Adaptive Management as an Information Problem

Holly Doremus*

Abstract: Enthusiasm for adaptive management has outrun evaluation of its usefulness as a natural resource management tool. Policymakers routinely endorse, and frequently require, it. Managers and academic observers alike have tended to assume that adaptive management is the best strategy. Little has been said, particularly in the policy literature, about how to decide whether an adaptive management approach makes sense. Looking at adaptive management as an information problem, this paper argues that adaptive management should be used only when it promises to improve management outcomes sufficiently to justify the additional costs it imposes. An explicit formal analysis of the prospects for learning and the value of learning for management should precede any decision to engage in adaptive management. For large-scale, long-term, or high-profile adaptive management programs, that analysis should be reviewed by outside experts and periodically re-examined. The type of analysis recommended here would help limit the use of adaptive management to appropriate circumstances, improve implementation when adaptive management is adopted, and enhance accountability. It would also highlight situations in which learning would be valuable for managers but appears too costly or difficult. In some cases, systematic barriers to learning can be reduced through targeted or general policy measures.

INTRODUCTION

This Symposium broadly considers the ability of law to change in response to changing circumstances and knowledge (adaptive capacity), and to retain its fundamental form in the face of exogenous challenges (resiliency).[1] In the natural resource management context, the current interest in resilience and adaptability is largely driven by climate change, which raises questions about whether law can keep up with an environment whose rate of change exceeds that for which human institutions were designed, and whether existing law can withstand the new stresses it is beginning to encounter.[2] This paper approaches those questions through the lens of adaptive

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[1] For definitions of both resilience and adaptive capacity, see J.B. Ruhl, *General Design Principles for Resilience and Adaptive in Legal Systems*, ___ N.C. L. REV. **[draft at 3, 14]** (2011).

[2] For discussion of the extent to which climate change exacerbates existing resource management

management, a strategy that theoretically promotes both adaptation and resilience. It argues that, despite its theoretical appeal, adaptive management is not useful for all management problems, and should not be adopted without an explicit evaluation of its benefits and costs.

The core concept of adaptive management is that the management process should incorporate, rather than follow, learning about the managed system. An adaptive management framework explicitly builds in opportunities for learning and adjustment.[3] Ideally, that creates a resilient institutional structure for adapting to change.

Adaptive management arouses both much enthusiasm and much skepticism.[4] The theory is an attractive one, promising a way to make decisions in the face of current uncertainty while also reducing uncertainty over time.[5] Enthusiasm has spilled over to the policy arena, where adaptive management is now routinely endorsed, and even mandated.[6] When it comes to implementation, however, skepticism becomes the rule. Documented instances of successful adaptive management are rare,[7] and many touted examples diverge significantly from the

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challenges and introduced new ones, see Alejandro E. Camacho,

[3] *See infra* text accompanying notes **____**.

[4] The literature "tells a conflicting story; one could conclude that adaptive management should either be relied upon heavily or criticized sharply when considering solutions to challenging resource management problems." R. Gregory, D. Ohlson, and J. Arvai, *Deconstructing Adaptive Management: Criteria for Applications to Environmental Management,* 16 ECOLOGICAL APPLICATIONS 2411, 2411 (2006).

[5] *See, e.g.*, James E. Lyons et al., *Monitoring in the Context of Structured Decisionmaking and Adaptive Management*, 72 J. Wildlife Mgmt. 1683, 1691 (2008) ("Adaptive management has been widely recognized as having tremendous potential to solve problems in natural resource management, and calls for implementation of adaptive management are becoming more common . . .").

[6] *See, e.g.*, Chesapeake Bay Protection and Restoration, Exec. Order 13508, § 203(e) (May 12, 2009) (requiring that federal agencies develop a Chesapeake Bay strategy that, among other things, "describe[s] a process for the implementation of adaptive management principles, including a periodic evaluation of protection and restoration activities"); Cal. Water Code § 85308(f) (mandating that management plan to be prepared by newly-established Delta Stewardship Council include "a science-based, transparent, and formal adaptive management strategy for ongoing ecosystem restoration and water management decisions."); Eric Biber, *Environmental Law's Monitoring Problem*, **[draft at 4]** (noting that agencies "have embraced" adaptive management; J.B. Ruhl and Robert L. Fischman, *Adaptive Management in the Courts*, 95 MINN. L. REV. 424, 424 (2010) (explaining that adaptive management "has infused the natural resources policy world to the point of ubiquity."

[7] *See, e.g.*, Beth C. Bryant, *Adapting to Uncertainty: Law, Science, and Management in the Stellar Sea Lion Controversy*, 28 STAN. ENVTL. L. J. 171, 209 (2009) (noting that large-scale

theoretical ideal.[8] Furthermore, adaptive management can create a new type of accountability problem, providing cover that allows resource management agencies to put off imposing politically controversial limits on economic activity.[9]

I share the skepticism about the politics of adaptive management, but I also share the sense that it is both inevitable and in some contexts desirable. That makes it important to examine and deal with its challenges. And that, in turn, is a tall order. Adaptive management is like the elephant being examined by the blind men in the well-known tale: every different aspect of it explored reveals a new challenge.

Several of the challenges have been recognized and are being addressed from both scientific and policy perspectives. Without denigrating their importance, therefore, I set them aside here. There is no question that adaptive management poses incentives problems, accountability problems, and flexibility problems.[10] In this paper, however, I choose to focus on a different part of the elephant, one that has been less explored by policy wonks. Adaptive management is, in important ways, an information problem. It can't be used appropriately or effectively without confronting that piece of the puzzle. I make no claim that information is the entire elephant – of course it is not. What I do claim, though, is that information is an important part of the elephant, one that deserves more of our attention.

I focus on information for three reasons. First, the information problem inherent in adaptive management is logically prior to the incentives, accountability, and flexibility problems for deciding whether to use adaptive management in a specific context. Only if learning is feasible does it make sense to worry about whether managers want to learn, can be forced to learn, or can use knowledge they acquire. Asking the information question is therefore a way of asking whether adaptive management can succeed under a best-case scenario. If the answer is yes, additional questions must still be asked about how close we can come to that best case. But if the answer is no those other problems are irrelevant; adaptive management simply is not a useful choice.

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adaptive management experimentation "presently suffers from a sorry success rate"); Catherine Allen and Allan Curtis, *Nipped in the Bud: Why Regional Scale Adaptive Management Is Not Blooming*, 36 ENVTL. MGMT. 414 (2005).

[8] Gregory, Ohlson, and Arvai, *supra* note **[4]**, at 2411.

[9] *Id.*; Holly Doremus, *Adaptive Management, the Endangered Species Act, and the Institutional Challenges of "New Age" Environmental Protection*, 41 Washburn L. J. 50, 52 (2001).

[10] For discussion of those problems, *see generally id.*; Ruhl and Fischman, *supra* note **[5]**; Biber, *supra* note **[6]**; Alejandro E. Camacho, *Can Regulation Evolve? Lessons from a Study in Maladaptive Management*, 55, UCLA L. REV. 293 (2007); J.B. Ruhl, *Regulation by Adaptive Management: Is It Possible?*, 7 MINN. J. L. SCI. & TECH. 21 (2005); John M. Volkman & Willis E. McConnaha, *Through a Glass Darkly: Columbia River Salmon, the Endangered Species Act, and Adaptive Management*, 23 ENVTL. L. 1249 (1993).

Second, there is good reason to think that the information problem will frequently be a difficult one. Adaptive management poses an underappreciated information conundrum.[11] It is needed only when lack of information undermines confidence in management decisions. It is substantively (as opposed to politically) useful, however, only if that inadequate information base can and will be supplemented over time in a way that increases confidence in future decisions. The learning needed to make adaptive management successful will often be difficult, even with the right motivation. It will typically be costly, requiring added modeling, monitoring and data evaluation.[12] The extra resources adaptive management requires will not be well spent unless they produce useful information.

Finally, the information problem represents a gap in the literature. Although some ecologists and economists have recognized the information problem and begun to develop decision support tools to address it,[13] other thoughtful commentators still leave it out of their descriptions of the prerequisites for adaptive management,[14] and policy scholars seem not yet to have given it much thought. Perhaps that is because solutions to the information problem seem, at least at first glance, to lie peculiarly within the expertise of natural scientists. Certainly natural science has a crucial role to play, providing tools and techniques for undertaking and interpreting experiments or other information-gathering efforts. But factors within the realm of law and policy are also important, because they can facilitate or complicate data generation, sharing, interpretation, and use.

In this paper, I set out to explore the policy and institutional context for the acquisition

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[11] *See infra* text accompanying notes **___**.

[12] *See, e.g.*, Carl Walters, *Challenges in Adaptive Management of Riparian and Coastal Ecosystems*, 1(2) Conservation Ecology 1 (1997), http://www.ecologyandsociety.org/vol1/iss2/art1/ (available online only, no pagination) (noting that costs of modeling, monitoring, and experimentation often stand in the way of implementing adaptive management); Biber, *supra* note **[6]**, at **[draft at 33]** (noting costs of monitoring).

[13] *See, e.g.*, Gregory, Ohlson, and Arvai, *supra* note **[4]**; Eli P. Fenichel and Gretchen J.A. Hansen, *The Opportunity Cost of Information: an Economic Framework for Understanding the Balance between Assessment and Control in Sea Lamprey (Petromyzon marinus) Management*, 67 Canadian J. Fisheries & Aquatic Science 209 (2010); Julien Martin, Michael C. Runge, James D. Nichols, Bruce Lubow, and William L. Kendall, *Structured Decisionmaking as a Conceptual Framework to Identify Thresholds for Conservation and Management*, 19 Ecological Applications 1079 (2009); Tracy M. Rout, Cindy E. Hauser, and Hugh P. Possingham, *Optimal Adaptive Management for the Translocation of a Threatened Species*, 19 Ecological Applications 515 (2009).

[14] *See, e.g.*, Lyons et al., *supra* note **[2]**, at 1691 (describing adaptive management as "the most effective and efficient way to achieve management objectives" when the basic conditions of a series of sequential decisions, uncertainty, and the ability to adjust are met, with no mention of the ability to learn).

and use of information in the course of adaptive management. This analysis builds on my earlier work on the "information supply pipeline," the sequence of steps needed to take information from the discovery phase to use in decisionmaking.[15] I assume for purposes of this analysis that managers are making good faith efforts to achieve the goals set out by their governing statutes and regulations.[16] I am under no illusion that this assumption is always (or even generally) correct. Indeed, the conviction that managers cannot be trusted surely motivates much of the work on the need to build accountability into adaptive management efforts.[17] But making this assumption allows me to highlight challenges distinct from the motivations of resource managers, challenges which must be dealt with even if the incentives and accountability problems are solved.

Analyzing adaptive management as an information problem produces two pragmatically useful results. First, and perhaps most important, it encourages recognition that adaptive management is not always a desirable strategy, and points to ways to determine whether adaptive management will be helpful in specific contexts. The current enthusiasm for adaptive management in the policy sector seems to ignore this step. There is debate about how to do adaptive management and a fair amount of handwringing about why it is not more fully pursued,[18] but not enough discussion about whether it ought to be used.[19]

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[15] Holly Doremus, *Data Gaps in Natural Resource Management: Sniffing for Leaks Along the Information Pipeline*, 83 INDIANA L. J. 407 (2008).

[16] I also assume that managers have as much access to information as the regulated community. Because my focus here is on public resource management, that is often, although not always, a good assumption. To the extent that actions affecting managed resources require government approval, it will generally be legally possible to require that those seeking approval provide needed information.

[17] *See e.g.*, Bruce Pardy, *The Pardy-Ruhl Dialogue on Ecosystem Management Part V: Discretion, Complex Adaptive Problem-Solving and the Rule of Law*, 25 PACE ENVTL. L. REV. 341, 347 (2008) (decrying the degree of administrative discretion in natural resource management). On the prevalence of the principal-agent problem in natural resource management and the need for accountability mechanisms to hold agencies to their statutorily assigned tasks, see Holly Doremus, *Using Science in a Political World: The Importance of Transparency in Natural Resource Regulation*, *in* WENDY E. WAGNER AND RENA STEINZOR, EDS., RESCUING SCIENCE FROM POLITICS 143, 144-145 (2006).

[18] *See, e.g.*, Carl Walters, *Challenges in Adaptive Management of Riparian and Coastal Ecosystems*, 1(2) CONSERVATION ECOLOGY 1 (1997), http://www.ecologyandsociety.org/vol1/iss2/art1/ (evaluating the "low success rates in implementing adaptive management").

[19] For an exception, see Gregory, Ohlson, and Arvai, *supra* note **[4]**, at 2414 (offering four criteria for deciding whether the use of adaptive management is appropriate). Their analysis, however, ends up focusing as much on the details of implementing adaptive management as on

That needs to change. Adaptive management is not an end in itself, nor is it always useful. It is a tool that can improve management outcomes over time in some contexts. It does not come free, however. Both the decision to employ adaptive management and decisions about how to implement it involve trade-offs. Adaptive management increases the costs of management, complicates oversight, imposes added institutional demands, and is subject to misuse for political ends.[20] It requires striking a balance between short-term management objectives and long-term learning,[21] between devoting resources to management and to monitoring,[22] and between finality and endless political squabbling.[23] It should only be used when the benefits of learning exceed those costs over the relevant time frame.

In order to make sure that adaptive management is employed only where it should be, before deciding to implement it resource managers should undertake, and policymakers should require, an explicit, formalized analysis of the prospects for learning and its expected value for management. That analysis, which should be reviewed by leading technical experts outside the management agency and periodically re-examined, can serve valuable internal and external ends. Internally, it can force managers to confront their assumptions about the system and their information needs, providing a kind of intellectual discipline that prepares the groundwork for learning. A thorough pre-adoption review of the prospects for adaptive management can lead to a better adaptive management program if one is ultimately adopted. Externally, it can provide a different kind of discipline, enhancing accountability to management goals by forcing managers to explain how they expect adaptive management to help them achieve those goals.

Second, approaching adaptive management as an information problem highlights systematic barriers to learning which can be reduced by changes in law, policy, or institutional structure. While a formal evaluation of the trade-offs should be a prerequisite to adaptive management, it is important to recognize that the calculus of learning is not fixed. If the evaluation suggests that learning will be difficult or costly, that need not be the end of the matter. Recognizing barriers to gathering, exchanging, or using information can help us address those barriers. It may turn out that some are illusory, or at least not as high as they appear, while others can be reduced through targeted or general policy choices.

Of course, many information challenges are context-specific, and cannot be resolved or

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the choice of whether to implement it.

[20] *See infra* text accompanying notes **____**.

[21] *See, e.g.*, Gretchen J.A. Hansen and Michael L. Jones, *The Value of Information in Fishery Management*, 33 FISHERIES 340 (2008); Michael A. McCarthy and Hugh P. Possingham, *Active Adaptive Management for Conservation*, 21 CONSERVATION BIOLOGY 956 (2007).

[22] Lyons et al., *supra* note **[2]**, at 1691.

[23] Sandra Zellmer and Lance Gunderson, *Why Resilience May Not Always Be a Good Thing: Lessons in Ecosystem Restoration from Glen Canyon and the Everglades*, 87 NEB. L. REV. 893, 945 (2009); Doremus, *Adaptive Management*, *supra* note **[9]**, at 55.

even recognized outside that context. There are some, however, which occur across a range of management contexts. At least some of these systematic challenges can be proactively addressed. Rapid diffusion of data, analytic tools, and theoretical insights is one recurring problem.[24] There are relatively straightforward (though not necessarily easy) ways to encourage better movement of information through the system. Other recurring challenges may require deeper policy and institutional changes that are not likely to occur unless their potential to improve management outcomes is recognized. Information generation can be promoted by designating areas for experimentation and crafting general rules specifying the conditions under which management experiments can be conducted. Information utilization can be promoted through employee selection and training, institutional design, and building more effective connections between academic and applied scientists.

The argument proceeds in two major parts. The first sets out a framework for evaluating the usefulness of adaptive management. It begins by reviewing the three elements that must be present before adaptive management should even be considered. It then considers in more detail how the most challenging of those elements, the costs and benefits (broadly defined) of learning, should be evaluated and proposes a formal analytic approach. The second part takes up the question of what to do when the benefits of learning appear high but are matched or exceeded by the costs. It contends that some systematic barriers to learning can be addressed through policy measures, and offers recommendations. Finally, the conclusion briefly recaps the argument and key recommendations.

I. EVALUATING ADAPTIVE MANAGEMENT IN CONTEXT

It is common ground at this point that natural resource management[25] decisions must typically be made in the face of incomplete knowledge about the systems being managed.[26] Knowledge gaps impede management success in a variety of ways. Most obviously, they undermine confidence in management decisions, because actions taken under uncertainty might move the system away from rather than toward the desired outcome. In addition to raising the risk of management failure, knowledge gaps can be paralyzing if managers are risk averse,

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[24] Doremus, *Information Pipeline*, *supra* note **[16]**, at 434-439.

[25] I use the terms "natural resource management" and "natural resource managers" in this paper inclusively, to refer both to those responsible for managing public natural resources, such as the U.S. Forest Service and National Park Service, to those responsible for managing built systems that use or impinge on public resources, such as officials at the Bureau of Reclamation and Army Corps of Engineers, and also to regulators responsible for setting limits on resource extraction and use, such as the U.S. Fish and Wildlife Service and National Marine Fisheries Service.

[26] *See, e.g.*, Holly Doremus, *Precaution, Science, and Learning While Doing in Natural Resource Management*, 82 WASH. L. REV. 547, 548 (2007) ("Uncertainty is the unifying hallmark of environmental and natural resource regulation.").

preferring passivity to taking the chance that their actions will make the situation worse.[27] That sort of passivity might be desirable from a conservation perspective where the relevant decision is whether or not to permit new environmental impacts, but it is problematic where the status quo itself is believed to be harmful to the environment, as is often the case for managed natural systems.[28]

Knowledge gaps also can interfere with political and judicial accountability. Uncertainty leaves managers free to make interpretive judgments. They can often conceal those judgments, and the reasons for the specific choices made, from public oversight with claims that they are simply following the science.[29] Uncertainty therefore makes it difficult for the public to discern whether managers are doing their best to follow legislative direction or instead bowing to political pressure. It also complicates judicial oversight. Federal courts must be at their "most deferential" when reviewing scientific determinations.[30] They generally will not disturb an agency's interpretation of limited or conflicting data.[31] Uncertainty may therefore, in effect, maximize management discretion.[32]

Adaptive management has been touted as a way to deal with the information deficit,

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[27] My view that many managers are risk averse in precisely this way may require some explanation. While I agree that resource management agencies often seem to bow to political pressures in ways that put the resources under their supervision at risk, that's a different problem. Recall that for purposes of this paper I assume that managers are pursuing applicable statutory and regulatory goals in good faith. That assumption is, at a minimum, not universally false; although their urge to act protectively surely can be overcome by political pressures, often managers do try to protect the resources they are charged with overseeing. In that context, I think there is good evidence that at least some managers show risk aversion with respect to the trade-offs between learning and risks to the resource, and little evidence that any are prone to risk-taking. Examples of risk aversion potentially inhibiting learning come from the reluctance of FWS to authorize experimental high flows on the Colorado River because of possible impacts on the Kanab ambersnail, Doremus, *Adaptive Management*, *supra* note **[9]**, at 78-79, and the reluctance of water managers to expend the resources of the Environmental Water Account created by the federal-state CalFed program lest they be caught without water later when the fish could need it more, EWA Review Panel, First Annual Review of the Environmental Water Account for the CalFed Bay-Delta Program (undated), available at http://www.science.calwater.ca.gov/pdf/2001_EWA_Science_Review_Workshop.pdf.

[28] Doremus, *Precaution*, *supra* note **[27]**, at 555.

[29] See Doremus, *Transparency*, *supra* note **[18]**, at **___**.

[30] Baltimore Gas & Elec. Co. v. Natural Resources Defense Council, 462 U.S. 87, 103 (1983).

[31] *See* Holly Doremus, *The Purposes, Effects, and Future of the Endangered Species Act's Best Available Science Mandate*, 34 ENVTL. L. 397, 429-30 (2004) (explaining how courts approach review of technical decisions).

[32] Doremus, *Precaution*, *supra* note **[27]**, at 574-577; Biber, *supra* note **[5]**, **[draft at 46]**.

allowing action in the face of uncertainty in the short run while information gaps are filled in over the longer term. The concept was developed before large-scale anthropogenic climate disruption was widely recognized as a problem,[33] but climate change makes it seem even more vital to effective resource management.[34] There is no universal definition of the term "adaptive management." It has been used to describe a range of management strategies, but fundamentally any adaptive strategy must include at least two key features: iterative decisionmaking and a commitment to learning over time.[35] As originally envisioned by its primary architects, adaptive management was a reaction to the perceived inadequacies of management based on pre-decision comprehensive analysis.[36]

In fact, many natural resource decisions need not be made once and for all at the "front end." For large managed systems, like the Florida Everglades, Chesapeake Bay, California Bay-

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[33] The foundational works are CARL WALTERS, ADAPTIVE MANAGEMENT OF RENEWABLE RESOURCES (1986), and ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT (C.S. Holling ed., 1978).

[34] *See, e.g.*, Joshua J. Lawler, *Climate Change Adaptation Strategies for Resource Management and Conservation Planning*, 1162 ANN. N.Y. ACAD. SCI. 79, 86 (2009) (for all its challenges, adaptive management "is still likely to be one of the best tools managers and scientists have to address climate change and to learn about its effects").

[35] *See, e.g.*, NATIONAL RESEARCH COUNCIL, PANEL ON ADAPTIVE MANAGEMENT FOR RESOURCE STEWARDSHIP, COMMITTEE TO ASSESS THE U.S. ARMY CORPS OF ENGINEERS METHODS OF ANALYSIS AND PEER REVIEW FOR WATER RESOURCES PROJECT PLANNING, ADAPTIVE MANAGEMENT FOR WATER RESOURCES PLANNING 2 (2004) ("There are multiple views and definitions regarding adaptive management, but elements that have been identified in theory and in practice are: management objectives that are regularly revisited and accordingly revised, a model(s) of the system being managed, a range of management options, monitoring and evaluating outcomes of management actions, mechanisms for incorporating learning into future decisions, and a collaborative structure for stakeholder participation and learning."). Unlike some adaptive management proponents, I do not include collaborative decisionmaking as a fundamental element. Adaptive management is a learning approach to management. Collaboration is one possible method for making management decisions, but it is not essential to learning, and in some circumstances might even be an impediment. Whether and in what circumstances collaborative management might be appropriate is a distinct question from whether adaptive management is appropriate, and the two are best addressed separately.

[36] Brad Karkkainen traces the roots of adaptive management much further back than the work of Walters and Holling, locating them in the pragmatism of John Dewey. Bradley C. Karkkainen, *Adaptive Ecosystem Management and Regulatory Penalty Defaults: Toward a Bounded Pragmatism*, 87 Minn. L. Rev. 943, 957-959 (2003). Others have made the same connection. *See, e.g.*, KAI N. LEE, COMPASS AND GYROSCOPE – INTEGRATING SCIENCE AND POLITICS FOR THE ENVIRONMENT __ (1993); BRYAN G. NORTON, SUSTAINABILITY: A PHILOSOPHY OF ADAPTIVE ECOSYSTEM MANAGEMENT __ (2005).

Delta, national forests, and national parks, decision points recur over time, providing repeated opportunities for reconsideration and adjustment. In other contexts, such as permits to fill wetlands or even permits to bury streams with the waste from mountaintop removal mining, individual decisions are made only once but the same type of decision is confronted repeatedly. Although individual decisions cannot be reversed, the effects of those decisions can inform later ones. Where either direct or indirect opportunities exist for "back end"[37] adjustment, management can be designed as a learning strategy.

Early proponents of adaptive management suggested that the most efficient path to increased knowledge would be to design management actions as deliberate and, to the extent possible, controlled experiments to test explicit hypotheses about the system. That strategy has come to be known as "active adaptive management."[38] Another version, known as "passive adaptive management," however, has been more commonly implemented.[39] Passive adaptive management involves structured learning in the absence of deliberate management experimentation.[40] It relies on monitoring the outcomes of management and using the information gained to update beliefs about how the system operates. In either form, adaptive management implies a humble attitude,[41] anticipating the possibility of surprise, and being prepared to detect and correct management shortfalls.

Currently, policymakers seem uniformly excited about adaptive management. It has been mandated by federal and state legislation, adopted by regulation, and applied through guidance and informal mechanisms.[42] Scholars are less sanguine. There is much enthusiasm for the

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[37] On the "front end / back end" distinction and the need to be able to adjust policies based on new information, see generally SIDNEY A. SHAPIRO & ROBERT L. GLICKSMAN, RISK REGULATION AT RISK: RESTORING A PRAGMATIC APPROACH 177 (2003).

[38] CARL WALTERS, ADAPTIVE MANAGEMENT OF RENEWABLE RESOURCES 232 (Wayne M. Getz ed., 1986). For a concise explanation of the distinction between active and passive adaptive management, *see* Julie Thrower, *Adaptive Management and NEPA: How a Nonequilibrium View of Ecosystems Mandates Flexible Regulation*, 33 ECOLOGY L.Q. 871, 885 (2006).

[39] Allen and Curtis, *supra* note **[3]**.

[40] WALTERS, *supra* note [**22]**, at 248-252. Brad Karkkainen has provided an excellent concise explanation of the difference between active and passive adaptive management. Karkkainen, *supra* note **[2]**, at 950.

[41] Virginie Maris & Arnaud Béchet, *From Adaptive Management to Adjustive Management: A Pragmatic Account of Biodiversity Values*, 24 CONSERVATION BIOLOGY 966, 967 (2010).

[42] In addition to the sources cited *supra*, note **[2]**, a few examples include: 32 C.F.R. § 651.4 (requiring that Army Director of Environmental Programs "[m]onitor proposed Army policy and program documents that have environmental implications to determine compliance with NEPA requirements and ensure integration of environmental considerations into decision-making and adaptive management processes"); 33 C.F.R. § 332.4(c)(12) (plan for mitigating permitted harms to aquatic resources must include adaptive management plan to "guide decisions for revising

concept; indeed, given the shortage of front-end knowledge about ecosystems and species, most observers agree that some form of adaptive management is a necessity in many systems.[43] Nonetheless, questions remain about both its feasibility and its potential political pitfalls. On the feasibility side, it is not clear that the law always does, or even should, offer enough flexibility to make adaptive management possible.[44] On the political side, claims of adaptive management have been criticized as a false front, allowing agencies to authorize environmental harm when it is uncertain whether the extent of harm will exceed applicable legal limits.[45]

Neither of those challenges are my concern here. Instead, I start at the logical beginning. The first question to be asked is what advantages, if any, adaptive management offers in any particular natural resource management context. As explained in the next section, adaptive management should be considered only if, at a minimum, three conditions are met. Any decision to employ adaptive management should be supported by an explicit analysis of all three questions. Although that analysis need not be precise or quantitative, it should be sufficiently detailed to justify the conclusion that the learning adaptive management is expected to generate will justify its costs. Requiring such an analysis at the outset would reduce the ability of policymakers or managers to use adaptive management as a tool for delaying or avoiding difficult decisions, counter temptations to convert management into a research exercise in which learning is pursued for its own sake or uncertainty becomes an endless excuse for inaction,[46] and improve the effectiveness of adaptive management when its use is appropriate.

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compensatory mitigation plans and implementing measures to address both foreseeable and unforeseen circumstances that adversely affect compensatory mitigation success"; 36 C.F.R. § 219.3(d)(8) (key elements of Forest Service planning include "[m]onitoring and evaluation for adaptive management". As Professors Ruhl and Fischman explain, "With its core idea of "learning while doing," adaptive management has infused the natural resources policy world to the point of ubiquity, surfacing in everything from mundane agency permits to grand presidential proclamations. Indeed, it is no exaggeration to suggest that these days adaptive management *is* natural resources policy." J.B. Ruhl and Robert L. Fischman, *Adaptive Management in the Courts*, __ MINN. L. REV. ___ (forthcoming 2010, SSRN draft at 1).

[43] As J.B. Ruhl has pointed out, for example, "No serious assessment of the [Endangered Species Act] fails to conclude that adaptive management . . . is the preferred method of implementation." J.B. Ruhl, *Taking Adaptive Management Seriously: A Case Study of the Endangered Species Act*, 52 U. KAN. L. REV. 1249, 1284 (2004).

[44] J.B. Ruhl, *Regulation by Adaptive Management: Is It Possible?*, 7 MINN. J. L. SCI. & TECH. 21 (2005).

[45] Doremus, *Adaptive Management*, *supra* note **[9]**.

[46] *See* Fred A. Johnson, William L. Kendall and James A. Dubovsky, *Conditions and Limitations on Learning in the Adaptive Management of Mallard Harvests*, 30 Wildlife Soc. Bull. 176, 182 (2002) ("managers must be careful not to turn large-scale management into a research endeavor").

A. Prerequisites for Successful Adaptive Management

Adaptive management is premised on the assumption that learning is both plausible and valuable. It makes logical sense only if three conditions are satisfied. First, there must be an information gap that is important to management choices. Second, it must seem possible to fill that gap on a management-relevant time scale. Third, it must seem possible to adjust the initial decision over time in response to new information.

1. Information Gaps

Adaptive resource management necessarily begins with an information problem. The very premise of adaptive management is that it will promote learning.[47] It is only useful if learning is needed, that is if information gaps limit resource managers' ability to evaluate, at the initial time point, the likelihood that their choices will achieve management goals.[48] Absent such uncertainties, managers could confidently act on the basis of front end knowledge. They would not need adaptive management to facilitate later adjustment.

Because there is so much we don't know about the systems we try to manage, uncertainty is nearly always great enough to justify invoking adaptive management. Natural systems are not static; they change over time in ways that are difficult to predict.[49] Climate change exacerbates

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[47] *See, e.g.*, Gregory, Ohlson, and Arvai, *supra* note **[4]**, at 2412 ("The generally stated goal of AM is to improve managers' knowledge . . .").

[48] I am concerned here only with technical uncertainties, primarily natural science uncertainties about the functioning of a species or ecological system and social science uncertainties about changes in human pressures on systems. For purposes of this paper, I put aside issues of "normative uncertainty," lack of knowledge about the values people place on managed resources and the potential for changes in those values. *See* Virginie Maris & Arnaud Béchet, *From Adaptive Management to Adjustive Management: A Pragmatic Account of Biodiversity Values*, 24 CONSERVATION BIOLOGY 966, 966 (2009). I recognize the importance of that type of uncertainty and unpredictability, particularly in the context of the massive reshuffling of the earth's systems that greenhouse gas accumulation is causing. Certainly we need measures for exploring societal conservation values, and for adjusting management efforts in response to durable value changes. But that is a set of issues for another paper. Here I follow the lead of early scientific advocates of adaptive management, who assumed that management goals are exogenously fixed. *See, e.g.*, Byron K. Williams, Fred A. Johnson & Khristi Wilkins, *Uncertainty and the Adaptive Management of Waterfowl Harvests*, 60 J. WILDLIFE MGMT. 223, 224 (1996) (describing adaptive management as "the ability to make optimal decisions over time pursuant to stated objectives, in the face of uncertainty and recognizing some constraints").

[49] *See, e.g.*, Gordon H. Reeves and Sally L. Duncan, *Ecological History vs. Social Expectations: Managing Aquatic Ecosystems*, 14(2) ECOLOGY AND SOCIETY article 8 (2009), http://www.ecologyandsociety.org/vol14/iss2/art8/.

the prediction challenge, increasing the probability that managed systems will change rapidly, in unexpected ways, and outside known historical boundaries.[50] But the move toward adaptive management predates widespread concern about climate change, because there is more to the information challenge than instability. The complex connections among biotic and abiotic elements of ecosystems are often poorly understood, as are responses to management actions.[51] Even far less esoteric knowledge, such as population sizes and trends, habitat requirements, and basic life history information is frequently lacking. Finally, the control of managed systems is always less than perfect. Rules do not automatically generate absolute compliance,[52] tracking of resource use may be poor,[53] and it may not be possible to keep the system absolutely within

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[50] Climate disruption is rapidly disassembling today's climate envelopes and biotic communities, and reassembling them in ways that have no current analog. *See* Robert L. Glicksman, *Ecosystem Resilience to Disruptions Linked to Global Climate Change: An Adaptive Approach to Federal Land Management*, 87 NEB. L. REV. 833, 844-49 (2009); J.B. Ruhl, *Climate Change and the Endangered Species Act: Building Bridges to the No-Analog Future*, 88 B.U. L. REV. 1, 17-26 (2008); John W. Williams, Stephen T. Jackson and John E. Kutzbach, *Projected Distributions of Novel and Disappearing Climates by 2100 AD*, 104 PROC. NAT. ACAD. SCI. 5738 (2007). Although natural resource management has long been plagued by uncertainty, climate change "raise[s] uncertainty to a level humans have never encountered and governments have never attempted to manage." Alejandro E. Camacho, *Adapting Governance to Climate Change: Managing Uncertainty Through a Learning Infrastructure*, 59 EMORY L. J. 1, 15 (2009).

[51]On the complexity of environmental systems and the difficulties that complexity poses, *see* Daniel A. Farber, Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty, 37 U.C. Davis L. Rev. 145 (2003); Stephanie Tai, *When Natural Science Meets the Dismal Science*, 42 ARIZ. ST. L. J. 949, 958-959; Beth C. Bryant, *Adapting to Uncertainty: Law, Science, and Management in the Stellar Sea Lion Controversy*, 28 STAN. ENVTL. L. J.171, 175-176 (2009) (explaining that at least nine theories have been offered to explain the decline of the Stellar's sea lion). Lack of knowledge about underlying biological mechanisms, and the corresponding lack of ability to predict responses to management, has been called "structural uncertainty." Williams et al., *supra* note **[31]**, at 225. Structural uncertainty may be rampant even in systems with a long history of management. As an example, although migratory waterfowl harvest has long been regulated, the relationship between harvest levels and population changes has been obscured by uncertainty about whether harvest adds another source of mortality or simply replaces other causes of death. *Id.*

[52] *Id.*

[53] In California, for example, where limited water resources are the subject of constant conflict, many diversions are still not directly monitored. Although diverters are required to file statements of diversion, enforcement has been weak. Last year a bill that would have strengthened enforcement and monitoring measures stalled because of opposition from water users. Senate Bill 565 (as amended Aug. 16, 2010), http://www.leginfo.ca.gov/pub/09-10/bill/sen/sb_0551-0600/sb_565_bill_20100816_amended_asm_v92.pdf; Elliott Rector, *From Paper to the Real World: Stopping Illegal Water Diversions in California*, Environmental

desired management parameters. Under the circumstances, the only real surprise for managers would be if they weren't surprised by the way the system reacts to their efforts and outside events over the course of time.

Although this requirement will rarely turn us away from adaptive management, directly confronting it is an important prerequisite to undertaking effective adaptive management. For one thing, it emphasizes the need for clear goals set exogenously to the adaptive management process. Without identified management goals, it is impossible to understand what relevant information is missing. Looking for information gaps, therefore, necessarily forces managers to identify their goals, and to seek clarification if those goals are inadequately defined.

Surprisingly, a substantial portion of the adaptive management literature rejects the idea that goals are exogenous to the adaptive management process. Although there are those who contend that clear goals are a necessary starting point for adaptive management,[54] others, including some leading adaptive management theorists, argue that management goals themselves should be evaluated and reconsidered as part of the adaptive management cycle.[55] That view is mistaken; it seeks to sweep too much into a process with important limitations. Management goals for public and quasi-public natural resources are, and should be, politically determined. What resources society should protect, and what trade-offs it should make between conservation and other values are not scientific questions. The answers are a function of social values rather than of technical understanding. Surely those values shift over time, and goals must periodically be re-examined and adjusted. But adaptive management as it is conventionally practiced does not provide the right forum for making such adjustments.

Adaptive management structures typically require periodic meetings of a select group to review data and technical documents.[56] Those meetings are effectively inaccessible to most members of the public. Only those with enough of a stake in the outcome to devote large amounts of time to it will even bother, and only technical experts or those who can afford to hire experts will be comfortable with the discussion.[57] Furthermore, management quickly becomes

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Defense Fund On the Waterfront Blog, Aug. 4, 2010, http://blogs.edf.org/waterfront/2010/08/04/from-paper-to-the-real-world-stopping-illegal-water-diversions-in-california/; Dan Bacher, Delta Advocates Oppose Fran Pavley's SB 565 (Aug. 25, 2010), http://www.indybay.org/newsitems/2010/08/25/18656797.php.

[54] *See, e.g.*, Lyons et al., *supra* note **[2]**, at 1684 ("a clear statement of objectives is essential").

[55] *See, e.g.*, NATIONAL RESEARCH COUNCIL, PANEL ON ADAPTIVE MANAGEMENT FOR RESOURCE STEWARDSHIP, COMMITTEE TO ASSESS THE U.S. ARMY CORPS OF ENGINEERS METHODS OF ANALYSIS AND PEER REVIEW FOR WATER RESOURCES PROJECT PLANNING, ADAPTIVE MANAGEMENT FOR WATER RESOURCES PLANNING 24 (2004); Lee, *supra* note **[20]**, at ___.

[56] *See, e.g.*, Lawrence Susskind, Alejandro E. Camacho, and Todd Schenk, *Collaborative Planning and Adaptive Management in Glen Canyon: A Cautionary Tale*, 35 Colum. J. Envtl. L. 1, 21-24 (2010) (describing the structure of the adaptive management program for Glen Canyon).

[57] *See* Joseph M. Feller, *Collaborative Management of Glen Canyon Dam: The Elevation of*

unwieldy as the size of the group increases; as a practical matter, adaptive management is incompatible with a large-scale, generalized, open-invitation political process. It is not, therefore, the right place to make decisions which should take account of all views.

A second benefit of explicitly identifying information gaps is that it would focus the attention of managers on areas where learning would be most helpful, and encourage them to identify uncertainties that may be hidden within their assumptions. Forcing people to explain and justify their understanding of a system sometimes leads to the discovery that they do not understand parts of it as well as they thought. Simply going through the exercise of drafting a model of the system and thinking through the various factors that might affect their ability to achieve management goals can help raise awareness of possibilities that might otherwise not be considered until much later.

Finally, an explicit information gap analysis is the first step in identifying why information is missing, and how it might be obtained. As discussed in more detail below, there are many potential sources of uncertainty, and distinguishing between them is crucial to understanding how likely it is that learning will occur, at what cost, and by what pathways.

2. Good Prospects for Learning

The second requirement for successful adaptive management is the ability to learn what we need to know. Adaptive management will not improve management outcomes unless important information gaps are narrowed over time. But therein lies a conundrum. If we know so little at the outset that we feel the need for adaptive management, why should we believe that we can learn rapidly enough to be able to correct management mistakes? The answer turns on the sources of initial uncertainty and the relevant management time frame.

If the source of key information gaps is simply that it is difficult to predict exogenous future changes to a managed system, then opportunities for learning should be plentiful and relatively inexpensive. As the future unfolds, some things will become apparent. For example, there is currently considerable uncertainty about how global warming will affect precipitation in California.[58] That makes it difficult for those who manage the state's water system to plan for the future, and in turn for those responsible for the conservation of aquatic ecosystems to evaluate the effects of water management on their charges. There is nothing conceptually difficult, however, about learning over time how precipitation patterns are changing. It requires only

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Social Engineering Over Law, 8 NEV. L. J. 896, 930-933 (2008) (describing dominance of economic interests in Glen Canyon adaptive management program).

[58] For the Sacramento region, for example, six global climate models project that precipitation may decrease by nearly 20% or increase slightly by the end of this century. California Dept. of Water Resources, Using Future Climate Projections to Support Water Resources Decision Making in California 8 (Aug. 2009), available at http://www.energy.ca.gov/2009publications/CEC-500-2009-052/CEC-500-2009-052-F.PDF.

regular observation coupled with regular updating of the climate models. That sort of learning does not seem to require any special efforts, and we can have high confidence that it will occur.

That does not automatically mean, however, that adaptive management will always be useful where uncertainty is primarily a matter of seeing how the future develops. That depends not only on the ability to fill information gaps but on the speed with which learning will occur. Although we can be confident that we will learn over time about altered precipitation regimes, we cannot be as confident that we will learn quickly. Because California's annual rainfall is already highly variable, and it is expected to become more so,[59] it may take many years before the new regime is well enough understood to support confident management decisions. Furthermore, because change will continue for decades or centuries,[60] the process of updating our understanding will have to continue as well.

Another common source of uncertainty is lack of knowledge about how potential management actions will change the system. Like uncertainty about the future, this type of uncertainty will sometimes be conceptually easy to address. Trial and observation may be all we need to reduce it. But observation is sometimes difficult, and again this sort of learning may take a long time by management standards. The Chesapeake Bay, for example, is impacted by nutrient pollution from many sources, including run-off from agricultural lands.[61] Although it is widely agreed that dealing with the Bay's pollution problem will require some changes to management of those lands, the learning curve will not be rapid. Scientists working on water quality in the region believe it will take at least nine years to recognize how changes in agricultural practices affect water quality in the Bay.[62] Nutrient pollution from farming practices also affects the Gulf of Mexico; run-off conveyed via the Mississippi River system is believed to be largely responsible for the low-oxygen "dead zone" which develops in the Gulf every summer. Given the larger size of the watershed and greater distance from the estuary, connecting

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[59] Bohumil M. Svoma and Robert C. Balling, Jr., *United States Interannual Precipitation Variability Over the Past Century: Is Variability Increasing as Predicted by Models?*, 31 PHYSICAL GEOGRAPHY 307 (2010).

[60] *See, e.g.*, Susan Solomon et al., *Persistence of Climate Changes Due to a Range of Greenhouse Gases*, 107 PROC. NAT. ACAD. SCI. 18354 (2010); Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The Physical Science Basis, Contribution of Working Group (WG) 1 to the Fourth Assessment Report of the IPCC (AR4)* 1-18 (S. Solomon et al., eds. 2007).

[61] EPA, Chesapeake Bay TMDL Executive Summary ES-3 (Dec. 29, 2010), http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/BayTMDLExecutiveSummaryFINAL122910_final.pdf.

[62] NATIONAL RESEARCH COUNCIL, COMMITTEE ON THE MISSISSIPPI RIVER AND THE CLEAN WATER ACT: SCIENTIFIC, MODELING AND TECHNICAL ASPECTS OF NUTRIENT POLLUTANT LOAD ALLOCATION AND IMPLEMENTATION, NUTRIENT CONTROL ACTIONS FOR IMPROVING WATER QUALITY IN THE MISSISSIPPI RIVER BASIN AND NORTHERN GULF OF MEXICO 21 (2009).

changes in agricultural practices to water quality in the Gulf with any degree of confidence could take decades.[63]

Other uncertainties carry a time lag for institutional rather than scientific reasons. In the Gulf of Mexico, for example, nutrient loading does not come entirely from non-point sources. The precise contribution of point sources such as wastewater treatment plants is not known, however, because few sources directly monitor their effluent for nutrients.[64] In theory, monitoring could be instituted immediately, and would immediately provide useful information. There is even a ready-made institutional hook for imposing nutrient monitoring requirements: point sources must have discharge permits,[65] and those permits must require monitoring and reporting of discharges..[66] Regulators could certainly require that sources which are likely to be discharging nutrients into impaired waterways monitor and report the nutrient content of their effluent. But that can't be done overnight. Regulators must wait until they are renewed to impose new conditions. That should not introduce a lengthy lag; under the federal Clean Water Act, discharge permits have a nominal 5-year life span.[67] In practice, however, many permits are allowed to run much longer than 5 years.[68] Regulatory agencies simply do not have the resources to review and revise each of the hundreds of thousands of discharge permits nationwide[69] every five years.

Learning about changes wrought by management actions is also conceptually straightforward, but the practical challenges quickly become steep. At the outset, we may have little confidence in our predictions about, for example, how restoring a seasonal floodplain will

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[63] *Id.*

[64] *Id.* at 15.

[65] *See* 33 U.S.C. §§ 1311, 1342, 1362(6), (7), (12).

[66] 40 C.F.R. § 122.41.

[67] 33 U.S.C. § 1342(b)(1)(B).

[68] Permits are administratively continued if the permittee timely files for renewal. Permits which are continued pending renewal are described as "backlogged." EPA's most recent backlog report shows that between 10 and 20% of permits (depending on the region) are backlogged. EPA, Permit Status Report for Non-Tribal Major Individual, Minor Individual, and Non-Stormwater General Permit Covered Facilities - December 2009 (1), http://www.epa.gov/npdes/pubs/grade_all.pdf.

[69] As of 2001, EPA reported that more than 400,000 facilities nationwide were required to have NPDES permits, and that number was growing. U.S. Envtl. Protection Agency, Office of Water, Protecting the Nation's Waters Through Effective NPDES Permits: A Strategic Plan, FY2001 and Beyond 1 (June 2001), available at http://www.epa.gov/npdes/pubs/strategicplan.pdf. There are over 33,000 point source permits in the Mississippi watershed alone. National Research Council, *supra* note **[42]**, at 15.

affect the population of an endangered fish that used to spawn on the site.[70] Monitoring population size and breeding success following restoration efforts should help us figure out how the fish have responded. The data are not likely to be as clearcut or easy to acquire as temperature and precipitation data, however. Many species are difficult to census accurately, even with considerable effort.[71] Furthermore, trends may be difficult to interpret. Natural variability in population size, breeding success, habitat usage, and other factors may be so high that it masks changes, positive or negative, caused by management actions.[72]

Confounding environmental variables add yet another layer of complexity. Pacific salmon offer a familiar example. Seeking to reverse the salmon's decline, resource managers have ordered reductions in irrigation deliveries and changes in the operation of hydropower dams.[73] But shifts in ocean conditions can mask the effect of those steps, so that managers may

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[70] The efficacy of flood plain restoration for delta smelt is one of many questions dogging efforts to improve the ecological health of California's Bay-Delta. A recent National Research Council report concluded that the relationship is still poorly understood and there is scant scientific justification for a regulatory requirement to create or restore habitat. National Research Council, Committee on Sustainable Water and Environmental Management in the California Bay-Delta, A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta 54-55 (2010).

[71] Again the Delta smelt, which is notoriously difficult to census, provides an example. *See, e.g.*, See, e.g., Wim Kimmerer & Randy Brown, CALFED Bay-Delta Program Environmental Water Account, Summary of the Annual Delta Smelt Technical Workshop, Santa Cruz, Cal., Aug. 18-19, 2003 (2003) (noting disagreement over population estimates); Natural Resources Defense Council v. Kempthorne, No. 1:05-cv-1207 OWW GSA (E.D. Cal., Dec. 14, 2007) ("All parties agree that there is no firm and reliable total population estimate for the Delta smelt and there never has been. No scientist was able to explain how, despite the marshaling of federal, state and private resources, over ten testifying experts presented in this case, and over ten years of study, what is necessary and how long it will take to produce a reliable total population estimate for Delta smelt.").

[72] *See, e.g.*, Helen M. Regan, Mark Colvyan, and Mark A. Brugman, *A Taxonomy and Treatment of Uncertainty for Ecology and Conservation Biology*, 12 ECOLOGICAL APPLICATIONS 618, 620 (2002) (explaining the role of natural variation in creating uncertainty); Biber, *supra* note **[5]**, **[draft at 26]** (noting the difficulty of distinguishing natural variability from anthropogenic impacts).

[73] *See, e.g.*, National Marine Fisheries Service, Southwest Region, Endangered Species Act Section 7 Consultation, Biological Opinion and Conference Opinion on the Long Term Operations of the Central Valley Project and State Water Project 574-580 (June 2009) (detailing changes to water project operations needed to comply with Endangered Species Act); Michael C. Blumm, Erica J. Thorson, and Joshua D. Smith, *Practiced at the Art of Deception: The Failure of Columbia Basin Salmon Recovery Under the Endangered Species Act*, 36 ENVTL. L. 709, 734-763 (2006) (detailing terms of biological opinions governing Columbia River hydropower

not be able to tell whether their efforts are helping or not.[74] Another example comes from the Colorado River system, where experimental releases from Glen Canyon Dam were instituted in the 1990s in the hope of promoting recovery of downstream aquatic ecosystems.[75] Populations of the native humpback chub rebounded somewhat after the experimental releases, but given the wealth of other factors, managers could not say with confidence that the rebound was directly linked to the releases, or determine exactly what their influence was.[76]

Controlled experiments potentially offer one way out of this type of indeterminacy. Indeed, the purpose of controlled experimentation is to sort among possible causes of an effect, distinguishing the most important factors from others or identifying the roles of multiple factors.[77] The potential informational power of experiments, explains the emphasis of early adaptive management theorists on management experiments.. But the ability to experiment may be, or at least appear to be, limited in managed systems. The potential for and limits of experimentation are considered in more detail in the next Part.

Two other sets of information gaps are more difficult to recognize and very challenging to fill. First, there is often a dearth of background information about managed systems. For many species and ecosystems it is literally true, as Joni Mitchell sang, that "you don't know what you've got till it's gone."[78] Research science is skewed toward subjects that are charismatic, economically valuable, or easy to study.[79] Often we don't realize how much we don't know

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operations).

[74] See NATIONAL RESEARCH COUNCIL, COMMITTEE ON PROTECTION AND MANAGEMENT OF PACIFIC NORTHWEST ANADROMOUS SALMONIDS, UPSTREAM: SALMON AND SOCIETY IN THE PACIFIC NORTHWEST 39-74 (1996) (detailing the effects of changing ocean conditions and a variety of human activities on salmon). How little is still known about the dynamics of salmon populations was brought home in the summer of 2010 when a record sockeye run, more than 20 times as large as the previous year, in British Columbia took fisheries scientists and regulators by surprise. Kate Larkin, *Canada Sees Shock Salmon Glut*, NATURE, Sept. 3, 2010.

[75] Sandra Zellmer, *Floods, Famines, or Feasts: Too Much, Too Little, or Just Right*, NATURAL RESOURCES & ENVT., Winter 2010, at 20, 24.

[76] Susskind et al., *supra* note **[59]**, at 28-29.

[77] Holly Doremus, *Listing Decisions Under the Endangered Species Act: Why Better Science Isn't Always Better Policy*, 75 WASH. U. L.Q. 1029, 1059-60 (1997) (explaining the power of experiments).

[78] Joni Mitchell, Big Yellow Taxi (1970).

[79] *See, e.g.*, Berta Martín-López, Carlos Montes, Lucía Ramírez and Javier Benayas, *What Drives Policy Decision-Making Related to Species Conservation?*, 142 BIOLOGICAL CONSERVATION 1370, 1379 (2009) ("Research goals, therefore, tend to focus on those species that have direct economic impacts or are considered "cute" or "charismatic" by society . . ."); John R.U. Wilson et al., *The (Bio)Diversity of Science Reflects the Interests of Society*, 5 FRONTIERS IN ECOLOGY AND THE ENVIRONMENT 409, 411 (2007) (finding that invasive vertebrates are more studied than

about a system and its components until it hits a crisis point.[80] At that point, it is too late to go back and generate historic data. The lack of such baseline information can pose a serious problem for adaptive management because some types of learning cannot be rushed. Years of data are required to understand the extent of natural variability in some populations and habitat conditions, for example, and that understanding in turn may be crucial to interpreting population fluctuations.

Finally, there are what Donald Rumsfeld famously called the "unknown unknowns," the things we don't even realize that we don't know.[81] They include facts or behaviors we could have discovered but hadn't thought to look for because we were focused on other aspects of the system. For example, protection of the marbled murrelet, a small Pacific coast bird listed as threatened under the Endangered Species Act, has focused on restricting timber harvest in the bird's nesting areas.[82] That is necessary, but it turns out that it may not be sufficient to protect the bird. Several years ago, a university research group decided to investigate whether changes in foraging conditions might also be contributing to the species' decline. They found that the amount of krill and small prey species in murrelet diets had increased over the past century relative to sardines and other larger predatory fish. This avian version of "fishing down the food web," they speculated, might be reducing the energy gain per amount of fishing effort, contributing to reduced reproductive success.[83] That discovery has led to increased attention to

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invertebrates or plants).

[80] In many cases, for example, little is known about endangered species before it is proposed for protected status. Dale D. Goble, *The Endangered Species Act: What We Talk About When We Talk About Recovery*, 49 NATURAL RESOURCES J. 1, 16 (2009); Holly Doremus, *Science Plays Defense: Natural Resource Management in the Bush Administration*, 32 ECOLOGY L. Q. 249, 297-298 (2005).

[81] Rumsfeld tied himself in verbal knots trying to explain to the press the various kinds of uncertainty. Donald H. Rumsfeld, Department of Defense News Briefing (Feb. 12, 2002), available at http://www.defenselink.mil/transcripts/transcript.aspx?transcriptid=2636 ("[A]s we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones."). Although his syntax was inelegant, the point is a good one; if you don't know what to look for, you are not likely to find it.

[82] Region 1, U.S. Fish and Wildlife Service, Recovery Plan for the Marbled Murrelet (Washington, Oregon, and California Populations) 79-111 (1997) (detailing regulatory protections implemented for the murrelet, almost entirely focused on protecting forest nesting habitat).

[83] Benjamin H. Becker & Steven R. Beissinger, *Centennial Decline in the Trophic Level of an Endangered Seabird After Fisheries Decline*, 20 CONSERVATION BIOLOGY 470, 476-477 (2006).

the potential effects of commercial and recreational fishing on murrelets.

Other “unknown unknowns” may include surprises in the form of unanticipated changes in the system, like the encroachment of the barred owl into the range of the threatened spotted owl, a stress which has interacted with others, including logging, to contribute to the owl’s decline.[84] Mistakes about parameters we think we understand also fall in this category. In the Chesapeake Bay, for example, EPA’s Draft TMDL specifies the total nutrient loading the agency believes the Bay ecosystem can tolerate while meeting the goal of preserving all its uses.[85] If that target turns out to be wrong (at least if it turns out to be wrong in the direction of allowing too much pollution), it will need to be adjusted if the management objective is to be met.

We cannot specifically identify unknown unknowns at the outset of a management program. As discussed in the next part, however, it is possible to structure management and monitoring efforts, and to coordinate them with outside research, in ways that enhance the likelihood that unknown unknowns will be sought and found.

3. Opportunities for Adjustment

The third prerequisite for adaptive management to be useful is that there must be opportunities to adjust management efforts over time. That means that initial management steps must not become immediately locked in, either formally by law or informally by reason of their practical effect. Adaptive management cannot help when there is no way to correct an initial mistake, as for example when the decision in question is to allow irreversible alteration of the environment. Even in that context, however, a form of adaptive management or progressive “learning while doing” can be helpful when managers face many similar decisions over time, such as evaluating permits to fill wetlands or take endangered species.[86]

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[84] The relative contributions of logging and invasive species became a topic of controversy in 2008, when the U.S. Fish and Wildlife Service issued a revised recovery plan for the threatened northern spotted owl which emphasized the contribution of the barred owl to the spotted owl’s woes. U.S. Fish and Wildlife Service, Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*) (May 2008), available at http://ecos.fws.gov/docs/recovery_plan/NSO Final Rec Plan 051408.pdf. Faced with highly critical peer reviews and litigation, FWS voluntarily withdrew the 2008 plan. **[I really don’t think anything more is needed. The new plan, to which I have cited, explains enough of the background.]**A new draft version has recently been issued. U.S. Fish and Wildlife Service, Draft Revised Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*) (Sept. 8, 2010), available at http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/Recovery/Library/Documents/2010NSODraftRevisedRecPlan.pdf.

[85] Environmental Protection Agency, Draft Chesapeake Bay TMDL (Sept. 24, 2010), available at http://www.epa.gov/reg3wapd/tmdl/ChesapeakeBay/drafttmdlexec.html.

[86] Doremus, *Precaution*, *supra* note **[27]**, at 557.

It also means that managers must periodically reconsider and re-evaluate their management decisions in light of their improved or revised understanding of the system. New institutional structures and legal mandates may be needed to make reconsideration both mandatory and transparent enough to allow effective public oversight, because management revisions are a notorious point of slippage between the theory and practice of adaptive management.[87]

Finally, it means that there must actually be alternative policy choices. Carl Walters, one of the fathers of the concept of adaptive resource management, once described a rich set of policy alternatives as the critical factor in the success of adaptive management.[88]

B. Doing the Math

Even if all of the required elements are in place, adaptive management is not necessarily the right strategy. A rough calculation is needed to determine if its benefits justify its costs. Adaptive management should not be undertaken lightly. It requires more resources than conventional management, because doing it right requires taking the time to carefully analyze the system at the outset, monitoring the results, and periodically reassessing and revising. It imposes unfamiliar demands on management institutions for long-term commitment of human and financial resources. In addition to government resources, adaptive management may impose greater demands on stakeholders, because they must monitor decisions and the decisionmaking process not just at one point in time but continually. Because it implies that decisions are always tentative, it may also increase or extend controversy and conflict, despite claims to the contrary. Finally, it may require trading the anticipated best outcome in the short-term for long-term learning and improvement. Adaptive management should be used only if that appears to be a good trade-off. The choice between adaptive management and other strategies must be based on the ability of adaptive management to improve the likelihood of meeting management goals;

Unless the three factors discussed above – significant information gaps, opportunities for learning, and opportunities for adjustment – are all present to some degree, adaptive management

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[87] *See e.g.,* April Reese, *Colorado River Adaptive Management Program Needs Overhaul, Critics Say*, E&E Land Letter, May 7, 2009 (noting that despite thirteen years of evidence-gathering, "the Glen Canyon Dam Adaptive Management Work Group, or AMWG, has never reached sufficient consensus to execute its primary charge -- recommending a new dam operations policy to the Department of Interior.").

[88] Noting the tendency for scientists charged with developing adaptive management programs to develop multiple hypotheses but gloss over policy alternatives, Walters noted: "[t]he few adaptive management success stories have involved the opposite: relatively few response hypotheses, but a very rich set of policy alternatives." Plan for Analyzing and Testing Hypotheses (PATH) Preliminary Decision Analysis Report on Snake River Spring/Summer Chinook, Reviews by the Scientific Review Panel, Review by Carl Walters, p.1 (undated), available at http://efw.bpa.gov/environment/path/reports/pdar/srprevda.pdf.

is a non-starter. But the analysis is more nuanced than that, particularly with respect to the prospects for learning, which is never a simple yes/no question. What is needed is a kind of broad-brush cost-benefit analysis evaluating the trade-offs inherent in choosing an adaptive approach. In most cases, that will boil down to estimating the expected value of learning for achieving management objectives, and comparing that added value to the costs and complications it will impose. That is not an easy task, and we should not expect anything like precise quantification. The analysis itself will, of course, consume agency resources. But I'm convinced it will be worth it, leading to more self-conscious management even if the choice is not to undertake an adaptive approach. And although it imposes significant costs at the beginning of a management program, it could save resources down the line by making it clearer what needs to be periodically evaluated and how that evaluation should be done.

The analysis I envision begins by setting out the applicable management goals. As discussed above, management goals should be exogenous to the adaptive management process. To the extent that statutory goals are, as is so often the case, vague or conflicting, they should be clarified at the outset. In other words, an agency planning to undertake adaptive management (or considering whether to undertake it) should identify what it views as its management goals as well as metrics believed to indicate achievement of those goals. The metrics, unlike the goals, are appropriately, even necessarily, subject to re-evaluation within the adaptive management process. Technical experts must periodically re-evaluate whether the selected metrics accurately represent achievement of the relevant management goals.

The next step is articulation of a model of the managed system. An explicit model is generally recognized as a core element of adaptive management.[89] It is also essential to making an informed decision on whether or not to undertake adaptive management. The model need not be elaborate. Depending upon the management goals and level of knowledge at the start, it can be as simple as a schematic diagram or brief narrative, or as elaborate as a detailed computer model. Its function is both to discipline managers' thinking and to make that thinking accessible to stakeholders. It should highlight key elements of the system for management purposes, their interconnections, their relationship to the management goals, and their expected response to management alternatives. It should explicitly acknowledge uncertainty and competing hypotheses.

Comparing the model to management objectives should highlight what managers hope to learn through adaptive management. In particular, it should make apparent the "known unknowns," areas of uncertainty or competing hypotheses that are important to achieving the desired management outcomes. The regulation of duck hunting in the United States, a longstanding and relatively successful example of adaptive management,[90] provides a good

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[89] *See, e.g.*, National Research Council, Adaptive Management, *supra* note **[40]**, at 24-25.

[90] The U.S. Fish and Wildlife Service, which regulates hunting of migratory waterfowl, has used a strategy it calls adaptive harvest management since 1995. Fred A. Johnson, William L. Kendall and James A. Dubovsky, *Conditions and Limitations on Learning in the Adaptive Management of Mallard Harvests*, 30 WILDLIFE SOC. BULL. 176, 176 (2002). That strategy has produced

example. The management goal is sustainable harvest; therefore the key management question is how hunting mortality will affect population abundance and productivity. The key uncertainties are whether most of the birds killed by hunters would have died from other causes anyway or whether instead their deaths must be added on to natural mortality;[91] and the extent to which reproduction declines with increasing population density.[92]

Using mathematical models groundtruthed by comparison to monitoring data, researchers showed in 1996 that harvest levels could be deliberately varied to distinguish between the two possibilities, accelerating learning.[93] There are often trade-offs between learning and resource protection, however; in the waterfowl example, the authors noted that "the most informative harvest strategy is also the most extreme."[94] Those trade-offs must be evaluated in context; the more irreplaceable the managed resources, the more conservative we may want to be in pursuing learning. On the other hand, the greater the economic consequences of the decision, that is the greater the economic value of resource exploitation, the more important learning may become.

Economic analysis,[95] structured decisionmaking,[96] and other tools[97] have been proposed for evaluating the trade-offs. Notably, in some cases running the analysis reveals that learning overall is less valuable than managers had expected,[98] or that "active" adaptive management, involving deliberate management experiments, adds little to simple observation of the results of

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significant learning, in the form of updated probabilities assigned to the four competing models employed. *Id.* at 180.

[91] The competing mortality models are generally referred to as additive or compensatory mortality, respectively. *See, e.g.*, *id.* at 177.

[92] *Id.* at 177-178.

[93] Williams et al., *supra* note **[31]**.

[94] *Id.* at 230.

[95] *See, e.g.,* Eli P. Fenichel and Gretchen J.A. Hansen, *The Opportunity Cost of Information: an Economic Framework for Understanding the Balance between Assessment and Control in Sea Lamprey (Petromyzon marinus) Management*, 67 CANADIAN J. FISHERIES & AQUATIC SCIENCE 209 (2010).

[96] Julien Martin, Michael C. Runge, James D. Nichols, Bruce Lubow, and William L. Kendall, *Structured Decisionmaking as a Conceptual Framework to Identify Thresholds for Conservation and Management*, 19 ECOLOGICAL APPLICATIONS 1079 (2009).

[97] Tracy M. Rout, Cindy E. Hauser, and Hugh P. Possingham, *Optimal Adaptive Management for the Translocation of a Threatened Species*, 19 ECOLOGICAL APPLICATIONS 515 (2009).

[98] RAY HILBORN AND CARL G. WALTERS, QUANTITATIVE FISHERIES STOCK ASSESSMENT: CHOICE, DYNAMICS AND UNCERTAINTY 494 (1992) ("Often this step in the analysis reveals that there is a "robust" policy that should do well, no matter which model is correct, so that only minor gains would be expected from having better information.").

more conventional management choices.[99] For our purposes, the precise tool employed is not crucial. What is important is that the analysis be done explicitly and transparently, that it consider the available avenues for investigation, observation, and hypothesis-testing, and that managers explain and justify their choice of analytic tools. Undertaking this analysis will also require managers to reveal the extent to which they believe their mandated goals require or permit discounting of future benefits. The value of learning in relation to its costs will depend critically on the extent to which long-term conservation is valued over the short-term economic consequences of experimentation or intervention.[100]

In cases of very high value resources, very high uncertainty, or very sharp political conflict over management choices, it may be useful to invoke peer review of the model and the prospects for learning. This is the sort of setting in which peer review can be most helpful, sharpening the agency's attention to gaps in its knowledge, unrecognized assumptions, and new or emerging methodologies.[101] Peer review at this stage is less likely to become a political football, or to be perceived as a threat to agency autonomy or authority, than review of individual regulatory decisions. Peer review of this sort seems likely to be most effective if it is conducted by outsiders with strong inside support and a medium- to long-term commitment. Outsiders should have independence from the agency's mission, culture, and process, so that they are able to take a fresh look, and to demand a clear explanation. Inside support, from the head of the agency or equivalent, can ensure that agency personnel take the peer review process and resulting critiques seriously, but can also provide a check on unrealistic reviewer assumptions. A long-, or at least medium-term commitment means that the review process, like the management process, is ongoing. Managers who must report every year to the same review committee are more likely to seriously address that committee's concerns than those who receive a one-time report but will never be faced with tough follow-up questions.

Together, the goals, model, and analysis of the prospects for and value of learning will point toward initial management actions, identify the degree of monitoring that seems initially to be optimal (although detailed monitoring is often assumed to be a necessary component of adaptive management, it is not always the best use of limited resources),[102] and set the stage for periodic re-evaluation by clearly setting out the assumptions to be tested.

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[99] Johnson et al., *supra* note **[59]**, at 179, 182.

[100] If an aggressive discount rate is applied, management as a learning exercise will rarely appear economically justified. Carl J. Walters and Roger Green, *Valuation of Experimental Management Options for Ecological Systems*, 61 J. WILDLIFE MGMT. 987, 996 (1997).

[101] For contrasting views on the role of peer review, *see* Holly Doremus and A. Dan Tarlock, *Science, Judgment and Controversy in Natural Resource Regulation*, 26 PUB. LAND & RESOURCES L. REV. 1, 32-35 (2005); J.B. Ruhl and James Salzmann, *In Defense of Regulatory Peer Review*, 84 WASH. U. L. REV. 1 (2006).

[102] Alana L. Moore and Michael A. McCarthy, *On Valuing Information in Adaptive-Management Models*, 24 CONSERVATION BIOLOGY 984 (2010).

One shortcoming of this sort of analysis is that it invites a static approach, taking as given the perceived limits on learning, such as restrictions on experimentation. It ought to highlight those constraints, but it is not likely to question them. Nor is it likely to address overarching features of a learning-friendly environment. In other words, by its very nature this sort of individual, project-specific approach is likely to treat the learning equation as fixed. But that is not the case. The costs of learning are not necessarily fixed. They can be altered by a variety of policy measures independent of any individual management effort. So while this sort of specific analysis is needed to make informed choices about specific uses of adaptive management, it is not the end of the story. At a broader level, we need to look at and address how learning occurs in natural resource management agencies and why it does not, with the aim of reducing the costs of learning and the time it takes.

II. Rewriting the Learning Equation

The structured analysis recommended above may conclude, for a particular resource problem, that learning would improve management but also that learning will be costly and challenging. That calculation would present a dilemma: will it be worth investing in adaptive management or not? One approach would be to adopt a less information-intensive strategy, such as technology-based or best-management-practices mandates, or precaution. For reasons I have previously explained,[103] I believe reducing information demands will often not be practical or politically palatable. It therefore becomes important not only to evaluate the relative costs and benefits of information, but to shift that equation by increasing the availability of useful information.

Whether, to what extent, and how the costs of learning can be reduced of course varies with the specific context. But there are some general policy steps that can improve the prospects for learning by natural resource managers. They fall in two categories: improving information production, and improving information diffusion.

A. Facilitating Information Production

Often, management-relevant learning requires the generation of new information. In some cases, that may mean that new tools for inquiry or methods for interpreting existing data need to be developed. Those are matters for the natural scientists to tackle. But in other cases, there are policy barriers, or at least apparent policy barriers, to inquiry or learning. Those are for the policy wonks to deal with. They may be context-specific, but some are general. They include barriers to experimentation and funding environments. There are policy steps that could reduce these barriers.

1. Experiments and Experiment Substitutes

[103] Doremus, *Information Pipeline*, *supra* note **[16]**, at 410-411.

There are often serious barriers to conducting experiments in managed natural systems. Some of the limits are technical; there may be so many confounding, uncontrollable factors that experiments would not generate useful information. Others are practical; the value of infrastructure like large dams to human populations, coupled with the expense and time needed to rebuild them, for example, precludes taking one out even if we thought we could thereby gain useful information about threats to imperiled salmon populations. Still others are policy-mediated; laws like the Endangered Species Act impose substantive limits on the risks to which some managed resources can be subjected,[104] and environmental analysis and planning laws may require that the impacts of management be articulated in advance and in detail.[105]

All of these barriers to effective experimentation, even those which do not originate from the legal or institutional regime, can be addressed to some extent by policy and institutional changes. Requiring the explicit analysis of prospects for and costs of learning advocated above is actually an important policy measure toward improved information production. Where learning is necessary and likely, but experiments seem too risky or impractical, managers can look for substitutes for direct, controlled experimentation. Model runs can sometimes substitute for active manipulation, although it may be difficult to gain enough confidence in the model without the ability to perform on-the-ground experiments, and modeling can itself become an excuse for an infinite search for perfect understanding prior to taking action.[106]

Models can serve another function, though, helping managers evaluate and limit the potential negative impacts of experiments. Simulating an experiment before actually attempting it, using a range of inputs reflecting the competing hypotheses, should signal the extent to which the experiment poses risks of disastrous impacts. Managers can then plan for that risk, developing monitoring plans to detect adverse effects and planning to end the experiment if those effects exceed pre-determined acceptable levels. A good analogy is medical trials, which test treatments thought to be beneficial against established or no treatment. The medical community understands the value of such trials, but is also sensitive to the twin risks that the experimental treatment may prove harmful or that it may prove so much more effective that the placebo or control treatment appears harmful by comparison. Ethical considerations require that the perils such trials pose be justified at the outset by the learning they promise, that outcomes be monitored on an ongoing basis, and that they be halted if new information shows that the risk-benefit balance is outside the acceptable range.[107]

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[104] On the ESA and experimentation, see Doremus, *Adaptive Management*, *supra* note **[9]**, at 79-80.

[105] On NEPA as a barrier to experimentation, see Doremus, *Information Pipeline*, *supra* note **[16]**, at 454-455.

[106] Carl Walters, *Challenges in Adaptive Management of Riparian and Coastal Ecosystems*, 1 CONSERVATION ECOLOGY 1 (1997) available at http://www.ecologyandsociety.org/vol1/iss2/art1/.

[107] Steven N. Goodman, *Stopping at Nothing? Some Dilemmas of Data Monitoring in Clinical*

Of course those decisions are not easy, and they depend on the relative value decisionmakers assign to learning and protecting the resource.[108] But articulating and justifying sideboards in advance would allow stakeholders to have their say about the value of learning and acceptability of risk. It also could solve a potential legal problem. Under the Endangered Species Act, federal actors must insure that their actions are not likely to jeopardize the continued existence of any listed species.[109] The Act allows federal authorities to issue permits for actions undertaken "for scientific purposes or to enhance the propagation or survival of the affected species,"[110] provided the jeopardy threshold is not crossed. Sideboards would make it easier to demonstrate at the outset that the jeopardy standard is satisfied, and perhaps more importantly could reassure risk-averse managers, overseeing wildlife agencies and environmental interests who might raise questions that the experiment will remain within acceptable bounds.[111]

Another potential strategy is to conduct experiments in limited portions of a system. For large systems, that may be practical even if the experiments pose the risk either of locally harming the managed resource or of locally imposing unnecessary economic costs. A National Research Council committee recently proposed such a strategy to test the effectiveness of nutrient pollution control actions for reducing the Gulf of Mexico's hypoxic "dead zone," and the social and economic effects of those actions. The committee suggested a set of pilot projects which could generate the information needed to guide larger-scale control efforts, and which if successful could later be incorporated into such efforts.[112] Pilot projects of the sort are always vulnerable to the criticism that they are simply delaying tactics; if they seem promising, advocates might ask, why not launch them at a large scale immediately? That question reinforces the importance of the analysis recommended in the first Part of this article. A clear explanation of the extent to which pilot projects will provide needed information, and the potential costs if they were undertaken more broadly but turned out not to be as effective as hoped, could help

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Trials, 126 ANN. INTERNAL MEDICINE 882, 882 (2007).

[108] Clinical trials pose exactly the same dilemma. Whether and when to stop them "is an extraordinarily difficult question, as scientists will differ in their assessment of both how much we have learned and how much we need to learn. There is no clear ethical guidance on the matter; a utilitarian perspective will put more weight on the fate of future patients, whereas ethical theories that place more value on obligations and individual dignity will favor the interests of patients in the trial." *Id.* at 882. *See also* Paul S. Mueller et al., *Ethical Issues in Stopping Randomized Trials Early Because of Apparent Benefit*, 146 ANN. INTERNAL MEDICINE 878 (2007) (warning against trial stopping rules that allow a trial to be terminated too easily based on the perceived benefits of the treatment because investigators may be biased in favor of overestimating benefits and underestimating adverse effects).

[109] 16 U.S.C. § 1536(a)(2).

[110] 16 U.S.C. § 1539(a)(1)(A).

[111] *See supra* note **[14]** and accompanying text.

[112] National Research Council, *supra* note **[42]**, at 28.

reassure a variety of publics about the need for and value of experiments.

A similar strategy could work to gain information about management actions that are taken in a number of different locations. Salvage logging, the rapid harvesting of timber after a fire, is a good example. Salvage logging is highly controversial; environmental interests often see it as an excuse to harvest trees that may not in fact be dead, and believe it harms wildlife and slows forest regeneration. Timber-dependent communities, on the other hand, think the detailed environmental study demanded by logging opponents causes the loss of valuable timber, which rapidly deteriorates after the trees are dead.[113] "The courts have been barraged with lawsuits by environmental groups over allegedly ill-conceived post-fire salvage logging projects."[114] In 2005, a Ninth Circuit panel chastised the Forest Service for ignoring opportunities to study and learn from salvage logging operations,[115] but later the full court decided that it owed the Service more deference.[116]

Alternatively, experiments might be possible in analogous systems that don't pose the same resource (or economic) risks. Networks of lands designated for experimental purposes could provide useful study sites. The Forest Service already has a system of 80 designated experimental forests and ranges scattered across the country.[117] Originally established in 1908, the system has grown in a fairly *ad hoc* manner, but it contains representatives of the majority of U.S. forest cover types and covers a broad range of environmental conditions.[118] The experimental forest system hosts a number of long-term studies with both management and basic science implications.[119] It could be put to better use to serve current management priorities, however, through better networking, more centralized management and oversight, and addition of new sights which provide good models for key management issues. Moreover, the system could be expanded to cover other federal lands.

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[113] *See* Kathie Durbin, *Unsalvageable*, HIGH COUNTRY NEWS, May 16, 2005 (explaining both points of view and the heated disputes over salvage logging); Reed F. Noss et al, *Managing Fire-Prone Forests in the Western United States*, 4 FRONTIERS IN ECOLOGY AND ENVT. 481, 485 (2006) (contending that salvage logging "does not contribute to ecological recovery; rather, it negatively affects recovery processes, with the intensity of impacts depending upon the nature of the logging activity.").

[114] Robert B. Keiter, *Breaking Faith with Nature: The Bush Administration and Public Land Policy*, 27 J. LAND, RESOURCES, AND ENVTL. L. 195, 217 (2007).

[115] Ecology Center v. Austin, 430 F.3d 1057, 1064 (9th Cir., 2005), *overruled by* The Lands Council v. McNair, 537 F.3d 981 (9th Cir. 2008) (en banc).

[116] The Lands Council v. McNair, 537 F.3d 981, 992-999 (9th Cir. 2008) (en banc).

[117] USDA Forest Service, Experimental Forests and Ranges, http://www.fs.fed.us/research/efr/.

[118] *Id.*; Ariel E. Lugo et al., *Long Term Research at the USDA Forest Service's Experimental Forests and Ranges*, 56 BIOSCIENCE 39 (2006).

[119] Lugo et al., *supra* note **[121]**.

Finally, natural resource agencies should be prepared in advance to take advantage of learning opportunities offered by unplanned "experiments" like the Deepwater Horizon disaster in the Gulf of Mexico, and by management actions which are likely to have later analogues, such as dam removals.[120] Some federal researchers should always be "on call" for reassignment to unexpected or rapid developments, and federal research units should plan studies of potentially precedent-setting events. A discretionary pot of rapidly-mobilizable grant funds should also be maintained for such contingencies.

2. Budgeting for Learning

The salvage logging and hypoxia examples mentioned above lead to another topic – budget structuring, which may unintentionally limit the ability to experiment. In federal natural resource agencies, research efforts are typically conducted by distinct divisions, under a separate budget than management operations. If researchers and managers jointly agree to conduct management experiments, there may be difficult issues about who should bear the costs. Research budgets may be too small to support large-scale management experiments, but managers may resist experiments if they have to pay the costs.[121]

A better architecture for learning could include research funding dedicated to projects jointly conceived and executed by research and management personnel. Alternatively or additionally, managers could be provided an incentive to devote more funds to research work by evaluations that include whether they have made progress in addressing key knowledge gaps. Researchers, at least those who control funding decisions, could be provided similar incentives by explicitly evaluating them on the extent to which they have helped resolve management uncertainties.

Finally, the federal research budget in a global sense needs to better support indirect learning, studies related to managed systems but not tied directly to short term management issues. A portion of federal research funding should be more closely coordinated with management priorities, but with a long-term focus. Such studies may be the best way to attack the "unknown unknowns." This sort of work can probably best be done in the academic world, where freewheeling inquiry is rewarded and failure is more likely to be tolerated. Admittedly, it will be tricky to distribute this sort of funding effectively, because the incentives are not well

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[120] *See, e.g.*, Noreen Parks, A Ravenous River Reclaims Its True Course: The Tale of Marmot Dam's Demise, U.S.D.A. Forest Service, Pacific Northwest Research Station, Science Findings, Mar. 2009, available at http://www.fs.fed.us/pnw/sciencef/scifi111.pdf; K.M. Kibler, D.D. Tullos, and G.M. Kondolf, *Learning From Dam Removal Monitoring: Challenges to Selecting Experimental Design and Establishing Significance of Outcomes*, 26 RIVER RESEARCH & APPLICATIONS __, DOI: 10.1002/rra.1415 (2010).

[121] Such budget issues reportedly doomed a proposed Forest Service large-scale salvage logging study. Interview with Ann Bartuska, U.S. Dept. of Agriculture, Deputy Under Secretary for Research, Education, and Economics, Nov. 8, 2010.

calibrated either for those who might distribute the funds or those who want to receive them. Managers typically want to emphasize short-term results, while research scientists are very good at claiming that their pet project fits whatever real-world priorities funders articulate. Perhaps the best way to distribute such funds would be through an advisory body with long-term ties both to management agencies and to academic researchers.

A potential model is EPA's Science to Achieve Results (STAR) program, which provides funding for "targeted research that complements" research done at federal laboratories.[122] STAR funds work EPA sees as important to its mission which it does not have the capacity to carry out at its own research facilities. EPA aspires to "focus STAR research on gaps in knowledge related to EPA's mission, its high-priority research needs, and subjects with the greatest uncertainty and potential impact."[123] Toward that end, review of STAR proposals includes a novel step: proposals rated as eligible for funding on the basis of scientific merit are then separately evaluated for relevance to the agency's mission.[124]It is not clear, however, that the STAR program has found the right balance between highly focused short-term research and longer term exploration. In a 2003 review, the National Research Council noted that the program had moved to a greater emphasis on solicitation of focused research as opposed to exploratory work.[125] The NRC also recommended that EPA engage outsiders in identifying research priorities, perhaps beginning with a "state of the science" review of key areas to identify potential for high-impact research.[126] That outside perspective could also be a valuable counterweight to the natural agency tendency to emphasize quick results.

B. Improving Information Diffusion

The production of information is only the first step in the information pipeline. Much data and information simply sits in reports or journal articles. It is not useful for management efforts unless it reaches the people who must make management decisions, and reaches them in a form they can use. Information diffusion is therefore a key step in learning. It is also one where bottlenecks are common.[127] Two major sets of policy efforts could reduce barriers to effective

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[122] EPA, National Center for Environmental Research, STAR Grants and Cooperative Agreements, http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.welcome/displayOption/grants.

[123] NATIONAL RESEARCH COUNCIL, THE MEASURE OF STAR: REVIEW OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S SCIENCE TO ACHIEVE RESULTS (STAR) RESEARCH GRANTS PROGRAM 123 (2003).

[124] *Id.* at 48-49.

[125] *Id.* at 24.

[126] *Id.*

[127] Doremus, *Information Pipeline*, *supra* note **[16]**, at 434-439.

information diffusion: improvements in data architecture and the creation or improvement of intermediaries who can more effectively link information producers with information users.

1. Data Architecture and Information Flow

One of the most frustrating impediments to learning in federal resource management agencies is lack of information sharing. It is widely recognized that data, including basic environmental documents like environmental impact statements and Endangered Species Act biological opinions are not archived in ways that facilitate sharing and searching within agencies, between agencies, and with the larger research community.[128] Nor are they produced in a common format that would facilitate data exchange and synthesis.[129] Even within a single agency, data may be collected and compiled at many different offices, in ways that make meaningful aggregation impossible. Modernizing environmental information architecture will impose some short-term costs, but could be accomplished in any administration willing to make it a priority.

Two key steps could make information more accessible and useful. First, the Council on Environmental Quality[130] should establish uniform standards for natural resource information formatting, presentation, and archiving, to facilitate aggregation, comparison, and cross-agency use. Second, individual agencies which generate or use classes of environmental analyses should make them available in searchable database form. So, for example, the various regional offices of the U.S. Fish and Wildlife Service and NMFS should digitize all their Endangered Species Act biological opinions (in the format established by CEQ) and make them available through a centralized access point with search capabilities. EPA, which is statutorily required to review all federal Environmental Impact Statements,[131] could host an EIS database. Forest Service, Bureau of Land Management, Park Service, and Fish and Wildlife Service land management planning documents could form another database. Modern information tools could do much more, of course, such as linking geographically related documents with geographic information system

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[128] *See e.g.*, Doremus, Information Pipeline, *supra* note **[16]** at 438; Daniel A. Farber, *Adaptation Planning and Climate Impact Assessments: Learning from NEPA's Flaws*, 39 ENVTL. L. REP. 10605, 10610-12 (2009); Edward A. Boling, *Toward a Better NEPA Process for Decisionmakers*, 39 ENVTL. L. REP. 10656, 10658-59 (2009); James L. Connaughton, *Modernizing the National Environmental Policy Act: Back to the Future*, 12 N.Y.U. ENVTL. L. J. 1, 8-9 (2003); Michael B. Gerrard and Michael Herz, *Harnessing Information Technology to Improve the Environmental Impact Review Process*, 12 N.Y.U. ENVTL. L. J. 18 (2003).

[129] Doremus, Information Pipeline, *supra* note **[16]**, at 433**.**

[130] CEQ, established by NEPA, is the environmental arm of the Executive Office of the President. Council on Environmental Quality, About CEQ, http://www.whitehouse.gov/administration/eop/ceq/about. It is, therefore, the office in the best position to centralize administration environmental policy.

[131] 42 U.S.C. § 7609(a).

(GIS) tags.[132] But the first step, which would be enormously helpful in facilitating the kind of learning needed for effective adaptive management, would be simply to create digital databases.

Such a step is conceptually simple, but of course more difficult in practice. It will impose short-term resource costs, while the pay-off will be slower to materialize. It will require commitment and leadership from the White House, and sustained funding from the Congress. But if we are to make learning-based management strategies effective, it's the sort of infrastructure investment we need to make.

2. Trusted Intermediaries as Information Diffusion Agents

The question of how managers seeking to implement adaptive management or other information-intensive strategies obtain useful information is one that has not received enough attention in the policy literature. Natural resource managers are, I believe, systematically risk-averse in the sense that they do not want the resources under their supervision to be harmed by their management choices, and perhaps even more strongly they do not want to be blamed for any harm the resources suffer.[133] They are also typically resource-limited, understaffed and overcommitted. They do not have a lot of time to keep up on the latest literature and ideas or to consider how ideas developed in other contexts might help them in their tasks. Their staff, which is often heavy on bachelors- and masters-level expertise, may not have the background or training to make those judgments effectively or with confidence. They may, therefore, fall behind on awareness of both data and new techniques that could be helpful in achieving their goals.

One way to read the much-criticized opinion of the Seventh Circuit in *Sierra Club v. Marita*[134] case is as a cautionary tale about knowledge diffusion. The *Marita* decision dealt with

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[132] *See* Farber, *supra* note **[95]**, at 10610-11.

[133] *See supra* note **[14]**.

[134] 46 F.3d 606 (7th Cir. 1995). For a sampling of critical commentary, *see, e.g.*, Courtney Schultz, *Responding to Scientific Uncertainty in U.S. Forest Policy*, 11 ENVTL. SCI. & POL'Y 253, 259-261 (2008); Doremus, *Precaution*, *supra* note **[27]**, at 576-579; A. Dan Tarlock, *Biodiversity and Endangered Species*, *in* STUMBLING TOWARD SUSTAINABILITY (John C. Dernbach, ed.) 311, 319 (2002); Brian Scott Pasko, *The Great Experiment that Failed? The Role of a "Committee of Scientists" as a Tool for Managing and Protecting Our Public Lands*, 32 ENVTL. L. 509, 532-536 (2002); Greg D. Corbin, *The United States Forest Service's Response to Biodiversity Science*, 29 ENVTL. L. 377 (1999); Patricia Smith King, *Applying Daubert to the "Hard Look" Requirement of NEPA: Scientific Evidence Before the Forest Service in Sierra Club v. Marita*, 2 WISC. ENVTL. L. J.147 (1995). *But see* Fred Bosselman, *What Lawmakers Can Learn from Large-Scale Ecology*, 17 J. LAND USE & ENVTL. L. 207, 247-252 2002) (arguing that scientific evidence does not support the notion that declines in forest species are primarily a result of fragmentation).

management of lands within the national forest system. Plaintiff environmental groups asserted that the Forest Service had ignored the theory of island biogeography and its lessons for the size of reserves needed to protect native species.[135] They contended that the Service had ignored well-established scientific principles, submitting more than 100 published articles in support of their position.[136] The Service responded that although the theory of island biogeography was "of interest," it had not yet been applied to forest management in the region.[137] In essence, the Service argued that it wasn't sure how to apply the theory to its work, and wasn't required to make figuring that out a priority.[138] To the horror of conservation biologists,[139] the court sided with the Forest Service, deferring to its determination that application of the theory was uncertain.[140] Of course it may be that the Forest Service rejected the Sierra Club's suggestions because it just wanted to get out the cut. But it is also the case that it is challenging for resource managers like the Forest Service to keep up with the latest developments, especially if their application to management problems is indirect or unclear. And it is certainly true that courts will be reluctant to disturb decisions justified by that sort of uncertainty.[141]

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[135]*Marita*, 46 F.3d at 610.

[136] Marita, 46 F.3d at 618.

[137] *Id.* at 618-619.

[138] *Id.*

[139] Both the Society for Conservation Biology and the American Institute of Biological Sciences appeared as amici in support of the Sierra Club. *Id.* at 621. Shortly after the decision was issued, for example, a letter to the editor in the Society for Conservation Biology newsletter called for members to write to the Chief of the Forest Service, urging greater use of conservation biology in forest management decisions. Letter to the Editor from Randy Webb, available at http://www.conbio.org/Publications/Newsletter/Archives/1997-5-May/nl-su018.cfm.

[140] *Id.* at 621. Of course there was more to *Marita* than the question of how specifically the plaintiffs' preferred scientific methodology had been articulated with respect to the lands in question. Doremus, *Precaution, supra* note **[27]**, at 577 ("*Marita* is a difficult case to parse, in part because the opinion wanders back and forth between disagreements about goals and disagreements about methods of ensuring that those goals are achieved."). At a minimum, the decision was motivated in part by the idea that the governing statutes required the Forest Service to consider values other than preservation, and the court's belief that even with respect to preservation the Forest Service was entitled to some deference to its understanding of what elements it was mandated to preserve.

[141] In *Marita*, the Forest Service argued that the theory in question**Error! Main Document Only.** "had been developed as a result of research on actual islands or in the predominantly old-growth forests of the Pacific Northwest and therefore did not necessarily lend itself to application in the forests of Wisconsin." Marita, 46 F.3d at 622. That may have been just an attempt to justify a management decision reached for other reasons, but it is not implausible that something like that reasoning may have been part of the decisionmaking process. In either case, the court

Efficient and effective knowledge diffusion often depends on the availability of intermediaries who have the trust of the parties to whom they are bringing knowledge as well as the expertise and resources needed to get that knowledge. One possible model for such an intermediary corps would be an academic corps modeled on the cooperative extension service. Cooperative extension was launched in 1914 to help bring the agricultural research being produced in the land grant colleges to farmers.[142] Its statutory purpose is explicitly one of knowledge diffusion: "to aid in diffusing among the people of the United States useful and practical information on subjects relating to agriculture . . . and to encourage the application of the same."[143] Extension, which includes specialist researchers based at the land grant universities and their experiment stations, and county agents with offices in rural areas, seems to successfully mediate both the transfer of knowledge from the universities to farmers and communication in the other direction of the issues farmers regard as research priorities. It transfers not only data but methods, such as up-to-date models, to diffuse users.[144]

Crucial to the transfer function is that extension agents enjoy the trust of farmers, and have regular opportunities to interact with them both formally at conferences and informally based on relationships built over the years. The trust of researchers is also important. In the case of Cooperative Extension, much of the applied research is carried out by extension specialists based at universities and agricultural experiment stations. Those researchers may themselves regularly meet with their agricultural constituents, or they may interact primarily with county agents who then interact with the farmers. The key point is that there needs to be an intermediary organization, enjoying the trust, respect, and attention of both knowledge producers and knowledge consumers.

In the resource management context, that role seems to be limiting. There certainly are extension agents and researchers who focus on the intersection between agriculture and resource conservation, but their association with agriculture can lead to distrust by environmental interests, and resource managers who view their mission as conservation. There also are research arms of federal resource management agencies, such as the Forest Service's Research and Development unit, which describes as its mission "to develop and deliver knowledge and innovative technology to improve the health and use of the Nation's forests and rangelands – both public and private."[145] But something seems not to be going as well as it could in the

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agreed, ruling that **Error! Main Document Only.**"however valid a general theory may be, it does not translate into a management tool unless one can apply it to a concrete situation." *Id.* at 623.

[142] David W. Cash, *"In Order to Aid in Diffusing Useful and Practical Information": Agricultural Extension and Boundary Organizations*, 26 SCIENCE, TECH. & HUMAN VALUES 431, 433-434 (2001).

[143] 7 U.S.C. § 341.

[144] Cash, *supra* note **[82]**, at 439-40.

[145] U.S. Dept. of Agriculture, Forest Service, USDA Forest Service Research & Development,

delivery phase. Curiously, of all its various constituencies, the one least satisfied with the Forest Service's Research and Development operations is the Forest Service itself.[146] Federal information users had little confidence that products of the Research and Development operation would provide feasible solutions to their problems or help them anticipate emerging problems.[147] Moreover, the high rate of litigation focused on the science of Forest Service management decisions[148] suggests that external stakeholders are not satisfied with the way science is making its way into the management process.

To the extent that entities with a knowledge translation mission already exist, perhaps they simply need more funding or a renewed focus on delivering useful information to resource managers in a timely fashion. I believe, however, that some structural and cultural changes would also be useful. There should be more opportunities for research and management personnel to work together on designing and implementing studies designed to address management needs.[149] Performance measures for research units should explicitly include the development and provision of management-relevant information, in conjunction with managers.[150] In addition, more emphasis should be put on synthesis, and on conveying information not generated by the intermediary organization. Resource managers do not need to

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Strategic Plan, 2008-2012 at 1 (Feb. 2008) (on file with author).

[146] U.S. Dept. of Agriculture, Forest Service R&D, Customer Satisfaction Survey 15 (Aug. 2006) (showing satisfaction rate of 68% for Forest Service "customers," lower than other federal agencies, nongovernmental organizations, educators, or any other users), available at http://www.fs.fed.us/research/pdf/2006_fs_rd_customer_satisfaction_survey_final_report.pdf

[147] *Id.* at ___.

[148] For a review of this litigation in the Ninth Circuit and the difficulties it has caused that court, *see generally* Sara A. Clark, *Taking a Hard Look at Agency Science: Can the Courts Ever Succeed?*, 36 ECOLOGY L. Q. 317 (2009).

[149] *See* David W. Cash, Jonathan C. Borck and Anthony G. Patt, David W. Cash, Jonathan C. Borck and Anthony G. Patt, *Countering the Loading-Dock Approach to Linking Science and Decision Making: Comparative Analysis of El Niño/Southern Oscillation (ENSO) Forecasting Systems*, 31 SCIENCE, TECH. & HUMAN VALUES 465, 467-468 (2006) (noting the need for "co-production" of information through collaborations between researchers and users. At least some Forest Service researchers are well aware of the value of these kinds of cooperative efforts, and their role in promoting knowledge diffusion. *See* Emile Gardiner, et al., *Establishing a Research and Demonstration Area Initiated by Managers: The Sharkey Restoration Research and Demonstration Site*, 106 J. FORESTRY 363 (2008).

[150] On this score, the Forest Service's current strategic plan is lacking. The performance measures it proposes for the Research and Development office include only slightly improved overall "customer satisfaction scores," and additional patent applications. U.S. Dept. of Agriculture, Forest Service, USDA Forest Service Strategic Plan, FY 2007-2012 at 24 (July 2007) (on file with author).

learn of every individual study relevant to their work in isolation. Indeed, paying too much attention to individual studies outside the larger context can increase confusion, leaving resource managers uncertain whether they should recast their management efforts every time a new study comes out.[151] Unfortunately, synthesis tends to fall between the cracks. Researchers tend not to be rewarded for it, while managers tend not to have the time or expertise to do it well.

Although some of the needed entities, or similar entities which could be converted to a diffusion function, already exist within the federal government, there is no reason why this role needs to be confined to government entities. It is essential only that intermediaries have the trust of both researchers and managers. In the resource management world, there may be non-governmental organizations, such as The Nature Conservancy, which are well-positioned to fulfill that role.

CONCLUSION

Adaptive management subsumes many different challenges. It is an incentives problem, an accountability problem, and a flexibility problem. But it is also an information policy problem, and that aspect has been underappreciated. Before deciding to employ, or to continue to employ, an adaptive approach to management, and before determining the parameters of such an approach, managers should undertake an explicit, structured analysis of the need for and practicality of learning. This is not a new or radical idea; Hilborn and Walters, who are among the leading scientific proponents of adaptive management, called for it nearly twenty years ago in the context of fisheries management:

> Once a clear set of alternative hypotheses or stock response models is available, it is worth doing a simple calculation of the expected value of perfect information in order to determine whether further adaptive policy analysis is worthwhile. The essential idea behind this calculation is to find the policy option that would be best if there is no future learning . . ., then to see how much improvement could be obtained from that nonadaptive baseline if it were known for certain which model is correct, that is, if perfect information were suddenly available.[152]

Yet many policymakers and public resource managers still have not learned this important lesson. As a result adaptive management, which is a form of structured

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[151] Health care providers and consumers suffer this sort of confusion when they are buffered by unfiltered news of, for example, every major study on the efficacy of mammograms for breast cancer detection and treatment. *See, e.g.*, *Sorting Through Mammogram Confusion*, NPR Talk of the Nation transcript, Oct. 14, 2010, available at http://www.npr.org/templates/story/story.php?storyId=130569731.

[152] RAY HILBORN AND CARL G. WALTERS, QUANTITATIVE FISHERIES STOCK ASSESSMENT: CHOICE, DYNAMICS AND UNCERTAINTY 493 (1992).

decisionmaking,[153] is frequently required or adopted without any structured analysis of the benefits it is expected to produce or the trade-offs inherent in realizing those benefits. That in turn leads to the cynical (but not necessarily false) assumption that the purpose of adaptive management is to reduce political pressures or evade oversight, rather than to improve management outcomes. If adaptive management is truly necessary, the ongoing confidence of stakeholders as well as policymakers will be needed to sustain it. If it is not truly necessary, it should not be employed. Either way, a formal, structured analysis at the point of deciding whether to use it and how will be helpful.

In some crucial cases, that analysis will show that learning would be highly valuable but costly or difficult. We should be sensitive to the fact that some barriers to learning are the result of policy choices, and therefore that policy steps might be able to reduce them sufficiently to make important learning practicable. There are systematic steps we can take to encourage the production of relevant information and facilitate its diffusion to managers in a form they can trust and use. Those steps are not costless in the short run, but they should pay dividends over time.

[153] Lyons et al., *supra* note **[2]**, at 1684.