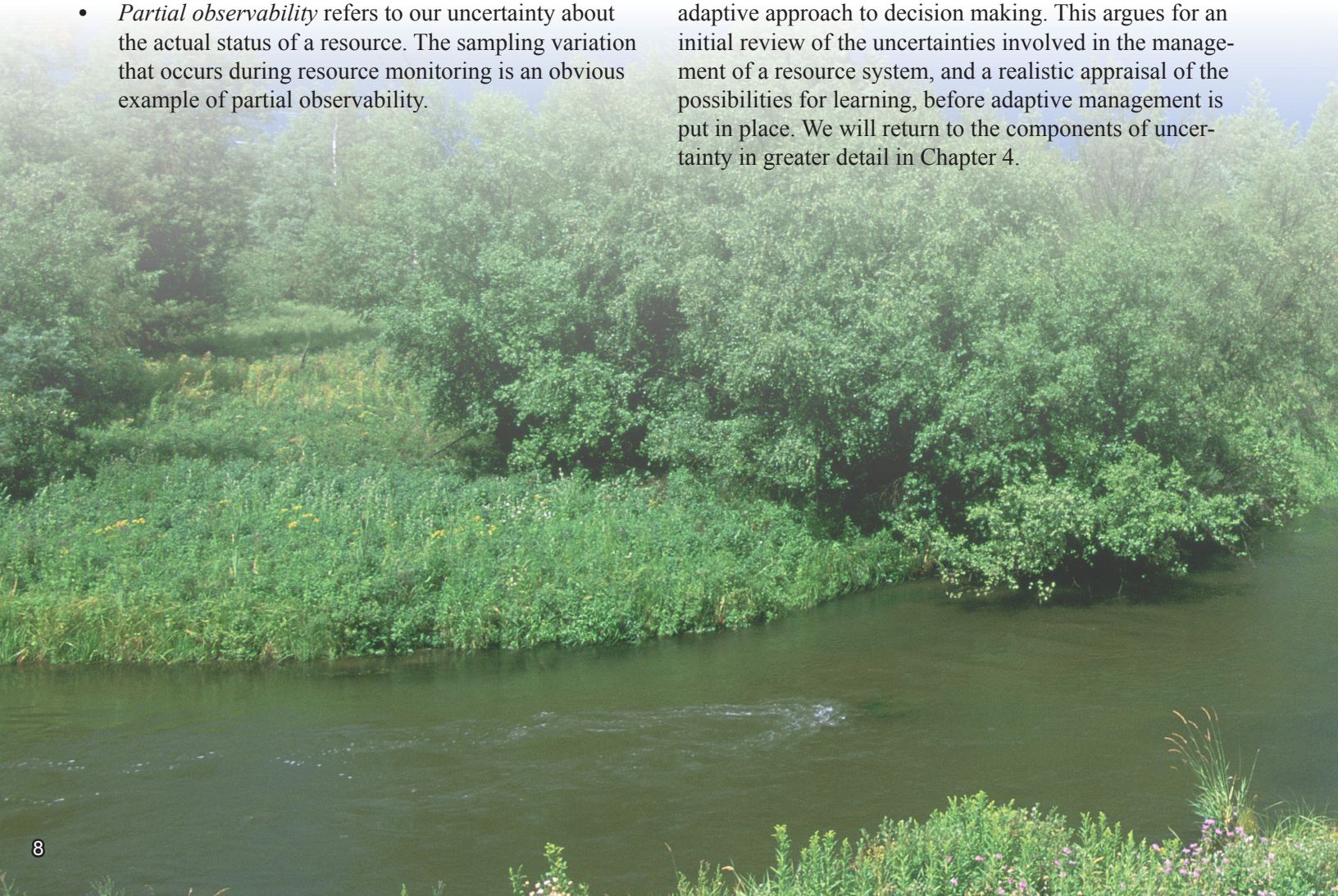
- *Environmental variation* is a prevalent source of uncertainty, which is largely uncontrollable and possibly not even perceived as such. It often has a dominating effect on natural resource systems, through factors such as climatic variability.

- *Partial observability* refers to our uncertainty about the actual status of a resource. The sampling variation that occurs during resource monitoring is an obvious example of partial observability.

- *Partial controllability* refers to the difference between the outcomes intended by decision makers and the outcomes that actually occur. This uncertainty can arise when indirect means (for example, regulations) are used to achieve an intended outcome (for example, a particular harvest or stocking rate). Partial controllability can lead to misrepresentation of management interventions, and thus to an inadequate accounting of their influence on resource behavior.

- *Structural or process uncertainty* refers to a lack of understanding – or lack of agreement among stakeholders – about the structure of the biophysical processes that control resource dynamics and the influence of management on them.

Environmental variation, partial observability, partial controllability, and structural uncertainty all limit our ability to manage natural resources effectively. In this guide we emphasize structural uncertainty, and the use of adaptive decision making to reduce it. It is reasonable to expect that learning will slow as the number and magnitudes of the uncertainties increase. Beyond some limit, uncertainty can become too great, learning too slow, and opportunity and other costs too high to justify a structured adaptive approach to decision making. This argues for an initial review of the uncertainties involved in the management of a resource system, and a realistic appraisal of the possibilities for learning, before adaptive management is put in place. We will return to the components of uncertainty in greater detail in Chapter 4.



2.3. Adaptive decision making defined

A number of formal definitions have been advanced for adaptive management. For example, the National Research Council (2004) defines it as a decision process with

> … 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 discussions 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 1995). In all cases adaptive management is seen as an evolving process involving learning (the accumulation of understanding over time) and adaptation (the adjustment of management over time). The sequential cycle of learning and adaptation leads naturally to two beneficial consequences: (*i*) better understanding of the resource system, and (*ii*) better management based on that understanding.

The feedback between learning and decision making is a defining feature of adaptive management. Thus, learning contributes to management by helping to inform decision making, and management contributes to learning by using interventions to investigate resources. Management interventions in adaptive management can be viewed as experimental "treatments" that are implemented according to a management design. However, the resulting learning should be seen as a means to an end – namely, effective management – and not an end in itself (Walters 1986). The ultimate focus of adaptive decision making is on management, and learning is valued for its contribution to improved management.

A distinction is often made between "passive" and "active" adaptive management (Salafsky et al. 1991, Bormann et al. 1996, Schreiber et al. 2004). Though there is considerable variability in the use of these terms (e.g., Williams 2011*b*), they are usually distinguished by the way uncertainty and learning are treated. As suggested by the wording, active adaptive management pursues the reduction of uncertainty actively through management interventions that emphasize rapid learning. On the other hand, passive adaptive management focuses less on the reduction of uncertainty and more on the status of the resource, with learning a useful by-product (Walters 1986). In practice the main difference between passive and active adaptive management is the degree to which management objectives emphasize the reduction of uncertainty (Williams 2011*b*).

Great Falls National Park, Virginia

Ambiguities in the use of these terms arise from the fact that there are several approaches to both active and passive adaptive management. For example, a common (but not the only) form of active adaptive management involves experimental management, in which decision making is focused on rapid learning (Williams 2011*b*). In this case different interventions are applied simultaneously at different sites in the spirit of designed experiments, with experimental learning used to guide future decision making. On the other hand, a common (but not the only) form of passive adaptive management involves decision making based on a single parameterized model. Here the focus is on achieving resource objectives, with little emphasis on learning per se. Different parameter values essentially represent different hypotheses about the effects of management, and learning occurs as data from post-decision monitoring are used to update the parameter distributions over repeated cycles.

Whatever the treatment of uncertainty, the heart of adaptive decision making is a recognition of alternative hypotheses about resource dynamics, and assessment of these hypotheses with monitoring data. These same features are shared with scientific investigation. That is, both science and adaptive management involve (*i*) the identification of competing hypotheses to explain observed patterns or processes; (*ii*) the use of models embedding these hypotheses to predict responses to experimental treatments; (*iii*) the monitoring of actual resource responses; and (*iv*) a comparison of actual versus predicted responses to gain better understanding (Williams 1997*a*, Nichols and Williams 2006). This overlap is the main reason that adaptive management is 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, as opposed to experiments chosen for the pursuit of learning through hypothesis testing. Our case study of protecting nesting golden eagles in Denali National Park provides a good illustration of the scientific aspects of adaptive management.

Finally, it is useful to distinguish between adaptive management and the trial-and-error approach of "try something, and if it doesn't work try something else," which involves an ad hoc revision of strategy when it is seen as failing. In contrast to trial and error, adaptive management involves the clear statement of objectives, the identification of management alternatives, predictions of management consequences, recognition of uncertainties, monitoring of resource responses, and learning (National Research Council 2004). Basically, learning by ad hoc trial and error is replaced by learning through careful design and testing (Walters 1997). Adaptive management can be seen as a process of structured decision making (Williams et al. 2007), with special emphasis on iterative decisions that take uncertainty and the potential for learning into account. In later sections of this guide we develop the framework and components of adaptive management, with adaptive decision making seen as an iterative process of structured, objective-driven, learning-oriented decision making that evolves as understanding improves.

We describe adaptive management as the interplay of decision and assessment components, in an iterative process of learning by doing and adapting based on what's learned. Adaptive management involves key activities such as stakeholder engagement, resource monitoring, and modeling, none of which is sufficient by itself to make a decision process adaptive. The integration of these components is what defines an adaptive approach to natural resource management. In Section 3.4 we compare and contrast adaptive management with alternative management approaches.

2.4. Conditions warranting the use of adaptive management

Not all resource management decisions can or should be adaptive. In some cases there is no chance to apply learning. In other cases, there is little uncertainty about what action to choose, or there are irreconcilable disagreements about objectives. But the concept of learning by doing is so intuitively appealing that the phrase "adaptive management" has been applied almost indiscriminately, with the result that many projects fail to achieve expected improvements. In many instances that failure may have less to do with the approach itself than with the inappropriate contexts in which it is applied (Gregory et al. 2006).

Whether or not a management problem calls for adaptive management is an important question that should be addressed at the outset of a project. In one form or another, the following five conditions are usually associated with adaptive management.

The first and most fundamental condition is that management is required in spite of uncertainty. In other words, the problem is important and timely enough that management action must be taken, though its consequences cannot be predicted with certainty.

Second, clear and measurable objectives are required to guide decision making. The articulation of objectives plays a critical role in evaluating performance as well as making decisions. Without useful objectives, and metrics by which they can be evaluated, it is difficult to determine what actions are best, and whether they are having the desired effect.

Third, there must be an opportunity to apply learning to management. Among other things this means that there is an acceptable range of management alternatives from which to make a selection, and a flexible management environment that allows for changes in management as understanding accumulates over time. It is the prospect of improved decision making that ultimately justifies adaptive management. Conversely, an adaptive approach is not warranted if potential improvements in management are insufficient to justify the costs of obtaining the information needed.

A fourth condition is that monitoring can be used to reduce uncertainty. The analysis and assessment of monitoring data result in better understanding of system processes and the opportunity to improve management based on that understanding. Without periodic monitoring of the relevant resource attributes, learning about resource responses and subsequent adjustment of management actions are not possible.

Finally, most expositions on adaptive management recognize the importance of a sustained commitment by stakeholders, including – but certainly not limited to – decision makers. Stakeholders should be actively involved throughout an adaptive management project, from the identification of objectives and management alternatives to the recognition of uncertainty and collection and analysis of monitoring data. Stakeholders are often diverse groups with different social, cultural, or economic perspectives. Active involvement means an ongoing commitment of time and resources by stakeholders (Lee 1999), among other things. Stakeholder engagement in discussions from the beginning of a project can help to reconcile polarized perspectives and facilitate collaboration in decision making. Our case study of flow management on the Tallapoosa River shows how stakeholders can become, and remain, deeply involved in all aspects of an adaptive management project.

2.5. Set-up phase of adaptive management

Adaptive management can be described in terms of a set-up or planning phase during which some essential elements are put in place, and an iterative phase in which the elements are linked together in a sequential decision process (Figure 2.2). The iterative phase uses the elements of the set-up phase in an ongoing cycle of learning about system structure and function, and managing based on what is learned.

In this section we summarize the elements in the set-up phase, namely stakeholder involvement, management objectives and options, predictive models, and monitoring protocols. Each of these elements has been described in greater detail in a companion publication, the DOI Adaptive Management Technical Guide (Williams et al. 2007).

Stakeholder involvement. A crucial step in any adaptive management application is to involve the appropriate stakeholders (Wondolleck and Yaffe 2000). It is particularly important for stakeholders to take part in assessing the resource problem and reaching agreement about its scope, objectives, and potential actions, even if differences of opinion about system responses remain.

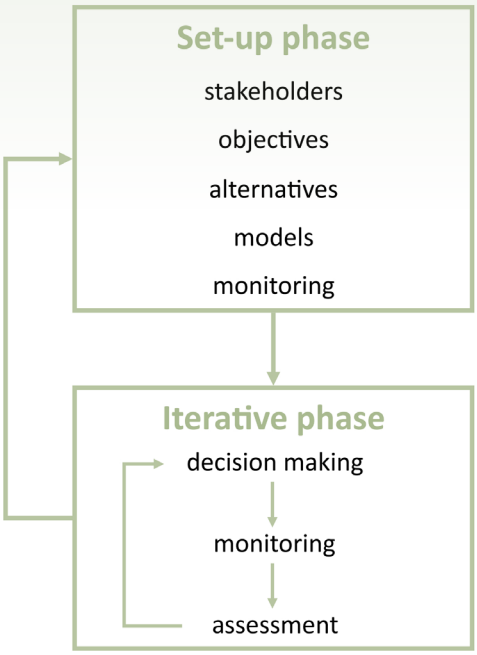


Figure 2.2. Two-phase learning in adaptive management. Technical learning involves an iterative sequence of decision making, monitoring, and assessment. Process and institutional learning involves periodic reconsideration of the adaptive management set-up elements.

Involving stakeholders in discussions at an early stage enhances their engagement in the management approach and highlights different stakeholder values, priorities, and perspectives. By defining the operating environment of an adaptive management project, stakeholders directly influence both decision making and learning. Adaptive decision making is not prescriptive about how many stakeholders there are, who they are, 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 problem (Comprehensive Everglades Restoration Plan Adaptive Management Integration Guide 2011).

In general, recognizing stakeholders' interests and ensuring their involvement are necessary for successful learning–based management. Frequently, decision making is undertaken without agreement, even among managers, about scope, objectives, and management alternatives. Without this agreement, management strategy is likely to be viewed as a reflection of partisan objectives or unnecessary constraints on decision making. The prospects for failure increase dramatically in such a situation.

Stakeholder involvement in an adaptive management project requires commitments as well as opportunities for involvement. Thus, stakeholders must commit to an agreed-upon process of reducing uncertainties and disagreements about the effects of management. That is, having reached agreement on the scope of the management problem and its objectives and potential interventions, stakeholders must then commit to an iterative process of objective-driven decision making. The failure of participants to make these commitments can impede and even undermine an adaptive management project.

Often there is value in engaging individuals who can facilitate these efforts or provide expertise from outside the stakeholder community of interest. Facilitators can bring novel insights into stakeholder interactions, just as outside experts can bring insights about resource systems. They thus can promote the development of better technical frameworks and more effective governance.

Objectives. Objectives play a critical role in evaluating performance, reducing uncertainty, and improving management over time. Clear and agreed-upon objectives are needed from the outset, to guide decision making and measure progress. To be useful, objectives should be specific, measureable within a recognizable time frame, and results-oriented (Williams et al. 2007).

Often there are multiple objectives. For example, a manager might simultaneously want to maintain species richness, maximize visitor use, allow harvest of one or more wildlife species, and minimize costs of all these activities. It then becomes important to weigh different objectives in terms of their perceived importance, in order to compare and prioritize management alternatives (Burgman 2005).

Management alternatives. Like any iterative decision process, adaptive decision making involves selecting a management action at each decision point, on the basis of the status of the resource at the time. Resource managers and other stakeholders, usually working with scientists, must identify the set of potential actions from which a selection is made.

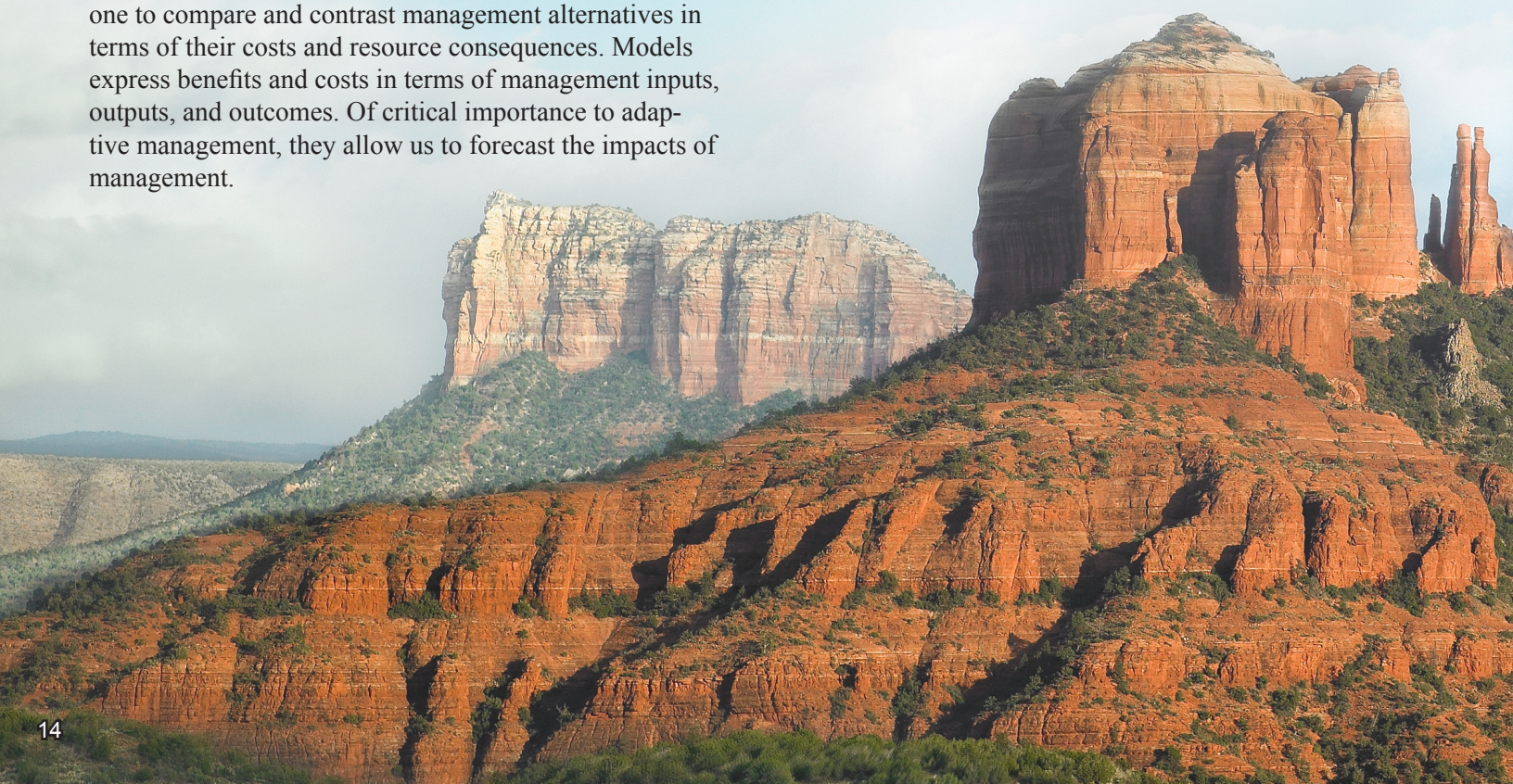
The alternative management actions are an important element of an adaptive management project's operating environment because strategy choices are always limited by the set of available management options. If these options do not span a reasonable range of management actions, or if they fail to produce recognizably different patterns of system responses, adaptive management will be less useful in producing effective and informative strategies. This argues for careful thinking about the potential management actions to be included in a project.

Models. Models that link potential management actions to resource results play an important role in virtually all applications of structured decision making, whether adaptive or otherwise. Smart decision making requires one to compare and contrast management alternatives in terms of their costs and resource consequences. Models express benefits and costs in terms of management inputs, outputs, and outcomes. Of critical importance to adaptive management, they allow us to forecast the impacts of management.

Models also play a major role in representing uncertainty. In adaptive management, structural or process uncertainty is expressed by means of contrasting hypotheses about system structure and functions. These hypotheses are represented by different models that forecast resource changes. At any point, the available evidence will suggest differences in the adequacy of each model in characterizing resource dynamics. As evidence accumulates, our confidence in each model (and its associated hypothesis) evolves, through a comparison of model predictions with actual data from monitoring.

Monitoring protocols. The learning that is central to adaptive management occurs by comparing model-based predictions with observed responses. These comparisons allow us to learn about resource dynamics and discriminate among alternative hypotheses about resource processes and 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 main 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 by comparing predictions with actual monitoring data; and (*iv*) to develop and refine models of resource dynamics. Monitoring is much more efficient and effective to the extent that it is designed to meet these purposes.



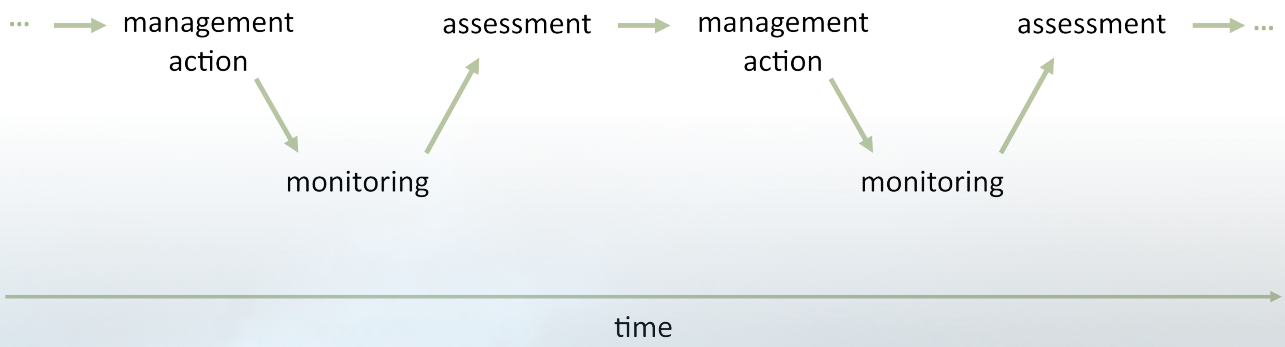


Figure 2.3. Iterative phase of adaptive management. Management actions are based on objectives, resource status, and understanding. Data from follow-up monitoring are used to assess impacts and update understanding. Results from assessment guide decision making at the next decision point.

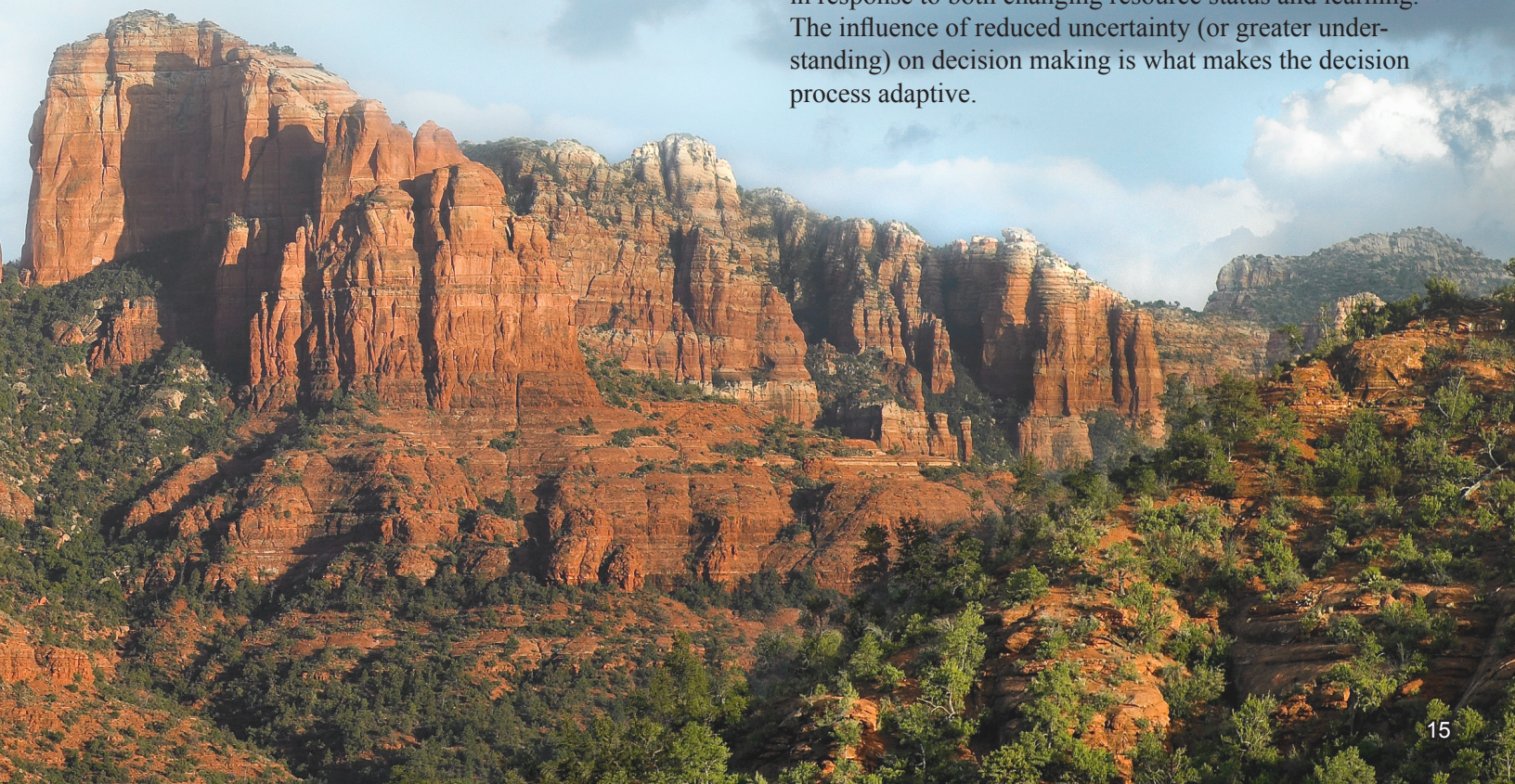
The focus and design of monitoring in adaptive management should be inherited from the larger management context of which monitoring is a part. The value of monitoring stems from its contribution to adaptive decision making, and monitoring efforts should be designed with that goal in mind (Nichols and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

Because the set-up elements just described are folded directly into the process of decision making, they need to be stated and agreed upon at the beginning of an adaptive management application. Of course, the elements themselves can change over time, as ecological conditions and stakeholder perspectives – and possibly the composition of the stakeholder group – evolve (see Section 2.7). For this reason the set-up phase is also referred to as "deliberative," to indicate the potential for changes in one or more elements.

2.6. Iterative phase of adaptive management

The operational sequence of adaptive management incorporates the set-up elements in an iterative decision process. Figure 2.3 shows the components of management. Steps in the iteration are described as follows.

Decision making. At each decision point in time, 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. Actions are likely to change through time, as understanding increases and the resource system responds to environmental conditions and management. That is, management is adjusted in response to both changing resource status and learning. The influence of reduced uncertainty (or greater understanding) on decision making is what makes the decision process adaptive.



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

Assessment. The information produced by monitoring folds into performance evaluation, learning, and future decision making. For example, the comparison of model predictions with data from monitoring is a critical part of learning. The degree to which the predictions match observed changes serves as an indicator of model adequacy. Confidence increases in models that predict change accurately, and confidence decreases in models that do not. In this way evidence accumulates for the hypotheses that best represent resource dynamics.

As important as it is, learning is not the only valuable outcome of analysis and assessment in adaptive management. Comparison of predicted and actual outcomes can also be used to evaluate the effectiveness of management and measure its success in attaining objectives. In addition, comparisons of projected costs, benefits, and impacts help to identify useful management alternatives.

Learning and feedback. At each particular time, the understanding gained from monitoring and assessment guides the choice of management actions. As understanding evolves, so does decision making based on that understanding. In this way, the iterative cycle of decision making, monitoring, and assessment leads gradually to better management as a consequence of better understanding.

2.7. Institutional learning

Adaptive decision making not only gives us the chance to learn about ecological structures and functions, but also about the decision process itself. Learning about the "architecture" of decision making is accomplished by periodically recycling through the elements in the set-up phase (Figure 2.2) and adjusting the elements as needed to account for evolving stakeholder perspectives and institutional arrangements. The broader context of learning that also recognizes uncertainty about these elements in the decision process is sometimes called institutional or "double-loop" learning (Argyris and Shon 1978, Salafsky et al. 2001).

The need to revisit and adjust the set-up elements of adaptive management often becomes more pressing as adaptive management proceeds over time. Stakeholder perspectives and values can shift as adaptive management progresses, previously unanticipated patterns in resource dynamics are exposed, and changes occur in social and cultural values and norms. Any of these changes can lead to adjustment of objectives, alternatives, and other set-up elements. In this sense, learning in adaptive management can focus on changes in institutional arrangements and stakeholder values as well as changes in the resource system itself.

A well-designed project provides a chance to learn at both levels. The technical learning in Figure 2.2 ideally occurs over a relatively short term during which objectives, alternatives, and other set-up elements remain unchanged. On the other hand, learning about the decision process itself occurs through periodic revisiting of the set-up elements over the longer term. If changes in the set-up elements are made as often as changes in management actions, these effects may become confounded and impede learning at either level.

Cypress swamp, Bond Swamp National Wildlife Refuge, Georgia