

Modelling the ecological consequences of global climate change

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The Earth's climate is changing at an unprecedented rate and, moreover, changes are not driven mainly by natural variations, rather by anthropogenic causes. The recently released Intergovernmental Panel of Climate Change (IPCC) Summary on the Physical Science Basis of global climate change [IPCC, 2007a] stated: "the global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture". Carbon dioxide (CO₂) atmospheric concentration has increased from a pre-industrial value of about 280 ppmv to 384 ppmv in 2008, which is the highest concentration in the past 650,000 years [Siegenthaler et al., 2006]. In the last decade an exceptional increase of 1.9 ppmv per year has been experienced [IPCC, 2007a].

The 2007 IPCC report showed that the average surface temperature of the Earth increased more than projected in the 2001 Third Assessment Report [TAR; IPCC, 2001]: the 1906-2005 linear trend indicates a temperature increase of 0.74±0.18°C, which is larger than the corresponding trend of 0.6±0.2°C for 1901-2000 [IPCC, 2001]. The 8 warmest years recorded since 1680, when instrumental measures of temperature became available, occurred in the last 14 years and 2005 has been the warmest year ever. Europe is experiencing even higher rates of temperature increase: 0.95°C versus 0.74°C [EEA, 2004].

The detection of global and regional trends for precipitation is more difficult because precipitation regimes are inherently stochastic and strongly depend on local climatic and morphological characteristics. Nonetheless, improvement in data analysis and modelling have been made and, according to the IPCC report [IPCC, 2007a], significant precipitation increase has been observed in eastern parts of North and South America, in northern Europe and in northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.

1. THE IMPACTS OF GLOBAL CLIMATE CHANGE ON ECOSYSTEMS

There are numerous impacts of Global Climate Change (GCC) on ecosystems: climate is in fact one of the factors that determines ecosystems' composition, productivity and structure. Several plants can successfully grow and reproduce in a specific range of temperatures and precipitation regimes. Regional climate is one of the factors that influences species geographical distributions through physiological tolerance thresholds, e.g., of temperature and rainfall, and through food or nutrient availability. Biota with narrow physiological and phenological ranges will be the most vulnerable to climate change.

Climate change can affect ecosystems, populations and individuals directly (e.g., via rising average temperature) or indirectly (e.g., via changes in the availability of resources). Impacts imply changes in the structure and functioning of ecosystems, in the physiology and phenology of plant and animal species, in their range distribution.

A major negative impact is given by the increased frequency of extreme events (e.g., heat waves, droughts, storms), that directly affects ecosystems; at the same time, small, continuing and progressive variations of temperature and of other climate drivers can affect the biological cycle of many species. Mild winters can affect the competitive interactions existing within the species, altering the structure of the biological community and, in some case, enabling the spread of pathogens that would otherwise die during winter [Harvell et al., 2002].

2. MODELLING THE IMPACTS

One of the most important questions for ecologists is whether GCC will imply a a small or large decrease of biodiversity (at both species and ecosystem level). Biodiversity conservation is usually based on the idea that species extinction occurs on very long time scales; however, the speed of climate change makes this assumption untenable. We must know how species and ecosystems will react on a short time scale [Araújo and Rahbek, 2006].

To predict the expected impacts of GCC on biodiversity and the ecosystem functioning it is necessary to know how climatic variables will evolve in the future and how ecosystems will respond to climatic variations. Present day's AOGCMs (Atmospheric-Oceanic Global Circulation Models) outline scenarios on the future evolution of temperature, precipitation and other climatic variables on geographic grids of approximately 200 x 200 km. There is agreement among the different models as concerns temperature, while there is some disagreement on precipitation trends. Also, AOGCMs do not incorporate soil and coast morphology, the presence of water bodies and differences in vegetation cover, which affect the local climate. This is of course an important limitation for the study of the ecological consequences of GCC [Metzger et al., 2004]. However, efforts are undertaken in several research centers to downscale the AOGCM predictions to a finer scale so that they can be used to assess the vulnerability of the different areas of our planet [IPCC, 2007b].

There are several categories of models that link climatic variation to ecosystem response. First of all we can contrast static vs. dynamic models. Static models use empirical relationships between abiotic factors (including climate) and biotic variables. Biosphere is considered at equilibrium. The relationships are usually obtained via statistical methods (such as logistic regression, generalized linear models, etc.) applied to the past data. Dynamic models simulate one or more ecological processes (such as population reproduction or species migration) that typically vary in time. These models produce transients, not only equilibria. A second contrast is between single species and ecosystem models. The first simulate single populations isolated from other components of the ecosystem to which they belong. The latter simulate changes in ecosystem/biome function and composition, whether at the level of species or of functional groups. A final contrast is between models at the global or local scale. Ecological models that directly use the outputs of AOGCMs on large grids simply predict the presence or absence of species and are frequently based on so-called climate envelopes, i.e., relationships between mesoscale climate variables and species presence. Local models, instead, must be based on predictions downscaled from AOGCMs and can detail the abundance and demography of animal or plant species, the physiological processes, the ecological interactions and local species diversity.

The great majority of the existing models are static, single species and global scale. Actually all the predictions on the future loss of biodiversity [Thomas et al., 2004, Thuiller et al., 2005] are based on models of this type. We will present examples of these predictions and discuss their shortcomings. To increase the realism and utility of

predictions, next generation models should necessarily take steps towards being dynamic and local scale with at least a simple description of ecosystem functioning. To exemplify, we will present preliminary results for some Alpine species with particular regard to the distribution and demography of the Alpine ibex (*Capra ibex ibex*) in the two national parks of Adamello and Gran Paradiso, Northern Italy.

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