

Climate Change

Biological and Human Aspects
Second Edition

JONATHAN COWIE



CAMBRIDGE
UNIVERSITY PRESS

<i>Figures</i>	page xiii
<i>Acknowledgements for the first edition</i>	xix
<i>Acknowledgements for the second edition</i>	xxi
Introduction	1
1. An introduction to climate change	4
1.1 Weather or climate	5
1.2 The greenhouse effect	5
1.3 The carbon cycle	14
1.4 Natural changes in the carbon cycle	23
1.5 Pacemaker of the glacial–interglacial cycles	24
1.6 Non-greenhouse influences on climate	31
1.7 The water cycle, climate change and biology	33
1.8 From theory to reality	35
1.9 References	37
2. Principal indicators of past climates	40
2.1 Terrestrial biotic climatic proxies	42
2.1.1 Tree-ring analysis (dendrochronology)	42
2.1.2 Isotopic dendrochronology	45
2.1.3 Leaf shape (morphology)	47
2.1.4 Leaf physiology	48
2.1.5 Pollen and spore analysis	49
2.1.6 Species as climate proxies	52
2.2 Marine biotic climatic proxies	54
2.2.1 ¹⁸ O Isotope analysis of forams and corals	54
2.2.2 Alkenone analysis	58
2.3 Non-biotic indicators	59
2.3.1 Isotopic analysis of water	59
2.3.2 Boreholes	61
2.3.3 Carbon dioxide and methane records as palaeoclimatic forcing agents	61
2.3.4 Dust as an indicator of dry–wet hemispheric climates	62
2.4 Other indicators	62
2.5 Interpreting indicators	63
2.6 Conclusions	63
2.7 References	64

3. Past climate change	66
3.1 Early biology and climate of the Hadean and Archean eons (4.6–2.5 bya)	66
3.1.1 The pre-biotic Earth (4.6–3.8 bya)	66
3.1.2 The early biotic Earth (3.8–2.3 bya)	67
3.2 Major bio-climatic events of the Proterozoic eon (2.5–0.542 bya)	71
3.2.1 Earth in the anaerobic–aerobic transition (2.6–1.7 bya)	71
3.2.2 The aerobic Earth (from 1.7 bya)	74
3.3 Major bio-climatic events of the pre-Quaternary Phanerozoic (542–2 mya)	80
3.3.1 Late-Ordovician extinction (455–435 mya)	80
3.3.2 Late-Devonian extinction (365–363.5 mya)	81
3.3.3 Vascular plants and the atmospheric depletion of carbon dioxide (350–275 mya)	81
3.3.4 Permo–Carboniferous glaciation (330–250 mya)	84
3.3.5 End-Permian extinction (251 mya)	85
3.3.6 End-Triassic extinction (205 mya)	87
3.3.7 Toarcian extinction (183 mya)	88
3.3.8 Cretaceous–Tertiary extinction (65.5 mya)	89
3.3.9 The Eocene (55–34 mya) and the Initial Eocene Thermal Maximum (~55 mya)	92
3.3.10 Eocene–Oligocene extinction (approximately 35 mya; or 33.9 mya?)	106
3.3.11 Late-Miocene expansion of C ₄ grasses (14–9 mya)	107
3.4 Summary	112
3.5 References	113
4. The Oligocene to the Quaternary: climate and biology	119
4.1 The Oligocene (33.9–23.03 mya)	119
4.2 The end Miocene (9–5.3 mya)	121
4.3 The Pliocene (5.3–2.6 mya)	122
4.4 The current ice age	126
4.5 The last glacial	132
4.5.1 Overview of temperature, carbon dioxide and timing	132
4.5.2 Ice and sea level	135
4.5.3 Temperature changes within the glacial	135
4.5.4 Biological and environmental impacts of the last glacial	147
4.6 Interglacials and the present climate	156
4.6.1 Previous interglacials	156
4.6.2 The Allerød, Bølling and Younger Dryas (14 600–11 600 years ago)	160
4.6.3 The Holocene (11 700 years ago–the Industrial Revolution)	166
4.6.4 Biological response to the last glacial, LGM and Holocene transition	178
4.7 Summary	189
4.8 References	190

5. Present climate and biological change	198
5.1 Recent climate change	198
5.1.1 The latter half of the Little Ice Age	198
5.1.2 20th-century climate	202
5.1.3 21st-century climate	203
5.1.4 The Holocene interglacial beyond the 21st century	203
5.1.5 Holocene summary	207
5.2 Human change arising from the Holocene climate	208
5.2.1 Climatic impacts on early human civilisations	208
5.2.2 The Little Ice Age's human impact	216
5.2.3 Increasing 20th-century human climatic insulation	224
5.3 Climate and business as usual in the 21st century	225
5.3.1 The IPCC Business-as-Usual scenario	225
5.3.2 Uncertainties and the IPCC's conclusions	240
5.4 Current human influences on the carbon cycle	249
5.4.1 Carbon dioxide	250
5.4.2 Methane	253
5.4.3 Halocarbons	256
5.4.4 Nitrous oxide	256
5.5 References	257
6. Current warming and likely future impacts	262
6.1 Current biological symptoms of warming	262
6.1.1 Current boreal dendrochronological response	262
6.1.2 Current tropical rainforest response	264
6.1.3 Some biological dimensions of the climatic change fingerprint	266
6.1.4 Phenology	273
6.1.5 Biological communities and species shift	278
6.2 Case study: climate and natural systems in the USA and Canada	297
6.3 Case study: climate and natural systems in the UK	312
6.4 Case study: climate and natural systems in Australasia	324
6.5 Biological responses to greenhouse trends beyond the 21st century	328
6.6 Possible surprise responses to greenhouse trends in the 21st century and beyond	329
6.6.1 Extreme weather events	330
6.6.2 Greenhouse gases	333
6.6.3 Sea-level rise	334
6.6.4 Methane hydrates (methane clathrates)	342
6.6.5 Volcanoes	346
6.6.6 Oceanic and atmospheric circulation	349
6.6.7 Ocean acidity	353
6.6.8 Climate thresholds	355
6.6.9 The probability of surprises	358
6.7 References	359

7. The human ecology of climate change	367
7.1 Population (past, present and future) and its environmental impact	367
7.1.1 Population and environmental impact	367
7.1.2 Past and present population	375
7.1.3 Future population	378
7.1.4 Food	380
7.1.5 Impact on other species	382
7.2 Energy supply	385
7.2.1 Energy supply: the historical context	385
7.2.2 Future energy supply	391
7.3 Human health and climate change	395
7.3.1 Health and weather extremes	398
7.3.2 Climate change and disease	404
7.3.3 Flooding and health	412
7.3.4 Droughts	421
7.4 Climate change and food security	422
7.4.1 Past food security	422
7.4.2 Present and future food security and climate change	425
7.5 The biology of reducing anthropogenic climate change	432
7.5.1 Terrestrial photosynthesis and soil carbon	433
7.5.2 Manipulating marine photosynthesis	438
7.5.3 Biofuels	439
7.6 Summary and conclusions	442
7.7 References	443
8. Sustainability and policy	449
8.1 Key developments of sustainability policy	450
8.1.1 UN Conference on the Human Environment (1972)	450
8.1.2 The Club of Rome's Limits to Growth (1972)	452
8.1.3 World Climate Conference (1979)	453
8.1.4 <i>The World Conservation Strategy</i> (1980)	453
8.1.5 The Brandt Report: Common Crisis North-South (1980)	454
8.1.6 The Brundtland, World Commission on Environment and Development Report (1987)	455
8.1.7 United Nations' Conference on the Environment and Development: Rio de Janeiro (1992)	456
8.1.8 The Kyoto Protocol (1997)	457
8.1.9 Johannesburg Summit: UNCED+10 (2002)	459
8.1.10 2002–2007	460
8.1.11 The run-up to Kyoto II (2008–2011)	461
8.2 Global energy sustainability and carbon	463
8.2.1 Prospects for savings from changes in land use	465
8.2.2 Prospects for savings from improvements in energy efficiency	466
8.2.3 Prospects for fossil carbon savings from renewable energy	470
8.2.4 Prospects for carbon-capture technology	472

8.2.5 Prospects for nuclear options	476
8.2.6 Overall prospects for fossil carbon savings to 2025	480
8.3 Energy policy and carbon	481
8.3.1 Case study: USA	482
8.3.2 Case study: Canada	486
8.3.3 Case study: UK	489
8.3.4 Case study: China and India	498
8.3.5 Case study: Australia and New Zealand	504
8.4 Possible future energy options	508
8.4.1 Managing fossil carbon emissions: the scale of the problem	508
8.4.2 Fossil futures	510
8.4.3 Nuclear futures	511
8.4.4 Renewable futures	512
8.4.5 Low-energy futures	513
8.4.6 Possible future energy options and greenhouse gases	514
8.5 Future human and biological change	515
8.5.1 The ease and difficulty of adapting to future impacts	518
8.5.2 Future climate change and human health	524
8.5.3 Future climate and human-ecology implications for wildlife	525
8.5.4 Reducing future anthropogenic greenhouse gas emissions	526
8.5.5 A final conclusion	528
8.6 References	528
Appendix 1 Glossary and abbreviations	535
Glossary	535
Abbreviations	539
Appendix 2 Biogeological chronology	543
Appendix 3 Calculations of energy demand/supply and orders of magnitude	546
Calculations of energy demand/supply	546
Orders of magnitude	547
Sources	547
Appendix 4 Further considerations: climate science and policy beyond 2013	548
<i>Index</i>	551