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Scientific Information and Uncertainty: Challenges for the Use of Science in Policymaking

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ABSTRACT: *Science can reinforce the healthy aspects of the politics of the policy process, to identify and further the public interest by discrediting policy options serving only special interests and helping to select among "science-confident" and "hedging" options. To do so, scientists must learn how to manage and communicate the degree of uncertainty in scientific understanding and prediction, lest uncertainty be manipulated to discredit science or to justify inaction. For natural resource and environmental policy, the institutional interests of government agencies, as well as private interests, pose challenges of suppression, over-simplification, or distortion of scientific information. Scientists can combat these maneuvers, but must also look inward to ensure that their own special interests do not undermine the usefulness of science.*

A. Introduction

Potentially important scientific information is often suppressed, ignored, or distorted. The fact that science inevitably entails some degree of uncertainty makes science and scientists especially vulnerable to these problems. Although expressing uncertainty is a crucial responsibility, it may undermine the credibility of scientific inputs and the urgency of taking this input into account. This paper focuses on how scientists can address and express uncertainty to overcome these dangers, in order to make more effective contributions to the public policy of natural resources and the environment.

We are especially interested in the relationship between scientific uncertainty and the application of adaptive management. Adaptive management entails "treating

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economic uses of nature as experiments, so that we may learn efficiently from experience."[1 (p.8)] One can learn from different sources of experience: 1) pre-existing policies, 2) new policies believed to be optimal, and 3) policies not expected to be optimal in themselves but valuable for the lessons of the experience *per se.* We shall see that the confidence or lack of confidence in existing science plays a huge role in determining the importance of experimentation of various forms and risks; how much policy, informed by scientific judgments, should cling to existing policies rather than bold departures; and whether short-term benefits should be risked in order to learn how to pursue longer-term improvements.

The backdrop for scientists and resource managers struggling with these dilemmas consists of a policy process and a political climate that often treats uncertainty as a pretext for inaction, a rationale for self-serving selection of scientific opinion, or a license to ignore scientists. Despite the plethora of government documents that emphasize the need for more and better science, government officials are not simply consumers of science, they often attempt to manipulate it. Consider the following examples:

- In the United States, as well as other countries, the rationalization often invoked for delaying action on global warming is that more research is needed before any potentially costly action should be taken.[2,3,4,5] The argument, that scientific uncertainty must be resolved before action should be taken, disregards the fact that no amount of data or theory will be able to eliminate all uncertainty regarding future temperature changes.
- The U.S. Forest Service buried scientific studies, conducted by its own Forest Service analysts, that demonstrated the dangers of an absolute fire-suppression strategy and thereby the importance of controlled burning to reduce the biomass in American forests.[6, 7]
- In Indonesia during the Suharto administration, the government's reaction to calls for reduced logging of the forests of Kalimantan and Sumatra was to assert that the precise causes of rapid deforestation were unknown; that the practice of slash-and-burn agriculture by the local people may be the problem; and that much more study is needed before logging policy could sensibly be changed.[8 (p.3)] A very similar situation occurred in Malaysia.[9 (p.103)]
- The Indonesian Forestry Ministry's harvesting regulations called for selective thinning, which permitted loggers to remove the most valuable stems. This harvesting system was inconsistent with the emerging scientific knowledge that "mast fruiting" of the predominant dipterocarp trees is an evolutionary adaptation that permits regeneration only if tree density is great enough to generate enough seeds from large mother trees to satiate seed-eaters; pollination can only occur if the trees are located in clumps. The Indonesian Forestry Ministry ignored these scientific understandings.[9]
- By 1990, Costa Rica had ten different land-classification systems, employed by twenty-two government agencies. Each system was based on different, and often conflicting, scientific premises, including principles that were designed specifically for temperate rather than tropical zones.[10 (pp. 6-8)]

Thus natural resource policy often reflects the politics of sleight of hand: environmental and biodiversity costs of natural-resource exploitation are unclear; scientific findings that challenge existing resource policies are distorted or suppressed; scientific "lessons" are over-simplified or distorted; resource-exploitation doctrines and classifications are only superficially related to scientific principles; resource policy failures are not attributed to the appropriate actors; and scientific uncertainty (on such issues as global warning) is used to rationalize inaction rather than guiding the more constructive strategy of hedging to address risk.

The premise of this article, therefore, is that if scientists and scientific organizations understand both how uncertainty can be responsibly addressed, and how special interests, from both the private sector and government agencies, try to suppress or distort sound science and its applications to natural-resource and environmental policy, scientific contributions can become significantly more useful. Yet the special interests of scientists and scientific institutions must also be checked, lest collusion with other special interests arise. Thus scientific information can play a crucial role in reining in special interest politics, but it can also be abused, rendering scientific inputs into the policy process ineffective.[11]

B. Roles of Science and Politics

Legitimacy of Politics. Politics *per se* is not pernicious; it is essential as the process for "shaping and sharing of values"[12] (p.345) that inevitably gives rise to some degree of conflict. When we speak of the "political uses" of scientific information, we must keep in mind that this information is often used properly in the "politics of the policy process." Healthy politics and sound science can serve to clarify and secure the public interest.[13]

It is crucial to develop a meaningful concept of the "public interest." Without such a concept, we lack a standard by which to identify policies that are at variance with the public interest. Yet if the "public interest" is defined in the conventional fashion as *the* optimization of societal utility, there will always be disagreement, and the very concept erodes in the face of the multiplicity of principles by which different elements of society could assert the societal optimal. Kai Lee[1] (p.96) writes of the increasingly prominent view in the United States that

> policy and learning are the by-products of competition among policy actors, including experts, politicians and bureaucrats, all of whom act as advocates.
>
> *Fundamental to this change of perspective is the abandonment of the concept of the public interest.* If no one really is a steward of the public interest, then the playing field is level: no one is more legitimate than anyone else, even though different institutional positions still constitute different roles. Only a senator can vote on the floor of the Senate, but his or her statements—drafted by a staffer from materials provided by a lobbyist or bureaucrat—are no more likely to be an articulation of the public good than is a statement by any other partisan. (emphasis added)

Therefore I suggest a different concept: the *public interest range*. Assume that there are multiple conceptions of the public interest in terms of values and their distribution – again derived from the concept of the "shaping and sharing of values." Any given outlook will privilege a particular balance of values (e.g., material prosperity, personal security, civil liberties) and a particular distribution of these values to the population. For example, a Benthamite conception would argue for a policy that provides the greatest good for the greatest number.[14] A Rawlsian conception would argue for a policy whose outcomes bring the distribution of benefits closer to what people operating under the "veil of ignorance" as to their own standing would regard as the fairest outcome.[15,16] A radical redistributionist conception might call for a policy that levels the total distribution of benefits drastically, even beyond considerations of fairness regarding effort and ability. This set of conceptions of the societally optimal constitutes a range that bounds the *arguably optimal*, but most important it defines what is beyond this range. Special interests, then, are defined as those who advocate policies expected to lead to outcomes beyond this range.

The utility of this approach rests on the assumption that while it is difficult or perhaps even impossible to define *the* public interest conceived as a specific societally objective function, it is often easy to identify what is not in the public interest. Even the most selfish individual would acknowledge that his or her monopoly over all that is valuable is not a societally optimal outcome. Moreover, some policy options would not optimize for anyone. Some natural-resource policies and practices are glaringly not in the public interest. The important point is that better scientific information can often reveal this.

C. Taxonomy of Uncertainty

The first obvious step in assessing the vulnerability that scientific input faces with respect to uncertainty is to differentiate among the types of uncertainty. This will permit us to see how different forms of uncertainty challenge the standing of scientific input.

A first-cut distinction often made in the literature on uncertainty is the "epistemic vs. aleatory" distinction. The Senior Hazardous Analysis Committee of the U.S. Nuclear Regulatory Commission[17] notes that:

> The two fundamental types of uncertainty are defined…as:
>
> - Epistemic: the uncertainty attributable to incomplete knowledge about a phenomenon that affects our ability to model it.
> - Aleatory: the uncertainty inherent in a nondeterministic (stochastic, random) phenomenon.

These two widely recognized forms of uncertainty stem from the possibility of straightforward inapplicability of a theory to a case within its domain (so-called "epistemic uncertainty,"[a] and the built-in uncertainty of theories that posit stochastic rather than deterministic processes in order to represent approximations because some information is unknowable or infeasible (so-called "aleatory uncertainty").[b] Both forms of uncertainty have been thoroughly analyzed.

While important, this distinction is insufficient, in two respects. First, the boundaries between epistemic and aleatory uncertainties shift over time and according to the models employed.[18] A model establishes what variation is accounted for and what is not. Except for sub-atomic and atomic-level uncertainty, as captured by the Heisenberg uncertainty principle and Brownian motion, apparent randomness really consists of what is left unexamined. For example, misunderstanding the behavior of earthquake faults would constitute epistemic uncertainty for a model that includes the analysis of these faults, but the uncertainty arising from the unexamined behavior of specific faults would be considered as aleatory.

Second, different reactions will be elicited by subtypes within each of these categories. Credibility depends on whether the nature of uncertainty reflects on the expertise of the scientists. Therefore we suggest a more elaborate taxonomy. It recognizes that the nature as well as the magnitude of uncertainty can only be defined with respect to a particular model or understanding of science.

Within the Category of Epistemic Uncertainty:

- *Laws of Nature Uncertainty: reflecting ignorance about the principles of system behavior*
- *Subtle-Effects Uncertainty: reflecting the inability to demonstrate small effects even if they are implied by principles of system behavior* (e.g., very small effects of pollutants at historically low concentrations, but potentially of great significance at higher dosages
- *State of Nature Uncertainty: reflecting ignorance about past or current conditions*
- *Parametric Uncertainty: reflecting ignorance about the parameters or weights to be assigned to the effects of particular principle* [c,19(p.3),20]

  It is possible that the dynamics of a theory are fully correct for a given

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[a] For example, a theory may predict that the higher temperature of a given body of water would be detrimental to a particular fish population, based on assumptions about physiological processes, prior cases, or both. Yet the physiology of that particular species may not function as hypothesized, reduced fertility may be offset by higher survival rates, and so on. In short, the theory may simply be incorrect for that particular case. Within positivist, "general-law" epistemology, such cases may disqualify or "disprove" the theory, but a more pragmatist approach may be more tolerant because of the possibility that the theory is useful in other cases.

[b] Seismic, weather and climate models are of this nature.

[c] Kaplan[20 (p.218)] labels a closely related concept "statistical uncertainty" ("…we do not know what law is operative. We are ignorant, not necessarily of all the circumstances, but of enough of the significant ones so that we cannot assign a determinate probability to possible outcomes.") However, this term is overly broad.

case, but it can fail in its predictions because the effects it would predict are swamped by the effects of other dynamics.[d]

- *Incalculability Uncertainty: reflecting the impossibility of calculating outcomes because of the multiplicity of interactions* – Even the most powerful computers cannot determine the outcomes of particularly complex models within feasible time scales, even if the system is completely understood and the initial conditions are known. Long-range weather forecasts encounter this constraint.

Within the Category of Aleatory Uncertainty:

- *Intrinsic Nano-level Uncertainty: due to truly unknowable and unpredictable factors*, such as atomic or sub-atomic phenomena, knife-edge unstable equilibria, and so on.
- *Non-modeled Uncertainty: due to factors excluded from the model, whether at a more micro-level* (e.g., the earthquake models that do not resolve to the level of specific faults) *or at the macro-level* (e.g., solar flare impacts on weather patterns)
- *Application-Case Uncertainty: due to the fact that the actual cases do not precisely fit the specification presumed by the model* (e.g., the theory is based on the physiology of healthy salmon, but the actual population is heavily stressed by pollution or abnormal water temperatures).

D. Taxonomy of Policy Options

A classification of policy options, differentiated in terms of the premises of uncertainty and their implications for adaptive management, can help to understand both the decision issues and the politics of resource policy. Imagine a policy space of *n* options, which can be partitioned into different sets and subsets, as presented schematically in Figure 1.

One set consists of the "science confident" policies believed to be optimal on the basis of existing science. The "science confident" attribution is premised on low uncertainty. In other words, the projected impacts of scientific models are believed to further one or more conceptions of the public interest, *because* scientific knowledge can accurately predict positive outcomes of these policies.

Within this set of "science confident" options is an important subset relevant to adaptive management: highly ambitious, non-incremental options that have not been tested through experience, but are projected by scientific theory to have very positive impacts. The theory has to predict the behavior of the system beyond the parameters

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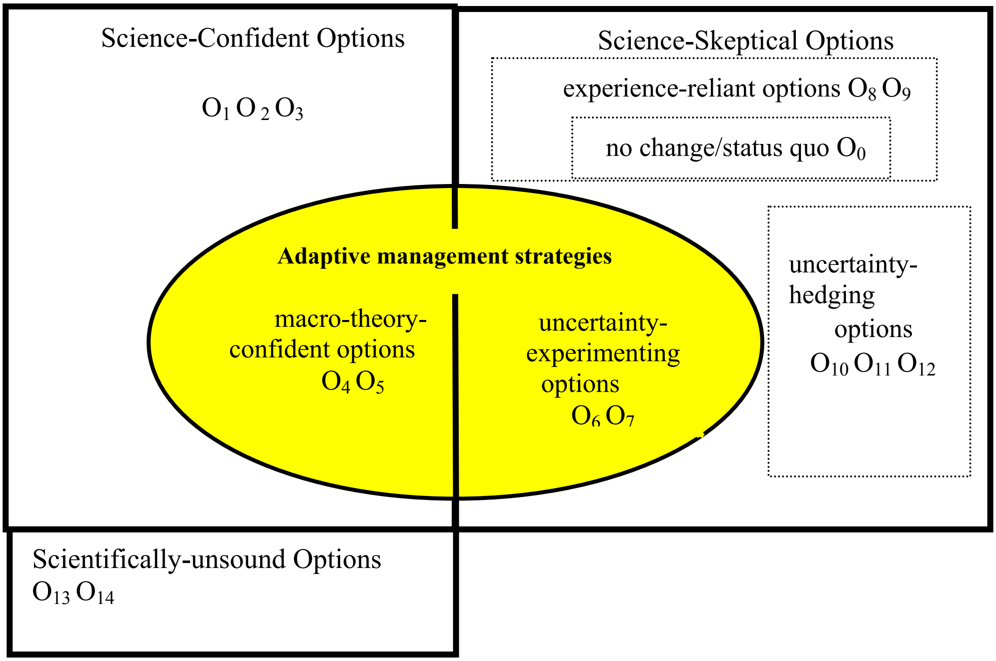
[d] For example, theories pertaining to the possibility of global climate change include the theory that the changing layers of high- and low-salinity waters in the North Atlantic will lead to different patterns of currents and subsequent changes in temperature and precipitation. They also include a theory that particles will increase atmospheric albedo and thereby deflect solar radiation away from the Earth. These theories do not conflict, but the impact of one may swamp or at least alter the effects predicted by the other.

that have pertained thus far; therefore one must be confident in the "macro" capacity of theoretical understandings. Accordingly, we label these "macro-theory-confident" options. Adaptive management advocates may argue for "experimenting" with ambitious options constituting major deviations from the *status quo* because of confidence in the science behind such options even though, absent experience, the risk of unexpected negative consequences may be high. Or they may argue for theory-confident options because they regard the existing and related policies to be severely suboptimal, and if the bold experiment fails, it can be reversed. Thus the key premises behind advocating these "macro-theory-confident" options are the soundness of theoretical understandings, the suboptimality of current policies, and the reversibility of possible failures.

Another set of policies consists of "science-skeptical" options. One subset of these options consists of policies that rely on experience rather than scientific knowledge developed from theory—this would include the *status quo* option and incremental changes from the *status quo*. This is in accord with the "muddling through" incrementalism of Charles Lindblom[21] that becomes a prescription as well as a description of policymaking if one accepts that our limited knowledge of system behavior makes non-incremental changes too risky to entertain. "Experience-reliant" options may reflect high satisfaction with current performance, but very often they reflect the fear that scientific understandings are insufficient to predict the outcomes of bold changes. The most extreme option in this regard is, of course, the *status-quo*, no-change option, O_0.

Figure 1



Another subset of options reflecting skepticism toward the state of science may be regarded as optimal in and of themselves in light of science's uncertainties. This subset of "uncertainty-hedging" options is comprised of policies believed to be optimal in light of the possibility that the science-confident options may be wrong, and therefore hedging strategies are needed to avoid highly costly outcomes that may occur even if science does not predict them. Policy should not simply rely on the predictions generated by scientific understandings, but rather hedge against the possibilities that what seems to be the optimal policy really is not, just as a wise stock investor will not buy only one stock even if that stock is believed to be the most promising. For example, scientific analysis may conclude that draining wetlands for development or for mosquito control would not trigger species population declines and broader food-chain disruptions. But if the costs of this occurrence are very high, policymakers skeptical of the scientific analysis may choose the option of draining only a limited portion of wetlands, or attempting other means to provide land or to control mosquitoes.

Another subset of science-skeptical options is designed principally to be useful for learning—again relevant for adaptive management. These "uncertainty-experimenting" options may not be expected to produce optimal results in themselves, but rather to prepare policymakers to select policies that are more likely to be optimal and are more science-confident. The logic of these options, also at the heart of the strong versions of adaptive management,[22,23] shares with "theory-confident" options the premise that existing resource and environmental management is not worth preserving, but goes further in assuming that existing science is so weak that learning more through real-system experimentation is worthwhile even if it means that the experiments will not themselves yield optimal results. Obviously, if policymakers were confident in the science relevant to the policies, this form of experimentation would be unnecessary. Thus we see that adaptive management options straddle the divide between science-confident and science-skeptical premises.

Finally, there are options that no accepted scientific theories at a point in time would predict to yield improvements by any conception of the public interest; nor would they contribute adequately to learning more science in order to identify better options. In labeling these as "science-contrary options," we are of course aware that scientists never agree fully on what is scientifically sound, and that what may be rejected by science at one point in time may come into favor at another. However, just as we can rather easily conceive of outcomes that are beyond the range of the public interest under different conceptions of the public interest, we can conceive of options that scientists with any claim to standing within the scientific community would judge as counter-productive when policy decisions need to be made. For example, it is highly doubtful that any scientist today would endorse the introduction of the exotic Nile perch into Lake Victoria, which was done in the 1950s and 1960s, knowing what is now known about the collapse of native fish species and the apparent decline of the Nile perch population as well, due to eutrophication triggered by the impact of the Nile perch on the food chain.[24]

Roles of Science. These distinctions can help to understand the five major policy roles of science.

The first function of science is to identify issues requiring public policy attention, by focusing attention through analysis of trends and projections. The status quo or do-nothing option, O_0, may be advisable if the actual trends indicate that a significant problem will not materialize. However, uncertainty as to future trends greatly complicates this identification. Whether a fish population will or will not recover; whether global warming will continue in the face of uncertainties about natural temperature fluctuations – these are, to a greater or lesser degree, matters of uncertainty.

The second function is the most obvious: to help identify the policy options that can address problems constructively. This is partly a matter of discarding the clearly scientifically-unsound policy options. The political role lies in the fact that by proclaiming these policies as unsound, scientists can impose a political cost on any policy advocate or government official who tries to pass off a policy that does not serve the public interest. Sound, credible science discredits self-serving politics. In some circumstances, this is accomplished through the easy route of simply dispelling scientific myths that are revealed as unsound through obvious findings or logic. For example, the myth that complete fire suppression can succeed in maintaining healthy forests with low vulnerability to accidental or naturally occurring fires, despite accumulated biomass, has been dispelled through both empirical outcomes and the rather obvious logic of the vulnerability of overly-dense forest stands. The myth that India's *sal* trees could be harvested without concern over regeneration can easily be discarded through simple empirical demonstration. But of course it is more difficult to discredit self-serving politics with a scientific theory that *projects* outcomes; this depends on the acceptance of a scientific theory. Science in the adaptive management vein serves to identify constructive policy options in a different way. In choosing the experiments intended to learn about ecosystem behavior and the impacts of alternative policies, decision-makers applying adaptive management must apply science to design the experiments. Often a simulation, based on current science, will be used to project the outcomes of a range of policy options.

The choice between science-confident options and hedging options is far more complicated, and justifies the third, less intuitively obvious function of science: to convey scientific uncertainty. As Funtowicz and Ravetz argue,[25 (p.178)]

> Whereas science was previously understood as steadily advancing the certainty of our knowledge and control of the natural world, it is now seen as coping with many uncertainties in urgent technological and environmental decisions…A new role for scientists will involve the management of the crucial uncertainties: therein lies the task of assuring the quality of the scientific information provided for policy decisions.

Similarly, van Asselt[26] argues that because complexity implies irreducible uncertainty, "integrated assessment models" are needed to explore where the uncertainty lies, how the intricate interactions among different subsystems can add to uncertainty, and how probabilistic models can express such uncertainty.

This is certainly a valid and useful distinction, but it may give rise to the impression that risk analysis, if it attempts to take both types of uncertainty into account, can free itself of the bounds of epistemic uncertainty in gauging the levels of either epistemic or aleatory uncertainty. Assessments of either still can only be conducted from the vantage point of the scientific understandings of those conducting the assessments. Yet predictions, even if they express the forecasters' self-ascribed level of uncertainty, typically do not convey the uncertainty as to whether the forecaster is using an appropriate model. The forecaster's self-ascribed uncertainty may be a combination of so-called aleatory uncertainty, reflecting the stochastic nature of a correct model, and epistemic uncertainty reflecting the forecaster's awareness of his or her own fallibility in selecting and using a model. It is difficult for experts to gauge their own error-proneness; if they have recognized the sources of past errors, they typically would have tried to correct them, and assume that the corrections are in the right direction. The "track record" of past errors is of limited utility to the forecaster for this reason, and it is of limited utility to forecast users because of systemic changes over time. Forecast users nonetheless ascribe degrees of confidence to predictions of abrupt climate change, often on the basis of an unpredictable mixture of both sensible and rather superficial factors such as form of presentation, apparent disagreement among experts, the success of immediately preceding forecasts, etc.

In light of the distinctions of our policy taxonomy, the issue is that the advisability of adopting a science-confident policy depends on the degree of certainty of the most likely trend or outcome. The science-confident options are not hedged for the possibility that the science is wrong. Hedging options may address this uncertainty, but, like choosing a mixed stock portfolio rather than the one stock with the highest expected return, the hedging comes at a price. *If* the science is correct, hedging options will be suboptimal. Therefore the decision to choose hedging options must rely on reliable assessments of uncertainty. Similarly, the viability of "theory-confident" options depends on assessing the certainty of scientific theory.

At this point it is important to note the importance of parametric uncertainty. The relevance of this source of uncertainty is that scientists working on different phenomena relevant to the same problems or issues (e.g., ocean currents, atmospheric reflectance, and vegetation growth are all relevant to climate change) may project different outcomes without any disagreement on dynamics or challenges to the validity of the theories[e, 27,28,29,30] The problem is that few research scientists have the capacity or incentive to examine whether other dynamics will dominate over, or even interact with, the dynamics specified by their own theories. Thus the validity of the theories within their domains is distinct from their predictive capacity in a complex, non-controlled

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[e] The July 20, 2001 issue of *Science* presents a remarkable range of partial theories to account for global climate change. See especially Allen, Raper and Mitchell;[27] Reilly et al.;[28] and Wigley and Raper,[29] for accounts of how uncertainty in climate change predictions comes about. See also Mahlman.[30]

system. It is, of course, well known that one can be right for the wrong reasons, and Milton Friedman[31] has argued that the intrinsic correctness of a theory is irrelevant, and perhaps even meaningless, if the predictions are sound. However, the inverse can also be true: a "correct" theory, if this designation is based on the validity of the dynamics specified by the theory, can produce incorrect predictions. Equally important for the credibility of science, apparent disagreements among scientists can arise even when there is no scientific disagreement regarding the validity of the various partial theories.

The fourth function of science in the service of policy is to assist in the choice of policy options, whether hedged or not, whether viewed as experiments or not. Given the assessment of uncertainty, scientific input is required to project the likely outcomes of the options within each set or subset. Scientific input for projecting outcomes may conclude that the status quo is the optimal choice, given the projected costs and risks of other options, but this is very different from the decision rule of selecting O_0 until the uncertainty is resolved. For many policy issues for which scientific issues are at stake, there will always be remaining uncertainty. Therefore delaying decisions because certainty exists is often a poor decision.

Finally, science serves policy by accounting for the reasons for policy success or failure. The fact that positive or negative outcomes follow the adoption of a policy does not necessarily mean that any particular aspect of the policy, or for that matter, the policy as a whole, is responsible. Evaluation requires theories of linkage, which are themselves scientific theories. One of the least examined challenges to adaptive management is the difficulty of knowing what ought to be learned from experimentation. For example, the recovery of a fish population *may* be the result of dismantling dams on the river, but may instead be due to greater rainfall or other natural factors. Policy evaluation, in attributing causality, requires scientific theory just as projecting outcomes does. Yet again the uncertainty of the theory must be assessed continually to determine the validity of the evaluation.

E. The Vulnerability of Expressing Uncertainty

The need to account for and convey uncertainty thus presents a multiplicity of dilemmas for scientists. Conveying uncertainty is the key to knowing when and how to hedge or experiment, yet expressing uncertainty risks discrediting science and providing a pretext for inaction. Expressing uncertainty may trigger the use of analytics based not on the specific case, but rather on "heuristics" based on other cases that may or may not be useful for understanding the case at hand.[32]

Dismissing science is often accomplished by pointing out that scientists disagree, and therefore do not know what they are doing. Of course scientists disagree – if all scientific questions were resolved, there would be no need for scientific investigation or for scientists, other than those who write science textbooks. The question is whether scientists agree on enough to provide reasonable confidence in scientific understandings. Paradoxically, science has to be able to state, with reasonable confidence, what is known and how much is unknown.

F. Science, Uncertainty, and Credibility

These dilemmas highlight the challenge of maintaining credibility and expressing uncertainty at the same time. For science to be effective against self-serving politics, it must be credible. At the same time, science must be open about its own limitations. Even leaving politics aside, science faces major challenges in communicating both uncertainty and credibility to the public.

Scientists face several challenges to their credibility, even if they are doing their science with the greatest possible professionalism. First, public views of science, if they are informed at all,[f] often correspond to the Baconian-Popperian[g, 33] positivist view of the scientific method—the view so often taught in high school and college courses: theories are formulated, hypotheses generated, critical tests undertaken, and theories thereby rejected are supported (but never definitively proved). This model implies linear progress and continual progress toward truth and exactitude. In the United Kingdom, a prominent Royal Society study of public attitudes toward science revealed a "view of science as a simple logical process producing unequivocal answers, and of scientists as correspondingly always logical, unemotional and somehow impersonal individuals removed from the messiness of 'real life'."[34 (p. 98)] There is very little tolerance for prolonged scientific debate on anything but the most esoteric topics such as particle physics or cosmology; on practical issues, scientists are supposed to apply their tools and come up with correct answers. While scientists are often inspired when old ideas are overturned, the public may perceive this as a troubling sign that even the accepted may be wrong. Expressions of ignorance by scientists are often seen (sometimes correctly) as self-serving; but more importantly, expressions of uncertainty are often seen as expressions of failure. In the United States, the 2002 National Science Foundation *Report on Public Understanding of Science* found while that scientific accomplishments—essentially technological advances—are widely appreciated and admired, the use of the scientific method is poorly understood and attitudes toward the role of science in policymaking are much more ambivalent.[35]

Second, when policy advocates discover that they can thrive on scientific ambiguity, they can highlight and exaggerate the significance of scientific disagreement, downplaying the degree of scientific agreement. The false but widespread syllogism that scientific disagreement means that science is weak plays into the hands of interests that benefit from discrediting mainstream scientific opinion.

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[f] Surveys by the National Science Foundation in the United States and the House of Lords Select Committee on Science and Technology in the United Kingdom reveal that the bulk of the adult populations in both nations have quite rudimentary ideas about science and processes of scientific inquiry. The U.S. National Science Foundation 2001 Report survey shows that half the U.S. adult population does not know that the earliest humans did not live at the time of dinosaurs, that the Earth revolves around the Sun once a year, that electrons are smaller than atoms, that antibiotics do not kill viruses, and that lasers do not work by focusing sound waves (NSF, 2001: Appendix Table 7-10).

[g] See Karl Popper's classic 1963 articulation of what he labelled *the* "scientific method.[33]

Third, policymakers and the public often have deterministic understandings of the physical/natural world that lead to exaggerated expectations of the possibilities for eliminating uncertainty. The stochastic nature of El Niño and its consequences on the fish stocks off the Pacific coast of South America, the effects of weather on the competition among species, the impossibility of making precise estimates of subsoil resources such as oil and hard minerals are frequently lost on those who have not had occasion to study these problems in depth and understand the *intrinsic* limitations of knowledge. Scientists are in a poor position to gauge and convey the uncertainty of their own work. Whatever accumulated knowledge of the sources of possible error, especially bias, that scientists may have of the weaknesses of their own models, should be incorporated into these models.

Fourth, the policy experimentation called for by adaptive management, though often motivated by the need to resolve uncertainty, may be perceived as gambling with the stakeholders affected by policy impacts. Learning is a value for scientists, and of value for policy, but appreciating this point when facing the risks of the unknown is much to ask of the public and the policymakers responsible for protecting the public.

All four of these sources of skepticism toward current science and scientists carry the ironic implication that complicates the situation even further: although expressions of uncertainty may reduce the credibility of today's science, the premises underlying the skepticism also imply exaggerated faith in the *long-term* capacity of science to resolve uncertainty. Therefore the argument of the opponents of proactive approaches to conserve natural resources or to preempt environmental degradation may be "Today's scientists don't know what they are doing, but if we wait long enough, science will give us clear signals." Those who wish logging to continue will often invoke the uncertainty to delay any action. Those who do not want to address the causes of global warning will frequently try to capitalize on the allure of waiting until the question of whether warming trends will continue is resolved. Relying on science to reduce all uncertainty is obviously a poor way to approach the challenge of formulating hedging strategies.

G. Government Motives and Maneuvers for Distorting Science

Despite the common association of "special interests" with interests outside of government, government agencies and the science community itself also have their own *institutional interests*, which can contribute to the problem. The policymakers within government agencies often strive to expand the jurisdiction of the agency, with the motives of enhancing its authority, budget, opportunity to fulfill the agency's mandate, and often, the opportunities for personal benefit. They also strive to increase the internal manageability of their agencies; this is a major reason why agency leaders push for the simplification of resource management and environmental-protection doctrines. And, of course, agency personnel, whether in leadership or rank-and-file positions, are motivated to avoid blame.

To pursue these objectives, government agencies will often:

1. *Interpret the implications of scientific information in ways that ignore the complexity of the situations, to support simplified procedures and decision criteria that reduce the agency's uncertainty of control.* For example, for decades the U.S. Forest Service reduced the enormously complex issue of fire management, biomass accumulation, and the risks of deliberate burning to the "simple" conclusion that fire is too risky to tolerate, and therefore fire suppression ought to be the unquestioned doctrine.[6,7]

2. *Restrict or bias information gathering, to minimize information and analysis that challenges the agency's performance or jurisdiction.* Pyne[6 (Ch.5),7] notes that the U.S. Forest Service suppressed research on the problems of biomass accumulation. Gillis[36 (pp.71-72)] notes that "the Indonesian forests are much less accessible to researchers than anywhere in Africa except the Congo – which is one reason it took eight months to get even a preliminary assessment of damage from the forest fires of 1983."

3. *Dismiss scientific input as biased, by interpreting the scientists as advocates, or as interest-servers, rather than as impartial or objective.* This tactic takes advantage of the confusion between having a position and having a bias, whether because of ideology or who pays for the research. Scientists have an obligation to act as citizens as well as scientists. If research reveals that certain policies are compelling, scientists should not be faulted for pressing for those options. Yet it is quite common for the input of ecologists to be rejected as the "environmentalists' position."

4. *Endorse resource-use classification schemes that reinforce the agency's jurisdictional claims, at the expense of choosing the most scientifically appropriate classifications.* The Costa Rican case cited at the beginning of this paper is not unique. Referring to Indonesia, Hurst[37(pp.11-12)] observed, "[d]espite classifying forested areas the system is applied only by the Forestry Department. Other government departments frequently override these classifications for their own ends. This frequently results in dual purpose sites and also creates great confusion over natural resources data."

5. *Inappropriately generalize the "lessons" of experience, reaching self-serving conclusions regarding responsibility for past successes or failures, and implications for jurisdiction.* The U.S. Forest Service's interpretation of previous efforts at controlled burning should have been nuanced, pointing out that the failures of controlled burning efforts that got out of hand were balanced by the successful efforts. Instead, until the 1990s the Forest Service's interpretations took the extreme view of regarding burning as a failure, thus supporting the fire-suppression doctrine – until a plethora of fires triggered by biomass accumulation, and the deterioration of forest health, highlighted the failure of the fire-suppression strategy.[38]

6. *Attributing scientific causation that minimizes the agencies' responsibility for failures, at the expense of distorting the true causal relationships.* The example of

attributing deforestation to so-called “slash and burn” agriculture is a way for the governments in Indonesia and Malaysia to avoid blame for permitting what might very well have been excessive commercial logging.

7. *Over-simplifying models that make the agency’s policies seem less prone to uncertainty.* Again, the fire suppression policy is a case in point, but so too are the examples of reforestation policies, in such countries as Costa Rica, that have treated different tree species and different geographic areas uniformly, as if they had uniform regeneration and growth rate characteristics.[9 (pp.151-52)]

8. *Misinterpreting scientific uncertainty as justifying the agency’s inaction, when uncertainty actually calls for wise hedging strategies.* This often entails exploiting scientific disagreement on secondary issues to convey that scientific accord is lacking, so that the agency can justify inaction or excuse policy failures. Deliberate ignorance about the sources of deforestation and the degree of fire damage in Indonesia provided a ready excuse for inaction. Uncertainty concerning the impact of greenhouse emissions has often been invoked as a rationale for taking no action on global warming policies.[3,4,5]

The frequent result of these practices is to cast science as either simplistic or unreliable, and to generate natural-resource policies that are also simplistic and self-serving with respect to the status quo jurisdictions and approaches. Scientists can counter these practices in several ways. Here we list just six strategies.

First, scientists can probably make quite significant inroads on the problems of credibility by being more explicit about the types of uncertainty that prevail in any particular situation. As previously mentioned, the credibility costs of admitting to ignorance about the state of nature are likely to be much less than the costs of admitting to ignorance about the laws of nature. Similarly, the most relevant uncertainty about global climate change is parameter uncertainty, rather than true disagreement among scientists about the various dynamics that affect long-term climate.

Second, and related to the first point, the allocation of resources for resolving uncertainty should be based on considerations of increasing credibility as well as on the obvious objective of reducing uncertainty *per se.* Most efforts at integrated assessment modeling advocate allocating resources where the greatest resolution of uncertainty will occur;[h] our suggestion is that the increase in credibility should also be taken into account.

Third, by articulating *provisional* agreement, scientists can counter the tendency to equate uncertainty with the need to delay action. Institutionally, this is done best by the National Resource Council (NRC) of the U.S. National Academy of Sciences. Provisional agreement is the essence of the NRC panels that summarize the state-of-the-art knowledge on policy-relevant issues. When the NRC panels estimate the likelihood of resource shortages, or evaluate particular resource-management

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[h] See, for example, van Asselt.[26]

techniques, scientists have the opportunity to express what they agree on and what they do not. Uncertainty can be expressed without implying ignorance or disunity.

Fourth, insofar as the manipulation of science is occasioned by inter-bureaucratic conflict, the collaboration among scientists and officials from *multiple* government agencies can yield resource policies based on sound science rather than ploys to expand a particular agency's jurisdiction or resources. In Costa Rica, a new inter-agency commission was formed in 1990 to formulate a unified classification system. Because the most relevant government agencies (including the forestry agency, the land reform agency, and the planning agency for agriculture and renewable resources) worked together, along with the two major Costa Rican universities and the prestigious Centro Científico Tropical, the result was sounder from a scientific perspective and more broadly accepted by government agencies. Similarly, following the bankruptcy of the Indonesian state oil company Pertamina, an inter-ministerial commission assumed oversight of the company, greatly increasing the company's transparency and reducing its tendencies to suppress or distort information.[9 (p.66)]

Fifth, scientists can avoid, or at least minimize, the risk of having their work dismissed as biased if they participate in research that is co-funded and co-organized by groups on different sides of any given issue. In the United Kingdom, the House of Lords' Select Committee on Science and Technology survey of attitudes toward science revealed that the public has much greater confidence in scientific sources perceived as independent of industry and government, regarding such issues as biotechnology.[39 (ch.2)] George Busenberg, examining how the risks of oil terminal vapor emissions and oil spills can be subjected to scientific analysis, has shown how "collaborative research" sponsored by both sides of environmental or conservation disputes can enjoy higher credibility and facilitate agreement.[40] When groups are truly interested in having reliable science, these arrangements can go far in ensuring both the reality and the image of impartiality.

Sixth, scientists should include projections of the O_0 option in their projections. If demonstrating that inaction may have higher likely costs than waiting for more research, publicizing such results would increase the pressure on policymakers to take action when appropriate. The process of critically examining each new policy initiative that may bias the decision process may culminate in rejecting alternatives to the status quo because of their weaknesses or risks, but without fully appreciating the weakness and risks of the existing policies.

H. Scientists as an Interest Group[i, 41]

One might expect that scientists and the administrators of science institutions would fight tooth and nail against the distortions and suppression of scientific information, and they often do. However, the scientific community, like any other set of people, also has interests. Respect, professional reputation, funding, and discretion to pursue preferred research projects can all be strong motivations. While some of the problems

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[i] These points are elaborated in Brunner and Ascher.[41]

of science in conveying useful information may be due to lack of knowledge of how to maximize its effectiveness, we must also ask whether self-serving motives may also be involved. Consider the following possibilities.

First, scientists frequently emphasize the need for more research, which, of course, would imply more science funding. However, the call for more research also defines the key issue as eliminating uncertainty, rather than accommodating existing uncertainty.[3,4,5] Therefore such calls also reinforce delaying decision rather than coping with uncertainty through hedging strategies. Even adaptive-management experimentation, if it leads to multi-year experiments, may lead to delays in coming to grips with the need to select hedging strategies. Moreover, the attractiveness of using the ecosystem as a laboratory to strengthen scientific understanding may prompt scientists to experiment more than is justified. Of course, some cases may warrant the need to experiment with policies designed to enhance learning rather than to find the immediately optimal. Yet scientists may tend to put a higher priority on the opportunity to experiment than is truly justified, insofar as experimentation exposes stakeholders to the potentially negative outcomes.

Second, scientists often resist the demands to justify their research by relating it to societal needs. A common reaction is to invoke those occasions when serendipity yielded major societal benefits, with the implicit argument that science does not need to be held accountable *a priori* for its likely or unlikely contributions. Yet the serendipity argument is specious, because the question is not whether societal benefits ever emerge accidentally, but rather whether science that is oblivious to societal issues would produce equally beneficial results as science that is anchored in a logic of how scientific knowledge can be of societal utility. The desire for autonomy, the convenience of not having to make the effort of thinking through possible societal benefits, and the luxury of following one's curiosity will inevitably come at some cost to society.

Third, scientists often resist the calls to acknowledge that considerable agreement does exist on a broad enough set of issues to constitute a provisional consensus to guide public policy. Again, this does not have to mean that all or even most scientists agree on the science; indications of uncertainty can be as important for knowing whether hedging options are required. Debate on the issues of remaining disagreement is enough to warrant continued research; scientists should take pride that advances have led to considerable if not complete accord on a host of issues. For example, on the issue of global warming, many scientists have implied that scientific knowledge is almost hopelessly muddled. The reality is that the basic outlines of the issue—anthropogenic sources of warming, natural-systems' reactions to greenhouse gases, and the stochastic variations of external factors such as solar radiation—can be assessed for the convergence of understandings and the levels of remaining unpredictability. Policies can and must be based on such assessments.

Fourth, on other occasions, when the incentives for appearing definitive are strong, scientists may allow their findings to appear to be more definitive than is warranted. This specious certainty also undermines the adoption of hedging strategies. The temptation to exaggerate certainty is reinforced by the institutional interests of scientific agencies and the scientists within them. This was the problem with the research on forest biomass and fire suppression strategies mentioned above.

In short, scientists may also fall prey to their own narrow interests, and not deal with uncertainty in the most appropriate ways. In these circumstances, scientists must look to their own social responsibilities. The frequently limited role of science is sometimes due to the limited vision of scientists.

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