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KNOWLEDGE SYSTEMS ANALYSIS

A Report for the Advancing Conservation in a Social Context Project

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Abstract
Knowledge is a crucial element in decision-making for conservation. Yet, despite enormous successes in advancing the science of biodiversity, the capacity to use scientific knowledge to enhance biodiversity conservation continues to lag. We propose in this report that *knowledge systems analysis* may have value as a strategy for addressing this conundrum by revealing how and why knowledge does and does not link effectively to decision-making and by opening up new ways of organizing the production, validation, circulation, and use of knowledge in conservation policymaking.

Knowledge is a crucial element in decision-making for conservation. Yet, despite enormous successes in advancing the science of biodiversity, the capacity to use scientific knowledge to enhance biodiversity conservation continues to lag. We propose in this report that *knowledge systems analysis* may have value as a strategy for addressing this conundrum by revealing how and why knowledge does and does not link effectively to decision-making and by opening up new ways of organizing the production, validation, circulation, and use of knowledge in conservation policymaking.

Knowledge Systems Analysis: Core Definitions

Let us begin with some important definitions. Knowledge, as we define it, goes beyond a simple notion of truth or true claims about the world. We do not deny the possibility of achieving truth; rather, we acknowledge the complexity and difficulty of achieving objective facts about the world, especially in the often uncertain and contested contexts that characterize biodiversity conservation. To tackle these challenges, we adopt a more sociological approach to thinking about knowledge

Knowledge, for us, refers to claims made by actors (who can be individuals or institutions) that either purport to tell us something of a factual character about the world (of potentially varying degrees of certainty) or are taken by actors to tell us something factual about the world. Knowledge is thus closely related to the notion of idea or belief, but in this case it refers to an idea or belief that one or more groups have accorded the special status of being at least somewhat reliable as a guide to the real state of some feature of the world. Knowledge refers to an idea or belief that someone, whether an individual or a community, takes to be true, or at least relatively more true than other kinds of statements, and therefore of sufficient character to guide his, her, or their reasoning or, especially for our purposes here, action.

In building this definition, there are several important features that should be highlighted. First, it is very general. It is meant to apply to scientific knowledge but also to other kinds of claims, ideas, and beliefs that people take to be true. Our purposes here are not to evaluate whether or not the knowledge in question is or is not true. Rather, we seek to assess what is or is not taken to be true by a particular individual or group and what that means for how that person or group chooses to act. Second, it is also important to understand why and how such judgments of truth get made. Some judgments may be purely personal and experiential. A person may believe she knows whether or not she can rely on her sister to be reliable based on a series of observed experiences. Or she may know where in town to get the best prices on different kinds of goods. Other knowledge may be passed down through community, for example, through processes of socialization, story-telling, or apprenticeship. Still other knowledge may be formalized and learned through instruction and education, much as most of us learn physics or chemistry in school and from textbooks. Or knowledge may be vetted through complex social and institutional processes like those we attribute to science, via experimental practices, modeling and simulation, and review and validation exercises.

Finally, it is important to observe that knowledge claims frequently come associated with a wide range of qualifications. Knowledge about one's sister's reliability may very well be contextual: if her own interests are at stake, she may be very reliable, but less so if the question at hand affects only others. Thus, one must make a judgment for each specific context about whether the sister is likely to be reliable for this task. Qualifications may also arise from assessments of the knowledge provider. We may have great confidence in some teachers but less in others to provide us with high quality, useful information. Farmers may be skeptical of learned know-it-alls who show up with unsolicited advice about how to run their farm. Spend a few days with them helping out around the farm and demonstrating that you know something about how farming works, instead, and they may be more willing to listen to the knowledge in question. And, of course, qualifications may take the form of either formal or informal judgments of certainty and uncertainty. These may be statistical judgments of probabilities or error bars, intuitive or experiential judgments about the experimental skills of another researcher, or explicit or tacit assessments of whether the knowledge claims in question seem likely to be robust in the face of new knowledge or new experiences down the road or rather whether there seem likely to be significant unknown unknowns that are likely to crop up. Qualifications, as we describe them here, overlap considerably with but are not entirely the same as the concept of credibility we will introduce below.

Based on this foundation, we define a knowledge system as a suite of interconnected individual, social, and/or institutional practices by which knowledge claims get formulated (what we might call knowledge-in-the-making), validated, circulated, and put to use in making decisions. The label *system* is meant to imply only that the spaces or sites in which these practices are exercised, as well as the practices themselves and the people who exercise them, are connected together in some fashion, potentially more or less tightly. Some "systems" may be tightly coupled, while others are connected only through the very loosest of networks.

Each of the four elements of a knowledge system—production, validation, circulation, and consumption—is important. In knowledge production, we are particularly interested in the ways that knowledge claims arise and get stabilized as, specifically, claims to know something. Laboratories are obvious sites of scientific knowledge production, but there are many other spaces and means by which claims to knowledge may arise, e.g., through modeling, routine observation, accumulated wisdom, hearsay, etc. The key to analysis of knowledge production is to understand both the practices, routines, discourses, methodologies, forms of reasoning, etc., by which knowledge claims are being generated, as well as the epistemic characteristics of the claims themselves.

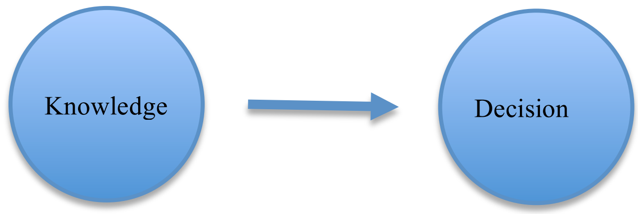
Knowledge validation refers to the practices, processes, and routines by which purported claims to knowledge are subject to review, critique, assessment, check, etc. In science, labs will often repeat their own work to ensure they get similar results. Scientific journals typically require peer reviews of manuscripts by experts in the field. In the US, administrative agencies may hold hearings at which stakeholders will be allowed to present competing evidence and interpretations regarding a particular question of knowledge or action. Scientific assessments are typically formal processes through which a group of scientists will systematically scour the scientific literature on a subject, evaluate a range of claims, and produce a synthetic report summarizing what they believe to be legitimate knowledge on the subject of the assessment. Editors typically insist that journalists check the facts of their story before publishing it.

Knowledge circulation refers to the set of routines, practices, and processes by which knowledge claims are exchanged, circulated, transmitted, or translated from one location or group to another. In science, we might think of this as ranging from informal and formal mechanisms for knowledge sharing within the scientific community, such as conferences and meetings, pre-publication archives, and scientific journals. Also crucial are the means by which science is communicated more broadly, including popular science journals, NGO magazines (e.g., for policy-relevant environmental knowledge), the mainstream media, books about science, and increasingly blogs and other web-related content. We might also want to look at the circulatory system for knowledge in and around the policy process, including formal hearings, personal networks, expert advisory processes and committees, the production and circulation of reports by government agencies, national academies, think tanks, and academic institutes seeking to shape policy decisions.

Knowledge uptake, use, or consumption refers to the social and institutional practices by which knowledge is factored into decisionmaking. When constructing a new regulatory rule, for example, the EPA or FDA Administrator will oversee a process of accumulating, sifting, and judging knowledge claims that might be relevant to the final decision. This will involve: internal and external processes of review of relevant scientific research; administrative hearings in which one or more presentations of relevant scientific evidence will be presented, perhaps by an agency official, perhaps by interested parties; informal and formal conversations within the agency about the available evidence; and a formal statement of the new rule by the Administrator, coupled with the development and publication of the scientific rationale for the rule. Subsequently, there may be legal suits brought against the agency, challenging the ruling, resulting in formal legal proceedings in which the agency's scientific reasoning may come under challenge as well. At a far more informal level, individual consumers may also use knowledge to inform their purchasing decisions, using a very different form of knowledge uptake and processing.

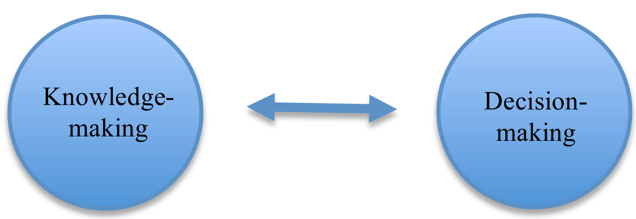
Knowledge Systems Analysis: Conceptual Framework

In developing a model of knowledge systems analysis, it is perhaps worth starting from the simplest model traditionally offered for thinking about the relationship between knowledge and decisionmaking.

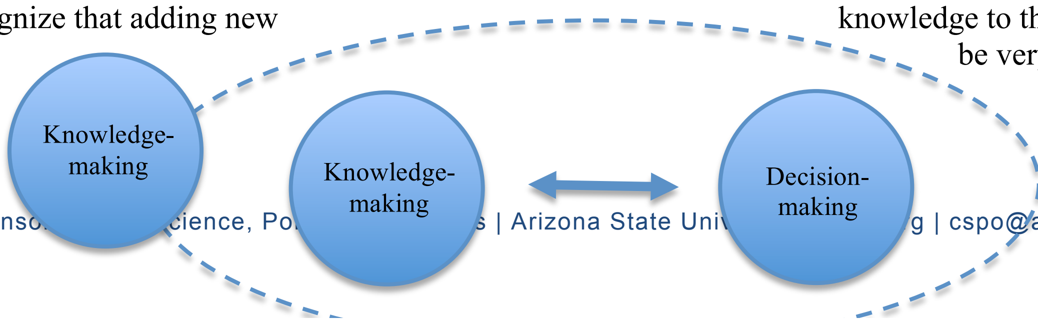


While this model will strike many readers as highly oversimplified, nonetheless, it is remarkable how ubiquitous the idea is that decisions would be better if we could just get the right information to the people who make those decisions. Indeed, in discussions of biodiversity conservation, as well as sustainability more broadly, the notion that there are those who have knowledge (scientists, NGOs, local communities, indigenous communities) and those who just need to be exposed to that knowledge in order to make better decisions is widespread.

A key part of the Advancing Conservation in a Social Context (ACSC) project is to explore the social contexts within which conservation decisions take place, and this idea can be applied here to begin to improve this model. The first advance in the model is to recognize that both knowledge-making and decision-making are social activities that take place within social contexts, institutions, communities, etc. Moreover, where the relationship between knowledge-making and decision-making works well (which is to say, where particular knowledge claims are used to good effect in making decisions that then have arguably good outcomes), we often find that there are dynamics links that tie the social contexts of knowledge-making to the social contexts of decision-making. This may be direct: e.g., when Congress asks the National Academy of Sciences to produce a specific report addressing specific questions. Or it may be indirect: e.g., when a knowledge-producer and decision-maker have both been trained in the same methods and problem-orientation.



Even this simple step of acknowledge that both knowledge-making and decision-making occur within social contexts and that those social contexts likely interact in some fashion takes us a long ways. But we can also go further. One of the most important next steps, we believe, is to recognize that adding new knowledge to this system can be very complex.



Especially where decision-making is routinized or bureaucratic, but even where it is not, knowledge-making and decision-making frequently become more or less tightly connected and bound up with one another. To the extent that they do, re-opening these ties to allow for new forms of knowledge to enter the decision-making process can be quite difficult.

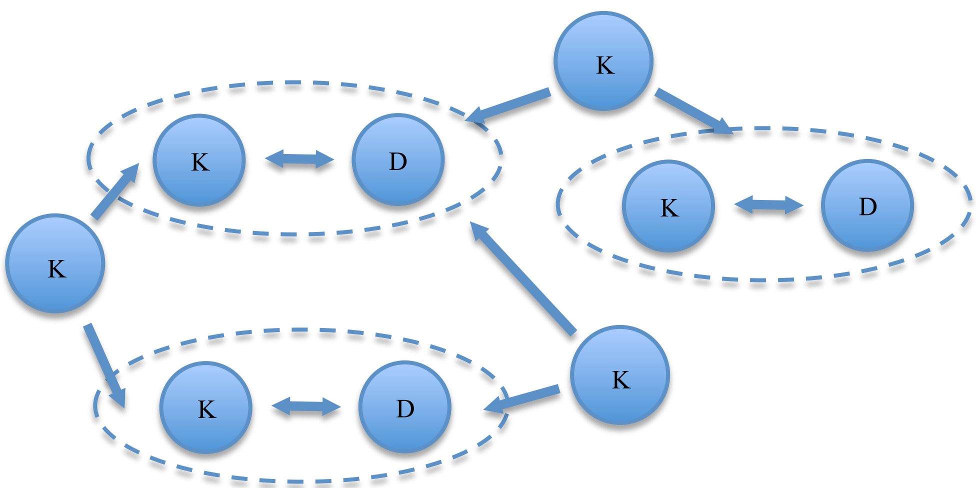
Proponents of conservation for fish species that are consumed in restaurants have faced this challenge directly. When ordering off a menu, most people derive the knowledge they use from their own experiences (what do they like to eat, what does this restaurant do well, what have they had before), the server (what's the special, what's good today), and the menu (what's offered, how much does it cost). Getting even conservation-minded people to stop and think about whether a particular fish is caught sustainably or not turns out to be hard and, even when they do, getting them information is also hard. Some groups have adopted cards that the person can put in their wallet and carry with them, but of course this does not allow for change over time, nor do people necessarily always take the card out and look at it (peer pressure may mitigate against this when going out with a client or the boss, e.g.), and the restaurant may use a different name than is found on the card. Another approach might be to get the restaurant to put the information on the menu, but this may be unreliable, unless you can convince the chef to only serve sustainable fish. In the latter case, of course, you've shifted to a different decision-maker; one who operates in a different context and on the basis of different kinds of knowledge. Introducing sustainability information when shopping for household goods has many of the same problems.

Last, we need to add one final layer of complexity to the model. For the ACSC project, a critical element is also the idea of ecosystem services trade-offs. In a land conservation case, e.g., the land may continue to be protected as a forest, which provides an array of ecosystem services (sustainably harvested forest products, wildlife viewing opportunities, perhaps some water quality improvement, and so forth). Or the land may be converted into agricultural use, which would provide a different set of ecosystem services trade-offs (enhanced production of food or fibre, loss of soil nutrients, and so forth). This is a case where one must make a trade-off decision about which ecosystem services one prefers.

From the perspective of reasoned decision-making, trade-offs present a knowledge problem of the type described above. Knowledge of trade-offs among ecosystem services is often absent from or neglected within decision-making processes, leading to decisions that have unexpected or problematic outcomes. Solving the problem of opening up closed systems that link knowledge and decisionmaking is therefore a critical problem for ACSC.

At the same time, trade-offs among ecosystem services raise an added layer of complexity for knowledge systems analysis that stems from the multiplication of social contexts of either decision-making or knowledge-making. When deciding whether to convert land from forest to agriculture, it may be that many individual land owners are involved or that a natural park owned by the government nonetheless also has individuals who (legally or illegally) use part of the forest for various purposes. Or, it may be, in a democratic society, that environmental NGOs, farm cooperatives, large agribusinesses, and indigenous communities all feel they have a stake in any decision that may be taken.

Likewise, the same decision may give rise to multiple knowledges and knowledge-making contexts. Two scientific studies of the potential agricultural value of the land may arrive at very different estimates of its long-term productivity. Indigenous communities may hold knowledge of the forest and its ecosystem services that isn't contained in scientific research. And, at the same time, consistent with our sociological model of knowledge, different groups may diverge in how they interpret and judge evidence and uncertainty, thus giving rise to different conclusions about what claims should be accorded the status of knowledge. It is highly common in biodiversity conservation settings, for example, to observe these kinds of conflicts over knowledge and its meaning or value for a particular conservation decision.



Here we see clearly the challenge of shifting from a problem of policy optimization (assuming a unitary decisionmaker) to governance. Once we recognize that we are generally working in a governance context, with multiple knowledges and multiple decisionmakers, the requirements for knowledge systems alter dramatically. Consider, for example, the simple case of two groups and two potential ecosystem services, where the two groups must agree on a collective solution through bargaining and/or persuasion. Here, there are several possible approaches to knowledge system design. One might, as was the case with the US Office of Technology Assessment before its dissolution, create a neutral organization that sought very carefully to create an objective body of evidence that would fully outline the various trade-offs available, so that the collective bargaining could occur on the basis of the best possible overall knowledge. Or, one might, as is often the case in US legal settings or adversarial politics, provide both groups with sufficient funding to establish their own knowledge system. In this latter case, one is likely to get studies that are more clearly skewed toward one side or the other, but long experience has shown that such an arrangement is also much more likely to bring to light hidden aspects of the underlying trade-off problem that a neutral knowledge system might miss. One reason for the difference is that the latter is often constrained in how widely it can pursue questions that would result in the appearance of bias from one side or the other. More generally, the challenge can be understood as to where and how to consider trade-offs within the knowledge system. Is the goal of the system simply to highlight trade-offs for decision-makers, or is it to conduct analyses that help resolve trade-offs? Or is it to highlight the unique trade-offs that face multiple knowledge holders and decisionmakers within a particular conservation context? Or something else entirely?

Knowledge Systems Analysis: Key Ideas (and Further Reading)

Production – Production can be understood as the set of practices, processes, and institutions through which new knowledge claims are formulated and made. New knowledge claims do not merely appear, fully formulated. Rather, they are the product of sometimes long and involved work. In field research, for example, field sites will need to be selected, travel to field sites accomplished, samples collected and analyzed, data refined and processed in relationship to theoretical understandings, and final results drafted into a publishable form. These practices are likely to be quite different from experimental research taking place in a laboratory and yet again different from efforts to build a computational model of natural processes. All of these are likely to be still different from the social practices and processes by which farmers develop a knowledge of their land or local communities develop knowledge over time of the ecological landscapes that they inhabit. Production also includes a potentially large set of practices and processes involved in enabling knowledge-making activities. These can include the funding of research (including granting agencies and activities), the building of research infrastructure (such as laboratories, field stations, etc.), the training of personnel, etc.

Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton University Press: Princeton), 1986.

Karin Knorr-Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Harvard University Press: Cambridge), 1999.

Robert Kohler, *All Creatures: Naturalists, Collectors, and Biodiversity, 1850-1950* (Princeton University Press: Princeton), 2006.

Marybeth Long Martello, "Negotiating Global Nature and Local Culture: The Case of Makah Whaling," in S. Jasanoff and M. Martello, eds. *Earthly Politics* (MIT Press: Cambridge), 2004.

Rebecca Ellis and Claire Waterton, "Environmental Citizenship in the Making: The Participation of Volunteer Naturalists in UK Biological Recording and Biodiversity Policy," *Science and Public Policy* 31(2): 95-105.

Validation – Early philosophies of science highlighted the idea of replication as the primary form of activity by which scientists validated their own and others' work. The reality of validation is more complex, however. On the one hand, work done to ensure the reliability of data and findings is almost always an integral element of the work done by scientific groups as they develop their knowledge claims. Modelers will compare their models to theories and/or data to confirm, as best they are able, to ensure that the models work. Likewise, laboratory and field scientists will often do a great deal of work to ensure that their experimental or observational data are not the product of artifacts or flaws in method and procedure. In all cases, scientists will also compare or triangulate their own results to the results of other researchers to attempt to make sure they have not made obvious mistakes. A second level of validation activity occurs as other groups then try to assess the implications of new knowledge claims on their own work to help judge whether they find it reliable or not. In the case of climate modeling, for example, the past decade has seen extensive field research carried out to determine whether model predictions for a wide range of parameters are being observed in nature. This process, informally referred to as "fingerprinting," has gone a long way toward convincing the climate science community that its models are, in fact, describing real behaviors of the climate system. Another approach to model validation has involved research comparing the outputs of different models to see how they align with one another and to seek an understanding of where and why models agree and disagree.

Zachary Pirtle, Ryan Meyer, and Andrew Hamilton, "What does it mean when climate models agree? A case for assessing independence among general circulation models," *Environmental Science and Policy* 13(5): 351-361.

Harry Collins, *Changing Order: Replication and Induction in Scientific Practice* (University of Chicago Press: Chicago), 1992.

Review – Processes of review involve subjecting knowledge claims to evaluation and judgment by others beyond those who have made the particular claims. In science, a wide variety of review mechanisms are practiced, the most obvious being the peer review of journal articles before publication. Prior to publication, preliminary results are often presented at conferences, where questions and comments are raised by fellow panelists and audience members. Both prior and subsequent to publication, extra review may also occur if results are seen as pertinent to important societal choices. In the case of clinical trials, for example, NIH and the FDA audit laboratories conducting research, in order to ensure good scientific practices are being followed. Then, if the research is used to justify or oppose decisions to approve a drug for marketing, the research findings will be reviewed again, formally, several times as the process proceeds, including review by FDA researchers, expert advisory committees, and the FDA Administrator. Similarly, the Intergovernmental Panel on Climate Change and Millennium Ecosystem Assessment constitute forms of extra review for policy-relevant knowledge claims. Many other kinds of knowledge systems also employ review. While farmers may not formally subject their knowledge to external review, nonetheless, their conversations about their ideas with neighbors, extension agents, seed company representatives, etc., constitute a form of review in which their assumptions may be challenged or reaffirmed based on the observations of others.

Sheila Jasanoff, "Peer Review in the Regulatory Process," *Science, Technology & Human Values* 10(3): 20-32.

Darryl Chubin and Ed Hackett, *Peerless Science: Peer Review and US Science Policy* (SUNY Press: Albany), 1990.

Paul Edwards, "Self-Governance and Peer Review in Science-For-Policy: The Case of the IPCC Second Assessment," in C. Miller and P. Edwards, *Changing the Atmosphere* (MIT Press, Cambridge: 2001).

Synthesis – Synthesis has been formalized as an explicit technique within the sciences only recently. Nonetheless, the concept and practice that underlies synthesis of integrating multiple knowledge claims together, often from across a wide range of disciplinary or epistemological perspectives, has been a feature of human reasoning one suspects as long as there have been humans. Often seen as an integral component of leadership skills, the ability to pull together a wide range of knowledge and insights to create an integrated or synthetic viewpoint is today seen as essential to solving the complex, multifaceted problems that face 21st century societies. Still, synthesis takes many forms. Formal synthesis processes, such as those operated by the National Center for Ecological Analysis and Synthesis offer only one model. Researchers have begun to develop synthetic research projects, built out of interdisciplinary teams (see, e.g., *Experiments in Consilience*), while the work of expert advisory committees and international scientific assessments can be seen as blending functions of review with functions of synthesis. Less formalized forms of local knowledge often operate in more seemlessly synthetic fashions, without much attention to explicit processes of synthesis at all.

Hackett, E. J., J. N. Parker, D. Conz, D. R. Rhoten, and A. Parker. "Ecology transformed: The National Center for Ecological Analysis and Synthesis and the changing patterns of ecological research." Pp. 277-296 *in* G. M. Olson, A. S.Zimmerman, and N. Bos, eds., *Scientific Collaboration on the Internet* (MIT Press: Cambridge), 2008.

Carpenter, S. R., E. V. Armbrust, P. W. Arzberger, F. S. Chapin III, J. J. Elser, E. J. Hackett, A. R. Ives, P. M. Karieva, M. A. Leibold, P. Lundberg, M. Mangel, N. Merchant, W. W. Murdoch, M. A. Palmer, D. P. C. Peters, S. T. A. Pickett, K. K. Smith, D. W. Wall, and A. S. Zimmerman. "Accelerate synthesis in ecology and environmental sciences." *BioScience* 59(8):699-701. 2009.

Westley, F., and P. S. Miller. *Experiments in Consilience: Integrating Social and Scientific Responses to Save Endangered Species* (Island Press: Washington, D.C.), 2003.

Miller, C. A. "Assessments: Linking ecology to policy." *In* S. Levin, ed., *The Princeton Guide to Ecology* (Princeton University Press: Princeton), 2009.

Framing – Framing refers to the set of perceptual lenses, worldviews or underlying assumptions that guide the interpretation and definition of particular issues. Framing is a critical element in knowledge production, circulation, and use. Framing can shape the kinds of knowledge that are produced in the first place, e.g., by prioritizing certain kinds of research over others. Framing can impact to what extent and to whom knowledge circulates. And framing can shape how decisionmakers weigh different kinds of knowledge in making choices. Consider, for example, various possible framings of the object of conservation biology: *endangered species*, *biodiversity* and *ecosystem services*. Each framing creates a demand for different forms of research: identifying endangered species and the causes of population decline; identifying species rich areas and the forces that threaten their destruction; identifying ecosystems that provide important services to humans and the trade-offs involved in enabling them to continue to provide those services or substituting for them using alternative approaches. Each targets different spaces with different stakeholders for protection. And each involves different kinds of decisionmaking, involving different agencies, different knowledge systems, and different decision criteria. Framing is relevant to knowledge systems analysis in various ways. If we understand diverse framings as different slices of a problem, analysts may want to explicitly adopt multiple framings of a policy problem in order to ensure that they have a rich understanding of the issues at stake. Diverse stakeholder groups may bring different problem framings to the table, causing them to interpret evidence differently and arrive at different judgments regarding the best way to proceed. Embedded problem framings may cause knowledge producers or decisionmakers to inadvertantly ignore important evidence and thus arrive at faulty understandings or decisions. Framing may be critical from a strategic communication perspective to ensure that insights or decisions are broadly viewed as credible among diverse audiences.

Clark Miller, "The Dynamics of Framing Environmental Values and Policy: Four Models of Societal Processes," *Environmental Values*, Vol. 9, pp. 211-233, 2000.

James Fairhead and Melissa Leach, *Reframing Deforestation: Global Analyses and Local Realities: Studies in West Africa* (Routledge: London), 1998.

Sheldon Krimsky and Alonzo Plough, *Environmental Hazards: Communicating Risks as a Social Process* (Auburn House: Cambridge), 1988.

William Cronon, "A Place for Stories: Nature, History, and Narrative," *The Journal of American History* 78(4): 1347-1376, 1992.

Styles of Reasoning – Attention to styles of reasoning reflects growing recognition that variations across knowledge systems come not only in how each frames its analysis and problems but also diverse approaches to reasoning within each. Philosophers, historians, and sociologists have identified multiple styles of reasoning within the scientific community, each differing in terms of the kinds of problems highlighted, methods adopted, evidence employed, and conclusions drawn. While differing deeply in terms of degree and form of institutionalization and variation, variations within science have been described in terms of paradigms, disciplines, schools of thought, epistemologies, methods, etc. Scholars have also identified styles of reasoning as a critical variable of difference across communities, countries, and political cultures. This work has demonstrated the extent to which how communities reason is bound up in—both shaping and shaped by—forms of social and political organization.

Ian Hacking, "Inaugural Lecture: Chair of Philosophy and History of Scientific Concepts," *Economy and Society* 31(1): 1-14, 2001. (Topic: styles of scientific reasoning)

Ian Hacking, "Statistical Language, Statistical Truth, and Statistical Reason: The Self-Authentication of a Style of Scientific Reasoning," *The Social Dimensions of Science* 1992.

Jane Maienschein, "Epistemic Styles in German and American Embryology," *Science in Context* 4(2): 407-427, 1991.

Simon Shackley, "Epistemic Lifestyles in Climate Change Modeling," in C. Miller and P. Edwards, *Changing the Atmosphere* (MIT Press, Cambridge: 2001).

Arthur Daemmrich and Georg Krucken, "Risk vs. Risk: Decisionmaking Dilemmas of Drug Regulation in the United States and Germany," *Science as Culture* 9(4): 505-534, 2000.

Clark Miller, "Civic Epistemologies: Constituting Knowledge and Order in Political Communities." *Sociology Compass*. Vol. 2(6): 1896-1919. 2008.

Ontology – Knowledge systems vary not only in how they reason but also with regard to sets of objects they consider to be epistemically significant and how those objects get classified. Classifying living organisms by biome, by phylogenetic relationships, or by use to humans not only relies on different criteria for sorting organisms but different levels of organism difference also become significant. Varieties may be relatively insignificant in comparison to species, in terms of demarcating phylogenetic variation, but they may be tremendously important in demarcating major cereal crops from wild types of the same species that grow in only a few places and not used at all for human consumption (although some of the latter may have significant value as sources of potential genetic variability for crossing into new cereal crop varieties in the future). Differences in ontology and classification are even more marked between scientific and other forms of knowledge, including especially indigenous knowledge systems. Another significant aspect of ontology regards the bringing into being of new ontological categories and the reordering of social, legal, and political relationships around such categories. Consider ecosystem services. Such services have existed since humans were hunters and gatherers, yet major policy-relevant knowledge systems did not have a stable category for all such services until very recently. The resulting conceptual reconfiguration may give rise to new public policies, new institutions, and new relationships between nature and society as the latter rethinks its choices regarding conservation and development.

David Takacs, *The Idea of Biodiversity: Philosophies of Paradise* (Johns Hopkins University Press: Baltimore), 1996.

Ian Hacking, "Making Up People," in I. Hacking, *Historical Ontology* (Harvard University Press: Cambridge), 2002.

Charis Cussings, "Ontological Choreography: Agency Through Objectification in Infertility Clinics," *Social Studies of Science* 26(3): 576-610, 1996.

Clark A. Miller, "Climate Science and the Making of Global Political Order," in Sheila Jasanoff, ed., *States of Knowledge: The Co-Production of Science and Social Order* (London: Routledge). pp. 46-66. 2004.

Uncertainty – Uncertainty marks the degree to which knowledge claims are thought to be reliable representations of underlying truths. Uncertainty can arise from a wide range of factors. Uncertainty can be internal to the knowledge claim. Error bars on measurements, for example, reflect a kind of internal uncertainty. They note that measurement instruments are not precise but rather provide a measurement to a certain degree of accuracy, but no more. For example, public opinion polls typically report their results with error bars of a few percentage points. This reflects a probability distribution that indicates how likely it is that the actual distribution of opinion in the population lies within one standard deviation of the measured distribution of opinion within the polled sample. This, in turn, depends on the characteristics of the sampled and full populations and the ratio of the sampled to the full population size. Uncertainty may arise from other considerations, also. Computational modeling techniques can introduce errors, as can the applicability of theoretical or mathematical tools, or unknown factors that are not included in scientific analyses. Uncertainty may also be social in source. Frequent errors on the part of one scientist may lead his or her colleagues to discount the reliability of new claims made by the initial scientist. Different conclusions drawn by multiple scientific groups from ostensibly the same data and models may also introduce uncertainty regarding the validity of particular claims.

D. Sarewitz, R. Pielke, and R. Byerly, *Prediction: Science, Decision Making, and the Future of Nature* (Island Press: Washington, DC), 2000.

Brian Wynne, "Uncertainty and Environmental Learning: Reconceiving Science and Policy in the Preventive Paradigm," *Global Environmental Change* 2(22): 111-127, 1992.

Andy Stirling, "Risk, Uncertainty, and Precaution: Some Instrumental Implications from the Social Sciences," in F. Berkhout, M. Leach, and I. Scoones, eds. *Negotiating Environmental Change* (Edward Elgar: London), 2003.

Evidentiary Standards – Evidentiary standards constitute the formal and informal criteria against which evidence is measured in making decisions. Such standards are critical to understanding how knowledge and uncertainty are managed in decisionmaking. Legal doctrines, which typically formalize evidentiary standards, make their significance especially clear. To insist that something be shown plausible, for example, requires a far lower standard of evidence than to demand that it be shown beyond a reasonable doubt. Decision rules that adopt the former standard will encourage positive action—e.g., a verdict of conviction—considerably more frequently than ones that insist on the latter. Such standards reflect values regarding how much certainty or proof is required before a decision can be made or an action taken. Evidentiary standards may vary across institutions, cultures, or even decisions within a single agency. Evidentiary standards can also include standards of admissability—i.e., which evidence is allowed to be considered in a decision. Again, we typically think of such rules as the province of legal systems, but all decision processes include either formal or informal processes or practices that filter evidence reaching decisionmakers. The Intergovernmental Panel on Climate Change, for example, operates under a rule that no research may be incorporated into its assessments unless that research has been published in a peer-reviewed, scientific journal. In political institutions, the President's advisors often act as filters on which knowledge claims reach the President and which do not.

Sheila Jasanoff, "Acceptable Evidence in a Pluralistic Society," in R. Hollander and D. Mayo, eds. *Acceptable Evidence* (Oxford University Press: Oxford), 1991.

Sheila Jasanoff, "Just Evidence: The Limits of Science in the Legal Process," *Journal of Law, Medicine, and Ethics* 34(2): 328-341, 2006.

Credibility – Credibility is defined here as the degree to which knowledge claims and/or knowledge claimants are believed by individuals or communities. Credibility is thus, as Steve Shapin has aptly noted, the problem of King Lair and his daughters: whom to believe, about what, and on what grounds? As a matter of sociological observation, it is crucial to observe here that credibility is rarely if ever simply a matter of the characteristics of the knowledge claim itself. A knowledge claim produced using rigorous scientific methods may nonetheless be greeted by a skeptical audience if it is presented poorly, championed by an individual considered unreliable, contradicted by other claims that have already achieved credibility, or contested by someone whose views are trusted. These dynamics can be observed even among scientists working in the same subfield, although the specific social dynamics that contribute to credibility are likely to be different in such groups than between scientists and other audiences (policy officials, publics, etc.). Keep in mind, of course, that credibility is also rarely simply a matter of social relationships. Knowledge claims, their characteristics, and the processes by which they are produced, validated, and reviewed can matter enormously in the judgment of their credibility. Unreliable people can nonetheless make claims that audiences judge credible, while broadly credible individuals and institutions can make claims that ultimately are not believed to be true. Like uncertainty, credibility resides on a continuum from not believed at all to believed fully, with many degrees of confidence in a claim in between. Perhaps most important, credibility—along with trust—is achieved or lost dynamically, over time, with work and effort.

Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England* (University of Chicago Press: Chicago), 1994.

Steven Shapin, "Cordelia's Love: Credibility and the Social Studies of Science," *Perspectives on Science* 3(3): 255-275, 1995.

Steven Epstein, *Impure Science: AIDS, Activism, and the Politics of Knowledge* (University California Press: Berkeley), 1995.

Thomas Gieryn, *Cultural Boundaries of Science: Credibility on the Line* (University of Chicago Press: Chicago), 1999.

Stephen Hilgartner, *Science on Stage: Expert Advice as Public Drama* (Stanford University Press: Stanford), 2000.

Legitimacy – Legitimacy reflects the challenge of matching knowledge systems to not just the epistemic expectations of communities but also their political expectations. The legitimacy—or lack thereof—of a knowledge system can be critical to its acceptance as an input to policy decisions. Lack of political legitimacy can contribute, on the one hand, to a loss of credibility. Knowledge claims may be rejected as not credible if the participants in a review mechanism or advisory process appear to reflect the political positions or interests of policy opponents. EPA's Science Advisory Board suffered from serious credibility problems until EPA acknowledged a need to at least implicitly balance representation on its committees between scientists representing industry and those representing environmental advocacy groups. Likewise, the Intergovernmental Panel on Climate Change has had significant credibility problems among developing country audiences, given the relatively poor representation of scientists from developing countries involved in its work. Other kinds of political expectations may also be significant. US political institutions are expected to operate in an open and transparent fashion, for example, and this requirement has been extended by law to scientific advisory committees constituted by the federal government through the 1972 Federal Advisory Committee Act. In other countries, such as Britain, lower priority is attached to openness and transparency as principles of democracy, and expert advisory bodies are freer to work in relative secrecy. It should be noted, however, that legitimacy is not only related to credibility. A process may be judged credible yet still be rejected as an input to policy decisions should it be seen as illegitimate. The rejection of evidence collected illegally in court trials offers a nice illustration of this principle. Evidence found during an illegal search may conclusively demonstrate guilt, but if the judge disallows its presentation to the jury, their verdict will not reflect that knowledge.

Yaron Ezrahi, *The Descent of Icarus: Science and the Transformation of Contemporary Democracy* (Harvard University Press: Cambridge), 1990.

Sheila Jasanoff, *The Fifth Branch: Science Advisers as Policymakers* (Harvard University Press: Cambridge), 1990.

Clark A. Miller, "Democratization, International Knowledge Institutions, and Global Governance." *Governance* 20(2): 325-357. 2007.

Accountability – One particularly important element of the political legitimacy of a knowledge system are the accountability structures and relationships built into it. These structures and relationships determine, in the final accounting, who is responsible to whom with regard to knowledge production, circulation, and use, as well as how power is allocated within a knowledge system. Attention to accountability dynamics and structures can be relevant for understanding how and why gaps occur between knowledge production and use, why knowledge and decisionmaking outcomes take the paths that they do, as well as how knowledge systems impact the broader distribution of power in society, including their implications for broader normative questions of justice and democracy.

Clark A. Miller, "Resisting Empire: Globalism, Relocalization, and the Politics of Knowledge," in Sheila Jasanoff and Marybeth Long-Martello, eds., *Earthly Politics: Local and Global in Environmental Governance* (Cambridge: MIT Press). pp. 81-102. 2004.

Clark A. Miller, "Interrogating the Civic Epistemology of American Democracy: Stability and Instability in the 2000 U.S. Presidential Election," *Social Studies of Science*. Vol. 34. No. 4, pp. 501-531, 2004.

Clark A. Miller, "Knowledge and Accountability in Global Governance: Justice on the Biofrontier," in M. Tetreault and R. Teske, eds., *Partial Truths: Feminist Approaches to Social Movements, Community, and Power, Volume 2* (Richmond: University of South Carolina Press). pp. 315-341. 2003.

Peter Weingart, "Scientific Expertise and Political Accountability: Paradoxes of Science in Politics," *Science and Public Policy* 26(3): 151-161, 1999.

Boundary Work – An important feature of knowledge systems is their ability to project the objectivity of their knowledge production practices. In many contexts, the appearance of objectivity is (although it should be noted not always) crucial to both the credibility and legitimacy of knowledge-making processes and, therefore, also to the credibility and legitimacy of decision-making processes founded on the resulting knowledge claims. We observed above, in the first section, that knowledge-making occurs in close dialogue with—and often integrated into—decision-making processes. Indeed, this integration is often so systematic (and, often, as a consequence, unapparent even to participants) that it is impossible to fully separate knowledge-making and decision-making activities. Consequently, knowledge systems face a constant risk of the appearance of policy or political considerations relevant to decision-making inappropriately influencing knowledge-making. Boundary work is a term sociologists and political scientists have developed to refer to the work done—rhetorical, procedural, institutional, and otherwise—to create the appearance of a rigid boundary between knowledge-making and decision-making, especially where such a rigid boundary does not (and, arguably, cannot) exist for the overall knowledge system to function effectively and efficiently.

Thomas Gieryn, "Boundary Work and the Demaracation of Science from Non-Science," *American Sociological Review* 48(6): 781-795, 1983.

Sheila Jasanoff, "Contested Boundaries in Policy-Relevant Science," *Social Studies of Science* 17(2): 195-230, 1987.

Thomas Gieryn, "Boundaries of Science," in S. Jasanoff et al., eds. *Handbook of Science and Technology Studies* (Sage: Thousand Oaks), 1995.

David Guston, "Boundary Organizations in Environmental Science and Policy," *Science, Technology & Human Values* 26(4): 399-408, 2001.

Clark Miller, "Hybrid Management: Boundary Organizations, Science Policy, and Environmental Governance in the Climate Regime," *Science, Technology & Human Values* 26(4): 399-408, 2001.

Reflexivity – Reflexivity is the idea that knowledge makers and users should be aware of how they are producing and using knowledge. Knowledge claims and knowledge systems inevitably involve embedded assumptions, framings, uncertainties and values that are sometimes explicit but often tacit. One approach to reflexivity is to view it as an ongoing, systematic effort to uncover these embedded elements and ensure that they do not create problems for how knowledge is being used. When applying knowledge claims in contexts that differ markedly from the contexts in which those claims were developed, for example, tacit assumptions or framings may lead to unforeseen errors unless users can identify relevant assumptions and correct for them. Another approach to reflexivity is to routinely be on the lookout for early signs that the outcomes of applying knowledge claims are at odds with expectations. Variations in outcomes may highlight where tacit assumptions, framings, uncertainties, or values are going wrong.

Jameson Wetmore, "Engineering with Uncertainty: Monitoring Airbag Performance," *Science and Engineering Ethics* 14(2): 201-218, 2008.

Brian Wynne, "Public Uptake of Science: A Case for Institutional Reflexivity," *Public Understanding of Science* 2(4): 321-337, 1993.

J. P. Voss, D. Bauknecht, and R. Kemp, *Reflexive Governance for Sustainable Development* (Edward Elgar: London), 2006.