Dragnet Ecology—"Just the Facts, Ma'am": The Privilege of Science in a Postmodern World

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When *Dragnet* protagonist Joe Friday investigates a crime, there is almost always someone "who done it," and usually we know who it is in the first few minutes of the episode. In one episode concerning a retired actress who falls victim to a confidence trick, Sergeant Friday sweeps aside the irrelevant circumstantial details offered by the actress and solves the puzzle with characteristic ease. Friday's sidekick, Bill Gannon, responds to a different challenge and touchingly asks for the faded actress's autograph. "I didn't know you collected autographs," says Joe, as they leave the scene. "I don't," replies Bill. *Dragnet* is a modern version of a morality play, myths and all, the prevailing myth being that it may take time to apprehend the suspect, but eventually "just the facts" will inexorably solve the crime. But isn't Bill Gannon essential to this process?

Many scientists share Joe Friday's mythic goal. In the simple world of Sergeant Friday, there is a single true answer; in the scientific equivalent, the scientist believes that there is a single truth, and attempts to find it. Much scientific activity uses simple models, and thus amounts to no more than calibration. But as our colleague John Norman in the Department of Soil Science at the University of Wisconsin points out, "I can do a lot with those calibrations" (and he can, too), so we must not underestimate the importance of focusing situations until they become simple. Successfully casting a system as simple results in consistent and singular answers as well as reliable predictions. However, from that consistency it does not follow that the singularity of answers arises from their being expressions of singular truths. It could easily be that the consistency results from the constraints we scientists impose on the system in order to make it simple. Furthermore, the scientist has no way to distinguish between singular truth and constraint when the data are applied to a simple model, no matter how meticulous the collection of those data. Much as *Dragnet* has a mythic quality, so does science that seeks out the single quantified truth. Such science would remain mythic, even in the extremely unlikely event that the simple model could indeed reflect the reality fully, for the argument about truth turns not directly on data per se, but on the belief that the perception of data yields truth. There can be no such thing as an observer-free observation (Tainter and Lucas 1983).

SCIENCE OF INTRINSIC QUALITY NEEDS NARRATIVES WITH EXPLICIT VALUES—NOT JUST FACTS—PARTICULARLY AS IT FACES MULTIPLE-LEVEL COMPLEXITY IN ADVISING ON ENVIRONMENTAL POLICY, SUCH AS PLANNING FOR ENERGY FUTURES

During the past few years, a few outspoken scientists have taken it upon themselves to defend science from postmodern critics on the "academic left" (Gross and Levitt 1994, Sokal and Brimont 1998). The irony is that these opponents of the "flight from reason" often use the same kind of overblown, simplistic rhetoric they so strongly condemn in others. Although we certainly do not agree with every postmodern

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critique of science, we invite scientists to move beyond bickering and explore the literature of science studies for themselves (see Biagioli 1999 for a recently edited volume on science studies, Kleinman 1998 on the social relevance of science studies, Hacking 1999 for a discussion on social construction, Natoli 1997 for a humorous introduction to postmodernism, and Pickering 1995 for a postmodern case study in physics). Denying the Enlightenment project may seem pessimistic, but we have seen the man behind the curtain and objectivist realism is now compromised.

A belief that good data give direct access to the truth of the material situation is an extreme form of realism, but there are many other realist positions that are entirely respectable and rather more philosophically sophisticated. Indeed, there is a plurality of notions of "realism" that occupy what is generally considered an intuitive and commonsense middle ground. The philosophy of constructivism, well established in psychology by Jean Piaget (1963), is one such moderate position. Piaget identified that humans learn neither from a simple process of maturation (*nature* in a nativist worldview) nor from a process of being directly informed by the material world (*nurture* in an empiricist worldview). In constructivism, the subject is not given direct access to the material world but rather is held behind a barrier of definitions and values. The development of knowledge consists of a set of changes in the subject in response to interactions with the material system (see Figure 1; Ahl and Allen 1996). Constructivism does not give the privilege of being the fixed reference point to the external reality, but neither does it suggest that concepts and understanding arise entirely independent of an external world. Rather, constructivism bestows privilege on the happenings at the barrier at which the subject acts and the world reacts. The purview of this article does not include a review of realism and constructivism (Putnam 1987, Sismondo 1996, Hacking 1999); we simply want to point out that there are many middle-ground alternatives to objectivism and the more extreme forms of relativism and subjectivism.

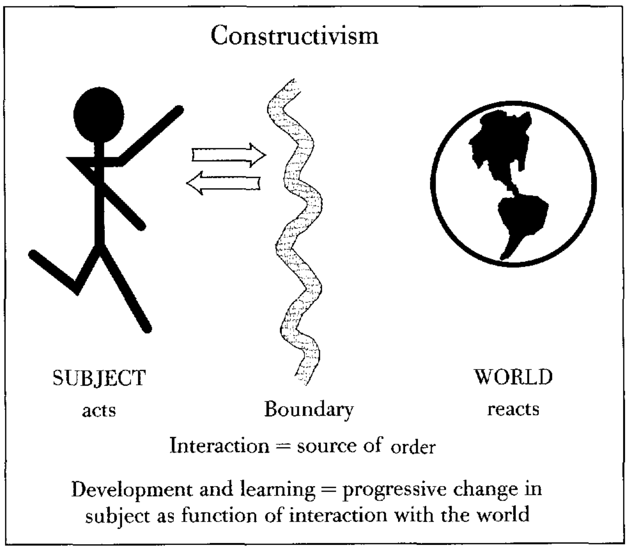

Figure 1. The origins of order in constructivism. The constructivist position gives privilege to neither the observer nor the objective reality, but is informed by happenings at the barrier between the two (figure from Ahl and Allen 1996, with permission).

Beyond a need to seek a moderate position so as to escape naive realism, there are the added problems when values explicitly enter scientific discourse. Because the arena where science and policy interface is inherently value laden, there is an urgent need for concern about qualified access to reality and the material world. Science must adapt by using high-quality data to make high-quality challenges to prevailing beliefs honestly. Science also needs to be conscious that the currency of communication is always some sort of narrative. The postmodern world may be a nightmare for Joe Friday and normal science (Kuhn 1962), but science still deserves to be privileged, because it is still the best game in town.

Many questions posed by the human condition in today's world are not susceptible to a single answer; one needs Bill Gannon's sensibilities to deal with the complexities of our time. For instance, one cannot calibrate the way to ascertaining the exact degree to which human activity is responsible for global warming. First one needs to define "human activity," then what one means by "responsible," not to mention global "warming" scenarios that involve the triggering of a new ice age in Europe. And finally, if we may borrow from a recent president, it depends on what the meaning of "is" is. All those decisions produce alternative answers, and each is necessarily value laden. When the model is complex and values cannot be fixed by fiat, conventional paradigmatic approaches to scientific modeling and forecasting are inappropriate. Orthodoxy will fail when one is trying to predict the behavior of complex systems, whether or not the calls of judgment are overtly value laden. Complex systems exhibit emergent phenomena and relatively sudden reconfigurations from one system organization to another (Kay et al. 1999). Worse than that, when issue-driven science occurs in the context of policymaking, "typically facts are uncertain, values in dispute, stakes high, and decisions urgent" (Ravetz 1999, p. 647). At that point, the difference between uncertainty being merely epistemological and being metaphysical is moot. The postmodern world is problematic for Joe Friday and normal science (Kuhn 1962), the metaphysics of reality notwithstanding.

The privilege accorded science in the merely modern world turns on science being objective and having access to how the world really works. So if in the postmodern world the single truth is not the benchmark, whence comes scientific privilege over other human ways of knowing? There are many issues in the nature and role of science for a postmodern age, but we choose to focus on two ways to evaluate and pursue issue-driven science: *quality* and *narrative*. Quality has been addressed by Funtowicz and Ravetz (1992, 1993) in what they call "post-normal science" (Ravetz 1999), which combines postmodernist themes with their previous work on uncertainty and quality at the science–policy interface (Funtowicz and Ravetz 1990, 1991, 1997). Kay and his colleagues (1999) in systems ecology suggest that scientists should provide descriptive narratives (rather than singular predictions). They recommend a style of adaptive management that ties multiple possible system descriptions to issues of human preferences. Our goal in this article is to elaborate on the concepts of quality (Pirsig 1974) and narrative as they relate to scientific privilege in argumentation and society. We will differentiate the process of *complication* from *complexification*, and distinguish *high-gain* resources from *low-gain* resources because making such distinctions will give us new ways to describe system organization and behavior. We will conclude by suggesting that science should not retreat defensively from postmodernism, but instead should reinvent and adapt itself in a rapidly changing postmodern age.

Quality and narrative

For Funtowicz and Ravetz (1992), the concept of *quality* has internal and external components that can be applied to the interpretation of the notions of classical and merely modern scientific privilege. They point to the achievement of quality at three levels of skill: Become dexterous: the novice. Become a craftsman: the apprentice. Finally, become so adept and in command as to achieve creativity: the master—it is not a masterpiece until it breaks new ground. These levels of quality are *internal* to the creative process. By contrast, *external* quality is defined by a relationship with a broader community of users and has its own criteria and modes of assessment. Quality assurance in industry, with concepts of reliability and economy, guides externally assessed quality. External quality and internal quality may differ dramatically. In Woburn, Massachsetts, for example, community advocates for a response to water quality related to a leukemia cluster used external quality, whereas epidemiologists in that same situation used internal quality. Local residents, who were the first to notice a leukemia cluster, hypothesized a link between local water and disease, and prodded government officials to undertake tests. Given the high stakes, communities advocating such "popular epidemiology" would rather make type one errors (that is, false positive errors) so as to meet external criteria of not overlooking insidious danger. Meanwhile, professional epidemiologists prefer any error they make to be type two, or false negative (Brown and Mikkelsen 1990), to ensure that meticulous science will never overextend itself (Funtowicz and Ravetz 1990, Epstein 1996, Kleinman 1998, Healy 1999).

Funtowicz and Ravetz (1992) posit three ideals of quality: classical, modern, and postmodern. In classical times, painting was largely done by apprentices, with, for instance, Titian effecting the design and making the finishing touches. The external referent was the patron, and quality was measured in value for ducats. Titian would be given the credit and would be recognized as a master even by the naive observer. Privilege that caused something to be taken seriously in classical times, therefore, came not only from elite critics but from a wider audience that could appreciate the external quality of the reality being represented: It looks like the king, and it is a nice picture.

Under the modern rubric, the tension shifts to one between reality and quality. The reason Pablo Picasso's cubist portraits have distorted noses and eyes is that the artist is aware of the profile that is the alternative point of view to full face. Modern art, as well as modern science, goes beyond mere representation to capture various "essences" of reality. Picasso said that by the age of 14 he could paint like Leonardo, but it took another 30 years for him to learn to paint like a child. Naive external spectators often cannot distinguish a high-quality Picasso from a child's scribbles (see Figure 2); nor do they know how a cyclotron works or why it is important. Thus, privilege in the modern style of art and science is in the hands of an "expert" audience of cultural connoisseurs or peer scientists who are committed to a particular shared reality, the external referent of quality. Privilege is conferred by the wider audience upon the experts because the experts claim that their notion of reality is "objective" (or the closest thing to it) and there is the promise of enlightenment, if not material goods and services. In terms of science, the singularity of the original in modern art and culture transfers into the singularity of ultimate truth that is the reason for conducting scientific experiments.

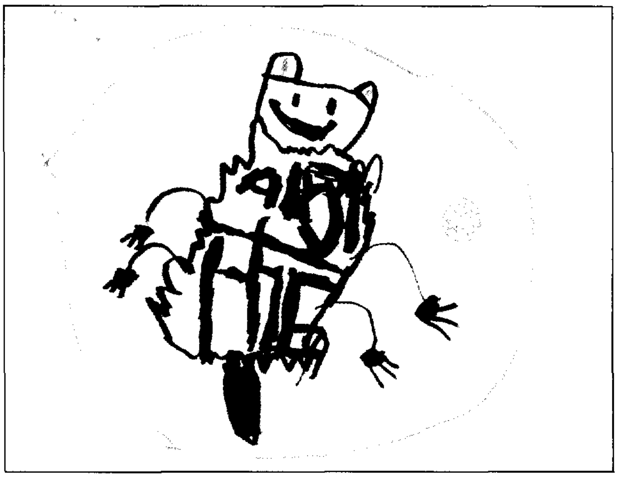

Figure 2. A picture of a cat by Josephine Allen, age 3 years. Much as Pablo Picasso knew that there was a profile to go with the full face, children characteristically draw all the legs on a cat or chair, not because they can see them but because they know that in reality they are there.

In the postmodern style, when Funtowicz and Ravetz discuss art-based and science-based technology, they borrow Baudrillard's (1974) notion of "hyper-reality." Hyper-reality arises when copies and images of the original, perhaps created by publicists and other spin doctors, become the reality that is taken seriously. Celebration, a town in Florida managed by the Disney Corporation, is the "reality" derived from Disney movie myths of what a town should be. Technology allows copies to possess superb quality, thus devaluing the exemplar and often making it indistinguishable from copies. In postmodern art, technology not only allows the juxtaposition of Marilyn Monroe with the Mona Lisa to create a new image but also allows for near-instantaneous global distribution. Which is the original? In the hip-hop music scene, the practice of "sampling" previous recordings has created a new frontier for copyright.

All of these examples show that the original, along with its external referent to a shared reality, is denied privilege over copies. Quality shifts away from the realism of the message in the merely modern world to the technical achievements necessary to maintain hyper-reality under postmodernism. Thus, the maintenance of quality in a postmodern world becomes problematic: If one tears down the elite high culture of critics and does not base standards on easily identified "originals," how will standards and quality be maintained? For Funtowicz and Ravetz, high standards lie in defining and practicing "post-normal science" (1992, 1993, Ravetz 1999), which confronts this contradiction of our time with an explicit emphasis on quality.

According to Funtowicz and Ravetz (1997), postnormal science needs better definitions of quality to circumscribe good science. They refer to Robert Pirsig's distinction between *structural* quality and *dynamical* quality (1974, 1992). Structural quality is elaboration of form or relationship such that there is reliable desired function, which is achieved only with difficulty through care. Structural quality is primarily static, is responsible for high-quality day-to-day performance, and is exemplified by Thomas Kuhn's (1962) "normal science" or Joe Friday's style of detective work. Dynamical quality is an improvement on structural quality, because it denies the premise on which particular structural qualities are based. Dynamical quality is the antithesis of structural quality. It is creative, and so changes the functioning of what is already functioning well in a state of high structural quality. The priest represents structural quality: He is always there to give sermons and offer absolution. In contrast, the prophet shows dynamical quality: Do not expect him to turn up to hear confession when the parishioner needs it; he is too busy turning over tables in the temple (Funtowicz and Ravetz 1997).

Like a good ministry, good science has high structural quality in the care and consistency of its methods (the "give me the facts" account). But scientific process also prizes high dynamic quality, in the constant challenges to prevailing models at every level: the confrontation of the null hypothesis every time an experiment is performed; assaults on paradigms, as when plate tectonics challenged the view of fixed continents in the 1960s. By contrast, the messages in the tabloid press do not deserve the privilege of being taken seriously precisely because they are concocted with minimal observation and are not subjected to challenge in the process of their production. The fact that the tabloid press is believed by a large number of people does earn it a certain currency, but in a different arena of discourse. The privilege of science, the reason why it should still be taken more seriously than idle journalistic opinion, thus rests on meticulous observation combined with confrontation and self-reflection.

Whereas in a modern world there is a belief in an ultimate true reference, in a postmodern world there is no such belief. In a postmodern world there are only narratives, and you must take responsibility for the narratives you tell. It is inadequate to pretend some direct connection to truth and ontological reality when the scientist dons the white coat of authority. Remember the line in the 1984 movie *Ghostbusters*, "Back off, man, I'm a scientist." Instead of falling back on this outmoded authority, scientists must see their work as creating narratives. Narratives always have a narrator, who chooses when was "once upon a time," and when "they all lived happily ever after." The beauty of narrative is that it is a powerful device that normalizes across scales. Narrative deals with sequences of events, and although events may be time dependent, they are also rate independent, and so possess a structural quality that makes events into static things. It is possible to link them in equivalent terms, be they large and slow or fast and ephemeral. Narratives can normalize events of different spatial and temporal scales so that they can be linked in one narrative in an unequivocal order. An earthquake can be followed by a decade-long drought, and then the arrival of the first individual of a species of invasive insect. Narratives are selective in what they report and the meaning they impart. Most of the analysis of narrative as a way of knowing and creating disciplinary knowledge has been done in the humanities and social sciences, but the natural sciences can benefit from being more explicit about narrative. Although the calibrations in science may not be richly narrative, the synthesis that is the raison d'être of the calibration is in fact a narrative, even if the scientist does not normally think of it that way.

An example of how a narrative perspective can shape science can be seen in Cronon's comparison of two historical narratives. Cronon (1992) looks at accounts of the historical ecology of the Great Plains. He notes that Bonnifield (1979) and Worster (1979) appear to agree on most of the facts of the white settlement of that region and the events immediately following the ecological disaster of the Dust Bowl. And yet Bonnifield's story is heroic, with the European Americans changing their technology to accommodate drought, while Worster's narrative is a tragedy of ecological degradation. Tragedies have a certain structure. That is, an accidental death is not a tragedy; a tragedy would be more like what befell Oedipus, who married a woman who, unbeknownst to him, was his mother. Cronon quotes the heart-rending closing lines of the autobiography of Plenty-coups, chief of the Crows: "After the buffalo went away, the hearts of my people fell to the ground and they could not lift them up again. After that nothing happened" (Linderman 1962, p. 311). Cronon continues, "The story that Plenty-coups loved to tell ended when the buffalo went away. All subsequent happenings were part of another story and there was neither sense nor joy in telling it.... After this nothing happened: not frontier progress, not the challenge of adaptation to an arid land, not the Dust Bowl. Just the nothingness that follows the end of a story" (p. 1367). How can there be agreement on the facts, as some science would have it, but diametrically opposed narratives in the minds of Bonnifield and Worster, or no narrative beyond the end of Plenty-coup's story?

The critical point is that scientists always use narrative, and thus benefit from being self-conscious narrators. Science cannot make an infinite number of observations, and so selects, just like a narrator (Feyerabend 1962, Tainter and Lucas 1983). Narrative is always selective and gains significance from how events are signified, as does good science when it gives reasons for its interpretations. As Cronon (1992) shows, two historians (they could have been scientists) with the same "facts" in front of them can construct two entirely different scenarios simply by changing the narrative. The full chronicle helps not a bit, because not only is a full accounting of everything an impossibility, it is not a narrative, because no narrator has decided what mattered. Neither is attempting to make science account for everything a proper narrative, but is instead some version of laboratory stamp collecting. A narrative is not a chronicle of everything that happened, so there is no such thing as the ultimately true story. Therefore, in narrative, ultimate verity is beside the point.

A logically consistent, formal model in science, much the same as a consistent narrative, is not in itself either true or false. All a model says is that if the world worked in such and such a fashion, then such and such results would follow. And they would! For instance, despite criticism of their usefulness, Lotka–Volterra equilibrium-based models are not false. The fact that material populations only sometimes appear to live up to Lotka–Volterra assumptions is a different matter. Of course, making mistakes in a model's formulation does give wrong results, but such models are not logically consistent. While there is a plurality of stories that are consistent with the facts, some narratives are plain false. Like a false narrative, the use of the model by Ruckleshouse et al. (1997) was just plain wrong, fully at odds with how they achieved the reported results, a fact that blunts the attacks on individual-based models by Karieva and his colleagues (Meir and Karieva, 1997, Karieva et al. 1997; see Mooij and DeAngelis 1999 for details). Scientists do have to be internally consistent and get their sums right, but that is just the beginning. In our view, the strength of scientific models lies not in their verity, nor even in their approach to the truth. Scientific models are at their best when being used to test the consequences of making their assumptions.

Assumptions underpin models, and all assumptions are, in a sense, false. For instance, identifying an object or structure in space is an arbitrary assertion that there is discontinuity, when in fact a closer look identifies that the object in question has fuzzy boundaries, and so embodies a degree of continuous change. Therefore, truth in assumptions is a moot point, and the scientist is not trying to ascertain which assumptions are true. While confirmatory science makes reasonable assumptions and gets reasonable results, normal science's refutation is more powerful. Unreasonable results are helpful in that they point to a flaw in logic or an assumption one cannot afford to make. Counterintuitively, it is often particularly useful to make unreasonable assumptions. Of course, a combination of unreasonable assumptions and unreasonable results invites the comment "What did you expect?" However, the combination of unreasonable assumptions and reasonable results is cause for celebration (see Figure 3). For instance, the primitive individual-based models for forest simulation, such as the FORET models of Shugart and West (1977), make grotesque assumptions about the arrangement of trees on the ground. Yet the models give remarkably reasonable results, when their parameters have been tweaked. The upshot of their discovery is that the most important constraints in a forest are all vertical, so data about tree placement in detail can be safely ignored for most purposes, a useful thing to know. Scientists use models to find out which assumptions they can afford to make, and when. Science identifies which lies we scientists can tell and still get predictions. We learn more when assumptions of models demonstrably fail than when assumptions appear to be verified.

The challenge of complex systems

Like Joe Friday, we might avoid all the complications by keeping things simple. We can avoid complications, but the cost is that we cannot then put together answers for complex

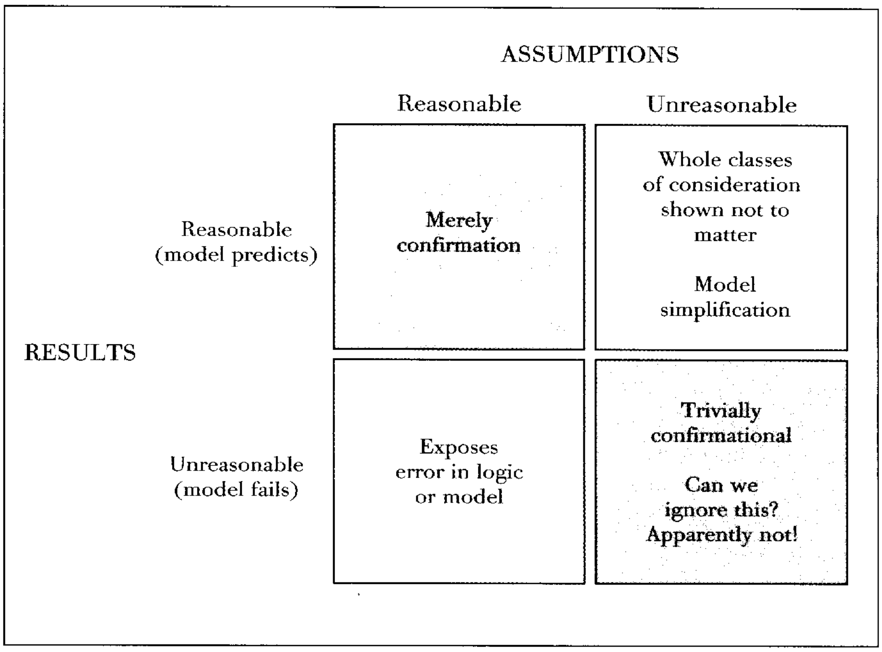

Figure 3. Reason and assumptions: Strategies for science. Assumptions may be reasonable or unreasonable, and can be useful in both forms. Results can either be reasonable as predicted or unexpected and unreasonable from the position of the prior logic. This gives four possible combinations, and science uses all four possibilities at different stages and with different styles of investigation.

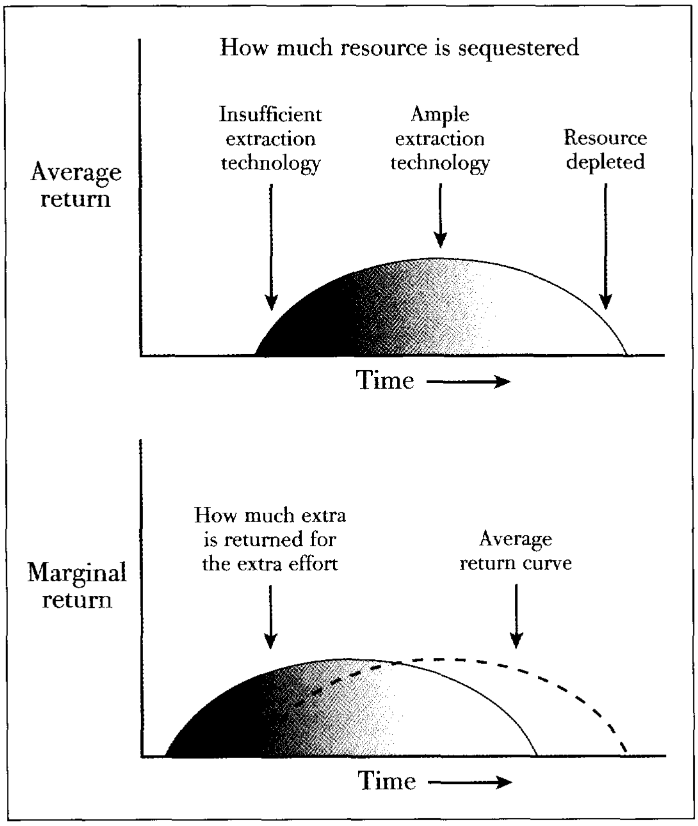

Figure 4. Diminishing returns: Marginal returns against time. The cost of problem solving generally increases and the benefit decreases as the easy solutions are replaced by difficult solutions. The marginal return curves in economics show diminishing returns on effort. Some societies have managed to complexify anew with subsidies from territorial or fossil fuel inputs. These societies entered new marginal-return scenarios with better returns, but these returns in turn diminish.

systems. We do not need to philosophize much about the truth in narratives in simple situations, but confusion reigns if the narrator fails to take responsibility for the narrative when the situation is complex.

The fixed protocols of simple systems disarm complex systems by imposing an effective social normalization so that there are no surprises. The price is a ritualized paradigmatic dance whose purpose is to keep complexity caged. A paradigm change modifies protocols, vocabulary, or tacit agreements not to ask certain questions. At that point, the simple system is allowed to escape and becomes again a complex system. In escaped or still-wild complex systems, things appear from nowhere, as continuous change finally forces a discrete change. In complex systems, each stakeholder must decide on what is continuous as opposed to discrete, what constitutes behavior as opposed to structure, and what is dynamical as opposed to meaningful, or rate dependent as opposed to rate independent (Pattee 1979).

Most important questions in ecology and resource management are complex. As an extended example, we consider changes in human and animal use of resources, with a view to clarifying scientifically the policy issues of the First World's energy future. Societies are always constrained by resources, but the constraints are more often subtle and indirect than simple and immediate. Complex societies, for example, have historically collapsed, not directly because of resource shortages, but indirectly through the effects of diminishing returns on problem solving (Tainter 1988, 1995). Human societies tend to apply the easiest solutions first, so that problem solving grows progressively more costly. As the cost of solving problems (including problems of resource capture) grows and net benefits decline, inefficiency and economic weakness make simplification likely or even attractive (see Figure 4). Sometimes societies manage to subsidize complexity through new energy sources, as ancient empires attempted by spatial expansion (Tainter 1988, 1994) and recent societies have done with fossil fuels (Wilkinson 1973).

Understanding these problems of complexity demands a new kind of analysis. Allen and colleagues have distinguished recently between processes that complicate and those that complexify (Allen et al. 1999, Allen 2001). On the one hand, complications arise in the horizontal proliferation of similar structures: more bureaucratic offices to resolve society's problems, or more computer programs to find and filter information. Complexification, on the other hand, involves the emergence of new levels of organization with new rules to constrain behavior. Complication elaborates existing structure, while under complexification new organization emerges (see Figure 5). Such new organizations in complexification may arise through feedbacks that result from novel steep gradients, often of raw energy. While complication is the addition of structure financed by increasing debt or the acceptance of diminishing returns, complexification emerging through such feedbacks depends on energy that is newly available. Without energy to support them, complexifying positive feedbacks languish as potentialities (see Figure 6).

Complexification simplifies behavior because the new, steep gradient forces energy to flow always in one direction. With the large flux on the gradient, positive feedbacks emerge until negative feedbacks generate constraints. When constraints are encountered inside the system, the behavior of the system's parts is reliably pinned against those constraints by the powerful flux down the gradient, making the system behave simply and predictably (Figure 7). This process can be seen, for instance, in ants that cultivate fungi, the emergence of whirlpools, and human societies that acquire new energy subsidies.

Societal complexifications, in the form of the acquisition of new resources, reset the problem-solving process by discretely moving the goalposts. The initial cost comprises the expense of discovering the new resource, learning how to use it, and developing infrastructure to harvest, process, and distribute it. Compared to the cost of maintaining the old system a little longer, such investments in new resources initially seem costly to decisionmakers. That explains why, in human history, there is resistance to making the initial moves that lead

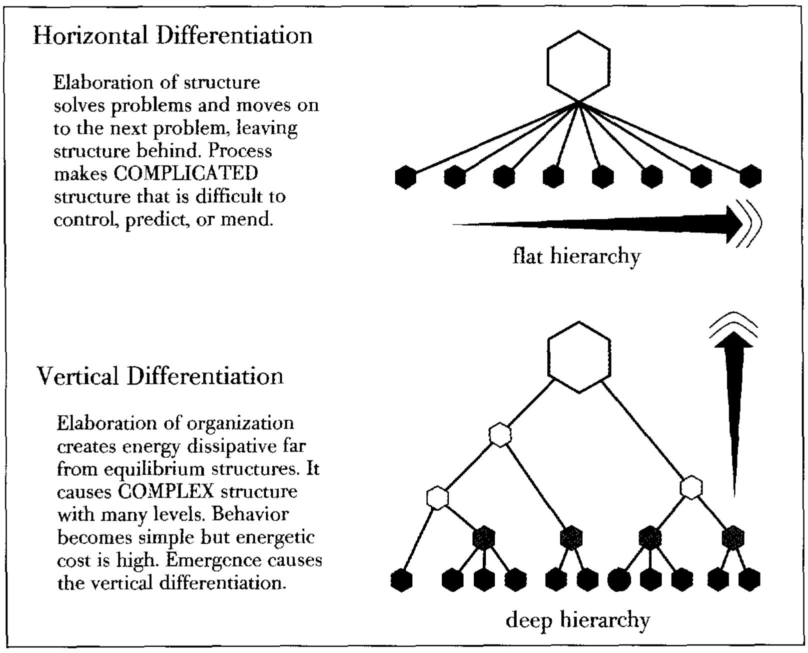

Figure 5. The distinction between continuous processes of complication and discrete events of complexification. Complication elaborates existing structure with symmetric relationships, whereas complexification elaborates organization through new asymmetric relationships.

to societal complexification. However, once the change to a new resource is achieved, it produces increasing returns as positive feedbacks (e.g., technologies) emerge to use the resource creatively. Thus, energy dissipation in the aftermath of complexification increases considerably, so that, in comparison, the cost of bringing the new resource on line is small. Before complexification, the cost appears great, but in retrospect, after the resource goalposts have been moved, the energetic cost of the transition appears trivial.

Ants of the *Atta* genus are instructive here. *Atta* species farm fungi on various organic resources, and they make an interesting comparison to human agriculturalists (Rindos 1980). Species in a related genus determined by systematists to be primitive use caterpillar feces as the substrate (Weber 1972). If you are raising fungi, guano is jet fuel. The advanced ants are the famous leaf-cutting ants, with their large and elaborate colonies, highways through the jungle, and great gardens of fungi on cut leaves (Burd 1996). Both the caterpillar-feces-using ants and the leaf-cutting ants represent complexifications beyond regular ant organizations. It is no accident that the leaf-cutter colonies are larger and more complicated in their arrangements than colonies of the primitive caterpillar-feces-using species. Leaves are closer to the sun in the energy stream and so are a ubiquitous source of energy. The lower-quality energy in leaves requires development of highly self-organized ant colonies to make the energy capture worthwhile. Caterpillar feces are made of highly processed material, at least two trophic levels away from primary production. In contrast to the low-quality energy in leaves, the high-quality energy in guano works as an externality to organize the ants.

Funtowicz and Ravetz (1997) are explicit in their use of the word *quality* to refer to quality of narrative in science and quality of energy in a thermodynamic setting. For them the relationship is stronger than an analogy, in that the two sorts of quality are equivalent. Dynamical quality in human endeavors demands the destruction of static quality of exquisite order. In the same fashion, in order to measure quality of energy, a physicist has to use up that quality in doing work, in the strict energetic sense of thermodynamics. It is no accident that we immediately recognized high-gain, high-quality resources as the example to use in this section of the article to help explain how to seek high-quality narratives in applying science in a postmodern world.

It is also no accident that the caterpillar-feces-using ants are the primitive species. If evolution is going to achieve such an unlikely setup as fungi farming, the path to the elaboration must be energetically easy. Caterpillar feces are the easiest point of entry into such an organization, so that is what the primitive species use. It is a simple matter, although not very scientific, to invent narratives for how ants began to farm on caterpillar feces. Perhaps ants gathered fungi and brought them to the

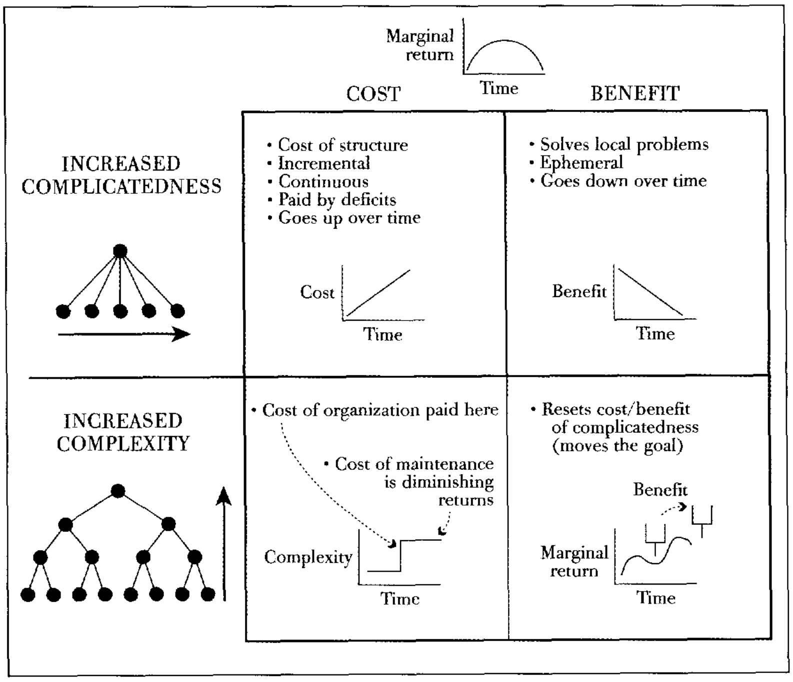

Figure 6. The costs and benefits of complication and complexification. The cost of becoming complex is different from the cost of maintaining complexity.

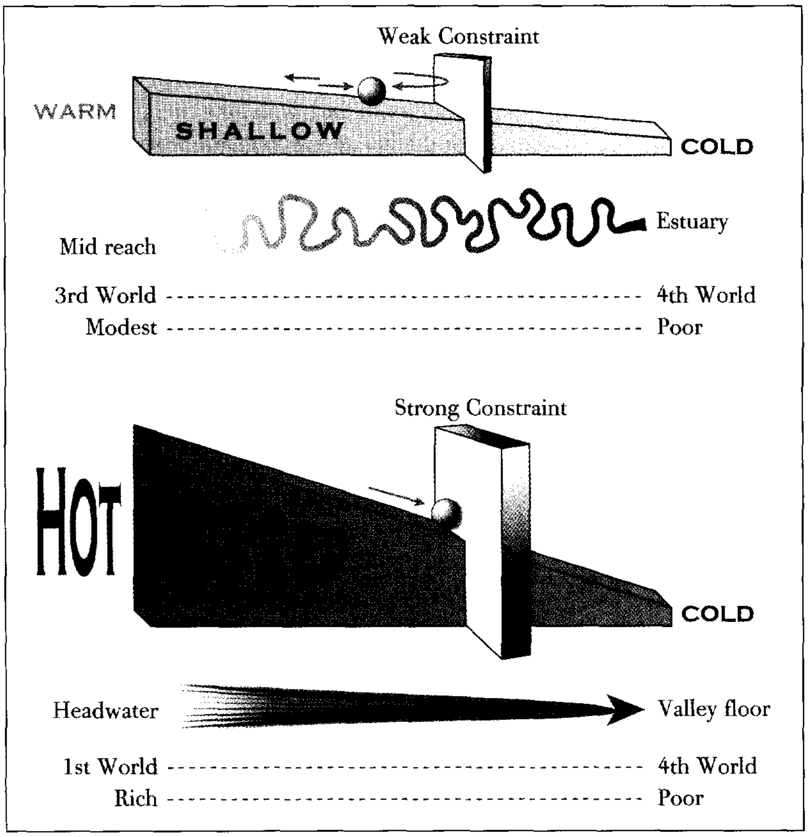

Figure 7. Steep gradients generate structure. If a gradient of energy, resource concentration, or riches is shallow, there is little tendency toward flux in any direction. The weak flux cannot support positive feedbacks, so no new structure emerges. If the gradient is steep, and the flux down the gradient is great, positive feedbacks emerge on the back of the resource dissipation. These feedbacks run until they come to lean against negative feedbacks, which are the parameters of the new, higher level of organization.

colony along with some substrate. The accumulation of substrate could plausibly get the farm going by accident. The point is that, by contrast, reasonable scenarios for the origins of leaf-cutting ants do not come to mind, because it is altogether a more difficult arrangement to get started. Gould (1998) refers to Rudyard Kipling's *Just So Stories*, such as the fanciful tale of how the leopard got his spots. As a children's story it is of high quality. However, Gould complains that "just so" evolutionary scenarios, such as textbook accounts of the length of the giraffe's neck, are low-quality speculation. There are many narratives, and we scientists must distinguish those of high quality. There is logic to saying that leaf cutting for fungus farms would have to arise as a modification of some other form of fungus farming, and it is supported by ant systematics. This logic and support from normal science make a narrative of entry into leaf cutting via guano gathering a high-quality narrative.

A general case is suggested here. We characterize energy sources on a spectrum from high to low gain. High-gain resources consist of concentrated energy but, being several steps removed from primary production, are of limited availability. They yield high net energy—that is, high return on acquisition costs—but may foster or even require centralized distribution. Low-gain resources are closer to primary production. They yield lower net energy, but are widely and easily available. Low-gain resources are often dispersed, and most efficiently used correspondingly. They yield energy gains that are slight in the individual instance but great in the aggregate.

Highly organized systems exist far from equilibrium, for they exist under significant energy inputs that are then dissipated to achieve order. It helps to distinguish energy dissipation from energy degradation. All these systems dissipate energy and resources by degrading the quality of inputs. If the input is resources of high quality, then degradation is easily achieved, and the favored strategy is to dissipate resources inefficiently. If the resource is of low quality, then dissipation to match that of the inefficient system with high-quality resources is hard to achieve. However, it can be done by efficiently degrading the low-quality resource to a much greater degree. Thus, efficiency becomes the touchstone. Table 1 links these energetic considerations to degree, type, and scale of organization that emerges in the system. As an example, we counterpose guano ants with leaf-cutting ants, so that those attributes that are distinctly characteristic of human systems lower in the table may be understood through a more value-neutral biological system.

Order in a complex system depends on the order that is carried in free energy. To enter a fundamentally new arena of resource capture, the easiest route is to use an energy source with as large a concentration of free energy as possible. High-quality energy sources embody the organization that can then support the system that employs the resource. In the case of Attoid ants it is the high-gain resource of caterpillar feces. In a later complexification, it is then possible to move closer to the sun, and employ a ubiquitous low-gain energy source. The general pattern applicable to understanding human societies is therefore the succession from high-gain to low-gain complexifications, as resource capture becomes organizationally more elaborate. As with ants of the genus *Atta*, the larger accumulation of capital is potentially in the phase of low-gain resources, because there is functionally no limit to the quantity of energy that is close to the sun (Figure 8).

The foraging activities of the American Indians of the Pacific Northwest provide an example of resource capture as practiced by humans. These people used concentrated, high-gain resources (salmon runs) whenever they could (Suttles 1990). When only low-gain resources are available, foragers must disperse across the landscape, even in individual families (Steward 1938, Lee 1968, 1972). Conversely, agriculture permits sedentism by simplifying ecosystems, intentionally favoring domesticated species. Agricultural fields are energetically close to the sun and fundamentally low gain, so they must be dispersed. Yet subsistence agriculturalists may be coaxed or coerced into producing individual surpluses that cumulatively can support complex hierarchies and even empires. The expansive tendencies of ancient states had the consequence of increasing the land area from which a dominant power could capture solar energy. Yet for a one-time, high-gain infusion of capital from each dominated people, a conqueror would have to assume garrison and administrative costs that could last centuries. It became necessary to pay for new complex superstructure out of the low-gain surplus of yearly agricultural production (Tainter 1988). Empires, consequently, never lasted.

For millennia, humanity bumped against the constraint of low-gain subsistence agriculture. Then, in Britain, accelerated population growth during the past millennium resulted in the depletion of wood supplies so that people had to rely increasingly on coal. A set of related positive feedbacks—efficient steam engines, canals, and railways—led to the structural changes known collectively as the Industrial Revolution (Wilkinson 1973). The gradient of high-gain fossil fuels, coupled to industrial production methods, in turn supported greater levels of complexity than were ever before necessary or possible.

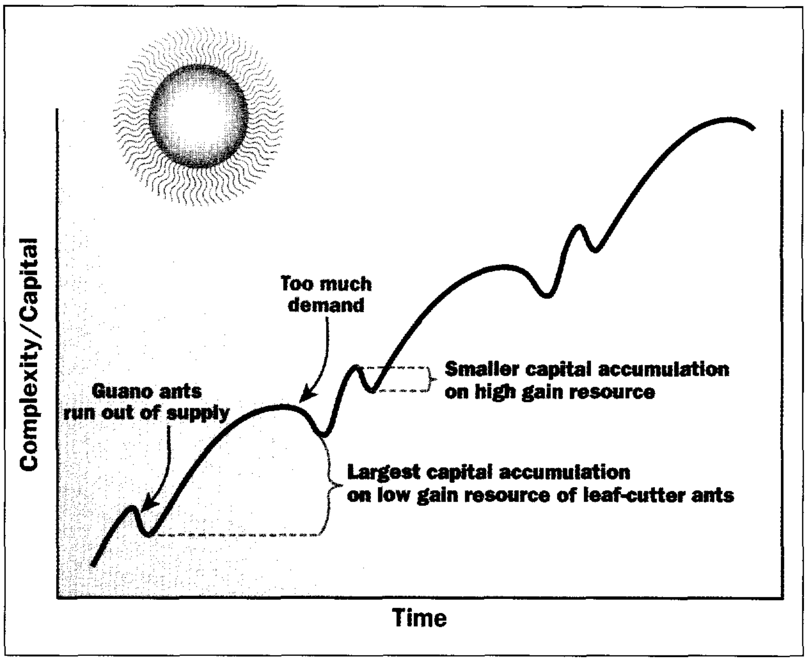

Figure 8. Contrasting use of high- versus low-quality resources. High-gain phases cause organization simply by using the high-quality resource. The complexification is short lived, since the resource becomes depleted. High-gain complexification can, however, lead to exploitation of low-quality but ubiquitous resources in a second round of complexification. Because the low-quality resource is plentiful, much capital can be accumulated in a low-gain phase. The end of a low-gain phase results from the buildup of excess demand.

Table 1. Comparison of systems on the basis of resource quality.

A system with a high-quality resource	A system with a low-quality resource
Uses a steep energy gradient	Has been forced onto a shallower gradient
Remains small and local	Exploitation expands across space
Exploits a new type of resource use	Expands an extant resource use
Is dissipative and inefficient	Degrades energy more efficiently
Uses resources that are abundant	Uses resources that are scarce
Experiences minimal demands	Experiences great demands
Is more organized but is impressive in its capture of energy	Captures more energy but is impressive in its increased organization
Lasts a short time	Lasts a relatively long time
Is self-organized by its history	Is organized by an external design element
Creates new levels at the top of its hierarchy	Inserts new levels in the middle of its hierarchy
Can be controlled only by altering context, so the gradient cannot regenerate structure that thwarts management actions	Has insufficient generative power to overcome management actions that manipulate critical parts
Has a steep gradient that makes high-gain expansion probable	Has a shallower gradient that leaves low-gain transition subject to chance

This discussion confirms that one option for the human energy future is to use the current output of high-gain energy as a springboard to a phase of low-gain, dispersed energy sources such as wind, solar, and wave power. Like *Atta*, the First World would not be able to enter this low-gain future if it had not first gone through a high-gain phase that produced the knowledge, capital, and technology to make it possible. In complex systems, the trajectory is strongly influenced by historical accidents. Thus, the precise route to the energy future of humanity cannot be foretold in detail, but general scenarios can be anticipated.

One route to the human energy future—perhaps the most likely one—is to continue to develop centralized infrastructure for the present petroleum and electrical distribution systems. For a while, this route continues to institutionalize high-gain energy, but comes to rely on high-sulfur coal, tar sands, and oil shale. Environmental degradation would occur as extensions of the present-day problems of sulfur and global warming. Eventually, these dirty and difficult sources of carbon become too expensive, but the period over which they are used allows time for a move to low-gain sources of energy, such as wave, wind, or solar, but in a centralized fashion. While many advocate a future that relies on renewable energy, its full implementation would not make good environmental news: Entire coastlines would be modified to capture wave power, while deserts would be covered with arsenic-containing solar panels. The century or so of dirty carbon use would provide the massive infrastructure, and the central distribution system would remain useful before, during, and after the transition to renewable, low-gain energy.

In an alternative narrative description, the First World rapidly abandons the centralized distribution of the present high-gain phase, in a shift that is abrupt, traumatic, and impoverishing for many. In this low-gain future, diffuse energy is captured by dispersed technologies, and much of the centralized energy infrastructure becomes unnecessary. There would be great political conflict over such a path. The diffuse system would gradually consolidate over time, much as primitive dry agriculture led to massive Sumerian hydraulics. In the end, the full flowering of renewable energy resources would generate concentrated electricity that would be used to make hydrogen, and so lead to the same place as the first scenario. Notice that both nuclear and renewable energy sources share comparatively low-gain energy characteristics, in that they are both closer than chemical carbon energy to the ubiquitous energy of the atom. With nuclear energy, fission power applies, whereas with wind, wave, and solar, the energy source is the fusion power in the "renewable" energy of the sun.

These narratives differ in the rates of structural change that they foresee. Yet under either scenario the energy future is like the present in one way: There is no simple answer, no solution that is clearly preferable. All answers depend on scale, so that one must always ask: *Cui bono*? (Who benefits?) Individuals, firms, nations, ecosystems? All paths involve calculation of the ever-shifting balance of the benefits society desires versus the costs it is willing to bear. The overarching goal should be an energy future that can yield positive feedback and increasing returns, and so can finance complex efforts at problem solving (Tainter 1988, 1995). In characteristically postmodern fashion, science and society can see this future as consisting of nothing more definite than possibilities, contingencies, and infinitely varied shades of gray. We must treat the future as a complex system.

Conclusion

In postmodern style, Norman Mailer (1968) took exception to conventional journalism, which always tries to give both sides of the story, as if there were only two. The *New York Times* "was not ready to encourage its reporters in the thought that there is no history without nuance." He preferred to report a rich picture of what it was like to be there at the 1968 Democratic convention police riot in Mayor Richard Daley's Chicago. We need new myths for new times, and the myth of the fair-minded, evenhanded journalist is as inappropriate as the myth of science finding the truth.

The postmodern world denies science the privilege of being objective. But that does not and should not mean science has lost its privilege as something that should be taken more seriously than most other human endeavors. It is important that much science should continue to be conducted in a narrowly focused arena of discourse, so that we scientists get high-quality models of how various small bits of scientific models and their corresponding materiality work. We need to continue to be meticulous and quantitative. But more than this, we need scientific models that can inform policy and action at the large scales that matter. Simple questions with one right answer cannot deliver on that front. The myth of science approaching singular truth is no longer tenable, if science is to be useful in the coming age.

Joe Friday can handle simple situations, but if you have a complex problem it is better to follow the lead of Agatha Christie's Miss Marple. Rather than constrain little old ladies to give "just the facts, ma'am," Miss Marple engages the ladies of the village, and weaves a complex narrative. Her story is created from careful, rich observation, not just of what people say, but also of the manner in which they hesitate or are circumspect as they say it. Miss Marple imposes dynamical challenges on what she is told. As she tells her narrative, Miss Marple most particularly takes responsibility for being the narrator, and with Bill Gannon's sensitivities, she even lets the foolishly or incidentally guilty off the hook.

The material world will not tell you what decisions you must make as a scientist, much as a statistician does not tell the scientist which decision to make. Informed as to the consequences and probabilities associated with a decision, good scientists make up their own minds, and take responsibility for that. Science can offer a high-quality justification for making decisions and taking actions, and scientists must not shirk that responsibility just because the situation faced by everyone in policy and resource management is complex. Indeed, because the situation is complex, policymakers, managers, and the lay public need scientific counsel all the more. Because the situation is complex, as opposed to merely complicated, scientists need to recognize that the most valuable contributions are not proof and truth, but good judgment achieved in an intellectually honest arena of discourse. It is dishonest, or at least it shows a lack of courage, to pretend we live in a classical or modern world. It is now a postmodern world, with its attendant responsibility for determining what constitutes structure, continuity, behavior, and all the other possible devices for description and representation. Instead of retreating to naive objectivism, scientists need to adapt to a postmodern age by becoming conscious of the significance of their narratives. Reconceptualizing science and scientific privilege at the science–policy interface is not just exciting, it is necessary.

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