Conservation and Climate Change: the Challenges Ahead

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Climate Change and Ecological Responses

Climatic changes in the distant past were driven by natural causes, such as variations in the Earth's orbit or the carbon dioxide (CO_2) content of the atmosphere. Today, and even more so in the future, climatic changes have another driver as well: human activities (IPCC 1996). The natural greenhouse effect from clouds, water vapor, and CO_2, primarily, is responsible for some 33° C of surface warming. Human use of the atmosphere to dump gaseous wastes adds to the natural greenhouse gases and is typically projected to result in a global warming of about 1.5°–6° C in the next century (IPCC 2001*a*). This range—especially if beyond 1–2° C—could result in ecologically significant changes (Thomas et al., 2004), which is why climatic considerations are fundamental in the discussion of conservation strategies for the twenty-first century.

The transition from extensive glaciations of the Ice Age to more hospitable landscapes of the Holocene took from 5,000 to 10,000 years, during which time the average global temperature increased 5–7° C and the sea level rose some 100 m. Thus, we estimate that over the last 20,000 years, the natural rates of warming on a *sustained global* basis are about 0.5°–1.5° C/thousand years. There is, however, evidence amassing of regional, rapid (i.e., abrupt nonlinear) changes as well (e.g., Schneider 2004 provides an overview). Both the slower and more rapid changes radically influenced where species lived and their extinction rates. Climate change was a potential contributor—along with hunting and other human activities—to the extinctions of woolly mammoths, saber tooth cats, and enormous salamanders.

During the last Ice Age, most of Canada was under ice. Pollen cores indicate that as the ice receded, boreal trees moved northward "chasing" the ice cap (i.e., moving with the warming temperature). But did the species within the boreal tree community shift in lock-step with the trees? In historic times many thought that biological communities moved intact with a changing climate. Darwin (1859) asserted as much:

> As the arctic forms moved first southward and afterward backward to the north, in unison with the changing climate, they will not have been exposed during their long migrations to any great diversity of temperature; and as they all migrated in a body together, their mutual relations will not have been much disturbed. Hence, in accordance with the principles inculcated in this volume, these forms will not have been liable to much modification.

If this were true, the principal ecological concern over the prospect of future climate change would be that human land-use patterns might block what had previously been the free-ranging movement of natural communities in response to climate change. The Cooperative Holocene Mapping Project, however, discovered that during the transition from the last Ice Age to the present interglacial, nearly all Northern Hemisphere species moved generally north, as expected, but for a significant portion of the transition period different species moved at different rates and directions, not as groups (Cooperative Holocene Mapping Project 1988; Overpeck et al. 1992; Wright et al. 1993). The relevance of these "no-analog" habitats is that today and in the future ecosystems will probably not move as a unit as climate changes.

Furthermore, because the forecasted global average rate of temperature increase over the next century (approximately 1–5° C/century) greatly exceeds those typical of the sustained average rates experienced during the last 20,000 years, it is unlikely that paleoclimatic conditions will provide analogs for a rapidly changing anthropogenically warmed world. Nevertheless, understanding past changes is important, not as a spatial analog to future conditions, but rather as means to construct or verify the

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behavior of models of climate and ecosystem dynamics. Tested models are needed to project the future conditions given the rapid time-evolving patterns of anthropogenic forcing (Crowley 1993; Schneider 1993).

Meta-analyses provide methods for combining results from various studies, whether statistically significant or not. Results from meta-analyses determine whether there is a consistent "signal" or "fingerprint" among the studies. The balance of evidence from two such meta-analyses done on species from many different taxa examined at disparate locations around the globe (Root & Schneider 2002; Parmesan & Yohe 2003; Root et al. 2003) suggests that a significant impact from recent climatic warming is discernible in the form of long-term, large-scale alteration of animal and plant populations. The latter conclusion was extended by Intergovernmental Panel on Climate Change (IPCC 2001*b*) to include "environmental systems"—sea- and lake-ice cover and mountain glaciers. Clearly, if such climatic and ecological signals are now being detected above the background of climatic and ecological noise for a twentieth century warming of "only" 0.6° C, it is likely that the expected impacts on ecosystems of temperature increases up to an order of magnitude larger by 2100 AD will be dramatic.

The meta-analyses have established that many plant and animal species are responding to regional climatic changes, but can the extent to which such regional warming is natural variation as opposed to attributable to human activities be teased apart? If there is a discernible impact of human activities on climate (IPCC 1996, 2001*a*) and a discernible impact of climate on plants and animals (e.g., IPCC 2001*b*), can it be asserted that there is a discernible impact of human-induced climate change on plants and animals, so-called "joint attribution"? Root et al. (2005) correlated the phenological responses of plants and animals reported to be changing over the past 50 years to spring temperature data produced by climatic models (HADCM3 general circulation model). These models were driven by three sets of observed potential causes: (1) only natural forcings (e.g., solar activity and volcanic dust veils, (2) only anthropogenic forcings (e.g., CO_2 and aerosol increases), and (3) combined forcings (i.e., natural and anthropogenic forcings together). Given the many uncertainties and missing factors, it is not expected that most of the variance of observed phenological changes in the past 50 years can be attributed to anthropogenic forcings. Thus, the key question is: Did the correlations between observed plant and animal phenological records improve when anthropogenic forcing was driving the models relative to the correlations when only natural forcings produced the climate model records? Root et al.'s (2005) results show a clear signal that, despite known uncertainties and missing factors, temperatures driven by anthropogenic forcing are much more highly correlated with observed phenological changes in plants and animals than natural forcing. This result provides strong support for the joint-attribution hypothesis.

Research Challenges: Multiscale, Multitaxa, Transient Regional Predictions, and Synergistic Effects

Conservation biologists and others face a number of challenges regarding climate change over the next several decades, both in predicting and documenting its patterns and in dealing with its effects, including improvement of regional analysis, study of transients, inclusion of many variables, multiscale analyses, and synergistic effect of habitat fragmentation.

The most reliable projections from climatic models are for global-scale temperature changes. Ecological impact assessments, however, need time-evolving (transient) scenarios of regional- to local-scale climate changes. Besides temperature, other factors needed to understand possible ecological impacts include changes in precipitation; severe storm intensity, frequency, and duration; wind; drought frequency, intensity, and duration; soil moisture; frost-free days; intense heat waves; ocean currents; upwelling zones; near-ground ozone; forest canopy humidity; and ultraviolet and total solar radiation reaching the surface. Data gathered at many scales and by coordinated volunteer and professional sources are needed for archives of these regional and local variables, which, in turn, can be used to develop and test models or other techniques for climatic-impacts forecasting. The data sets available today provide only limited information. Certainly, more long-term studies at various locations around the globe are needed. Without such data sets, progress in determining large-scale patterns of associations among ecological and climatic variables will be limited.

Small-scale studies informed by large-scale patterns are then needed to refine causal mechanisms underlying such large-scale associations, thereby testing the projections of various species or biome responses to hypothesized global changes. One obvious truism emerges: credible modeling required for forecasting across many scales and for complex interacting systems is a formidable task requiring repeated testing of many approaches. Nevertheless, tractable improvements in refining combined top-down and bottom-up techniques can be made. It will, however, take more than one cycle of interactions and testing with both large- and small-scale data sets and modeling frameworks to address reliably the cross-scale and multicomponent problems of ecological assessment, what we (Root & Schneider 1995, 2003) have elsewhere labeled strategic cyclical scaling (SCS). The SCS paradigm has two motivations: (1) better explanatory capabilities for multiscale, multicomponent interlinked social-natural systems (e.g., climate-ecosystem interactions or behavior of adaptive agents in economic models responding to the advent or prospect of climatic changes); and (2) more reliable impact assessments and problem-solving capabilities—predictive capacity—as has been requested by the policy community.

One of the potentially most serious conservation problems is the synergistic effect of habitat fragmentation and climate change. As the climate warms, individual species of plants and animals will be forced to adjust if they can, as they have in the past. During the Ice Age transition many species survived by moving to appropriate habitats. Today such dispersal is more difficult because they need to travel across freeways, agricultural areas, industrial parks, and cities. An even further complication arises with the imposition of the direct effects of changes in CO_2, which can change terrestrial, aquatic, and marine primary productivity, drop the pH of the oceans significantly, and alter the competitive relations among plants and animals.

Conservation biologists not only need to anticipate the phenology and movements of individual species in response to climate change but must also project potential changes to biological communities. Disruption of competitive or predator-prey interaction could jeopardize sustainability of ecosystem services on which we rely (Root & Schneider 1993; Millennium Ecosystem Assessment 2005) and lead to numerous extinctions. This is one of the most important challenges for conservation biologists in the next several decades as extensive land use and rapid climatic changes are likely to accelerate.

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