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Uncertainty, Climate Change, and Adaptive Management

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INTRODUCTION

Humanity's transformation of the Earth has increased the concentration of greenhouse gases, thereby altering Earth's climate (Walker and Steffen 1997). The drivers and the potential consequences of climate change are interwoven with a huge variety of biogeophysical and human−caused processes that complicate the analysis of policies designed to mitigate and adapt to climate change. In this paper, we explore how adaptive management (Walters 1997) can be used to grapple with the regional and global scientific, economic, and political uncertainties of climate change.

CLIMATE CHANGE AND ITS IMPACTS

Atmospheric change

Climate change policy has focused upon the reduction of greenhouse gas emissions. Emission reduction must be a central component of any climate policy; however, reorganizing society to reduce greenhouse gas emissions quickly will be difficult. Atmospheric concentrations of greenhouse gases will probably continue to increase in the near future. Existing concentrations of greenhouse gases are likely to alter climate, and future emissions will only add to that alteration. Although the extent of this alteration is uncertain, it could prove significant (Azar and Rodhe 1997). Extreme impacts are likely in some regions (Mahlman 1997).

Resilience

Walker and Steffen (1997) point out that global changes, such as biodiversity loss, land use/land cover change, hydrological modification, and the alteration of global biogeochemical cycles, will interact with climate change to alter ecosystems in complex ways across a broad range of scales. Ecological resilience, the ability of an ecosystem to persist despite disruption and change (Holling 1973), depends upon the continuity of ecological processes at smaller and larger scales (Peterson et al. 1998). The pervasive and synergistic impacts of global change threaten to reduce ecological resilience at local to global scales, producing ecosystems that are increasingly brittle and sensitive to disruption.

Ecological reorganization

Climate change affects species individually (Root 1993, Pitelka et al. 1997). Different species and populations migrate, establish, and become extinct at different rates. Climate change, therefore, will cause the dissolution of existing ecosystems and the formation of new ecosystems. Ecological collapses will probably eliminate some species entirely, and these species losses may cause the elimination of entire ecosystems. The Earth may lose cold−adapted systems such as arctic and alpine communities to warming, and low−elevation islands to sea level rise. New ecosystems will form as a consequence of climate change, but the membership of these new systems will be drawn from the subset of existing species that can survive under the new conditions. Although climate change has occurred many times throughout Earth's history, the ecological impacts of the current climate alterations are amplified by other anthropogenically−driven global changes.

Walker and Steffen (1997) also note that the rate at which existing ecosystems dissolve will exceed that at which new assemblages form. Mortality of existing vegetation through processes such as insect outbreak, flooding, or fire − all processes projected to increases under climate change − will occur rapidly compared to the accumulation of vegetative structure in new ecosystems. Under global change, this rate difference, combined with the human removal of old−growth ecosystems, will increase the area covered by early successional ecosystems (Walker and Steffen 1997). Such a global increase in early successional ecosystems suggests that species dependent upon old−growth ecosystems will become increasingly vulnerable, whereas populations of early successional species, often "weedy" species, will potentially increase.

CLIMATE AND PEOPLE

Ecological services

The extent to which species populations can adapt and ecosystems can shift, disintegrate, or reorganize has implications for humans at cultural, economical, and ecological levels. Particular species and ecosystems hold cultural value for different societies (Colding and Folke 1997). Many species and ecological services are economically valuable. The spread of many diseases is mediated by specific species and ecological processes. Climate change will disrupt these and other relationships in uncertain ways that will benefit some, but will probably harm many.

Basic ecological services, such as carbon fixation, can be produced by simple ecosystems (Ewel et al. 1991); however, the elimination of more complex ecosystems may reduce the flexibility and range of ecological services generated globally. Simplification of ecological systems may also reduce their capacity to respond to novel conditions in the future. Although humans depend upon ecological products and services, there is little understanding of how these are produced, maintained, enhanced, or degraded (Daily 1997).

Vulnerability

Humanity is threatened by both direct and indirect consequences of climate change. Unlike other species, humans have the ability to plan for the future and to invest in technology and learning to mitigate and adapt to future changes. However, just as the climatic and ecological impacts of climate change are unequally distributed, so, too, is the adaptive capacity to cope with these impacts. Wealth, infrastructure, and political stability all contribute to a nation's capacity to anticipate and respond to change. A poorly educated populace, limited physical infrastructure, degraded natural capital, or ineffective governance can all contribute to the vulnerability of a region to climate change. Unfortunately, some areas that are already vulnerable due to social and economic circumstances, such as small island states and the arid tropics, are also predicted to experience larger than average impacts from climate change.

At the recent Climate Change conference in Kyoto, Japan, President Clodumar of the Republic of Nauru, one of the small island nations threatened by rising sea level, argued that it was unethical to ignore these ecological and social inequities, because "...the willful destruction of entire countries and cultures, with foreknowledge, would represent an unspeakable crime against humanity. No nation has the right to place its own, misconstrued, national interest before the physical and cultural survival of whole countries." (Mcilroy 1997)

Regional inequity

People have tried to organize a global response to climate change through the United Nations Framework Convention for Climate Change (FCCC). The Convention has focused attention on reducing emissions of greenhouse gases. In many ways, it is attempting to establish an international property rights regime to regulate the human use and modification of the world's carbon cycle. At the December 1997 meeting in Kyoto, the main issues were the distribution of rights to emit greenhouse gases to nation−states and the conditions under which such rights applied. Deferred for further discussion were trade in these emission rights and the allocation of credits for natural sinks that remove greenhouse gases from the atmosphere.

Allocating property rights for emissions is complicated by the inequities in past and current emissions, population growth, technical capacity, and vulnerability to impacts. These differences underlie the willingness, or lack thereof, of different groups to pursue such a global agreement. A durable agreement must address the relative situation of nations. For example, linking the reduction of CO_2 emissions to technology transfers or participation in emissions trading may provide a means to address regional inequities. These mechanisms may also provide a means whereby noncompliance can be punished and compliance can be rewarded.

Intergenerational inequity

To achieve intergenerational equity, we must leave the Earth no worse for our children than we received it from our parents. However, accomplishing such a goal is difficult. The dynamics of both atmospheric carbon and human society are slow. Choices made today will have consequences that extend over decades, but it is difficult to distinguish good choices from bad, given the uncertainties surrounding climate change.

Connecting the present to possible futures is necessary before good choices can be made. Work that demonstrates the future impact of specific individual, corporate, and societal choices provides a starting point. For example, the concept of emission corridors provides a means of linking long−term climate change to current policy decisions. An emission corridor defines the path from a range of short−term global greenhouse gas emission levels through intermediate climate goals to long−term targets such as the change in global average surface temperature or in sea level (Alcamo and Kreileman 1996). Work by the Potsdam Institute for Climate Impact Research (PIK) in Germany on what they call "Tolerable Windows" offers another approach to connecting present conditions with possible futures (Toth et al. 1997).

Reduction, mitigation, and adaptation

International negotiations have focused on limiting increases in greenhouse gas emissions. Decreasing emissions is a necessary, but not sufficient, step to address the consequences of human alteration of the atmosphere. Humanity has already increased atmospheric concentrations of CO_2 and other greenhouse gases. If nations follow the Kyoto protocol, levels will still continue to increase over the next two decades. Existing physical, institutional, and "behavioral" infrastructure limit our capacity to mitigate emissions in the short term. The lifetime of an electrical generating plant is several decades; transportation infrastructures are similarly "hardwired" and slow to change. It will also take time to change institutions, because current tax structures, resource and management policies, and lifestyles do not reflect climate change realities. Given these realities, not only must we strive to reduce greenhouse gas production, but also to mitigate and adapt to the consequences of atmospheric alteration to which the Earth may already be committed.

Climate change and global change

Climate change is ecologically and socially intertwined with other forms of global change (Vitousek 1994). Although the scientific investigation of these processes needs to be integrated, it is unclear whether similar integration would facilitate action on climate change at the global policy level. The negotiation of international treaties is likely to be aided by a narrow focus that considers interconnected issues in isolation. Without such isolation, efforts to reach agreement are easily stalled by calls to wait for clarification of all interconnections. However, a more integrated approach might better address synergisms between issues, decrease negative externalities, and reduce administrative costs. Although the first approach may be more practicable in the international political arena, narrowly focused environmental laws in the United States have led to calls for integrative ecosystem management (Christensen et al. 1996).

At the scale of cities or regions, the impacts, adaptation to, and mitigation of global change should be approached in an integrated manner, because the interwoven consequences of individual policy decisions will be more tractable at this smaller scale. For example, building a dam may emit methane, destroy fisheries, and generate "cheap" electricity. Is this better or worse than building a coal−fired power plant or investing in energy conservation? An integrated approach may actually strengthen the imperative to act on climate change. Overlap in benefits may be used to argue for action; for example, reforestation may improve habitat for wildlife, provide timber supplies for the future, and control soil erosion, as well as sequester carbon.

NAVIGATING IN AN UNCERTAIN FUTURE

Novelty and uncertainty

The ecological, social, and economic dynamics of the changing Earth all encompass uncertainties that can be categorized as statistical uncertainty, model uncertainty, or fundamental uncertainty (Hilborn 1987). Statistical uncertainty is the uncertainty that surrounds a variable when its state at any one point is unknown, but the probability distribution that characterizes that variable is known. For example, the probability of a tree being struck by lightning is a form of statistical uncertainty. Model uncertainty occurs when the connections between variables are uncertain. Such uncertainty allows the prediction of outcomes, but makes it difficult to assess their likelihood. For example, the Atlantic conveyor has periodically been turned off, but the processes causing this are not understood well enough to predict the likelihood that the event will occur under possible future climatic conditions (Broecker 1996). Finally, fundamental uncertainty describes novel situations for which existing models do not apply. The discovery of the ozone hole falls into this category of uncertainty. Careful science can reduce, but not eliminate, these uncertainties. However, such science is often expensive, especially for large, weakly replicable systems such as the global climate system.

The uncertainties and complexity of the forces driving the social, biological, and physical dimensions of global change ensure that it will have surprising consequences (Clark 1986, Schneider and Root 1996). The political challenges posed by the novelty of climate change are compounded by its scale. The human domination of the earth defines a new geological epoch (Vitousek et al. 1997). Although historical studies can help scientists to understand ecological processes, they do not provide analogues for a future Earth transformed by global change. As we continue to change processes at a global scale, past experience will serve less often as an accurate model of future conditions, shifting the balance of the uncertainties we face from the more easily managed categories of statistical and model uncertainty to that of fundamental uncertainty.

Adaptive management

Coping with novel situations requires the capacity to learn. Walter's (1997) paper discusses Adaptive Environmental Assessment and Management to manage ecological systems through a structured process of learning by doing (Holling 1978, Walters 1986, Lee 1993). The policy−based experimentation advocated by adaptive management is essential to reduce the ecological, social, and economic costs of learning. Adaptive management focuses upon developing alternative hypotheses, identifying gaps in knowledge, and assessing what knowledge would most effectively distinguish alternative hypotheses and, therefore, could be most useful in setting and updating research and action priorities.

We argue that climate change policy could benefit by taking an adaptive approach. Considering the uncertainty surrounding climate change, knowledge and policy need to be continually updated and challenged. The International Panel on Climate Change (IPCC) has managed such a process with the science of climate change. It would be ideal if a parallel adaptive approach could be incorporated into policy development. Such an approach would produce policies and treaties that are robust to key uncertainties, that test alternative policies, that provide opportunities for learning, and that monitor policy outcomes. Although it is difficult to conduct experiments at a global scale, there are many opportunities, regionally and nationally, to test competing models of effective and fair policies.

Models

Models are important tools for evaluating alternatives in an adaptive management framework. Models can be used to identify the important gaps that exist in understanding. If their dynamics and behavior are clearly communicated, models can serve to communicate possible futures and to bound the range of our uncertainty. They can help to make the link between local actions and the aggregation to global consequences.

It is crucial that models consider not only stable states, or the state at specific future dates, but the dynamic trajectories that are required to reach those endpoints. Models may produce similar endpoints, but exhibit substantial differences in their trajectories. Although the predicted endpoint may be acceptable, a specific path may not. Such trajectory analyses can elucidate regional disparities in impacts of not only climate change but also efforts to adapt to and mitigate climate change.

To be useful, models must help us to understand, rather than hide, important sources of uncertainty. The importance of uncertainties can be determined by assessing the degree to which model behavior is altered by changes in parameter values (sensitivity analysis), model organization, and external disturbances. Because one cannot address all sources of uncertainty, it is often useful to focus these analyses around a few relevant scenarios.

Evaluating alternatives

To evaluate alternatives, scientists and policy makers must develop a more sophisticated approach toward uncertainty than they have traditionally used. Rather than simply testing and rejecting individual hypotheses, scientists and decision makers must consider diverse sets of alternative hypotheses. Alternatives need to be continually revised, modified, and discarded, based upon how they fare in tests against empirical data (Hilborn and Mangel 1996). Maintaining the status quo must be explicitly examined as one alternative among many, with its attendant consequences, benefits, and costs.

Cost−benefit analysis is a technique that is commonly used to evaluate alternative projects or decisions (Cline 1992). The relative costs and benefits of each case over a time period are estimated, are discounted back to present values, and are summed to yield the net present value of the project. Cost−benefit analysis is useful in assessing the relative merits of alternative projects, but political and ethical issues are involved with its application. The choice of a discount rate is fundamentally an ethical choice about intergenerational equity (Howarth and Norgaard 1995). Similarly, when costs and benefits are shared over a group, the aggregation of individual preferences requires some method of assigning value to different preferences. Comparing different individuals' preferences is implicitly ethical and political, and is therefore an area that is contested. Similarly, because the members of a group and their preferences can change over time, cost−benefit analyses should assess the sensitivity of the conclusions reached to preference changes; such changes will affect the value placed on outcomes and discount rates, which will alter the end result of the cost−benefit analysis (Pearce and William 1994).

More often than not, policy decisions have multiple dimensions that are difficult, if not impossible, to convert into a single metric. In these cases, techniques such as multi−attribute utility analysis, wherein tradeoffs between alternatives are evaluated using multiple metrics, may be necessary. In either case, such methods of analysis are best viewed not as authoritative objective procedures, but as modeling processes that provide a means of making underlying valuations open to scrutiny, discussion, and sensitivity analysis.

Metrics

Comparison of alternatives requires the use of common metrics. Determining appropriate metrics to analyze global impacts is difficult because of heterogeneity between regions. Commonly, dollar values, adjusted for purchasing power parity, are used for cross−country comparisons. However, such comparisons do not accurately capture nonmarket services, including ecological services. Alternative indicators that include natural services and capital provide a means to capture a more complete view of the human impacts of climate change. Such methods include ecological footprint (Wackernagel and Rees 1995), the sustainable process index (Krotscheck and Narodoslawsky 1996), and the United Nation's Human Development Index (United Nations Development Programme 1997).

Communicating uncertainty

Uncertainty does not imply "no risk." Rather, it constrains our ability to precisely qualify and quantify the risks associated with different management actions. The precautionary principle suggests that the greater our uncertainty (i.e., the less our capacity to precisely define risk), the more cautious and "reversible" our management actions should be. Although future research may narrow uncertainties, the scale of our actions is creating new uncertainties, further reducing our capacity to predict risk.

We propose that policy−oriented science must actively address uncertainty, rather than simply focus on trying to eliminate it. Often, scientists have approached political questions by emphasizing the uncertainties surrounding particular policy issues and calling for further research. Not all uncertainties can be reduced by further research, and even where reduction is possible, it may come at great cost; hence, scientists should articulate where and how science can continue to reduce uncertainty and where it cannot. This approach acknowledges limits to scientific knowledge and constrains the growth of a technocracy. However, because it secedes scientific control over a policy question to a broader community, such an approach can be controversial.

Walters (1997) discusses how management agencies often suppress scientific dissent in order to present a unified, "certain" front to the outside world, thereby consolidating the political power of the agency. However, political power can rapidly dissolve when an agency's policies fail (Hutchings et al. 1997). We believe that an active approach toward uncertainty is necessary to produce policies that fairly and openly address the uncertain future.

Such an approach presents the opportunity to develop more sophisticated public debates on management issues.

Many individuals are concerned about the environment, but neither take nor advocate environmental action. One reason may be that the costs of such actions are near, whereas the benefits are far in both space and time. Another fundamental reason for inaction is uncertainty in determining the relative merits of different actions. In the absence of better information, people may assume that the status quo is preferable, because uncertainties about the positive and negative aspects of action balance one another. A clear discussion of uncertainty and its variety and location can alter people's perception of possible futures. We argue that effective public policy demands that scientists work to clearly communicate the uncertainties surrounding alternative futures, how those uncertainties can be reduced, and what actions provide the best insurance in the face of those uncertainties.

Politics and experimentation

Walters (1997) concludes that some of the most significant barriers and difficulties to applying adaptive management are social. Different people and different ecosystems benefit or lose from specific ecological changes, and, therefore, "conflicts over ecological values are likely to be one of the main impediments to policy design in adaptive management and ecological restoration". Attempting to overcome these social rigidities requires the integration of the political into adaptive management. This presents a challenge.

High levels of uncertainty provide a warning that surprises and unexpected events are likely to occur. A surprise event, such as a change in ocean circulation, could have both negative and positive consequences. What types of policies build social and ecological resilience to allow people and nature to react and adapt to surprise? What types of institutions can be developed to integrate experimental approaches to local emission reduction and adaptation with global agreements and coordination?

The need for scientific action

From a scientific perspective, multiple efforts to integrate the many aspects of global change are necessary. Increased interaction between scientists and policy makers offers the possibility to improve both decision−making and global change science. Often the range of policy alternatives considered is overly restricted. Scientists need to work to expand the range of polices that are proposed, debated, and implemented. Scientists need to make inaction uncomfortable. We need to inject novelty, new ideas about how society and nature can be organized, into the political debate, and we need to honestly test and explore all ideas to assess their relative merits. Science should visualize alternative futures, develop alternative policies, and develop opportunities for learning.

RESPONSES TO THIS ARTICLE

Responses to this article are invited. If accepted for publication, your response will be hyperlinked to the article. To submit a comment, follow this link. To read comments already accepted, follow this link.

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