Michael J. Conroy and James T. Peterson

Decision Making in Natural Resource Management

A Structured, Adaptive Approach

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Decision making in natural resource management: a structured, adaptive approach

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Preface

This book is intended for use by natural resources managers and scientists, and students in the fields of natural resource management, ecology, and conservation biology, who are or will be confronted with complex and difficult decision-making problems. This audience will find that you will be called upon to assist with solving problems because you have a technical expertise in a certain area. Perhaps you are a specialist in fish nutrition and physiology, or statistical modeling, or in spatial analysis; or, you may specialize in the human-dimensions side of the equation, dealing with people's attitudes, values, and behavior. Often you will be asked to provide input on just one narrow aspect of a problem, and you might assume that your client (e.g., the natural resources agency that pays your contract) knows how to take your information, apply it in the context of solving a bigger problem, and that all will be well. You would often be mistaken.

In our experience, agencies, NGOs, and other organizations dealing with conservation problems often seek technical solutions to problem solving, when in fact their difficulties lie at a deeper level. What these organizations typically lack is an understanding of how the components of their decision-making problem relate to one another, and to the overarching goals and mission of the organization. That is, typically their approach to decision making lacks *structure*. Besides being an inefficient use of resources (something we have little to spare in these days of economic belt tightening), this sort of ad hoc approach to decision making can play into the criticism emanating from some camps that conservation and natural resource management are not based on rigorous, repeatable methods and thus, need not be taken as seriously as "real" sciences. In fact, natural resource management draws from numerous scientific fields (ecology, biology, physics, and geography to name a few), as well as the quantitative (statistics, mathematics, computer sciences) and social sciences (economics, policy, human dimensions). However, when we see actual decision-making processes in action, they can appear fragmented and poorly focused, often using the (sometimes copious) information that is available from the sciences in an informal way. Our hope is that the methods describe in this book will help biologists and managers better focus the rich sources of knowledge we have from these fields to solving pressing conservation problems.

Acknowledgements

Many people have helped make this book possible, and we thank them. The authors thank their spouses, Liz and Rebecca, for putting up with us during this project. We thank our graduate students and colleagues at Georgia and Oregon State for their feedback and insights that help make this a better book. Between the two of us we have (either jointly or independently) now conducted over twenty workshops applying principles of Structured Decision Making to solving a wide range of natural resource problems. Each workshop has increased our understanding of how SDM works, and given us insights into why it occasionally does not work; this book is in large part the product of that experience.

We are especially grateful to the following colleagues who volunteered their time to provide us detailed reviews of each of the chapters: Paige Barlow, John Carroll, Sarah Converse, Jason Dunham, Andrea Goijman, Tom Kwak, Clint Moore, Rebecca Moore, Krishna Pacifici, Colin Shea, and Seth Wenger. Their comments were extremely helpful to us, both in catching errors as well as for insights on how to deliver our message with greater accuracy and clarity. Any remaining errors, which we hope are few and unimportant, belong to the authors. The use of trade, product, industry, or firm names or products is for informative purposes only and does not constitute an endorsement by the US Government or the US Geological Survey. The Oregon Cooperative Fish and Wildlife Research Unit is jointly sponsored by the US Geological Survey, the US Fish and Wildlife Service, the Oregon Department of Fish and Wildlife, the Oregon State University, and the Wildlife Management Institute.

Guide to using this book

This book is divided into three major parts: Introduction, Tools, and Applications, and we recommend some depth of reading for all users of all three parts. For Part I – Introduction, we recommend that all readers examine Chapters 1 and 2; however, those already familiar with the basics of SDM might quickly skim these sections, since presumably the major concepts will be familiar. We highly recommend that all readers who seek to actually develop decision models carefully read Chapter 3 on developing objectives, and those who plan to work with stakeholder groups should definitely read Chapter 4. We also recommend that administrators and policy makers read these sections, if for no other reason than to become familiar with the terminology of SDM, as well as to have a more realistic expectation of what can, and cannot be achieved.

Part II of the book gets into the nuts and bolts of how to assemble decision models and to use information from field studies and monitoring to inform decision making. These chapters should be read in depth and we recommend that everyone read the introductory sections of both chapters, scan the topic sentences for the remainders, and refer back in detail to specific sections as needed. For example, one not need have a detailed knowledge of linear modeling, to appreciate the fact that linear models can both capture essential hypothetical relationships as well as form testable predictions that can be used in decision making. Likewise, one need not know the details of dynamic programming to understand the basic principles of optimization, and appreciating that casting decisions in a dynamic framework greatly complicates this process. On the other hand, if one is actually constructing and applying linear models, or using dynamic decision models, a deeper understanding and a more comprehensive reading is essential.

Part III covers applications of these approaches, and should be read by all. In particular, our coverage of case studies that "worked" (Chapter 9) and those that were less than fully successful (Chapter 10) should provide important insights to those seeking to apply these methods.

We also have provided a glossary, several technical appendices, and an Electronic Companion, and we encourage readers to use all three of these resources. The glossary provides a comprehensive list of terms we have used, together with brief definitions for each; we think readers will find this a useful guide to navigating a sometimes confusing terrain. The appendices provide a level of technical detail that is important to have available, but was inappropriate to include in the body of the book, and should be referred to for elaboration on these topics. Finally, the Electronic Companion provides worked examples with computer code for all of the Box examples, except those with trivial solutions, some additional useful code and explanation, as well as links to other resources available on the Internet including example exercises (problems) for coursework.

Companion website

As noted above, we have provided a companion website for the book, which can be accessed via www.wiley.com/go/conroy/naturalresourcemanagement. Additional resources on the companion provide details for the Box examples, including data input and program output. In most cases (except commonly available commercial software like Microsoft Excel ®), the programs are freely available via the Internet. We have provided additional modeling software and examples that, while not directly referenced in the book, may be useful to readers. We also have provided links to both freely available as well as commercial software; readers should always obtain the most current versions of these applications. Finally, we have provided links to several workshops and courses we have conducted in this area, which should be of interest, especially to advanced undergraduates and graduate students seeking to use these approaches in their research.

PART I. INTRODUCTION TO DECISION MAKING

1

Introduction: Why a Structured Approach in Natural Resources?

In this chapter, we provide a general motivation for a structured approach to decision making in natural resource management. We discuss the role of decision making in natural resource management, common problems made when framing natural resource decisions, and the advantages and limitations of a structured approach to decision making. We will also define terms such as **objective, management**, **decision**, **model**, and **adaptive management**, each of which will be a key element in the development of a structured decision approach.

The first and obvious question is: why do we need a structured approach to decision making in natural resource management? We have thought a lot about this question, and realize that while the answer may not be obvious, it really comes down to some basic premises. For us, natural resource management is a developing field, and many aspects of it are not "mature." In many respects we think that conservation and natural resource management suffer from the perception that many have that it is an ad hoc and not particularly scientific field. In our view, we have a choice: we can either use ad hoc and arguably non-scientific means to arrive at decisions; or we can use methods that are more formal and repeatable. In our view, the latter will better serve the field in the long run.

We also want to emphasize that when we refer to "management" we are speaking very broadly. That is, "management" includes virtually every type of decision we could make about a natural resource system, which would include traditional game management tools (e.g., harvest and habitat management), but also reserve design, legal protection and enforcement, translocation, captive propagation, and any other action intended to effect a conservation objective. This means that we consider conservation and management as one and the

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same and believe that artificial distinctions only serve to confuse students and practitioners.

The role of decision making in natural resource management

Virtually all problems in natural resource management involve decisions: choices that must be made among alternative actions to achieve an objective. We will define "decisions" and "objectives" more formally in the coming chapters, but can illustrate each with some simple examples. Examples of decisions include:

- Location on the landscape for a new biological reserve.
- Allowable season lengths and bag limits for a harvested population.
- Whether to capture a remnant population in danger of extinction and conduct captive breeding.
- Whether to use lethal control for an exotic invasive limiting an endemic population, and if so, which type of control.
- Whether and how to mitigate the impact of wind turbines on bird mortality.

Note that in each case, there is a choice of an action, and that some choices preclude others. So for example, if we choose location *A* for our reserve, given finite resources and other limitations, we have likely precluded locations *B–D*. Similarly, if we close the hunting season we cannot at the same time allow liberal bag limits. If we capture the remnant population we have (at least immediately) foregone natural reproduction, and so on.

Also, each of the above decisions is presumably connected to one or more objectives. We will develop objectives more fully in Chapter 3, but broadly stated, the objectives associated with the above decisions might be, respectively:

- Provide the greatest biodiversity benefit for the available funds and personnel.
- Provide maximum sustainable harvest opportunity.
- Avoid species extinction and foster species recovery.
- Restore an endemic population.
- Minimize bird mortality while fostering "green" energy.

So, at a very basic level, decision making is about connecting decisions to objectives, and **structured decision making** (**SDM**; Hammond et al. 1999, Clemen and Reilly 2001) is just a formalized way of accomplishing that connection. For some of us this connection (and way of thinking) is so obvious that it hardly needs stating, and certainly doesn't require a book-length coverage. However, we have in our careers in academia and government, and working with natural resource management agencies, NGOs, and business, encountered numerous examples in which we believed that problems in the management of resources were exacerbated, and in some cases directly caused, by poor framing of the decision problem.

We also want to emphasize the important role of science in decision making. Science should inform decision making, but we must always recognize that science is a process and not an end. Thus, we can use science to inform decision making, but we must always be seeking to improve our scientific understanding as we make decisions. We sometimes use the analogy of a 3-legged stool of management, research, and monitoring to make this point (Conroy and Peterson 2009).

Common mistakes in framing decisions

Poorly stated objectives

It is apparent to us that, in many cases, the objectives of management are poorly stated, if they are stated at all. This can lead to decisions that lead nowhere – that is, they are not connected to any apparent objectives. This in turn means that the decisions do not address the management problem, waste resources, and potentially create unnecessary conflict among the stakeholders. The reverse also can occur when objectives are stated, but management decisions are apparently arrived at by an independent process. As a result, the objectives cannot be achieved because they are not connected to management actions. Again, the management problem is not addressed, resources are wasted, and unnecessary conflict created; additionally, **stakeholders** (parties who have an interest in the outcome of decision making, and who may or may not be **decision makers**) may feel disenfranchised, since apparently their input in forming objectives has been ignored.

Prescriptive decisions

A related situation arises in cases where "decisions" are formulated in a rule-based, prescriptive manner that presumes that certain sets of conditions (perhaps attributes measured via monitoring) necessarily trigger particular actions. Such formulaic approaches (common in many species recovery plans) may be useful tools in a decision-making process, but do not constitute decision making (except in the trivial sense of having decided to follow the formula).

Confusion of values and science

When attempts are made to define objectives, a very common problem that we see is the *confusion of values* (or objectives) with *science* (or data/ information). That is, conflating what we know (or think we know) about a problem, with what we are trying to achieve. Most natural resource professionals come from a background in the biological or earth sciences, and are more comfortable discussing "facts" and data than they are discussing values. As we will see, "facts" come into play when we try to connect candidate decisions to the objectives we are trying to achieve. Objectives, on the other hand, reflect our values (or the values of those with a stake in the decision whose proxies we hold). If we do not get the values (objectives) right, the "facts" will be useless for arriving at a decision. More insidiously, disagreements about "facts" or "science" are frequently a smokescreen or proxy for disagreement about values. One needs to look no further than the cases of the Northern Spotted Owl (*Strix occidentalis caurina*) or anthropogenic climate change. In each case, scientific belief (and supporting "facts") coincides remarkably with the values of the respective stakeholder communities, with for example timber industry advocates tending to be skeptical of the obligate nature of ancient forests for owls, and many political or social conservatives questioning the science of climate change (Lange 1993, McCright and Dunlap 2011, Martin et al. 2011, Russill 2011).

Poor use of information

Another very common disconnect we see is the *poor use of information from monitoring programs*. While some general-purpose monitoring can perhaps be justified (e.g., the Long Term Ecological Research Network [LTER; http://www.lternet.edu/] programs that provide baseline monitoring in relatively undisturbed areas), omnibus monitoring programs that are not connected to and do not support decision making are often unproductive (see also Nichols and Williams 2006). Rather, we agree with Nichols and Williams (2006) that changing the focus and design of monitoring programs as part of an overarching program of conservation-oriented science or management.

This is not to say that monitoring (of any kind) is an absolute requirement of decision making. In some cases, there are few data to support quantitative statements about a decision's impact, and little prospect that sufficient data will be acquired in the near term to allow unequivocal statements about management; many problems involving imperiled species and their habitats fall into this category. Nonetheless, it is incumbent on managers to make decisions given whatever data or other knowledge is available. Putting off a decision until more information is available is, of course, itself a decision, with potentially disastrous consequences ("paralysis by analysis" is another variant). The reality is that we can always learn more about a system; the trick is to use what we know *now* to make a good decision, while always striving to do better with future decisions.

What is structured decision making (SDM)?

SDM consists of three basic components. The first is explicit, quantifiable objectives, such as maximizing bear population size or minimizing human–bear conflicts. The second is explicit management alternatives (actions) (e.g., harvest regulations or habitat management) that can be taken to meet the objectives. The third component is models that are used to predict the effect of management actions on resource objectives (e.g., models predicting population size after various harvest regulations). Because knowledge about large-scale ecological processes and responses of resources to management are always imperfect, **uncertainty** is incorporated in SDM through alternative models representing hypotheses of ecological dynamics and statistical distributions representing error in model parameters and environmental variability.

Why should we use a structured approach to decision making?

Some decision problems have an obvious solution and need no further analysis. In such cases, two or more decision makers with the same objective would probably arrive at the same decision, perhaps without even consciously making a choice. Such decision problems probably do not require a structured approach.

However, we suggest that these types of problems are not typical of natural resource management. In our experience, natural resource decision problems are typically complex, and multiple decision makers can easily disagree on the best decision. Furthermore, the process by which natural resource decision makers arrive at decisions tends to be difficult to explain, which in turn makes it difficult to communicate. For example, a supervisor, who has much knowledge and experience to draw on, trying to explain decisions to a new employee, who has only a rudimentary understanding of issues. Inevitably, this results in miscommunication due to the ad hoc way decisions are typically made in natural resource management, which in turn makes them both difficult to convey as well as difficult to replicate. An SDM process can avoid these problems and foster better communication and knowledge transfer. For another example, before the advent of **adaptive harvest management (AHM)** for setting waterfowl harvest regulations, regulations were effectively decided by a small number of agency staff. While these staff received technical and other input, there was no clear, repeatable process by which decisions were reached, and thus decisions could appear arbitrary to outside observers.

A structured approach, on the other hand, clarifies the decision-making problem by decomposing it into components that are easier to understand and convey. A structured approach also provides *transparency* and *legacy* to the decision-making process, so that the process does not have to be reinvented every time there is institutional change or turnover. Finally, a structured approach should provide a clear linkage between research and monitoring components and decision making, and thus avoid waste and redundancy.

Examples of how SDM and **adaptive resource management** (**ARM**, defined below) can be, or are, currently applied to natural resource management include management of sustainable harvest from fish (Peterson and Evans 2003, Irwin et al. 2011) and wildlife (Anderson 1975, Williams 1996, Smith et al. 1998, Johnson and Williams 1999, Moller et al. 2009) populations, endangered species management (Moore and Conroy 2006, Conroy et al. 2008, McDonald-Madden et al. 2010, Keith et al. 2011), sustainable agriculture and forestry (Butler and Koontz 2005, Schmiegelow et al. 2006), river basin and watershed management (Clark 2002, Prato 2003, Leschine et al. 2003), water supply management (Pearson et al. 2010), management of air and water quality (Eberhard et al 2009, Engle et al. 2011), design of ecological reserves (McDonald-Madden et al. 2011, McGeoch et al 2011), control of invasive species (Foxcroft and McGeoch 2011) and climate change (Wintle et al. 2010, Conroy et al. 2011, Nichols et al. 2011). This list is selective and not exhaustive, and non-inclusion of a resource area by no means suggests that SDM or ARM would not be useful in many other areas. Conversely, not every SDM application has been successful or even well executed. We will consider some of the reasons why these approaches can and might fail.

Limitations of the structured approach to decision making

Above, we have discussed a number of advantages of a structured approach to decision making and how a structured approach can ameliorate common problems in framing decisions. To summarize, these include:

- transparency and improved communication;
- a clearer connection of decisions to stated objectives;
- institutional memory in the decision making process;
- better use of resources (e.g., in monitoring programs).

However, a structured approach can be viewed as having disadvantages to the way business might be conducted currently. First, a structured approach requires a long-term institutional commitment to carry through, and there is always the risk that a future administration will undo the process. Also, a structured approach can, at least in the short term, be threatening to the institutional way of doing business that lacks transparency and operates under hidden assumptions. Of course, these are not really arguments against taking a structured approach so much as they are obstacles that must be overcome (or navigated around) to make SDM work.

Finally, readers should not get the idea that we are promoting structured decision making as a foolproof way of making "good" decisions. A distinction must be made between being "wrong" in the sense of obtaining a less-than-desirable outcome following a sound decision-making process and being "wrong" by following a flawed decision process that occasionally leads to good outcomes by accident. By following a "good process" we do not assure ourselves of good outcomes, because of uncertainty (Chapter 7). We hopefully will experience more good than bad outcomes, but the bad outcomes we do experience are understandable in the context of our decision process. Furthermore, as we will see, they provide us with opportunities to learn and improve future decision making. Following a "bad process" *will* occasionally result in desirable outcomes, but these will not be understandable in the context of the decision process, and provide no potential for learning or improvement of decision making through time.

No one can be assured of a good result from any specific decision, but we *can* assure you that if you follow a sound decision process you will a) do better in the longer run than if you do not, and b) be in a position to defend your decision even when the results are poor. The distinction between *process* and *outcome* is emphasized (albeit in somewhat tongue-in-cheek fashion) by Russo and Shoemaker (2001). These authors describe good and bad outcomes following a good process as, respectively "a deserved success" and "a bad break". By contrast, these same outcomes following a bad process are respectively characterized as "dumb luck" and "poetic justice."

Adaptive resource management

Adaptive resource management (ARM; Walters 2002, Walters 1986, Williams et al. 2002, Williams et al. 2009) extends SDM to the case where outcomes following decisions are uncertain, which we argue is common in natural resource management. This uncertainty is incorporated via the use of alternative models representing hypotheses of ecological dynamics and statistical distributions representing error in model parameters. Each model (hypothesis) is assigned a level of plausibility or probability. The optimal decision then is selected based on the current system state (e.g., bear population size) and a prediction of the expected future state following a management decision, taking into account various sources of uncertainty.

When management decisions reoccur over space or time (e.g., annual harvest regulations), model probabilities are updated by comparing model-specific predictions to observed (actual) future conditions. The adjusted model probabilities can then be used to predict future conditions and choose the optimal decision for the following time step. This adaptive feedback explicitly provides for learning through time and, ideally, the resolution of competing hypotheses with monitoring data.

Under ARM, monitoring data serve two purposes. First, they provide an estimate of the current system state and a means of monitoring the responses of the system to management. This aspect of monitoring is shared with SDM when decisions are recurrent and state dependent. Under ARM, monitoring provides the additional role of learning about system dynamics, which in turn improves future decision making. Because of its great potential for integrating monitoring programs into decision making, ARM has now been formally adopted by the U.S. Department of the Interior (USDI) for managing Federal resources (Williams et al. 2009).

There is some confusion in the literature about what "adaptive management" means. Some of the confusion arises from differences in the relative emphasis placed on "learning" (that is reducing **structural uncertainty**; see Chapters 7 and 8) versus seeking an optimal resource outcome (Williams 2011) and the degree to which practitioners of ARM assert that experimental "probing" is required (e.g., Walters 1986, Walters et al. 1992). We deal with these issues to some degree in Chapter 8 and Appendix E but largely take the view that these are differences without a distinction. We see no conflict between "learning" and "gaining", particularly when it is made clear (Chapters 7 and 8, and Appendix E) that system uncertainty detracts from the latter, and thus "learning" and "gaining" are more properly viewed as synergistically related than in competition with each other. More serious, we believe, are usages of "adaptive management" that detract from it as a meaningful concept. For example, we have heard ARM referred to as "trial and error", "seat of the pants", "conflict resolution", or "building stakeholder collaboration." Certainly, these can be aspects of an ARM process but do not themselves constitute such a process.

In our view, three features absolutely must be present for the process to be deemed ARM:

1. Decisions must be **recurrent**. We cannot envision a role for ARM for one-time decisions, simply because there is no opportunity for learning to influence future decision making.
2. Decisions must be based on predictions that incorporate structural uncertainty (Chapter 7). Often this will be represented by two or more alternative models or hypotheses about system functionality.
3. There must be a **monitoring** program in place to provide the data that will be fed back into adaptive updating, without which there, by definition, can be no updating. Programs that do not contain these essential elements, in our view, are not, and should not be called, "adaptive management." We note that these essential elements *are* part of the USDI adaptive management protocol, which we hold as a model for other agencies and groups (Williams et al. 2009).

Summary

In this chapter, we have presented a broad overview of SDM and ARM, explained why we think a structured approach may be beneficial to a wider range of natural resource decision problems, and provided a wide array of examples that are currently or potentially amenable to SDM and ARM.

In the next chapter, we describe the key elements of SDM, including development of a problem statement, elucidation of objectives, specification of decision alternatives, and establishment of boundaries (temporal, spatial) for the decision problem. We then discuss some general principles for evaluating and selecting among alternative decisions. Finally, we will introduce the use of predictive modeling in decision making and discuss the issue of uncertainty. All of these topics will be developed in greater detail in later chapters.

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