

Climate Change Impacts on Freshwater Ecosystems

Edited by

**Martin Kernan, Richard W. Battarbee
and Brian Moss**

 **WILEY-BLACKWELL**

A John Wiley & Sons, Ltd., Publication

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Preface

The evidence that greenhouse gas emissions, primarily from fossil fuel combustion, is and will increasingly be a principal cause of climate change has been compelling for some time. Although uncertainties remain, the threat is sufficiently real for research now to focus not only on the climate system itself but also on how changes in the climate system in future might affect the functioning of natural ecosystems.

In this book, we are concerned with how climate change might affect freshwater ecosystems. The ideas and examples presented in the book stem largely from the 'Euro-limpacs' project, a major EU-funded project on 'the impact of global change on European freshwater ecosystems'. Euro-limpacs brought together lake, river and wetland scientists from across Europe to assess not only the direct impacts of climate change on freshwaters but also its potential indirect impact through interactions with other stresses such as changes in hydromorphology, nutrient loading, acid deposition and toxic substance exposure.

A wide variety of approaches was used in the project ranging from the analysis of lake sediment and long-term instrumental records to identify past impacts of climate change, to the use of experiments, space-for-time substitution and modelling to assess what might happen in future under different climate scenarios.

The project also considered the implications of future climate change for the management of freshwater ecosystems in Europe, especially the extent to which current policies and practices designed to improve the ecological status of freshwater ecosystems need to be modified in light of projected future climate change.

This book brings together the key results from the project. Its structure follows the design of the Euro-limpacs project, first assessing the probable effects of climate change and then considering management issues.

Richard W. Battarbee

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1

Introduction

Brian Moss, Richard W. Battarbee and Martin Kernan

Changing climate and a changing planet

In June 2008, one of us chanced upon a shepherd repairing his five-ft high (he didn't deal in metres) dry limestone walls on the uplands near Asby Scar in Cumbria, north-west England. We exchanged pleasantries that inevitably, this was Britain after all, embraced the weather. It was a bright warm day. But 'Bleak in winter up here' I said. 'Not so much in the past fifteen years' he replied, 'Before that the snow lay in drifts hiding the walls, but not any more'. It was yet another anecdotal sliver of evidence to complement the mass of information assembled by the Intergovernmental Panel on Climate Change (IPCC 2007) on the reality of global warming.

That Fourth Report of the IPCC summarized changes to date (Fig. 1.1) that included an almost 1°C increase in the northern hemisphere mean air temperature, over the years since the industrial revolution accelerated the yet unabated burning of fossil fuels. It presented evidence that these processes were related and that we could have high confidence that the temperature rise was largely human-induced. Linked with it have been changes in the distribution of rainfall, with generally more falling in winter or wet seasons and less in the summer and dry seasons. There has been an increase in sea level of about 20 cm, largely due to thermal expansion of the huge mass of oceanic water, to which the melting of the mountain and polar glaciers is now making a contribution. And there has been an increase in the frequency of extreme weather events, such as cyclones, droughts and floods. In turn, there have been numerous records of changes in the phenology of species (Sparks & Carey 1995; Roy & Sparks 2000; Parmesan & Yohe 2003; Hays *et al.* 2005; Adrian *et al.* 2006) and a steady migration polewards of a variety of the more mobile species (Walther *et al.* 2002; Root *et al.* 2003).

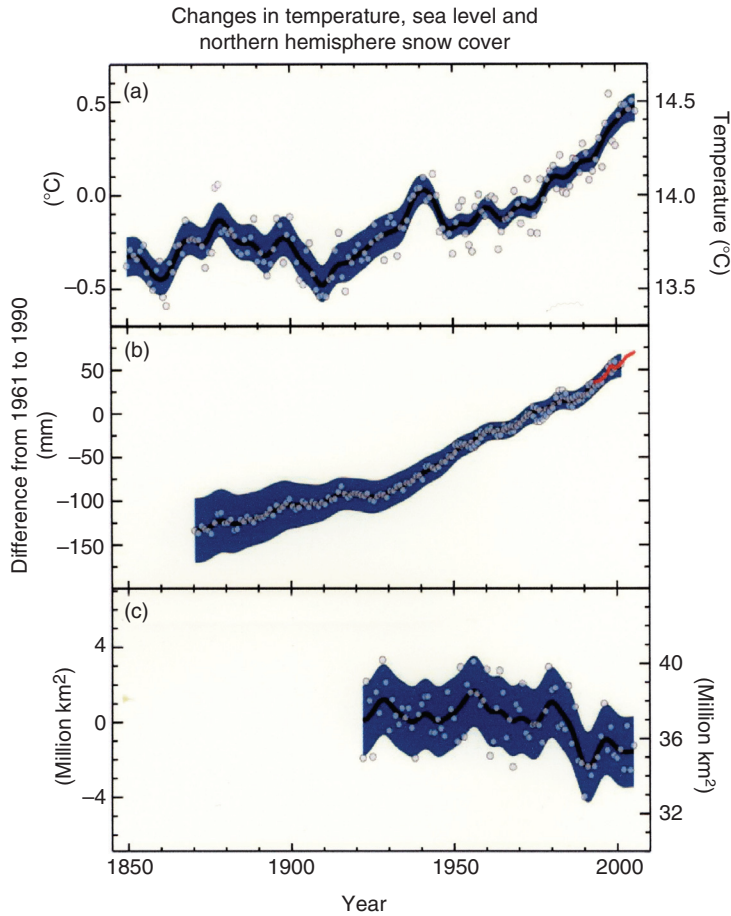


Figure 1.1 Summary of climate and sea-level change to date. (a) Global average temperature. (b) Global average sea level. (c) Northern hemisphere snow cover. (From *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds S. Solomon, M. Manning, Z. Chen, et al.). Cambridge University Press, Cambridge and New York.)

Climate is a master variable, and all activity on this planet eventually depends upon it. It determines the overall structure of natural biomes, be they deserts, grasslands or deciduous or evergreen forests. It has driven the evolution of life histories, the dynamics of food webs and the development of homeostases. It fixes the circulation of the oceans, the availability of nutrients to the plankton community, the onset of rain and ripening for crops and the reflectance of radiation from the Poles. It manifests itself in the day-to-day weather, a preoccupation of everyone, not just the British. It is the greatest determinant of leisure travel, and, in its extremes, a source of extreme misery to match its delights of balmy summer days, exciting ski runs and the fresh spring rain. A major change in climate is a very considerable issue.

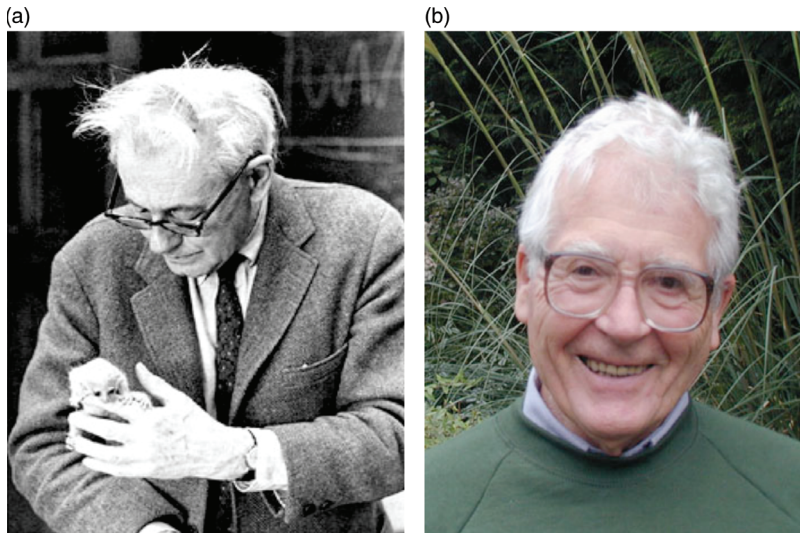


Figure 1.2 (a) G.E. Hutchinson and (b) James Lovelock.

Changing ideas on planetary function

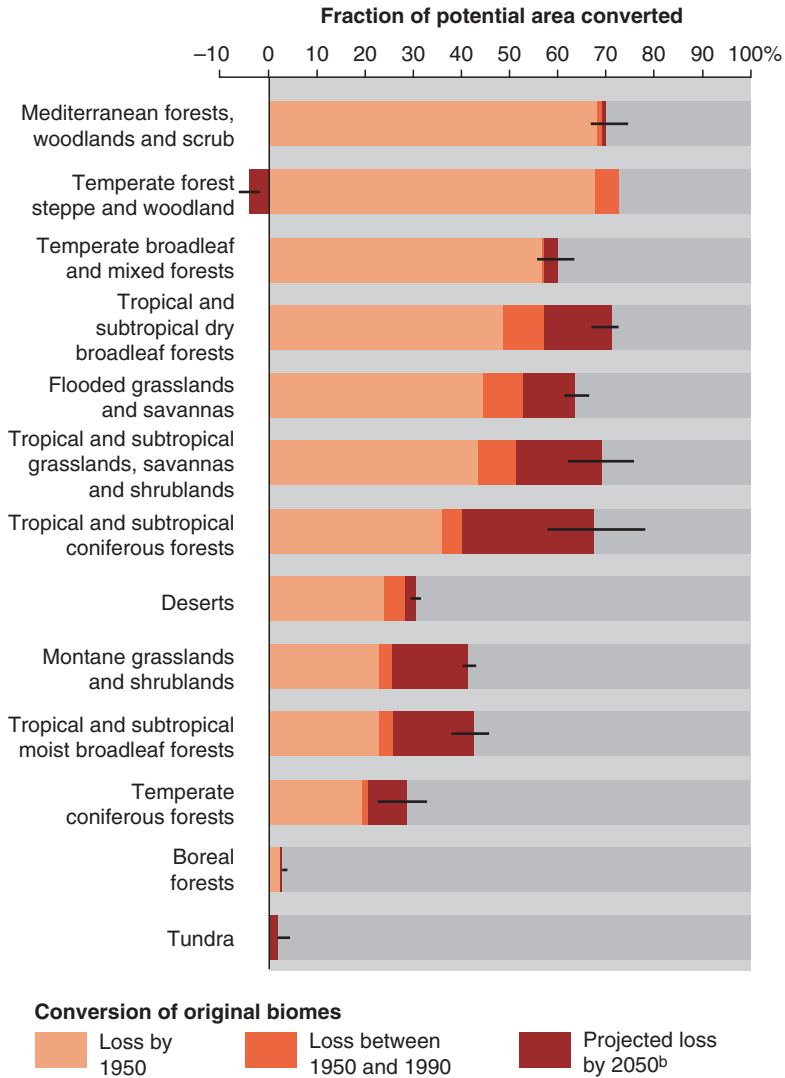
Ecologists have long sought to explain the huge variation of natural systems: the tapestry of weather and soil-related detail on land and physical and chemical detail in water that fits into a grand pattern of climate zones. G.E. Hutchinson (1965) (Fig. 1.2) linked the ways that organisms evolve, as both grand and local patterns change, in his metaphor of the ecological (or environmental) theatre and the evolutionary play. His concept, in the 1960s, was very much one of the players adjusting to the nature of the theatre and then to each other. The generally accepted paradigm was that the physicochemical setting, the geology and climate, determined the biology and ecology of living organisms. Twenty years later, James Lovelock (1988) (Fig. 1.2) began an overturning of this by a spectroscopic examination of the chemistry of the atmospheres of Earth and its sister planets and a study of Earth's oceans. He calculated that the chemical state of Earth was very far from that expected by a simple chemical equilibrium of the available elements, and inferred that it was determined, and maintained, by the activities of living organisms rather than physicochemically imposed upon them for their response. Moreover, the state was regulated within the limits between which our particular biochemical system could persist. There is still controversy about the underlying mechanism of the regulation, but not about its existence. Such a change in paradigm is key to our understanding of the mutual interactions of climate and living organisms that this book is about. By altering our atmosphere, we challenge the entire biosphere system, and although we can predict some immediate physical effects, we have little idea about what the ultimate biological consequences might be.

The IPCC has made a range of predictions about how climate will change over the regions of the Earth, based on a range of assumptions about how human

societies will react as the first of the changes are experienced. There is a problem, however, in these predictions. They all hold to the former model of living systems responding to imposed conditions. They are models of simple physicochemical control. They do not allow for the likelihood of positive ecological feedbacks. Temperature influences many biological processes, but not in a linear way. More usual is some sort of exponential relationship in which the process accelerates or decelerates to a point of death as temperature changes linearly. A key process in regulating the carbon dioxide content of the atmosphere is the storage of carbon as organic matter in soils and peat deposits or as calcite in the ocean sediments, derived from the scales of planktonic coccolithophorids or the matrices of corals (Lovelock 1988). If the temperature change induces more carbon dioxide or methane release, through increases of respiration using organic matter stored in soils and sediments, for example, or through inhibition of calcite formation in the walls of marine organisms, a positive feedback on further temperature increase may be induced and the greenhouse effect may be reinforced. Temperature changes predicted for the future may thus have been underestimated, and climate modellers are now attempting to rectify this.

The system that maintains the non-equilibrium, equable state of the planet is the biosphere. The biosphere has, for convenience, been divided up into atmosphere, hydrosphere and lithosphere: air, ocean and land. And the lithosphere is thought of in terms of biomes: tundra, coniferous forest, deciduous forest, tropical forest, scrub savannah, grassland and desert. In turn, these may be divided into constituent ecosystems, which Arthur Tansley (1935) defined as more or less self-contained systems of living organisms, and their biologically produced debris, in their physicochemical setting. In truth, this idea was an artefact of working in the greatly subdivided landscape of the British Isles, where several thousand years of human activity have entirely compartmented the landscape. Our upland shepherd, with his walls, in a sense influences our ecological as well as climatic thinking. For convenience we nonetheless talk of woodland, heath, saltmarsh, river and lake ecosystems. But the pristine biosphere was ultimately a continuum that adjusted mutually, gradually and in many dimensions to changing climatic and geological conditions, and in considering freshwaters in particular, the greatest understanding comes from seeing them as intimately linked with the land and atmosphere. It is sometimes convenient, however, for the process of accounting for change to see the parts rather than the whole.

A report as authoritative as that of the IPCC, the *Millennium Ecosystem Assessment*, appeared in 2005. It received much less publicity, for though weather is immediately noticeable to people everywhere, the fate of distant oceans, tundras and savannahs is not, unless you are a deep sea mariner, Inuit hunter or Masai herder. But major changes (Fig. 1.3) have happened to most natural ecosystems, and are continuing to happen to most of them, as a result of climate change and also because of many other, independent drivers that depend on the workings of global economics and the needs of a rising population. It is expected that we will have lost over half of the world's land ecosystems to agriculture or development by 2050. The urbanites may not be noticing this but the consequences will nonetheless be huge, for it is these natural ecosystems that regulate the nature of the biosphere. We have absolutely no idea how much of them can be damaged without serious consequences for human survival. All we know is



^a A biome is the largest unit of ecological classification that is convenient to recognize below the entire globe, such as temperate broadleaf forests or montane grasslands. A biome is a widely used ecological categorization, and because considerable ecological data have been reported and modelling undertaken using this categorization, some information in this assessment can only be reported based on biomes. Whenever possible, however, the MA reports information using 10 socioecological systems, such as forest, cultivated, coastal and marine, because these correspond to the regions of responsibility of different government ministries and because they are the categories used within the Convention on Biological Diversity.

^b According to the four MA scenarios. For 2050 projections, the average value of the projections under the four scenarios is plotted and the error bars (black lines) represent the range of values from the different scenarios.

Figure 1.3 Projected losses of major ecosystems and biomes^a. (From *Millennium Ecosystem Assessment* 2005.)

that such systems, honed by the utterly ruthless mechanisms of natural selection to be as near fit for purpose as possible, are just as crucial to us, indeed much more fundamentally so, than the local grocer, filling station or hospital. The chemistry of the biosphere is the ultimate *sine qua non* of our existence. Damaged ecosystems, including all agricultural ones, do not store as much carbon as intact ones. James Lovelock's contribution was to point this out.

We have responded rather oddly to the increasing damage we have caused by attempting to value in classical economic terms the goods and services we draw from ecosystems, to demonstrate their importance (Costanza *et al.* 1997; Balmford *et al.* 2002). This has been influential in drawing attention to their very great apparent value and in helping communicate with economists and politicians. But perhaps we have completely missed the point. They are not items that can be used, misused, repaired, ignored or traded at will. They are outside the current economic system. What they do in maintaining the equable state of the planet for all living organisms, including us, is so fundamental as to be priceless. It would be inconceivable, as William Shakespeare (1623) well knew 400 years ago, through the wonderful speech of Portia in *The Merchant of Venice*, to value the blood as a separate component of the body. What is *sine qua non* supersedes evaluation. Yet we damage the biosphere as casually as we throw away our rubbish, and in contemplating the hitherto effects of climate change, we fail to realize that the loss of ecosystems and the changing climate are mutually linked. Indeed, we blithely cost the damage of climate change (Stern 2006) as we cost the goods and services we are losing through application of the same approach of classical economics. We have failed to see the interaction of climate, ecology and equability. Our attempts to mitigate climate change, in a desperate bid to avoid disruption of our societies, may inevitably be doomed to failure unless we begin to see the whole picture and not just the components we find most convenient to our cash economy.

Water and the freshwater biota

Though the ultimate driver of climate change effects will be temperature, the immediate executive will be the availability of freshwater. Freshwater systems stitch together the biosphere through the hydrological cycle. The stitching, however, can become undone, and the surface freshwater component is perhaps the most vulnerable part of the hydrosphere. Living organisms absolutely need liquid water. The ability of liquid water to persist is a fundamental characteristic of a planet capable of supporting life based on carbon compounds. The creation of conditions allowing its existence is the ultimate triumph of the biosphere. The Earth in chemical equilibrium would be so hot as to bear only water vapour. Moreover, human history is, at bottom, an account of the availability of water for drinking, crop growing and sanitation. It follows from the effects of climate change through floods and droughts that the next century, even the next few decades, will likely see more disruption of human activities than has been experienced in the evolution of our species.

For the freshwater systems and organisms with which this book is concerned, the detailed effects of moderate climate change could vary from being disastrous

to locally positive. In the absolute scale of temperature, water has its boiling and freezing points very close to the mean surface temperature of the Earth. In its evaporation and condensation, water is the operative liquid of the earth's refrigerator. It follows that the denizens of freshwaters have had an evolutionary history in which their habitats have rather frequently frozen solid or evaporated to mud flats or rocky beds. Freshwater animals and plants are comparatively young in evolutionary terms for they have had repeatedly to recolonize newly constituted freshwaters from the land and the ocean following prolonged glaciation, volcanic disruption or periods of great aridity. They are creatures of continual disturbance (Milner 1996).

Some manifestations of this are that many aquatic insects and vascular plants retain land characteristics as adults or where they flower, respectively; the diversity of freshwaters is much lower, for example, lacking whole phyla, than that of the oceans; freshwater organisms may have particularly high rates of evolutionary change; resting spores and eggs to tide over inimical conditions are common (Pennak 1985). Marine organisms, in contrast, almost universally lack resting stages, for their medium, though changing in shape and depth, has persisted as a body of water for nearly 4 billion years. The longevity of freshwaters may sometimes be only weeks. The retention of adult flight allows movement for insects that cannot persist as resting eggs, and apart from fish, almost all the vertebrates associated with freshwaters are highly motile over land. Fish are vulnerable for few can survive drought, though they are adept at migration through river systems, using even the ocean as part of their life history in some cases. Some crustaceans, however, may respond genetically and very rapidly to thermal stress (van Doorslaer *et al.* 2007).

As climate changes, marine communities will have a continuity of habitat that will accommodate major changes in distribution, though for sedentary organisms like corals, the speed of change may cause severe difficulties. In contrast, land communities, subjected to more frequent drought and without the buffering medium of water, with its high specific heat, will be more vulnerable to extreme temperatures. But the freshwater biota might adjust most readily to climate change because of its preadaptation to disturbance. For them, however, there is a further complication. Freshwaters most immediately and most graphically reflect the many abuses an increasing human population, with its increasing demands for resources, increasing production of waste and rapidly accelerating ability to make changes through its technology, can impose. Freshwaters reflect all the activities that go on in their catchments, which means the entire land surface. Chemical and agricultural wastes, both dissolved and suspended, run into them or rain onto them. Rivers have been repeatedly used as cheap pipes to remove urban wastes. Floodplain wetlands have been embanked and drained so that their fertile soils might be cultivated. Fish communities, the main source of animal protein for many peoples, have been severely overfished. And the very ability of freshwater communities to accommodate change has led to the persistence of many introduced species that have sometimes become dominant and simplified the communities that they have invaded. Not surprisingly, the *Millennium Ecosystem Assessment* listed freshwaters as one of the most vulnerable of the ecosystems it considered (Fig. 1.4). Exactly how freshwater habitats will change,

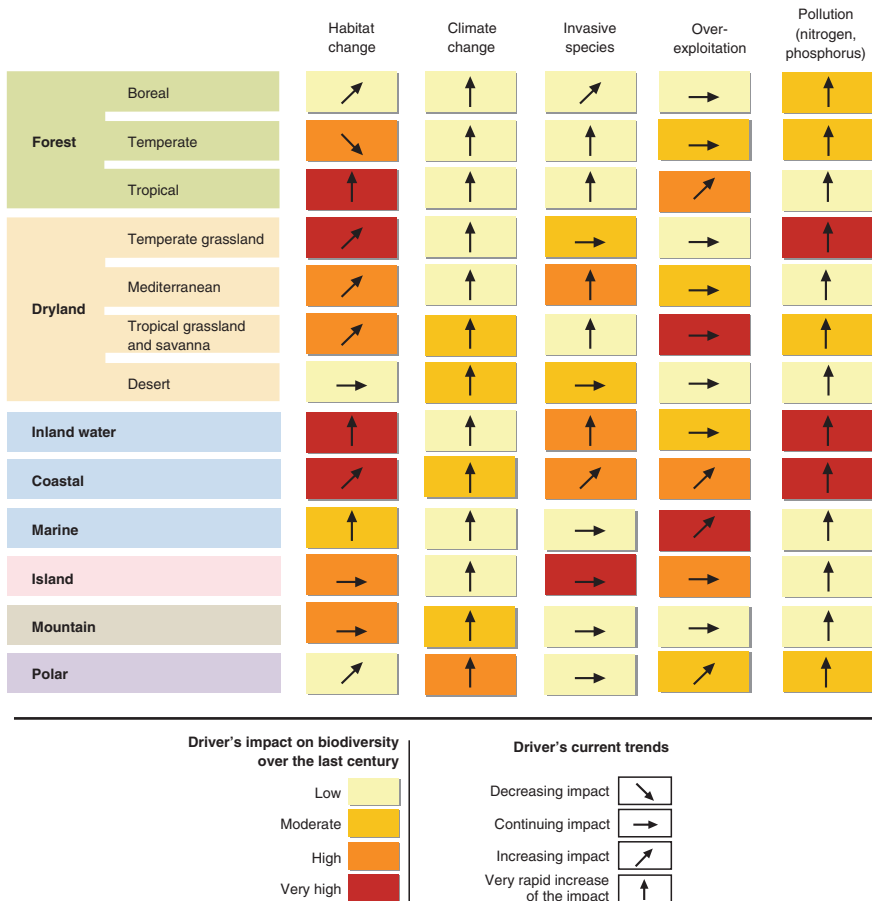


Figure 1.4 Summary of effects of major drivers on major biomes. (From *Millennium Ecosystem Assessment 2005*.)

how the adjustments of their communities will occur and what will be the detailed consequences of the changes for particular places and individual species are thus much more difficult to predict than if climate change were the only threat to them. Current attempts rest largely on expert opinion (Mooij *et al.* 2005). It is one role of this book to add to the factual basis for predictions.

Euro-limpacs, European freshwater systems and approaches to investigation

Europe provides a huge range of inland waters, from the Greenland, Icelandic and mountain glaciers to the streams and lakes of the arider parts of Spain, from the small crater lakes of the Azores to the expanses of Lakes Ladoga, Mälaren and Maggiore and from the tiny headwater streams of the hills to the large, if not

Amazonic, rivers of the Rhine and Danube. Of course, other continents contain an equal or greater variety, but Europe also offers the complication of major biological barriers to animal and plant movements in the Mediterranean, the Alps, the Baltic and the North Sea, the benefits of a long and sophisticated tradition of research in freshwater ecology, and a large concentration of freshwater scientists. Euro-limpacs, on which this book is based, has been a European-Union-funded, continent-wide research programme to further our understanding of the potential effects of climate change on freshwaters. It has contributed to our understanding of the direct physical and hydrological effects of warming in the past (Chapter 2) and present day (Chapters 3 and 4) and on the interactions with climate of nutrients (Chapter 6), acidity (Chapter 7) and toxic pollution (Chapter 7). It has looked at the implications for monitoring and restoration (Chapters 5 and 9) and the definition of reference conditions under the Water Framework Directive. Moreover, it has sought to use the results of these studies in modelling the future (Chapter 10) and in helping political organizations to make decisions on management (Chapter 11).

Euro-limpacs has been far from the last word, but it has contributed important advances, and its strength has been the wide range of approaches it has used. There is a nexus of stages in investigating any general phenomenon and climate change effects on freshwater systems are no exception. The first stage is simply in establishing their existence. There can be no doubt now that climate change is occurring and virtually no doubt that it has largely been caused by human activity. There is then a plethora of studies showing consequent effects (e.g. Carvalho & Kirika 2003; Berger *et al.* 2007), though, strictly speaking, it is rare for the consequence to be rigorously demonstrated. We are dealing with an unreplicated grand experiment with no control.

However, where changes occur in many different glaciers, rivers and lakes and where these correlate closely with changing temperatures or precipitation (Gerten & Adrian 2000; Straile 2002; Winder & Schindler 2004), there can be some confidence in the link. Such correlation, however, is made difficult because many other changes have occurred in freshwater systems over the same period as climate change, and most changes are ultimately caused by the increasing size, aspirations and technological development of human societies in the past 200 years or so.

The correlations of recent history can be placed in context by the reconstructions of the more distant past through analysis of lake and wetland sediments. The record is patchy and selective, and interpretations usually lack experimental validation, but where sediment and direct records have been compared over the past few decades, there is often a close relationship (Haworth 1980), and sophisticated statistical approaches (Birks 1998; Battarbee 2000) have been used to quantify the palaeoecological record.

For periods before the last few decades, or occasionally the last two centuries, where diary and documentary evidence exists, the sediment record is the only record and we must use it as efficiently as we can. The range of chemical and biological remains that can now be counted and calibrated against contemporary observations and sediments is very wide. It can be increasingly elaborated by the techniques of resurrection ecology where resting stages of invertebrates can be

hatched and their changing characteristics and genome traced through a period of environmental change (Mergeay *et al.* 2004).

A parallel approach to palaeoecological studies is to use space-for-time investigation, where existing climate gradients provide different systems for examination. The gradient from Greenland to Greece in Europe provides a wide range of systems in which processes and food webs can be compared to predict how they might change as temperatures increase (Moss *et al.* 2004; Meerhof *et al.* 2007). There are, as with every approach, problems with this otherwise attractive endeavour. Not only does climate change along the gradient, but so do relief, geology and the intensity of human activity. Good design of observational schemes can correct for these by stratified random sampling, but one major source of variation, accidents of history, cannot. Glaciation and the nuances of biogeography impose differences that can only be judged. A formerly glaciated lake in Finland, with an Ice-Age-depleted, still recolonizing biota, may not respond to temperature increase in the same way as a long-established Mediterranean lake that may have been affected but not obliterated by the ice of the glacial period, 20,000 years ago, even if the Finnish lake eventually becomes as warm as the Mediterranean one now.

The next stage of investigation is to attempt to reproduce alleged effects through experimentation. Experiments can reveal mechanisms because the drivers of change can be controlled, and experimental designs and adequate replication allow the study of several simultaneous drivers. Experiments are thus potentially more powerful than comparative observations. They also compel the creation of mechanistic hypotheses that force the experimenter to think through the processes that are going on. But the scale of the experiment is important in ecology. Whole-system experiments (Carpenter *et al.* 2001) (clear-felled versus undisturbed sub-catchments of a forested river system, lakes subdivided by curtains and parallel-engineered river channels) are ideal but liable to pseudoreplication because the experiments are so expensive, and the subjects so individual, that generally only one system can be handled at a time. In contrast, experimental laboratory microcosms (Petchey *et al.* 1999) can be replicated extensively but lack reality. The fashion of using micro-organism communities to mimic large-scale systems (Benton *et al.* 2007) is attractive but perhaps mostly to theoreticians.

The compromise is to use subsystems of real communities: mesocosms in lakes, artificial river channels or plots in wetlands, or mesocosm tanks big enough to contain all or almost all of the structures and food-web levels of a system (McKee *et al.* 2000, 2002, 2003; Liboriussen *et al.* 2005). Usually 'almost all' is apposite, for the top predators of a fish community need much more space than is possible in replicable mesocosms, and the complete complexity of a natural system, which, in rivers, for example, might involve interactions with large land mammals (Terborgh 1988; Ripple & Beschta 2004) and tonnages of dead timber, is beyond contemplation.

Another compromise is to do the experiments on simulated systems or models using computer technology. This is, of course, the approach taken by the IPCC in modelling future climate change. *Per se* it is relatively inexpensive, but the models are reflections of the data input to them. If there are unsuspected factors involved,

these cannot be included and the output of the model is a reflection of the perceptions of its perpetrators. The same is true of observational techniques and practical experiments. Through choice of variables or of initial experimental conditions, the conclusions are partly predetermined. Nonetheless, the failures of both models and experiments to replicate reality are valuable indicators of what might be missing from their designs. Such gaps are inexpensive to plug in modelling, if not in repeated large-scale experiments, and the behaviour of whole river systems, regions or the biosphere can ultimately be only the province of modelling.

The organization of Euro-limpac reflected these advantages and uncertainties by using a range of approaches. It had to build on existing experience and facilities for the most part and could not achieve the ideal of using all the approaches on a single habitat and a single aspect of climate change, even if such singularity exists. Understanding increases nonetheless, even if tidy systems of operating are inevitably confounded by the realities of funding and personal preferences. In the end, opinion will depend on expert judgement based on all lines of evidence, for precise prediction is only possible for simple systems, and nothing in earth system science, with its underpinning of living organisms, not least the human ones, is remotely simple.

Applications and the Water Framework Directive

Euro-limpac included substantial components concerning the application of the emerging scientific understanding. In Europe at present, water management is very much focussed on the Water Framework Directive (EC/2000/60). The Directive changes the previous approach to monitoring waters in Europe by emphasising a whole-basin approach and by requiring determination and restoration of ecological quality, as opposed simply to chemical water quality. This must be done with respect to reference systems, which are defined in the Directive as those unaltered or only negligibly altered by human activity. There are few, if any, such systems left in Europe, so great has been the impact of large population densities over several centuries, so determination of the schemes to determine ecological quality is problematic. Nonetheless, tools for determining the status of phytoplankton, aquatic plants, macroinvertebrates and fish are being developed (UKTAG 2007), often using particular indicator species or families. Climate change will inevitably upset these schemes as species become eliminated or new ones move into previous cooler habitats.

There is also the underlying issue that since climate is now strongly influenced by people, the establishment of reference pristine standards has become conceptually impossible (Moss 2007, 2008). These issues are discussed in Chapter 9. The Directive also requires restoration of aquatic systems to good ecological status, defined as only slightly different from the high ecological status of the reference standards. At this stage, the uncertainties become so great that schemes are needed to help the appraisal of the available scientific information by agencies and governments, and this issue is considered in Chapter 11.

Several reports have pointed out the economic consequences of climate change. The Stern Report (2006) concluded that climate change could be mitigated at the

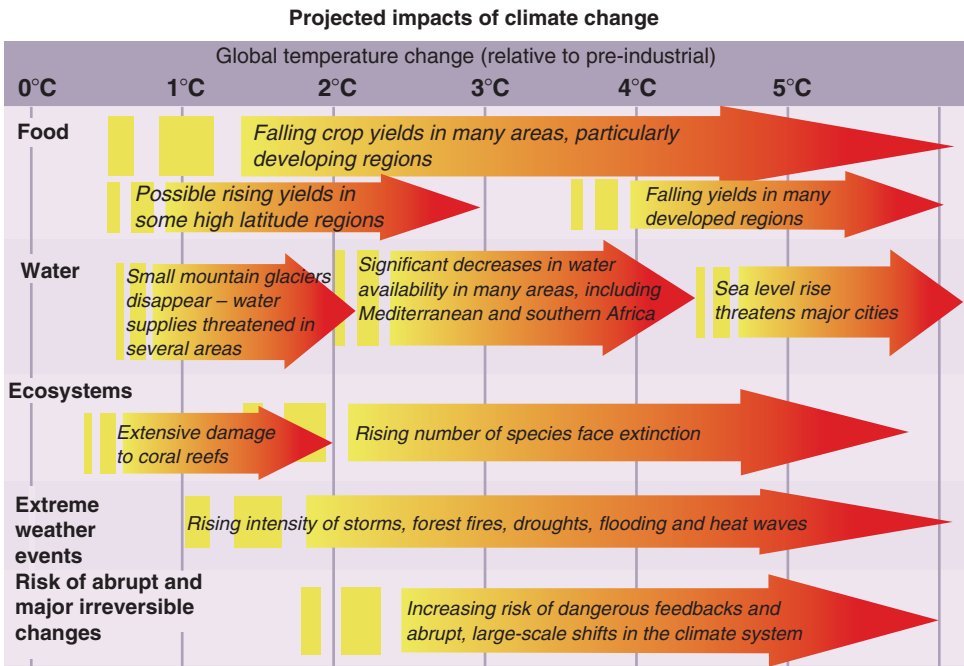


Figure 1.5 Projected effects of increasing temperatures on natural and human systems. (From Stern 2006.)

cost of a substantial but affordable sum, if there were reaction now, but much greater sums if there were delays. Governments have attempted to put in place mechanisms to generate energy by means other than burning fossil fuels, devices to encourage energy conservation and schemes to offset carbon usage by paying for trees to be planted. By and large none of these schemes has yet reduced fossil fuel consumption (Monbiot 2007) and it seems very likely that temperatures will rise later this century by several degrees. A 2°C rise may be held at a concentration of greenhouse gases equivalent to about 480 ppm carbon dioxide compared with the current value of 380 ppm carbon dioxide. It seems, however, more likely that concentrations will rise to at least 550 ppm, denoting a temperature rise of 3°C–4°C, which will bring many problems (Fig. 1.5). The possibilities of biological feedback mechanisms have not, of course, been factored into any of these targets.

A glance through any daily newspaper will reveal several pages of business and sports news that change in detail but not overall content. Pages of other news will change in scope more than business and sport and increasingly a consistent though still very small element of these will concern environmental issues. We might anticipate a time, however, when this formula will change. Sport will undoubtedly retain its hegemony, but the unfolding impacts of resource depletion, waste accumulation, ecosystem destruction, population increase and climate change must eventually displace the multi-page minutiae of stocks, shares, executive salaries and the fate of companies. A new economics will need to be in place or we may be

in our final human throes. But for the moment, this book essentially takes the emerging evidence from the physical to the sociological and applies expert judgement to it to assess the interplay between freshwaters and human societies as the climate drama, now just past the Prologue, unfolds. It brings together the major concepts of Hutchinson, Lovelock and Tansley in a crucial act of the evolutionary play as the theatre itself begins to change somewhat ominously.

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