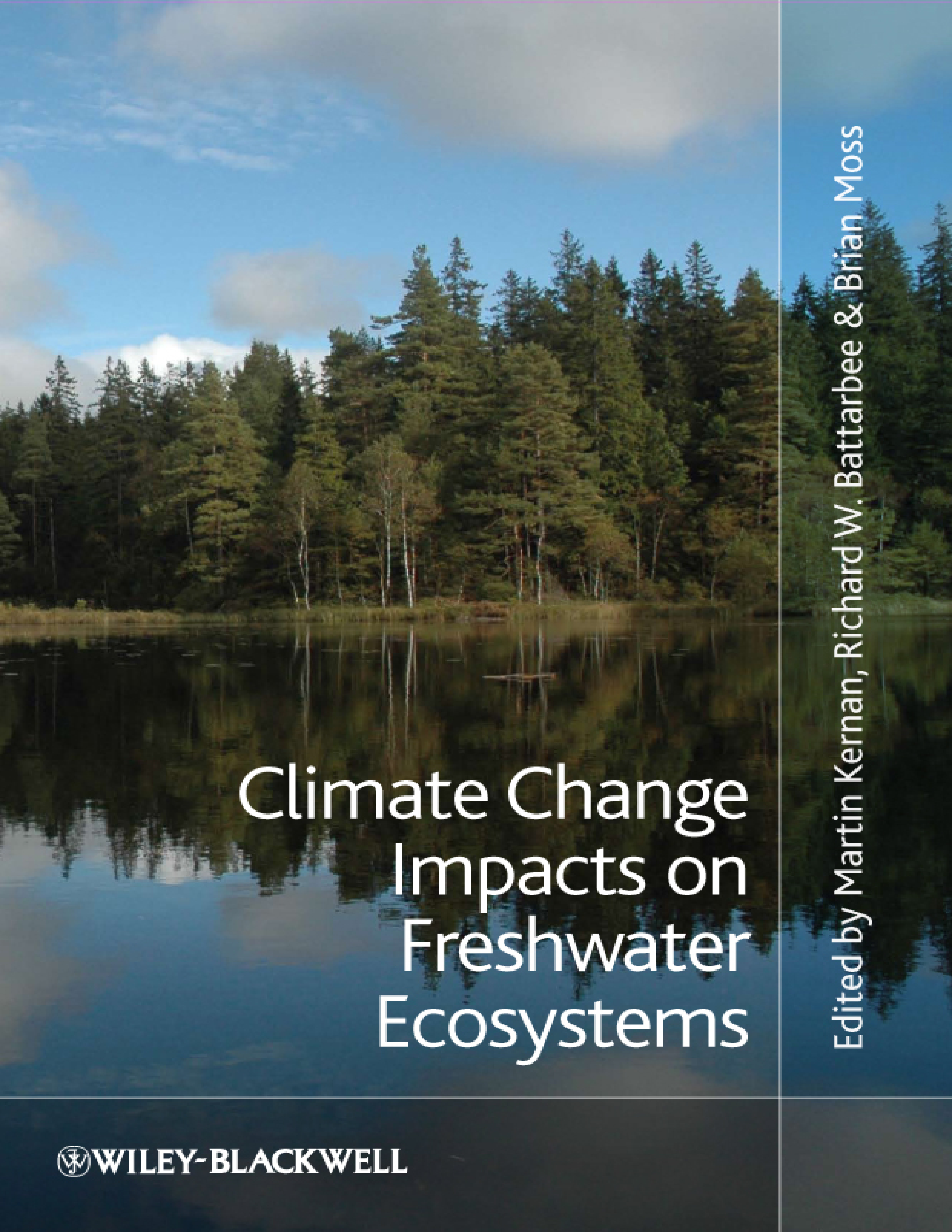


Climate Change Impacts on Freshwater Ecosystems

Edited by Martin Kernan, Richard W. Battarbee & Brian Moss

WILEY-BLACKWELL

Climate Change Impacts on Freshwater Ecosystems

Climate Change Impacts on Freshwater Ecosystems

Edited by

Martin Kernan, Richard W. Battarbee and Brian Moss

WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

This edition first published 2010, © 2010 by Blackwell Publishing Ltd

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical and Medical business to form Wiley-Blackwell.

Registered Office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices

9600 Garsington Road, Oxford, OX4 2DQ, UK

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

111 River Street, Hoboken, NJ 07030-5774, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell

Library of Congress Cataloging-in-Publication Data

Climate change impacts on freshwater ecosystems / edited by Martin Kernan, Rick Battarbee and Brian Moss.

p. cm.

Includes bibliographical references and index.

ISBN 978-1-4051-7913-3 (hardback)

1. Freshwater habitats. 2. Freshwater ecology. 3. Climatic changes–Environmental aspects. I. Kernan, M. R. II. Battarbee, R. W. III. Moss, Brian, 1943–

QH541.5.F7C65 2010

577.6′22–dc22

2010016420

A catalogue record for this book is available from the British Library.

Set in 10.5/12pt Classical Garamond by SPi Publisher Services, Pondicherry, India

Contents

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

Acknowledgements

We are very grateful to Gene Likens and Curtis Richardson for encouraging us to write this book. We acknowledge European Union 6th Framework RTD programme which provided the funding for Euro-limpacs (EU Contract No. GOCE-CT-2003-505540). We would like to thank our EU project manager, Christos Fragakis, for his support throughout the 5 years of the project. We owe our considerable gratitude to the many participants involved in Euro-limpacs who provided the data and analyses underpinning much of this book. From UCL, we would like to thank Cath D'Alton for her efforts with the diagrams, and Catherine Rose and Katy Wilson for the invaluable help they provided the editorial team in putting the manuscripts together. We would also like to thank those colleagues who provided anonymous reviews for each of the chapters. We dedicate the volume to the very many scientists in Euro-limpacs who are not included as authors in the book but who contributed to the success of Euro-limpacs and whose work is drawn upon throughout the book.

Contributors

Julian Aherne
Environment & Resource Studies, Trent University, Peterborough, ON, Canada

Hans Estrup Andersen
NERI, Aarhus University, Silkeborg, Denmark

Tom Barker
Institute for Sustainable Water, Integrated Management, and Ecosystem Research, University of Liverpool, Liverpool, UK

Richard W. Battarbee
Environmental Change Research Centre, Department of Geography, University College London, London, UK

Helen Bennion
Environmental Change Research Centre, University College London, London, UK

Ekin Birol
International Food Policy Research Institute, Washington, DC, USA

Kevin Bishop
Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden

Karel Brabec
Faculty of Science, Masaryk University, Brno, Czech Republic

Laetitia Buisson
Laboratoire Evolution et Diversité Biologique, Université Paul Sabatier, Toulouse, France

Dan Butterfield
Department of Geography, University of Reading, Reading, UK

Laurence Carvalho

Centre for Ecology and Hydrology, Midlothian, UK
Jordi Catalan
CEAB-CSIC, Blanes, Spain
Luc DeMeester
Laboratory of Aquatic Ecology and Evolutionary Biology, KULeuven, Leuven, Belgium
Peter J. Dillon
Environment & Resource Studies, Trent University, Peterborough, ON, Canada
Martin Erlandsson
Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
Chris D. Evans
Centre for Ecology and Hydrology, Environment Centre Wales,
Bangor, UK
Pilar Fernandez
Department of Environmental Chemistry, Institute of Environmental Assessment and Water Research, Barcelona, Spain
Heidrun Feuchtmayr
Centre for Ecology and Hydrology, Lancaster Environment Centre, Lancaster, UK
Martin Forsius
Ecosystem Change Unit, Natural Environment Centre, Finnish Environment Institute, Helsinki, Finland
Nikolai Friberg
Department of Freshwater Ecology, National Environmental Research Institute, Aarhus University, Silkeborg, Denmark
Mark O. Gessner
Department of Aquatic Ecology, Eawag: Swiss Federal Institute of Aquatic Science & Technology, Dubendorf, Switzerland and Institute of Integrative Biology, ETH Zurich, Zurich, Switzerland

Wolfram Graf
Department Water-Atmosphere-Environment, Institute of Hydrobiology and Aquatic Ecosystem Management, BOKU–University of Natural Resources and Applied Life Sciences, Vienna, Austria
Gäel Grenouillet
Laboratoire Evolution et Diversité Biologique, Université Paul Sabatier, Toulouse, France
Joan O. Grimalt
Department of Environmental Chemistry, Institute of Environmental Assessment and Water Research, Barcelona, Spain
Alexandra Haidekker
Department of Applied Zoology/Hydrobiology, Institute of Biology, University of Duisburg–Essen, Essen, Germany
David W. Hardekopf
Institute of Environmental Studies, Charles University in Prague, Prague, Czech Republic
Mariet Hefting
Ecology and Biodiversity, Institute of Environmental Biology, Utrecht University, Utrecht, The Netherlands
Rachel C. Helliwell
Macaulay Instititute, Aberdeen, UK
Daniel Hering
Department of Applied Zoology/Hydrobiology, Institute of Biology, University of Duisburg–Essen, Essen, Germany
Thomas Horlitz
Entera, Hannover, Germany
Jakub Hruška
Czech Geolological Survey, Prague, Czech Republic
Mike Hutchins
Centre for Ecology and Hydrology, Wallingford, Oxon, UK
Sonja C. Jähnig

Limnology and Conservation Department, Natural History Museum Senckenberg, University of Duisburg-Essen, Gelnhausen, Germany
Ron Janssen
Department of Spatial Analysis and Decision Support, Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands
Erik Jeppesen
Department of Freshwater Ecology, National Environmental Research Institute, Aarhus University, Silkeborg, Denmark
Richard K. Johnson
Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
Philip J. Jones
Centre for Agricultural Strategy, School of Agriculture, Policy and Development, The University of Reading, Reading, UK
Øyvind Kaste
Norwegian Institute for Water Research, Southern Branch, Grimstad, Norway
Martin Kernan
Environmental Change Research Centre, Department of Geography, University College London, London, UK
Jiří Kopáček
Biological Centre ASCR, Institute of Hydrobiology, Ceske Budejovice, Czech Republic
Phoebe Koundouri
Department of International and European Economic Studies, Athens University of Economics and Business, Athens, Greece
Pavel Krám
Czech Geolological Survey, Prague, Czech Republic
Hjalmar Laudon
Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Umeå, Sweden

Torbden L. Lauridsen
Department of Freshwater Ecology, National Environmental Research Institute, Aarhus University, Silkeborg, Denmark
Lone Liboriussen
Department of Freshwater Ecology, National Environmental Research Institute, Aarhus University, Silkeborg, Denmark
Conor Linstead
Institute for Sustainable Water, Integrated Management, and Ecosystem Research, University of Liverpool, Liverpool, UK
David M. Livingstone
Department of Water Resources and Drinking Water, Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
Armin Lorenz
Department of Applied Zoology/Hydrobiology, Institute of Biology, University of Duisburg–Essen, Essen, Germany
Hilmar J. Malmquist
Natural History Museum of Kópavogur, Kópavogur, Iceland
Edward Maltby
Institute for Sustainable Water, Integrated Management, and Ecosystem Research, University of Liverpool, Liverpool, UK
Linda May
Centre for Ecology and Hydrology, Midlothian, UK
Mariana Meerhoff
Department of Freshwater Ecology, National Environmental Research Institute, Aarhus University, Silkeborg, Denmark and Grupo de Ecología y Rehabilitación de Sistemas Acuáticos, Departamento de Ecología, Facultad de Ciencias, Universidad de la República, Montevideo, Uruguay
Filip Moldan
Swedish Environmental Research Institute IVL, Gothenburg, Sweden

Don Monteith
Centre for Ecology & Hydrology, Lancaster Environment Centre, Lancaster, Lancashire, UK
Brian Moss
Institute for Sustainable Water, Integrated Management and Ecosystem Research, University of Liverpool, Liverpool, UK
John Munthe
IVL Swedish Environmental Research Institute, Gothenburg, Sweden
John Murphy
FBA River Laboratory, The School of Biological and Chemical Sciences, Queen Mary, University of London, Wareham, Dorset, UK
Ulrike Nickus
Institute of Meteorology and Geophysics, University of Innsbruck, Innsbruck, Austria
Jon S. Olafsson
Institute of Freshwater Fisheries, Reykjavik, Iceland
Helle Ørsted Nielsen
Department of Policy Analysis, National Environmental Research Institute, University of Aarhus, Roende, Denmark
Benjami Piña
Department of Environmental Chemistry, Institute of Environmental Assessment and Water Research, Barcelona, Spain
Katri Rankinen
Finnish Environment Institute, Helsinki, Finland
Kyriaki Remoundou
Department of International and European Economic Studies, Athens University of Economics and Business, Athens, Greece
Michela Rogora
Institute of Ecosystem Study, CNR, Verbania, Italy
Neil L. Rose

Environmental Change Research Centre, University College London, London, UK
Leonard Sandin
Department of Aquatic Sciences & Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
Astrid Schmidt-Kloiber
Department Water-Atmosphere-Environment, Institute of Hydrobiology and Aquatic Ecosystem Management, BOKU–University of Natural Resources and Applied Life Sciences, Vienna, Austria
Anne Merete S. Sjøeng
Norwegian Institute for Water Research, Oslo, Norway
Richard A. Skeffington
Department of Geography, University of Reading, Reading, UK
Merel B. Soons
Ecology and Biodiversity Group, Institute of Environmental Biology, Utrecht University, Utrecht, The Netherlands
Sonja Stendera
Department of Aquatic Sciences & Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
Hansjörg Thies
Institute of Ecology, University of Innsbruck, Innsbruck, Austria
Piet F.M. Verdonschot
Freshwater Ecology, Alterra, Centre for Ecosystem Studies, Wageningen, The Netherlands
Jos T.A. Verhoeven
Ecology and Biodiversity Group, Institute of Environmental Biology, Utrecht University, Utrecht, The Netherlands
andrew J. Wade
Department of Geography, School of Human and Environmental Sciences, The University of Reading, Reading, UK

Paul G. Whitehead
Department of Geography, School of Human and Environmental Sciences, The University of Reading, Reading, UK
Heleen A. de Wit
Norwegian Institute for Water Research, Oslo, Norway
Richard F. Wright
Norwegian Institute for Water Research, Oslo, Norway

1

Introduction

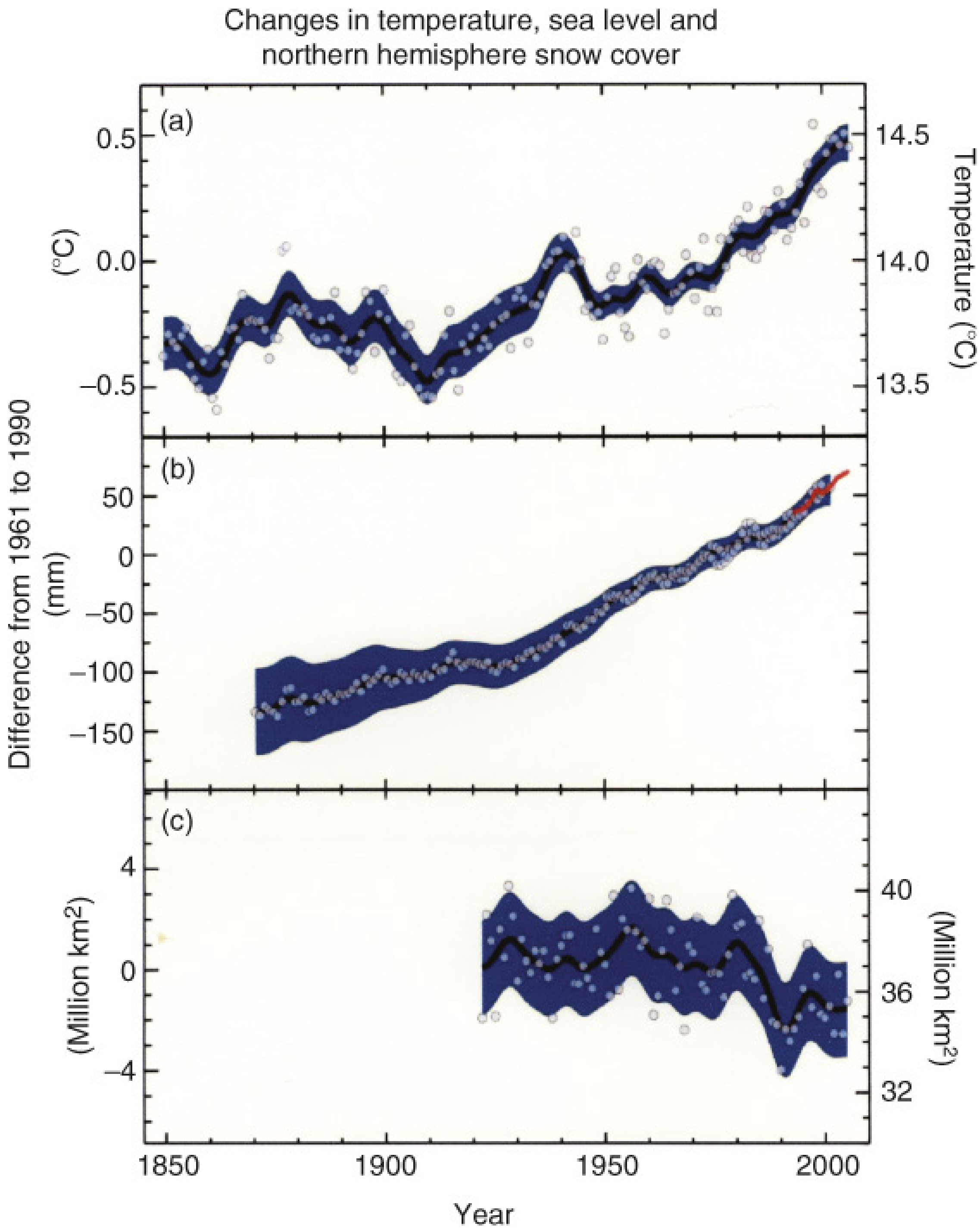
Brian Moss, Richard W. Battarbee and Martin Kernan

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.)

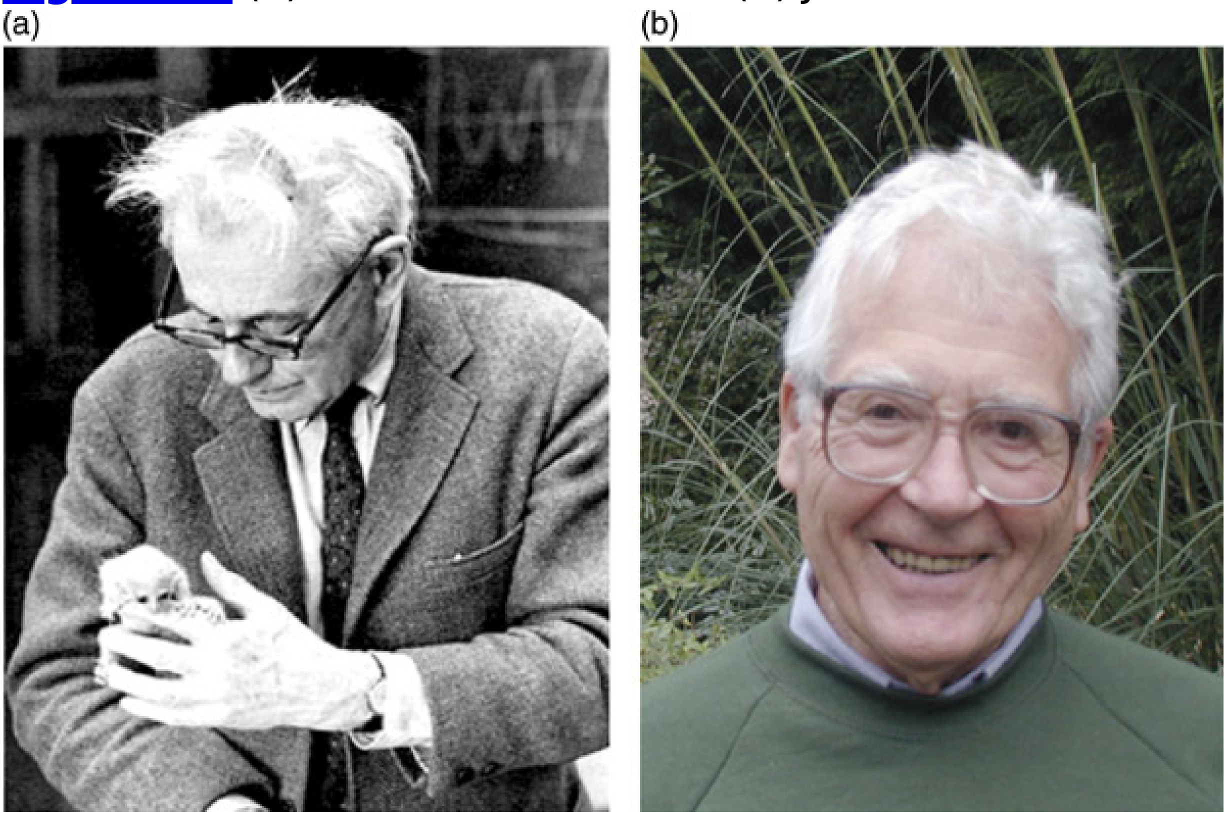


Climate is a master variable, and all activity on this planet eventually depends upon it. It determines the overall structure of natural biomes, be they deserts, grasslands or deciduous or evergreen forests. It has driven the evolution of life histories, the dynamics of food webs and the development 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.

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.

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

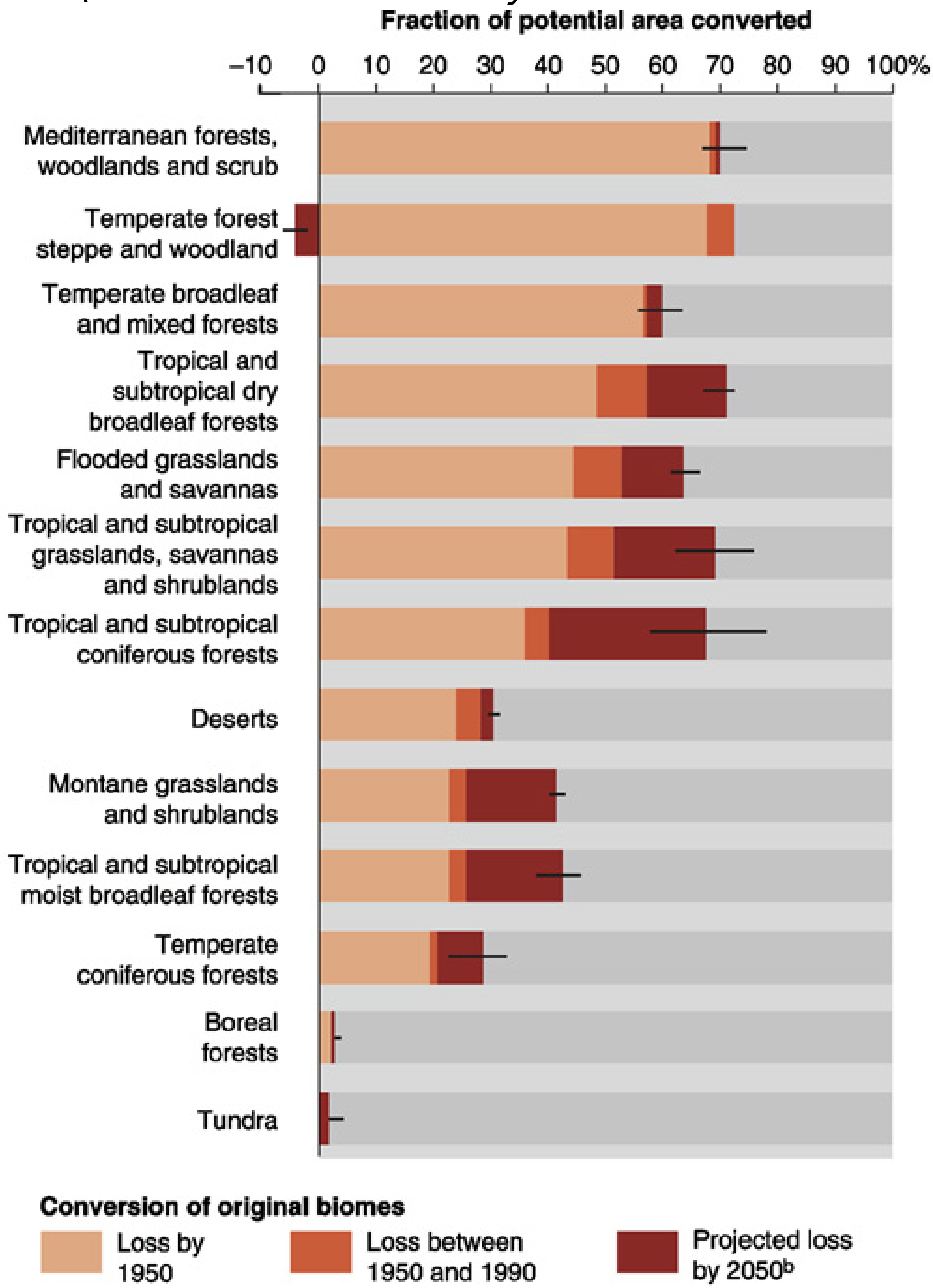


The IPCC has made a range of predictions about how climate will change over the regions of the Earth, based on a range of assumptions about how human societies will react as the first of the changes are experienced. There is a problem, however, in these predictions. They all hold to the former model 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 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.

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



[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 becuase 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.

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.