Some Pitfalls of an Overemphasis on Science in Environmental Risk Management Decisions

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Abstract

This paper addresses the question whether calls for “more” and “better” science will have the intended effect of improving the quality of decisions about environmental risks. There are reasons to be skeptical: key judgment tasks that fundamentally shape many aspects of decisions about environmental risk management lie outside the domain of science. These tasks include making value judgments explicit, integrating facts and values to create innovative alternatives, and constructively addressing conflicts about uncertainty. To bring new specificity to an old debate, we highlight six pitfalls in environmental risk decisions that can occur as the result of an overemphasis on science as the basis for management choices.

Key words

science, risk management, decisions, environmental policy

Some Pitfalls of an Over-Emphasis on Science in Environmental Risk Management Decisions

1.0 Introduction

Science has a central place in risk debates, and has played an important role in reducing environmental risks. But as the nature of environmental risks and our approach to managing them changes, the role of science is also shifting. In the early years of risk assessment, there were plenty of unambiguously dangerous environmental and health risks and thus, from a manager's perspective, plenty of low-hanging fruit -- low cost actions that could be identified by experts as unequivocally reducing risk without adversely affecting other endpoints. Lines were easily drawn in the sand: below some threshold level we were judged to be safe and, above it, we were not. Science-based management using these so-called "bright lines" was relatively simple and easily justifiable, enjoying both technical defensibility and widespread support.

Today, things have changed: risk management has been termed a "battlefield" (Slovic, 1999) and the era of low hanging fruit is over. Instead, choices are characterized by difficult and controversial trade-offs among competing ecological, health, and socio-economic objectives. Even modest improvements on one endpoint often are achieved only at the expense of other objectives, either because they are directly in conflict or because the risk-reduction action redirects funds away from other pressing needs. Nor are the consequences of risk-reduction actions always clear. Instead, they are often marked by profound uncertainties that hamper the ability of managers to judge the severity of a risk or the effectiveness of management interventions and, in many cases, leave room for different interpretations based on stakeholders' trust and perceptions of scientists' credibility.

In an effort to resolve these debates, calls for "more science" and to "just let science decide" are often heard in the context of developing acceptable management strategies. In widely cited testimony before the U.S. Congress on revisions to air-quality standards, for example, EPA administrator Carol Browner stated that "science now tell[s] us that our air pollution standards are not adequate to protect the public's health. Let us listen to science."[1] Nor is this emphasis on science limited to the US. In their review of New Zealand's debate on policies for managing risks of genetically modified foods, Walls et al (2005) conclude that "public participation is not seen as having the ability to influence policy due to the reliance on science-based approaches" (Walls, et al, 2005). But will more science really lead to better environmental management decisions? We argue that in some key respects it won't, not because of any failure of science, but because individuals are simply asking more from science than it can deliver. What is needed is better decisions -- and science, for all its important contributions, does not deliver decisions.

To the experienced risk management practitioner, this concept is not new; for at least the past decade there has been a growing recognition of the need to better integrate science and values in risk decision making (NRC, 1996). In several important instances there has been a shift toward more integrative practices, often focusing on ways to foster productive deliberations among diverse stakeholders (Renn, 2004; Wilsdon & Willis, 2002). However, these more enlightened processes remain the exception[2] and many high profile cases still call for "science based regulations."[3] In our own work with a variety of government agencies concerned with the day-to-day practice of environmental risk management, we continue to see an over-reliance on science as the means of making tough choices. This over-reliance on science has important consequences: resources spent on more and better science are not available to provide insight where it is needed. What we hope to do in the remainder of this paper is bring specificity to the ways in which risk management processes continue to over-rely on science, explicitly or implicitly, in the practice of risk management. The goal is to accelerate the transition from passive awareness to concrete changes in behaviour and, ultimately, to achieve better environmental risk management decision processes.

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[1] Hearings before the Senate Committee on Environment and Public Works, 1997; testimony of C. Browner, EPA.

[2] Nor do they result in guaranteed success; the review by Walls et al (2005: 28) of Britain's "GM Nation?" debates on genetically modified crops, widely cited as a promising approach for encouraging the integration of input from scientists and laypersons, concludes that "Despite a sincere attempt to include a range of social values, the polarized nature of most of the open public debates prevented the systematic social sharing of different perspectives."

[3] A search on Google for the term "science-based decision making" (March 1, 2006) indicated some 696,000 web pages. Of those consulted, the dates all were from 2003 to 2006, indicating a continuing strong role for science in risk management choices.

1.1 What we mean by science

There are many, often conflicting, definitions of science. For the purposes of this discussion, we focus on the intellectual core of science as opposed to the many other institutional roles it is regularly called upon to play (Fuller, 2002). This core is generally acknowledged as a process of organized inquiry into the nature of natural phenomena, human interventions, and (often) their relationships. The process of scientific inquiry, in turn, implies properties that include a systematic and repeatable methodology; an emphasis on scrutiny, skepticism, re-evaluation and learning; professional independence, objectivity and accountability; quality control by peer review; and transparency (Stirling, 1999).

These, we believe, are the characteristics and functions that people – citizens, politicians, managers and scientists alike – are calling for when they say “let science decide”. In the context of environmental risk debates, we further interpret these calls as referring specifically to the applied natural sciences -- including biology, chemistry, forestry, fisheries, ecology, health and engineering – rather than the social sciences of psychology, economics, sociology, anthropology or the management and decision sciences. Readers familiar with these latter disciplines will note that much of what we advocate in this paper stems from research and applications in these fields. This is not, however, what public and political leaders typically refer to, nor what managers and field scientists intend, when they call on “science” to resolve controversial policy questions. Instead, they look to the applied natural sciences, conducted in conformance with accepted standards of best practice in the relevant discipline(s).

Faced with technically complicated, economically costly, and often morally charged questions about diverse challenges -- such as the safety of our drinking water, the security of food supplies, the management of contaminated sites, and countless other environmental risk debates -- is it not reasonable to call for more and better science to make risk management decisions? Answering this question requires that we also review what we mean by decision-making.

1.2 What we mean by decision-making

In contrast to science, which describes what we know, decisions address what we want and, more specifically, what we choose to do, based on what we know and what we value. The core steps have been defined many times (Dawes, 1988; Hammond et al., 1999; Bazerman, 2002):

- Define the context for the decision: the question or problem being addressed, why it is important, who needs to be involved, and relevant timelines and budgets.
- Clarify the objectives or "ends" of the decision and the attributes or specific metrics used to measure progress toward them.
- Identify a range of alternatives for achieving these objectives.
- Examine consequences of the alternatives, including the associated uncertainties.
- Explore trade-offs and make recommendations or choices that reflect the values and preferences of stakeholders.

It follows that making good decisions requires (at least) three things. First, it requires good information concerning facts – how the world is (or might be) and the anticipated consequences of proposed actions. In this arena science has much to offer. Second, good decisions require good information about values – what matters to us, as individuals and as members of families, communities, regions, nations, and the globe – and what our priorities and preferences for different outcomes are. Here, science has no special expertise: understanding and clearly expressing their own values is no easier or harder for scientists than it is for any of the other stakeholders, nor are the values of scientists any more or less legitimate than those of other stakeholders. Third, and critically, making good decisions requires a process for integrating facts and values in relevant analysis and a constructive deliberative exchange. This need is the basis for the widely cited linkage between "analysis" and "deliberation" urged by the U.S. National Research Council (1996).

1.3 The role of science in decision-making

We are certainly not the first to consider the limitations of science. Kuhn (1970/96) exposed the insufficiency of methodological directives alone to provide objective answers to real world questions. Subsequent researchers have amplified this theme, including the work of Radovich (1981) in examining the values basis for disagreements among scientists as part of environmental conflicts, the work of Hacking and his colleagues on the social construction of science (Hacking, 1999), the findings of Slovic on the role of values, feelings and emotions in perceptions of risk (1999), and the views of Funtowicz and Ravetz on post-normal science (1993).

In our view, the role of science in the decision making process is critical but specific and limited. In defining the decision context, science can alert us to problems that may be potential targets of management action, but cannot tell us what to do or who should be involved. When addressing objectives, the role of science is a test of relevance: do the stated values of stakeholders have a realistic possibility of being measurably altered by the decision at hand? Science has a role to play in advising which attributes accurately describe key consequences and which realistically can be modeled or otherwise estimated. In creating alternatives, science has a role to play both in directly identifying candidate actions and in acting as a test of relevance for actions proposed by non-technical stakeholders: are they technically feasible, and do they have a realistic possibility of improving key concerns?

When addressing consequences, science is uniquely designed to identify the potential effects of proposed actions on the expressed objectives. From the air dispersion models of engineers to epidemiologists' calculations of health response effects or predictions of carbon sequestering by atmospheric scientists, few would argue that science is not a critical and necessary input to the decision making process. But these are questions of risk assessment (what are the likely consequences?), not risk management (what should we do about it?). As noted by the NRC (1996), scientific expertise can anticipate the health or ecological effects of different actions but cannot directly address the social, cultural or economic importance of these effects. Thus at the level of trade-offs and choices the role of science is minimal, limited to ensuring that decision makers are correctly interpreting and not overlooking critical information about consequences. Technical information can help decision makers put trade-offs in context – for example, graphs showing thresholds in biological effects or breakpoints in management costs can be indispensable. But this information is not sufficient to make choices.

Once a desired attribute has been defined, science can rank stressors or activities in terms of their relative impacts on it. Science can also rank risk-reducing activities in terms of cost-effectiveness (as measured by life-years saved per dollar of expenditure, for example). In all these cases, a single attribute or concern has been identified and a science-based assessment delivers a ranked list of risks affecting that attribute. However, a ranked list of risks is information, not a prescription. Except in the increasingly rare situations when a clear and uncontroversial threshold exists below which we are safe and above which we are not, science does not determine what level of risk is acceptable, nor does it tell us what to do about mitigating the listed risks (Fischhoff, Watson & Hope, 1984). Whether we choose to act to reduce a risk depends on many other factors, including our perceptions of the acceptability of the risk (related to affective responses, voluntariness of exposure, and the like; see Slovic, 1987) the feasibility and cost of risk-reducing activities, and the implied trade-offs.

Thus science, as it is normally conceived, is essential to the completion of only a portion of environmental risk management tasks, those involved with the identification and characterization of risks and estimation of the consequences of risk management actions. In contrast, science provides relatively little help in the initial structuring stages of risk management, or the final balancing stages of risk decision-making. Whenever public agencies claim that science can "make tough choices," then decisions that should be made on the basis of the values and tradeoffs of stakeholders are instead turned into technical debates. As noted by Coglianese and Marchant (2004: 1258), "agencies need to explain their decisions by reference not only to scientific evidence but also to policy principles that speak to the value choices inherent in their decision making." Using science to ostensibly make such choices means that our responsibilities as citizens are handed over to those with legitimated knowledge, resulting in a decision process that is incomplete and a loss of power that violates essential democratic principles (Lyotard, 1979).

In the remainder of this paper, we consider some specific examples of the pitfalls of relying too heavily on science, without sufficient recognition of the need for a sound decision process. What we hope to contribute is a greater awareness of what is needed from a decision-making perspective as a complement to "getting the science right" in environmental risk management deliberations.

2.0 Potential Pitfalls of an Overemphasis on Science

Problems in environmental risk decisionmaking can occur as the result of an over-reliance on science at various stages of the environmental risk management decision process. Six issues are identified, relating to the principal aspects of a decision process (Hammond et al., 1999): Defining objectives, selecting attributes, creating alternatives, estimating consequences, addressing uncertainty, and clarifying tradeoffs.

1. Unclear objectives

The values of participants, expressed in terms of their problem-specific objectives, determine why a possible environmental risk matters in the first place (Keeney, 1992). Despite widespread recognition of the importance of clear objectives, decision makers in environmental risk management often treat this stage cursorily, moving quickly into more familiar technical territory such as information gathering, modeling and analysis.

At the simplest level, failing to define objectives clearly will lead to different interpretations of the issues at hand and, in many cases, to the omission of concerns important to at least some stakeholders. This problem occurs both within and across stakeholder groups. For example, different scientists working toward a “best science” solution to a fisheries restoration problem may have fundamentally different objectives: one fisheries biologist may seek conservation of species diversity, another an increase in the production of harvestable fish, and a third avoidance of the low-probability collapse of a single endangered species. In the absence of clear objectives, even the best science has little chance of identifying the best management actions, and still less of securing agreement on those actions.

At an agency level, failure to set objectives carefully can lead to gross misallocations of resources: working on the wrong problem, for the wrong reasons, with the wrong participants. As Pielke and Rayner (2004) note: “Science can alert us to problems, and can help us understand our goals once we have decided them; but the goals themselves can emerge only from a political process in which science should have no special privilege.”

Another pervasive pitfall relating to objectives occurs whenever a disproportionate amount of resources is invested in the evaluation of impacts on a single or a limited set of objectives while leaving other objectives virtually unexamined. Scientists become frustrated when their recommendations on how to manage specific ecological variables are thwarted by “irrational social choices”. Yet when these irrational risk management choices are closely examined in the context of a multi-dimensional decision process, they frequently make good sense (Slovic, 1999). For example, public rejection of a prescribed burn (a forest management alternative often preferred by scientists to improve biodiversity) is not irrational when the full set of underlying concerns (including the potential for property damage from an escaped fire, or tourism losses due to air quality concerns) are exposed and evaluated (Ohlson et al., in press). What is required in these cases is not more detailed science about a single endpoint but a more balanced analysis of all the important endpoints, including the social and economic implications of actions. This same message is echoed by Renn & Klinke (2004), who emphasize that risk management “must integrate risk assessments into a comprehensive problem-solving exercise that encompasses economic, financial, and social impacts” to ensure that “information can be phased into the decision-making process.”

The need to define objectives extends to the ultimate (elected or unelected) decision makers. Calls for greater separation of science from the political process of decision-making can make it harder to understand what values and concerns matter to decision makers. There are legitimate reasons for this call, namely the fear that the science underlying the assessment of risks could be influenced by external factors or by concerns about the cost or feasibility of management options, and thus introduce dangerous biases into the assessment process (Loder, 2000; Ball, 2002). Such concerns are not new; they were highlighted over 20 years ago in the “red-book” report on risk in the US federal government (NRC, 1983). However, the desire for separating science from politics also has led to critical gaps between the needs of managers and the focus of technical analyses. Power and McCarty (2002) note this concern and highlight differences in the extent to which science and policy are separated as part of the risk management prescriptions adopted by major government agencies worldwide.

Defining objectives explicitly will help to make clear the value judgments that pervade a multitude of choices about analytical methods and data. In 1994, the U.S. National

Research Council listed 50 points at which policy-related value judgments could enter a technical risk assessment process (NRC, 1994). Examples included judgments such as: which epidemiological studies should be most relied upon? What statistical tests of significance should be used? How much emphasis should be placed on experimental animal data if the exposure routes to humans are different? Clearly it is difficult, perhaps impossible, to completely separate value from technical judgments. However, careful definition of objectives can lay the groundwork for distinguishing choices that are fundamentally value-based (e.g., how much to pay for a given level of protection) and judgments that are fundamentally technical in nature (e.g., the expected response of an ecological variable to a stressor). To the extent that the role of science is limited to the latter, and value judgments are identified and exposed where they occur, the quality and defensibility of environmental risk management decisions will be improved.

2. Irrelevant attributes

Attributes, also referred to as assessment endpoints or performance measures, refine the understanding of objectives and measure the extent to which risk management alternatives address the fundamental concerns of decision makers (Keeney and Gregory, 2005). An over-reliance on science in attribute selection can result in irrelevant attributes, the omission of concerns that cannot be objectively or scientifically evaluated, and a reluctance to report what cannot be estimated with confidence. All three effects can leave decision makers with critical information gaps.

Irrelevant attributes fail to provide information needed to inform choices among the actions under consideration and may, in fact, have the unintended result of making it more difficult to make a defensible choice. For example, an elaborate suite of indicators may be seen by scientists as essential to fully characterize biodiversity impacts. Yet detailed inventories of biological effects may obscure key relationships and are not needed if project impacts will have only a negligible effect on key endpoints or if the management options open to decision makers are so limited that little can be done about them (Failing and Gregory, 2003). Jones, Fischhoff & Lach (1999) consider this same question of relevance in the context of climate change research, where the detailed, long-term predictions of scientific studies may fail to be relevant to the more pressing, shorter planning horizons of policy makers.

In other cases, attributes selected by scientists may fail to capture the true underlying objectives of stakeholders. For example, as part of planning for exploratory drilling of off-shore oil and gas reserves in Alaska, the attributes defined by government and industry scientists were very different from those defined by stakeholders, even though there was initial agreement on the underlying objectives (U.S. Department of Interior, 1992). This dilemma arose because local citizens were not satisfied with maintaining highly visible species such as whales and seals (the regulatory focus of scientists) but rather interpreted environmental performance as requiring the enhancement of species diversity, a topic that scientists found more difficult to measure. Similarly, proposals from scientists focusing on minimizing worker fatalities were met with skepticism because citizen concerns extended to a variety of worker injuries and consumer illnesses. Only by highlighting such differences to determine a single set of agreed-upon, relevant attributes is it possible to improve communication among stakeholders and make progress on a management plan (Gregory and Keeney, 2002).

Of course, many considerations important to environmental risk management choices are not easily quantifiable: the quality of a recreational experience, for example, or the cultural value of a heritage site. Often these attributes are omitted from the evaluation process because they are “not scientific,” yet they may be critical to decision making. Methods have been developed for addressing qualitative factors that include the use of natural or constructed attributes (von Winterfeldt and Edwards, 1986). These approaches are not widely known in the scientific community, however, and as a result many science-based risk management initiatives omit considerations important to key stakeholders.

Problems also arise from the reluctance of scientists to include attributes for which the quality of information is perceived to be low. Often the solution is to select another indicator for which information is better, even though this approach will mean that concerns of direct significance are omitted or that uncertainty essential to understanding the implications of management choices will be masked (Gregory and Failing, 2002). In fisheries restoration and mitigation applications, for example, many scientists will prefer to report the impacts of a management option on food production, which generally can be estimated with confidence, rather than on fisheries abundance, which is more difficult to estimate. Yet fish abundance is likely what most stakeholders really care about. Although this reluctance of scientists is understandable, decision makers who care about fish abundance (and only care about food production insofar as it affects fish abundance) need to know that there are wide bands of uncertainty about the response of fish to food production. In a situation such as this one, using food production as an attribute can be misleading because it hides the uncertainty associated with the endpoint of fundamental concern.

3. Inadequate Alternatives

Alternatives provide a range of ways to meet the identified objectives; they are the ultimate means for achieving progress on those dimensions of the problem or action considered to be important. Whenever an emphasis on more or better science results in insufficient thought and attention going into the exploration of alternatives, risk management policies miss out on the possible achievement of a more favorable set of consequences.

An overemphasis on scientific input may reinforce the tendency to tweak one or two well-known alternatives rather than using the problem's underlying objectives to explore fundamentally new and creative alternatives. There are many reasons for this failure to sufficiently investigate alternatives. One is simply that because scientific data and models often are established for the status quo conditions, significant deviations from this status quo (as may occur under creative alternatives) are more difficult to predict. A second is a belief that it is the task of scientists (or the technical team) to provide decision makers with a single preferred or recommended alternative, accompanied by a justification – a problem we address in more detail later (Section 6, "avoiding trade-offs"). A third reason is the failure to use participants' values as the driver for identifying alternatives. Value-focused thinking (Keeney, 1992) helps overcome this common tendency to anchor on a familiar option (i.e., alternative-focused thinking) and to make only minor adjustments from an initial starting value or framing of the problem.

In Sabah, Malaysia for example, a land-use planning process was initially framed as a choice between a development option (mining of thermal coal reserves) and a preservation option (protecting biodiversity within the pristine rainforest) (Gregory and

Keeney, 1994). Scientific analyses fell into two camps, one favoring economic development and the other environmental preservation. Further scientific analysis was poised to focus on improving the quality of the associated baseline data by reducing the uncertainties that distinguished these two options. Instead, value-focused thinking transferred the attention of decision makers from these alternatives back to the underlying objectives. As a result, several new management options were identified that all parties agreed had a greater chance of providing both ecological protection and economic benefits. Scientific studies were then refocused, on a new set of issues and questions. In this decision, as in many others, reaching agreement and making a good decision hinged not on resolving differences in scientific opinion, but on creating more and better alternatives based on an exploration of stakeholders' objectives.

4. Exclusion of Relevant Knowledge about Consequences

While sound science must underlie estimates of the consequences of proposed alternatives, it is increasingly recognized that appropriate attention must also be given to the significant body of knowledge that is not grounded in conventional scientific methods. Some of the holders of this "local" knowledge are long-time community residents; some are aboriginal populations with special interests in cultural uses of environmental resources; some are resource users with specialized knowledge such as fishers, farmers, trappers, or hunters. Local knowledge, while often relevant and useful for decision-making, is not widely recognized as science. Calls for more science therefore can be in direct conflict with the growing social imperative, and in some cases legal requirement, that the knowledge held by community residents and aboriginal societies be more fully considered in resource and risk management. Substantive work remains to be done to examine when and how to integrate local and traditional knowledge with science as part of decision making, and to find ways to ensure the integrity of the information while respecting the knowledge bases of diverse stakeholders (Ford and Martinez, 2000). Yet calls for "more science" – taken to mean more western, conventional science -- do little or nothing to bridge the gap in knowledge systems or to bring together these diverse sources of knowing.

Of particular significance is traditional ecological knowledge (TEK). TEK is observation-based knowledge, generally more specific to local regions and more holistic than the analytical, decompositional approach of western science (Berkes, 1999). Parallels can be drawn between the development of traditional and scientific knowledge: phenomena are observed, hypotheses are developed that help to explain these phenomena and to predict other phenomena, outcomes are monitored, hypotheses are refined, and a community of peers judges the quality of the process. The difference is in how explicit the steps are, who conducts them, and what protocols or standards are in place for their conduct. From a decision-making perspective, one should not care whether information comes from conventional science or alternative knowledge sources; instead, one should accept – or reject – any information on the basis of its relevance to the context and the credibility of the process by which it was developed. Yet little has been written about how to examine and integrate the contributions of different knowledge sources, and most current assessment and deliberative processes strongly favor conventional scientific approaches (Oudwater and Martin, 2003).

One good way to avoid an over-reliance on western scientific data is for scientists to experience directly the benefits of integrating non-science inputs into environmental decision making. One of the primary benefits is filling in data gaps. As part of multi-party deliberations to develop a new water plan at a hydroelectric site in British Columbia for example, the results of conventional scientific analyses predicting fish responses to higher water flows showed disarmingly wide confidence margins. Traditional knowledge, obtained through interviews with elders, provided the only record of ecological processes prior to disruption of the riverine system and thus was a useful template for improving predictions of post-restoration ecological functions. During deliberations at another site, traditional knowledge inputs resulted in the addition of a new attribute to reflect concerns about tributary spawning success, the computation of which was designed to reflect traditional knowledge about flexibility in spawn timing and relative tributary utilization (Failing, Gregory & Harstone, 2006).

Certainly, no knowledge claim should be accepted without examination, regardless of its source. Yet there is ample evidence that a plurality of legitimate perspectives – local, traditional, scientific – can contribute to better quality decisions. What is needed is not an *a priori* commitment to more science, but openness to different knowledge sources, a process for the critical and collaborative examination of all knowledge claims, and a commitment to learning over time.

5. Incomplete understanding of uncertainty

Decisions about environmental risks typically focus on the evaluation of consequences, and estimates of consequences are complicated by uncertainty. The pitfalls of an over-emphasis on science at this stage are related to over-examining relevant uncertainties (from the perspective of decision making), dismissing expert judgment as unscientific, and as a result, failing to help decision makers make sense in a timely manner of the complex -- and often contradictory -- judgments of experts.

If the goal is to improve decisions, then the more salient uncertainties are usually those about how the system will respond to management interventions. In the context of understanding causal mechanisms and estimating future conditions for ecological processes, for example, typically there exist innumerable uncertainties. But many of them either do not affect the alternatives, or they affect all alternatives in the same way so that they are not critical for discriminating among them. Focusing on those factors that might influence the anticipated consequences of management alternatives can narrow down a long list of uncertainties into a short list of those most relevant to the decision at hand. This step will at least help to prioritize research efforts. Unless science is targeted toward evaluating the effects of uncertainty on the design and components of management alternatives, more and better science will not necessarily lead to better information for decision makers.

Even with well-targeted research there will be residual uncertainties, often ones that are significant. What is important to decision making is both the quality of the uncertainty judgments themselves and the ability of stakeholders and decision makers' to understand them, particularly when judgements are contradictory. Guidelines for eliciting quantitative probabilistic estimates using formal expert judgment methods have been well documented (Keeney and von Winterfeldt, 1991; Morgan and Henrion, 1990). These guidelines bring the principles of science to the practice of eliciting probabilities and confidence assessments by using a systematic and repeatable methodology, careful documentation, transparency, and quality control by peer review. Formal elicitation exposes the conditioning assumptions that underlie judgments, allowing for constructive and explicit dialogue about uncertainty and ultimately facilitating learning among experts. Structured approaches also help to create a comprehensible picture for decision makers of the range of scientific opinion, the degree of and reasons for consensus or disagreement, and its significance for the decision (Gregory, Fischhoff & McDaniels, 2005). Unfortunately, many scientists are unaware of the literature on expert judgment, coming as it does from the social sciences of psychology, behavioral decision theory, and policy analysis. As a result, they may agree only reluctantly to provide explicit judgments, making them apologetically and as a last resort.

One consequence of this reluctance is that enormous amounts of money have been spent to collect new data and build complex models in cases where elicitations with experts could have yielded more learning, and greater reductions in uncertainty, at a fraction of the cost. A second consequence is that many expert judgments have been done “on the cheap” (for example, without training participants in ways to anticipate judgmental biases) and consequently may be flawed by various methodological problems that have been extensively documented (Kahneman et al., 1982). Further, this reluctance perpetuates the myth that quantitative, computer-based models of ecological or other systems are “objective” whereas the expert judgments of individuals are not. In reality, such models are simply formalized collections of expert judgments, which may be supported by data of varying degrees of quality. There is nothing wrong with this; as Babich (2003: 142) notes, “… most risk assessment is neither good nor reliable science – it is merely the best science we have on the subject.” Problems arise only when the limitations of scientific inputs are neither revealed nor examined.

Our experience over the past decade suggests an increase in the willingness of scientists to try expert judgment approaches. In a recent project with fisheries scientists in the Pacific Northwest, for example, expert elicitations were used to reduce the uncertainty associated with assessments of the effects of alternative water flows on salmonid biomass and survival rates (Failing, Horn & Higgins, 2004; Gregory and Failing, 2002). In this case, scientists initially were opposed to providing quantitative probabilistic estimates, fearing that such estimates would provide a false sense of precision, and preferring instead to use qualitative descriptions (high, medium, low) or to wait until more data could be gathered or revisions could be made to existing models.

Their comfort level with the elicitations rose as they came to view their judgments as a method for drawing meaningful conclusions from existing data and for helping to prioritize the allocation of resources to further studies. Although expert judgments are a normal and unavoidable part of scientifically estimating consequences, we see little evidence that calls for more science are driving scientists or risk managers to invest in better processes for making use of the insights about uncertainty that are available through such structured processes.

6. Avoiding tradeoffs

Environmental risk management issues, at their core, are problems whose consequences involve multiple dimensions of value. These dimensions typically include human and environmental health, economic effects, and social or community impacts. Tradeoffs are often required among different types or incidences of health or economic or environmental impacts as well as across alternatives with varying levels of effects on different objectives, depending on the context-specific nature of the objectives and the probability-adjusted effects. Science itself provides no framework for making these values-based trade-offs.

“Trade-off” has become something of a bad word in some circles – it’s easier, after all, to talk about win-win results. But trade-offs are just choices, and facing tradeoffs head-on is often the only way to meet the concerns of different stakeholders. A decision process that does not present decision makers with choices has not done a very good job of identifying creative alternatives. One pitfall common to science-based processes is the belief that a sound technical process will result in a single recommended alternative. In such cases, the process moves quickly to that alternative -- often one that achieves a target for one prominent objective -- and then does all it can to minimize impacts on other objectives. What decision makers need, in contrast, is a set of fully developed alternatives that present them with real value-based choices across the different dimensions of value, such as different levels of protection of a target species and the different associated costs and benefits in terms of other objectives. In species at risk discussions in the province of British Columbia, for example, the implications of different levels of precaution in species recovery plans are being explored by developing distinct alternatives, in the form of management plans with different targets for the degree and timing of recovery, and then examining trade-offs among the principal ecological, social and economic objectives.

Identifying and discussing trade-offs in an explicit manner can be controversial. In most cases, however, we have found that once a technical team grasps the idea of exploring trade-offs through alternatives, they find themselves free to explore creative technical approaches that, ultimately, lead to better options. Further, we have found that open discussions of tradeoffs foster a better understanding of individuals' values and provide a necessary and welcome source of information for people who are asked to make choices about which they may have little experience. In discussions at Tillamook Bay, a National Estuary Program (NEP) site in Oregon, explicit consideration of tradeoffs among the different scientific and community stakeholders helped to create a common understanding and a basis for agreement about management plans because the discussions highlighted similarities in people's fundamental concerns (Gregory, 2000). Staff biologists and ecologists, responsible for scientific assessments, also cared about the economic, social, and cultural welfare of the community. Community members, worried about their jobs and the future of their community, also cared about the quality of scientific data and the long-term ecological consequences of actions. The assignment of explicit positive weights to these other dimensions helped to demonstrate shared concerns and to increase joint acceptance of estuary management plans. The same was true in the context of developing water use plans in British Columbia, where a strong focus on developing clear objectives and attributes and discussing the value trade-offs of both science and community participants led to consensus operating plans at 19 of 20 hydroelectric facilities (Gregory and Failing, 2002).

One of the most ubiquitous examples of avoiding trade-offs is the insistence of a regulatory agency that a policy or decision making framework is objective and science-based and, by implication, values-free. This was the message of EPA's Administrator Carol Browner when, in 1997, she defended proposed changes to the Clean Air Act standards at an Agency briefing by saying "I think it is not a question of judgment, I think it is a question of science." (cited in Coglianese and Marchant, 1994: 1273). But whenever costs are weighed against benefits, or short-term gains are balanced against long-term – and surely both are prominent in the context of the Clean Air Act – then value based trade-offs are being made. Wagner (1995) refers to this substitution of science for values as the "science charade," noting that [A]gencies exaggerate the contributions made by science in setting toxic standards in order to avoid accountability for the underlying policy decisions."

This same type of overly simplistic, covert, and misleading response to risk tradeoffs is typical of many agencies, whether representing government, industry, or NSOs. Yet in such situations, objective science is only capable of stating that one risk is likely to be more significant than another with respect to a given attribute; it cannot determine if that risk is "acceptable" or if the cost of reducing it is "worth it" or if changes should be made in the short-term or long-term. As soon as there are choices to make across multiple objectives, there are value judgments. Management and regulatory agencies would be far better off, and far more transparent, were they to acknowledge, consider, and document these value-based judgments and trade-offs than to pretend that the decision making framework is objective and value-free.

3.0. Conclusion

The development of standards and best practices in science has led to an extraordinary confidence in the scientific method as an approach to addressing environmental risk management problems. When intense controversy erupts (about, say, the safety of farmed salmon or the contamination of drinking water or the pros and cons of hormone replacement therapy) we hear calls from frustrated citizens, scientists and policy makers to "let science decide." These pleas assume that the rigor and "objectivity" of science will lead to sound decisions. Yet these are not questions that good science alone can resolve: suggestions to the contrary are misguided and misleading. Instead, these are questions that require the integration of facts and values, that require value-based procedures of evaluation and assessment, that are and will continue to be confounded by deep uncertainty, and that require risk managers to make (and subsequently defend) tough tradeoffs across multiple dimensions.

This paper focuses on the need for improved decision making as part of environmental risk management processes. We examine some of the pitfalls that can arise from an over-reliance on science at the expense of good decision analytic processes, emphasizing situations where science is asked to do something it was not designed to

do. Thus, most of the concerns highlighted in this paper stem not from the application of science per se but from what might be termed either “bad habits” in the practice of science or, more commonly, “bad expectations” of science on the part of non-technical stakeholders. Either way, we argue that – despite well-intentioned assurances to the contrary -- calls for more science will not solve these fundamental problems.
We are far from the first to address these issues: Lubchenco (1998: 495), for example, notes that “Many of the choices facing society are moral and ethical ones” for which “Science does not provide the solutions…” and Babich (2003) reminds us that “Risk assessment .. should be viewed as a policy tool based in part on the work of scientists, not as science.” There also are hopeful signs that this message is now beginning to have an effect on risk management policies. Of particular interest are numerous discourse-based approaches that seek to involve public participants in addressing controversial risk-management problems, such as the introduction of genetically modified foods (Walls et al, 2005) in the U.K., New Zealand, and Australia or the relicensing of hydroelectric facilities (Gregory & Failing, 2002) in Canada. These case studies are in turn supported by new institutional initiatives such as the UK government’s strategy for science and innovation (HM Treasury, 2004), which includes a commitment “to enable [public] debate to take place upstream in the scientific and technological development process,” and the German Scientific Advisory Council for Global Environmental Change (Renn & Klinke, 2004); both groups seek procedural improvements that will better integrate the analytical and deliberative components of risk management.

Our emphasis on six pitfalls of an over-reliance on science is intended to lend specificity to this debate about improvements in the process by which risk management decisions are made by helping to define more carefully the intersection of the facts- and values-based contributions. Understanding consequences and creating defensible alternatives requires that anticipated impacts be linked to values, and unless the same care and attention is given to understanding and probing and evaluating values as to facts, the solutions proposed by agencies or the public will fall short.

From an agency’s perspective, these rapid changes in the context for environmental risk management decisions mean that many of today’s environmental risk managers, trained as scientists, are expected to function to a surprising degree as decision makers within a multiple objective, multiple stakeholder environment. In this new context, discourse and deliberation are at least as significant skills as scientific analysis or investigation. Scientists thus may be proficient at their assumed job but find themselves in serious difficulty as risk managers because they lack important deliberative and decision making skills.

We agree with those who believe that good science is critical to good environmental risk decision-making. But an over reliance on science masks an important reality. The reality is that science informs. It does not, and fundamentally cannot, decide. Without closer attention to the requirements of an effective decision making process, for which there are increasingly clear guidelines and best practices, it is simply not possible for science to do its job as part of environmental risk management debates.

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