

Insight

Resilience: Accounting for the Noncomputable

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ABSTRACT. Plans to solve complex environmental problems should always consider the role of surprise. Nevertheless, there is a tendency to emphasize known computable aspects of a problem while neglecting aspects that are unknown and failing to ask questions about them. The tendency to ignore the noncomputable can be countered by considering a wide range of perspectives, encouraging transparency with regard to conflicting viewpoints, stimulating a diversity of models, and managing for the emergence of new syntheses that reorganize fragmentary knowledge.

Key Words: *resilience; adaptation; transformation; surprise*

INTRODUCTION

Although science has made enormous progress by framing problems in tractable ways, the same focus that produces excellence in science may prove shortsighted in solving complex environmental problems. Depletion of stratospheric ozone above the South Pole began in the 1970s but remained undetected for years because the computer programs that analyzed satellite data were instructed to reject measurements that deviated from expectations. The anomaly was seen to be real only when ground-based observations of rising UV-B radiation triggered a reanalysis. By the time the cod fishery of Newfoundland was finally closed in 1992, fishermen and some scientists had been aware of the impending collapse for years. The public and decision makers did not perceive the full picture for many reasons, including incentives for fishers to under-report bycatch and institutional practices that selectively filtered the evidence. Even open, transparent interdisciplinary assessment processes such as those of the Intergovernmental Panel on Climate Change have difficulties presenting the full range of possible climate trajectories because models are not available for all of the mechanisms (Oppenheimer et al. 2007).

In all of these cases, unknown threats are masked by assumptions that frame the questions that are

asked. The full complexity of the situation is not perceived because of two filters that constrain points of view:

- First, there is a tendency to focus on the computable, despite our awareness of other noncomputable aspects of complex problems.
- Second, there is a tendency to believe in dominant models even though they are incomplete, and this belief may be strong enough to filter out signals that are inconsistent with the dominant model.

Thus, shortsightedness prevents us from seeing problems on the horizon. The obvious solution is to take varied signals from diverse thinkers seriously, even if they strike us as strange and irrelevant. This seems at odds with the need to have the best specialists lead the way in crucial issues. Nevertheless, the consideration of a wide range of perspectives is a hallmark of resilient decision making in the face of unexpected change.

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WHAT WE DON'T KNOW

The social upheavals, natural disasters, and technological breakthroughs that have shaped the past and present could not be anticipated in their time. That is one reason why they stand out. There are several reasons why surprise (Gunderson 2003) will always happen:

- First, statistical extrapolation of the past may create a bias. At best, forecasts of massive events will be extrapolations from a few analogous experiences or based on a mechanistic model of processes that are thought to lead to the event. Such predictions are highly uncertain. At worst, an event will be completely unknown from past experience and will come as a bolt out of the blue.
- Second, in the absence of reliable models for mechanisms that can generate extreme events, such as the Greenland icecap sliding into the ocean, mechanisms of this type are simply left out (Oppenheimer et al. 2007).
- A third cause is that we routinely fail to ask the questions that would prepare us even for the anticipation of big, important change. We simply don't know what we don't know.

The unpredictability of extreme events may often be overlooked, because any given event is easily interpreted in hindsight. However, each extreme event is complex, affecting physical, ecological, economic, cultural, and social systems simultaneously. Although experts in some areas might predict some of these impacts, the sheer scale of a massive environmental change is the result of multiple interacting factors that no one anticipates. Who would have predicted that a global loss of liquidity would coincide with a fast rise in oil prices, which in turn raised food prices, as well as a boom in the demand for grain biofuel that put rich-world energy in direct competition with poor-world food? Each individual shock might have been on the radar screens of some of the people in an individual sector, but no one would have predicted the coincident crises in finance, energy, and food and the confluence of shocks. Because they are not easily computable, many important aspects do not find their way into the models that dominate policy decisions. Instead, the dominant models are a patchwork of rigorous but fragmented information (Fig. 1A).

THE PROBLEM OF DOMINANT MODELS

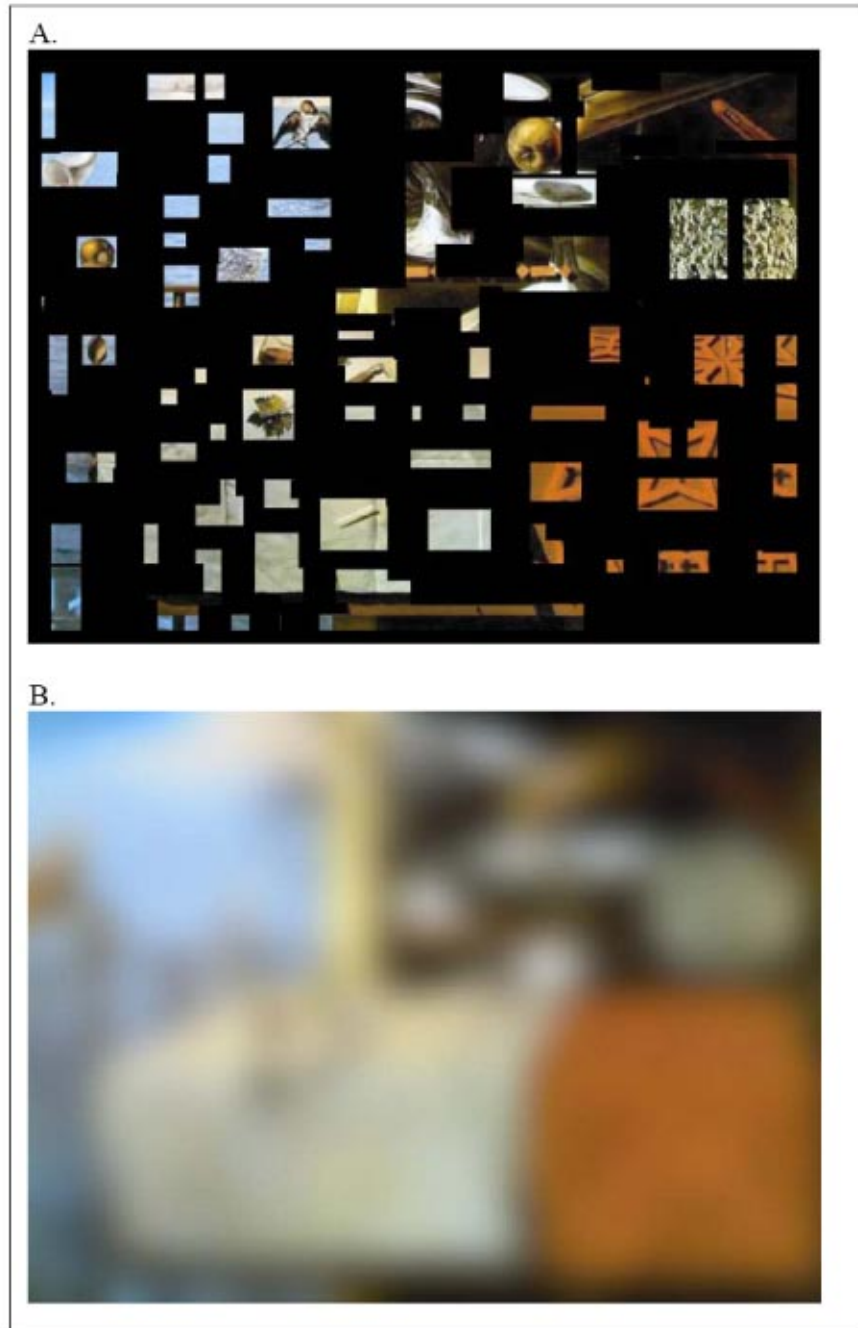
Narrow world views and incomplete models may exclude crucial information even if it is available. Hurricane Katrina, which hit New Orleans in 2005, caused approximately U.S. \$125 billion in damages. Odds makers had put the probability of an event of this magnitude at 1–2.5%, and insurance companies had estimated the potential damage at U.S. \$10–26 billion. The dominance of this view meant that no one was prepared. There were those who predicted the disaster more accurately, but their views were disregarded. Dominant models are often linked to hierarchy. The annals of medicine are replete with accidents that occur because the protocol of medicine privileges the decisions of doctors, often linked to the dominant paradigm of treatment, over the contradictory views of nurses, therapists, patients, and their families (Gawande 2002). The stronger the dominant view, and the more completely it dominates, the greater the myopia of what could otherwise be a broad problem-solving team.

In contrast, there are examples of scientific assessments of complex environmental situations that engaged diverse viewpoints and resulted in breakthroughs. In Madagascar, information provided by illiterate village hunters and loggers proved crucial for solving the scientific puzzle of the precipitous decline of the giant jumping rat and prompted new approaches to managing the species (CBSG 2002). Similarly, the inclusion of the viewpoints and knowledge of indigenous fishermen in the assessment of the endangered bumphead parrotfish provided breakthroughs that allowed for successful management (Aswani and Hamilton 2004). Although efforts like the Millennium Ecosystem Assessment (2005) brought in diverse knowledge systems and community-based experiences of ecosystem management along with scientific assessment, such examples are still the exception to the rule.

BALANCING DIVERSITY AND EXCELLENCE

Although the benefits of a diversity of viewpoints seem obvious, there are good explanations for why diversity is so often lacking. The payoffs from efficiency, rationality, and standardization have resulted in an emphasis on “best practice” and a tendency toward monoculture or the dominance of the few (Frank and Cook 1995). Dominance of the

Fig. 1. (A) Excellent disciplinary work can lead to precise pictures of parts of the whole. (B) A generalist perspective can encompass the whole, but precision may be low and uncertainty may increase temporarily.



few also affects the nature of progress in science and the use of science in decision making. The multiple filters required to establish scientific credibility and leadership create a hierarchy in which increasing dominance is exerted by nodes in which influence and citations concentrate (Newman 2004). Such repeated demands for decision making from a few increase efficiency but also reduce the diversity of potential responses.

The inclusion of diverse viewpoints should not lead to the replacement of the fragmented views of specialists by vague generalities (Fig. 1B). Rather, we need to become more effective at filling in the gaps in our incomplete world view while maintaining the high quality of the pieces we know. Ironically, this may require reducing the role of “the best.” Perhaps counterintuitively, complex problems, i.e., problems with many solutions that are quite different in execution and rankable in quality of outcome, may be solved better by a diverse team of competent individuals than by a team composed of the best individual problem solvers (Page 2007). Nonetheless, the tendency in science policy is to turn repeatedly to the best of the best even in situations of high complexity. The problem of dominant models implies that merely involving a wider group of advisers is not enough, because the diversity of viewpoints that might be the best tool for addressing uncertainty may easily be suppressed in the interests of achieving consensus (Oppenheimer et al. 2007).

Despite such difficulties, the tendency toward fragmentation can be countered without losing the value of expertise. To expand the diversity of models, it is helpful to increase the diversity of problem solvers on the team in terms of disciplinary background, methodology, conflict and learning styles, age cohort, gender, and cultural background, and also to use processes that stimulate a wide range of models and allow for transparency with regard to conflicting viewpoints. Scenarios or stories that evolve through structured conversation about change are a process for organizing diverse viewpoints of the future (Millennium Ecosystem Assessment 2005). Other approaches developed specifically to stimulate the diversity of models and the emergence of novel responses to complex problems consider a wide range of world views, expand the set of questions being asked, and thereby expand the set of models and options under consideration (White 2000). Such processes manage for emergence (Westley and Miller 2003).

The ultimate goal of a balanced confrontation of viewpoints is to reorganize our fragmentary knowledge and see a comprehensive sharp picture emerge (Fig. 2). The integrated synthetic picture may appear radical, unrealistic, and surprising from any particular perspective, but embraces the diversity of what we know about the problem and prompts vital questions about what we don't know that we don't know.

RESILIENCE FOR ADAPTATION AND TRANSFORMATION

Massive transitions have shaped the world. Disappearances of ancient urbanized societies were followed by intervals from which few artifacts remain to reveal human culture. The vegetation that we see now may reflect past volcanic eruptions, hurricanes, insect outbreaks, or mega El Niño events. Similarly, scientific thinking today reflects a legacy of incidental big changes in the past associated with groundbreaking insights by Galileo, Newton, Darwin, and others.

Unpredicted transitions will shape the future and may even become more common. Ecosystems and the services they provide to people are changing more than at any time in recorded history, and many drivers are intensifying (Millennium Ecosystem Assessment 2005). These trends may lead to more frequent, intense, and interconnected extreme events. Although environmental extreme events are now sometimes included in risk assessments (World Economic Forum 2007), we usually lack the information necessary to estimate the probabilities of the important ones and their cascading effects. The prospect that accelerating environmental change may increase the frequency, severity, and interconnectedness of such events raises the urgency of building resilience to address future large impacts on ecosystems and people.

If we fail, environmental problem solving will look very much like it does now: scientists working in their labs, managers working in agencies in which logics of action override logics of analysis, policy makers working in a political context in which knowledge is useful only if it is power. If we succeed, we will ask the excluded questions that must be asked to build resilience to unfolding environmental problems and a capacity to transform social-ecological systems as circumstances change.

Fig. 2. The challenge of integrating diverse disciplinary perspectives is to retain the precision of diverse elements of the whole to create an overarching picture. The results may seem strange, unrealistic, and surprising, but they allow for novel approaches and new questions to arise. The painting is *Nature Morte Vivante (Still Life Moving Fast)* by Salvador Dali, 1956, 125x160 cm. The original is in the Salvador Dali Museum, St. Petersburg, Florida, USA.



Nature Morte Vivante (Still Life - Fast Moving)

(1956) Oil on canvas

49 1/4 x 63 inches

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Collection of the Salvador Dalí Museum, Inc., St. Petersburg, FL, 2006.

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In this new approach to science, teams approaching complex scientific problems would from the beginning comprise diverse perspectives, including various experts, practitioners, and citizens, all equipped with the skills needed and an understanding of how to work together as a team. The process is one of uncovering, not masking, the heightened uncertainty created by engaging

multiple perspectives to interpret and act in a complex world. The outcome is the resilience needed to create the future.

Responses to this article can be read online at:
<http://www.ecologyandsociety.org/vol14/iss1/art13/responses/>

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LITERATURE CITED

- Aswani, S., and R. J. Hamilton.** 2004. Integrating indigenous ecological knowledge and sea-tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental Conservation* 31:69-83.
- Conservation Breeding Specialist Group (CBSG).** 2002. *Evaluation et plans de gestion pour la conservation (CAMP) de la faune de Madagascar: lémurien, autres mammifères, reptiles et amphibiens, poissons d'eau douce et évaluation de la viabilité des populations et des habitats de hypogeomys antimena (Vositse)*. CBSG, SSC/IUCN, Apple Valley, Minnesota, USA.
- Frank, R. H., and P. J. Cook.** 1995. *The winner take all society*. Penguin Books, New York, New York, USA.
- Gawande, A.** 2002. *Complications: a surgeon's notes on an imperfect science*. Picador Press, London, UK.
- Gunderson, L. H.** 2003. Adaptive dancing: interactions between social resilience and ecological crises. Pages 33-52 in F. Berkes, J. Colding, and C. Folke, editors. *Navigating social-ecological systems: building resilience for complexity and change*. Cambridge University Press, Cambridge, UK.
- Millennium Ecosystem Assessment.** 2005. *Ecosystems and human well-being: scenarios*. Island Press, Washington, D.C., USA. Available online at: <http://www.MAweb.org>.
- Newman, M. E. J.** 2004. Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences of the United States of America* 101:5200-5205.
- Oppenheimer, M., B. C. O'Neill, M. Webster, and S. Agrawala.** 2007. The limits of consensus. *Science* 317:1505-1506.
- Page, S. E.** 2007. *The difference: how the power of diversity creates better groups, firms, schools, and societies*. Princeton University Press, Princeton, New Jersey, USA.
- Westley, F., and P. Miller, editors.** 2003. *Experiments in consilience: integrating social and scientific responses to save endangered species*. Island Press, Washington, D.C., USA.
- White, L.** 2000. Changing the "whole system" in the public sector. *Journal of Organizational Change Management* 13:162-177.
- World Environmental Forum.** 2007. *Global risks 2007*. Available online at: <http://www.weforum.org/en/initiatives/globalrisk/index.htm>.