Limitations of science and adapting to Nature

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Received 12 December 2006
Accepted for publication 5 July 2007
Published 17 July 2007
Online at stacks.iop.org/ERL/2/034003

Abstract

Historically, science has pursued a premise that Nature can be understood fully, its future predicted precisely, and its behavior controlled at will. However, emerging knowledge indicates that the nature of Earth and biological systems transcends the limits of science, questioning the premise of knowing, prediction, and control. This knowledge has led to the recognition that, for civilized human survival, technological society has to adapt to the constraints of these systems. Simultaneously, spurred by explosive developments in the understanding of materials (non-biological and biological), applied scientific research pursues a contrary goal of controlling the material world, with the promise of spectacular economic growth and human well-being. If adaptation to Nature is so important, why does applied research pursue a contrary course? Adapting to Nature requires a recognition of the limitations of science, and espousal of human values. Although the concept of adapting to Nature is accepted by some, especially conservation ecologists, such an acceptance may not exist in other fields. Also, in a world dominated by democratic ideals of freedom and liberty, the discipline required for adapting to Nature may often be overridden by competition among various segments of society to exercise their respective rights. In extreme cases of catastrophic failure of Earth or biological systems, the imperative for adaptation may fall victim to instinct for survival. In essence, although adequate scientific know-how and technological competence exists to facilitate adaptation to Nature, choosing between that and the pursuit of controlling Nature entails human judgment. What that choice may be when humans have to survive under severe environmental stress cannot be predicted.

Keywords: science limitations, adaptive management, adaptive governance, resource management

1. Science and its limitations

Modern science endeavors to precisely describe the material world with numbers, and to predict and control the behavior of Earth systems for human benefit. Nevertheless, the credibility of this goal of prediction and control is becoming questionable as knowledge of Earth’s environmental and biological systems accumulates. Although geological processes are comprehended within the framework of mechanics and thermodynamics, precise quantification of Earth systems is exceptionally difficult, or even impossible, owing to difficulties of access and observation, sparsity of data, multiplicity of spatial and temporal scales, heterogeneity, coupling among diverse processes, feed-back among system components, and unknown forcing functions such as climate. The Earth’s biological systems pose a different challenge. Though much is known about the material make-up of living things, the non-material phenomenon of life itself has not been brought within science’s logical framework. Living things possess mind (or instinct), an attribute not possessed by inanimate objects. They have a will to survive, and the necessary ability to adapt. Survival, in turn, may involve a single individual, or a collection of individuals. While the instinct for survival of an individual may be rationalized in terms of a discriminating
mind, the question of how a whole species may sense its surroundings, evaluate consequences, and initiate suitable physical and chemical changes in the bodies of individual organisms for survival eludes comprehension. Darwin’s theory of evolution is observationally established, but science knows little about life’s abstract attributes that underlie evolution.

In the case of humans, qualities such as emotion, spirituality, aesthetics, morality, and values further complicate quantified understanding. These qualities are characterized by pairs of opposites such as love and hate, compassion and violence, greed and generosity, and rationality and irrationality. Invariably, human behavior depends on the relative magnitudes of these pairs of opposites that may coexist in a given situation. Consequently, human decision-making is subject to inherent unpredictability. Inanimate systems conform to immutable physical laws that have existed for billions of years. In contrast, laws and values governing human societies are transient (Narasimhan 2003).

Earth and biological sciences are interpretive and historical (Frodeman 1995). They can explain observed patterns with varying levels of quantitative detail. Extrapolating knowledge of the past to the future, however, is beset with uncertainty and imprecision (Scriven 1959). Mathematical models and computational tools are of practical use in providing insights about possible responses (rather than prediction) of Earth and biological systems over the near future. The primary value of these models is heuristic (Oreskes et al 1994).

2. Adapting to Nature

How then may humans sustain on a finite earth in which behavioral patterns of life-supporting natural resource systems can be understood, but cannot be predicted or controlled? Reason suggests that society must adapt its functioning to the constraints imposed by the nature of these resource systems. This general need to structure patterns of living within constraints that lie beyond human understanding or control may be referred to as ‘adapting to Nature’. Adapting to Nature in this philosophical sense has especially been recognized by ecologists and conservation biologists, as evidenced by an impressive body of literature on the topics of adaptive management or adaptive governance, devoted to a judicious management of wildlife populations, habitats, and ecosystems. In what follows, adapting to Nature is used in a broad sense of humans patterning their lifestyles in such a way as to have minimal negative impacts on natural resource systems. In general, adapting to Nature consists of timely recognition of unintended consequences of human actions, and initiation of changes in resource use patterns to avert deleterious responses of the systems involved.

The central challenge in adapting to Nature is planning for uncertainty of future resource availability. To this end, three approaches are commonly pursued: quantifying uncertainty, risk-based management, and monitoring of resource systems.

Quantification of uncertainty is based on probability theory and associated statistics. Estimates of probability, credible in the case of mutually independent discrete events, become progressively less so when the desired outcome depends on an increasing number of mutually influencing events, leading to conditional probability. Such mutual influence of a number of poorly known causes is the rule in the case of natural disasters such as earthquakes, hurricanes, droughts, or epidemics. Therefore, probabilistic estimates of the behavior of complex natural systems are of qualitative value at best under favorable circumstances.

Risk-based management is founded on the premise that potential benefits or losses of human ventures can be quantified in terms of a common denominator such as money, and that the relative ‘costs’ involved constitute a reliable measure to guide decision-making. Such an approach may be credible in narrowly defined ventures in which costs and benefits can be numerically quantified with some confidence. But, as the scope of a venture broadens to include an increasing number of components of Earth and biological systems, risk-based management too will be of qualitative value under favorable circumstances. Money is perhaps the most widely used common denominator in assessing risk. Yet, variations in the value of money from one component of society to another are so variable and transient that money cannot credibly serve as a common denominator when many segments of society are involved or when a venture cuts across national borders.

The limitations inherent in probabilistic analysis and risk-based management indicate that adaptive strategies will invariably have to rely on experience, or at best, semi-quantitative knowledge.

The rationale for monitoring is that it will (a) help continued learning about the nature of the systems of interest, and provide data for progressively adjusting the parameters of mathematical models, and (b) provide early warning of unforeseen consequences of human action so as to initiate timely corrective measures. Clearly, monitoring is essential for adapting to Nature.

In providing a geoscience perspective of earth resources, time and man, a committee of the International Union of Geological Sciences reflected on the future welfare of mankind, based on a knowledge of the world’s energy and mineral resources, and a consideration of the environment, ecosystems, and water resources (von Engelhardt et al 1975). The overall conclusion was that mankind is in a state of transition from a brief interlude of exponential growth to a much longer period characterized by very low growth or non-growth. The authors pointed out that, although the transition poses no insuperable scientific or technological difficulties, it required a revision of contemporary economic and social thinking of indefinite economic growth. Failure to respond promptly to the impending changes, they concluded, could lead to a catastrophic collapse of our global technological civilization. In essence, these earth scientists strongly pleaded for a need for adapting to Nature, failing which humanity could face devastating consequences.

3. Contrary trends

Although earth scientists and ecologists have, over the past few decades, recognized the imperative for adapting to Nature, it appears that the concept is appreciated by only a relatively
small section of the larger scientific community. This, in combination with explosive developments in materials science, bio-engineering, and information technology, has resulted in a current atmosphere of technological optimism for vigorous economic growth indefinitely into the future. Consequently, there exist social trends that contradict adaptation to Nature. For example, research is vigorously pursued to eradicate major diseases, or to prolong human life indefinitely through genetic engineering, novel materials, or nanotechnology. Scant consideration is given to the possibility that the material and psychological consequences of simultaneously supporting several generations of population can be as devastating as that of population explosion. Nor is attention given to the possibility that as science succeeds in controlling some diseases, Nature may respond with more virulent new maladies. In this atmosphere, impelled by aspirations of economic growth, rich and poor nations alike pursue policies of rapid resource depletion, environmental degradation, and endangerment of ecosystems. Legislators and policy makers who eagerly reap the benefits of science for economic growth are less comfortable in heeding what the same science has to say about the imperative for adapting to a finite Earth.

Central to the venture of adapting to an unpredictable Nature is continuous gathering of information through systematic monitoring of natural resource systems. Nevertheless, the concept of monitoring is often not looked upon favorably by those who develop and exploit natural resources. An innate concern is that monitoring might reveal information that may negatively impact resource use. Also, systematic monitoring of natural resource systems can be expensive. For these reasons, monitoring as a necessary adjunct for adapting to Nature is a concept that is as yet to gain the acceptance it deserves.

4. Science and societal attitudes

That science has limitations in comprehending Earth and biological systems does not negate its role in facilitating adaptation to Nature. Rather, the recognition calls for an examination of science as a human enterprise, and how society may draw upon science to facilitate adaptation to Nature.

During the nineteenth century, Maxwell (1864) and Thomson (1891) were so impressed by quantification as to believe that there was no science without numbers. This perception gained strength subsequently with explosive developments in the physical sciences. However, from what we now know about the functioning of the Earth’s hydrological, nutrient, and erosional cycles, the tenet that there is no science without precise quantification is open to question (Hubbert 1974).

As for social attitudes, democracy is presently the preferred form of governance around the world. Coming in the wake of political oppression, democracy is considered by many to be synonymous with rights of citizens. These rights, artifacts of transient human values, may not often be compatible with physical laws that govern the behavior of natural systems vital for human survival. Regardless, policies, regulations and laws are regularly set in place that are designed to assure citizens’ rights. Recognizing this, some countries are moving towards amending their Constitutions so that adapting to Nature may become more possible. In 1991, New Zealand enacted a Resource Management Act with the central theme of sustainable management of natural resources to meet reasonably foreseeable needs of future generations, safeguarding the life-supporting capacity of air, water, soil, and ecosystem, and avoiding adverse impacts of human activities on natural resources. South Africa’s National Water Act 34 of 1998 explicitly designates the Government as the Trustee of the nation’s water resources, and vests with the Government the responsibility of judicious and equitable use of water resources, recognizing justifiable economic and social growth and international responsibilities.

5. An example

The San Joaquin valley of California, a narrow intermontane basin in an arid region, has been transformed into one of the richest agricultural regions of the world through irrigation with imported water. For decades, the only challenge to irrigation technology was progressive, irreversible soil salinization caused by salt brought in with imported water. The salinization problem was kept temporarily in check by capturing salt-laden waters below the root zone with an elaborate system of subsurface drains, and conveying the effluents to a constructed wet land, the Kesterson wildlife refuge. Even as science was exploring more permanent technological solutions for the salinity problem, it was taken by surprise in 1983 by the discovery of selenium poisoning of wild fowl at Kesterson. Selenium, a redox sensitive metal, is present in the solid state in the valley-flank sediments that had originally formed under reducing (oxygen-deficient) conditions. When oxygen-rich imported irrigation waters were applied over these sediments, selenium was oxidized, became water-soluble, and found its way via the 83 mile San Luis drain to the Kesterson wetlands, endangering wildlife. Although the chemistry of soils and water of this area had been intensively studied by agricultural scientists from the late 19th century, the potential for selenium toxicity was never suspected.

The impact of irrigated agriculture on wildlife had an immediate effect on public perceptions. For the first time, environmental health was perceived to be more important than agricultural production, demanding higher priority than economic benefits. After vigorous public debate, the valley adapted to selenium toxicity in 1985 by prohibiting discharge of drainage effluents into the San Luis drain.

Soon thereafter, farmers of the affected areas sued the US Bureau of Reclamation on the grounds that the Federal San Luis Act of 1960 had mandated the Bureau to provide drainage facilities to mitigate salt accumulation. In 2000, the US Court of Appeals agreed with the farmers and ordered the Bureau to provide drainage for lands affected by selenium toxicity, duly complying with environmental regulations.
Accordingly, the Bureau has recently completed an Environmental Impact Statement (US Bureau of Reclamation 2006), evaluating the relative merits of seven alternatives, three involving off-valley disposal, and four involving in-valley disposal of drainage effluents. The off-valley alternatives involve retirement of 44 100 acres of land, and pumping of drainage effluents from the rest of the area via a 211 mile pipe line to the Pacific Ocean over the coast ranges, or conveying them to the northern part of the bay delta through a combination of a new canal and a pipeline over a distance of 150–175 miles. In the case of ocean disposal, concerns include impacts on ocean ecology, and potential impacts of pipeline failure. In the case of delta disposal, concerns include impacts on drinking water supplies, and impacts on bird and fish from selenium bioaccumulation.

The in-valley alternatives involve a combination of land retirement, drain-water recycling, shallow groundwater management, biological selenium treatment, reverse osmosis, and disposal of enriched effluents nearly as saline as sea water in evaporation ponds. The retired land acreage of the four alternatives would be 44 100, 92 600, 194 000, and 308 000. In these cases, major concerns include the impacts of evaporation ponds on migratory water fowl, reduction in economy due to land retirement, and technical and economic feasibility of selenium treatment. The retired lands will partly be fallowed, and partly put to alternate use such as dry-farming or grazing.

Of the seven alternatives, the Bureau prefers either of two inland alternatives involving retirement of 308 000 acres or 194 000 acres. The next step is for the Bureau’s proposal to be approved by the Congress, duly responding to various social and political factors. Preliminary estimates indicate that the Congress must appropriate between $825 million and $920 million for initiating necessary action.

This case constitutes an example of the technological and social issues that arise in adapting to Nature. Obviously, the Bureau did not foresee the complexities of drainage problems in 1960, certainly not the selenium toxicity problem. Instead, based on contemporary knowledge, it believed that drainage technology could control Nature at will to support vigorous agricultural production. Time has invalidated that belief. For the alternatives that are now contemplated to adapt to changed conditions, science cannot precisely predict future responses and impacts. Even with maximum land retirement, gradual salinization of land on a timescale of a century or longer cannot be avoided. Above all, the Bureau’s preference for retiring between 200 000 and 300 000 acres of land clearly indicates that historical economic expectations of the agricultural productivity of this area reflect human aspirations rather than what Nature could sustain. This part of the San Joaquin valley is in a state of transition from a period of vigorous agricultural production through technological control to one of sustained lower productivity over a long period of time.

6. Challenges

Although the concept of adapting to Nature makes rational sense, and although we have adequate scientific know-how and technological competence to successfully adapt, having the will to implement is fraught with difficulties stemming from human nature. The desire to comprehend the world around us precisely so as to control it for human benefit is a vision that dates four centuries back to Francis Bacon (Broad 1959). Modern science cannot easily give up this vision. For this reason, it is not surprising that the need for adapting to Nature is not given its due recognition in the broader science community, outside of Earth sciences and ecological sciences. Secondly, adapting to Nature requires a combination of quantitative thinking as well as non-quantitative, descriptive logic. For this to happen, science and the humanities (with the social sciences in between) have to come together in unprecedented ways. Wilson (1998) has passionately argued for such a coming together, which he refers to as consilience. Thirdly, the reality of a finite Earth and the imperative for living within its constraints must be recognized at the Constitutional level of national governments to facilitate emplacement of policies, laws, and institutions that are needed to achieve the complex task of adapting to Nature. The gaining momentum of a world-wide conservation movement, and the enactment of laws by the governments of New Zealand and South Africa aimed towards adapting to Nature’s constraints are clearly encouraging signs.

To put matters in perspective, consider a hypothetical case. Suppose, due to global warming, a gradual rise in sea level progressively inundates highly populated areas of the Texas gulf coast or Bangladesh. How will science and society respond? Will control-based policy advocate building dykes and barriers to protect local populations? Or will large sections of the population be relocated within or across national boundaries? How will policy respond when one section of the population asserts its rights to safety at a cost that is prohibitive to society as a whole? How may large, displaced populations be accommodated within or outside of national boundaries? What laws and policies must be created to meet these contingencies? It is impossible to foresee what the outcomes might be. The possibility of changing human values and violent conflicts cannot be ruled out. However, it is clear that major societal decisions can neither be based purely on technology, nor based purely on social values. Civilized adaptation will require a balancing of the quantitative and the descriptive, and an ability to make judgements under trying conditions. In order that these judgements may be wise, we have a long way to travel in closing the gap between the sciences and the humanities, between quantitative thinking and descriptive thinking.

Acknowledgments

Thanks to Stefan Finsterle, Ernest Majer, and Isaac Winograd for thoughtful suggestions. This work was supported partly by the Agricultural Extension Service, through the Division of Natural Resources, University of California, and partly by the Director, Office of Energy Research, Office of Basic Energy Sciences of the US Department of Energy under Contract No. DE-AC03-76SF00098 through the Earth Sciences Division of Ernest Orlando Lawrence Berkeley National Laboratory.
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