

The Human Impact

ON THE NATURAL
ENVIRONMENT

Andrew Goudie

The Human Impact

ON THE NATURAL
ENVIRONMENT

Past, Present, and Future

Sixth Edition



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PREFACE TO THE SIXTH EDITION

It is now a quarter of a century since the first edition of this book appeared. This period has seen a remarkable transformation in interest in the impact that humans are having on the environment, together with an explosion of knowledge. In this edition, I have made substantial changes to the text, figures, tables, and

references, and have tried to provide updated statistical information. The biggest change, however, has been to add four new chapters that explore the ways in which global climate change may have an impact on Earth.

ASG

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Farvar and J. P. Milton (eds), *The careless technology* (Tom Stacey, London, 1973); Brampton, A. H. 'A selection of "hard engineering" structures designed to afford coastal protection', from A. H. Brampton, 'Cliff conservation and protection: methods and practices to resolve conflicts', in J. Hooke (ed.), *Coastal defence and earth science conservation* (Geological Society Publishing House, 1998); Brimblecombe, P. 'Thunder in south-east England' and 'Thunder storms per year in London', from 'London air pollution 1500–1900', *Atmospheric environment*, 11, 1977; Brimblecombe, P. and Camuffo, D. 'Decadal means of the freeze–thaw cycles in Central England', from *The effects of air pollution on the built environment* (Imperial College Press, London, 2003); Brookes, A. 'Principal types of adjustment in straightened river channels', from 'The distribution and management of channelized streams in Denmark., *Regulated rivers*, 1, 1987; Brown, A. A. and Davis, K. P. 'The reduction in area burned per area protected for the USA between 1926 and 1969 as a result of fire-suppression policies', from *Forest fire control and its use*, 2nd edn (McGraw-Hill, New York, 1973, reproduced with permission of the McGraw-Hill Companies); Chapin,

- F. S. and Danell, K. 'Changes in areas of boreal forest' from F. S. Chapin, O. E. Sala and E. Huber-Sannwald, *Global biodiversity in a changing environment* (Springer, New York, 2001); Cochrane, R. 'The changing state of the vegetation cover in New Zealand', from E. G. Anderson (ed.), *New Zealand in maps* (Hodder & Stoughton Educational, London, 1977); Cohen and Rushton, 'The effect of air quality on plant growth in Leeds, England, 1913', data from R. Barrass, *Biology, food and people* (Hodder & Stoughton Educational, London, 1974); Cole, S. 'A Neolithic chert axe-blade from Denmark, of the type which has been shown to be effective at cutting forest in experimental studies', from *The Neolithic revolution*, 5th edn (The British Museum [Natural History], London, 1970); Cooke, R. U. and Reeves, R. W. 'A model for the formation of arroyos (gullies) in the south-western USA', from *Arroyos and environmental change in the American south-west* (Clarendon Press, Oxford, 1976, reprinted with permission of Oxford University Press); Council on Environmental Quality, 'Changes in water pollution in the Great Lakes of North America', from 17th (1986) and 22nd (1992) Annual Reports; Darby, H. C. 'The changing distribution of forest in Central Europe between (a) AD 900 and (b) AD 1900', from W. L. Thomas (ed.), *Man's role in changing the face of the Earth* (University of Chicago Press © The University of Chicago, 1956); Dolan, R., Godfrey, P. J. and Odum, W. E. 'Cross-sections of two barrier islands in North Carolina, USA', from *Man's impact on the barrier islands of North Carolina*, *American scientist*, 61, 1973; Doughty, R. W. 'The spread of the English house sparrow in the New World', from *The English sparrow in the American landscape: a paradox in nineteenth century wildlife conservation*, Research paper 19, School of Geography, University of Oxford, 1978; Edmonson, W. T. 'Changes in the state of Lake Washington, USA, associated with levels of untreated sewage from 1933 to 1973', from W. W. Murdoch (ed.), *Environment* (Sinauer Associates, Sunderland, 1975); Ehrlich, P. R., Ehrlich, A. H. and Holdren, J. P. 'The growth of human numbers for the past half million years', from *Ecoscience: population, resources, environment* (W. H. Freeman, San Francisco, 1977); Elton, C. S. 'The spread of the Japanese beetle, *Popilla japonica*, in the eastern USA', from *The ecology of invasion by plants and animals* (Methuen, London, 1958); Fenger, J. 'Schematic presentation of a typical development of urban air pollution levels' from *Atmospheric environment*, 33, 1999; Forman, S. L., Oglesby, R. and Webb, R. S. 'Summary of dune field activity' from *Global and planetary change*, 29, 2001; French, H. M. 'Projection of changes in permafrost with global warming' from *The periglacial environment* (2nd edn) (Longman, Harlow, 1996); Gameson, A. L. H. and Wheeler, A. 'The average dissolved oxygen content of the River Thames at half-tide in the July–September quarter since 1890', from J. Cairns, K. L. Dickson and E. E. Herricks (eds), *Recovery and restoration of damaged ecosystems* (University Press of Virginia, Charlottesville, 1977, reprinted with permission of the University Press of Virginia); Gilbert, O. L. 'Air pollution in north-east England and its impact upon growth area for lichens', from R. Barrass, *Biology, food and people* (Hodder & Stoughton Educational, London, 1974); Gorman, M. 'A set of general design rules for nature reserves based on theories of island biogeography', from *Island ecology* (Chapman and Hall Publishers Ltd, London, 1979, copyright with kind permission of Kluwer Academic Publishers); Gorman, M. 'Some relationships between the size of "islands" and numbers of species', from *Island ecology* (Chapman and Hall Publishers Ltd, London, 1979, copyright with kind permission of Kluwer Academic Publishers); Goudie, A. S. 'A schematic representation of some of the possible influences causing climatic change', from *Environmental change*, 3rd edn (Clarendon Press, Oxford, 1992, reprinted by permission of Oxford University Press); Goudie, A. S. 'The concentration of dust storms in the USA in 1939', from 'Dust storms in space and time', *Progress in physical geography*, 7, 1983; Goudie, A. S. and Wilkinson, J. C. 'The Ghyben–Herzberg relationship between fresh and saline ground water and the effect of excessive pumping from the well', from *The warm desert environment* (Cambridge University Press, Cambridge, 1977); Green, F. H. W. 'Annual total area of field drainage by the tile drains in England and Wales', from *Recent changes in land use and treatment*, *Geographical journal*, 142, 1996; Green, F. H. W. 'Percentages of drained agricultural land in Europe', from *Field drainage in Europe*, *Geographical journal*, 144, 1978; Gregory, K. J. 'Relation between drainage density and mean annual precipitation', from E. Derbyshire (ed.), *Geomorphology and climate* (Chichester: John Wiley and Sons. © 1976); Gupta, H. K. 'Worldwide distribution of reservoir-triggered changes in seismicity' from *Earth-science reviews*, 58, 2002; Haagen-Smit, A. J. 'Possible reactions involving primary and

- secondary pollutants', from R. A. Bryson and J. E. Kutzbach (eds), *Air pollution* (Commission on College Geography Resource Paper 2. Washington DC: Association of American Geographers); Haggett, P. 'Land rotation and population density', from *Geography: a modern synthesis*, 3rd edn (Prentice-Hall, London, 1979); Haigh, M. J., 'Some shapes produced by shale tipping', from *Evolution of slopes on artificial landforms – Blaenavon, UK*, Research Paper 183, Department of Geography, University of Chicago; Harris, J. M., Oltmans, S. J., Bodeker, G. E., Storlaski, R., Evans, R. D. and Quincy, D. M. 'Global ozone trends' from *Atmospheric environment*, 37, 2003; Hollis, G. E. 'Some hydrological consequences of urbanization', from *The effects of urbanization on floods of different recurrence intervals*, *Water resources research*, 11, 1975; Hughes, R. J., Sullivan, M. E. and York, D. 'Rates of erosion in Papua New Guinea in the Holocene derived from rates of sedimentation in Kuk Swamp', from *Human-induced erosion in a highlands catchment in Papua New Guinea: the prehistoric and contemporary records*, *Zeitschrift für geomorphologie, supplementband*, 83, 1991; Johansen, H. E. 'The spread of contour-strip soil conservation methods in Wisconsin, USA, between 1939 and 1967', from S. W. Trimble and S. W. Lund (eds), *Soil conservation and the reduction of erosion and sediment in the Coon Creek Basin, Wisconsin*, *US Geological Survey professional paper*, 1234, 1982; Judd, W. R. 'Relationships between reservoir levels and earthquake frequencies', from *Seismic effects of reservoir impounding*, *Engineering geology*, 8, 1974; Keller, E. A. 'Comparison of the natural channel morphology and hydrology with that of a channelized stream', from D. R. Coates (ed.), *Geomorphology and engineering* (Hutchinson and Ross, 1976); Kirby, C. 'Lead concentration (annual means) in UK sites' from *Geography*, 80, 1995; Komar, P. D. 'Examples of the effects of shoreline installations on beach and shoreline morphology', from *Beach processes and sedimentation* (Prentice-Hall, Englewood Cliffs, 1976); Laporte, L. F. 'Maximum temperatures for the spawning and growth of fish', from *Encounter with the Earth* (copyright © by permission of Harper and Row Publishers, Inc., 1975); MacGrimmon, 'The original area of distribution of the brown trout and areas where it has been artificially naturalized', from J. Illies (ed.), *Introduction to zoogeography* (Macmillan, London, 1974); Manshard, W. 'The irrigated areas in Sind (Pakistan) along the Indus Valley', from *Tropical agriculture* (Addison-Wesley-Longman, 1974, © Bibliographisches Institute A. G., Mannheim); McGlone, M. S. and Wilmshurst, J. M. 'Summary percentage pollen diagram', from *Quaternary international*, 59, 1999; Meade, R. H. and Trimble, S. W. 'The decline in suspended sediment discharge to the eastern seaboard of the USA between 1910 and 1970 as a result of soil conservation measures . . .', from *Changes in sediment loads in rivers of the Atlantic drainage of the United States since 1900*, *Publication of the International Association of Hydrological Science*, 113, 1974; Mellanby, K. 'The increase of lichen cover on trees outside the city of Belfast, Northern Ireland (after Fenton)', from *Pesticides and pollution* (Fontana, London, 1967); Meybeck, M. 'Recent trends of nitrate concentration in some rivers', from B. von Bodungen and R. K. Turner (eds), *Science and integrated coastal management* (Dahlem University Press, Dahlem, 2001); Midgley, G. F., Hannak, L., Millar, D., Thiuller, W. and Booth, A. 'Current mapped Fynbos biome', from *Biological conservation*, 112, 2003; Nature Conservancy Council, 'The changing range of the little ringed plover, related to habitat change, especially as a result of the increasing number' and Trimble, S. W. 'The decline in suspended sediment discharge to the eastern seaboard of the USA between 1910 and 1970 as a result of soil conservation measures of gravel pits', from *Nature conservation and agriculture* (Nature Conservancy Council, Her Majesty's Stationery Office, London, 1977); Nature Conservancy Council, 'Losses of lowland heath in southern England', from *Nature conservation in Great Britain* (Nature Conservancy Council, Shrewsbury, 1984); Nature Conservancy Council, 'Reduction in the range of the silver spotted skipper butterfly (*Hesperia comma*)', from *Nature conservation and agriculture* (Nature Conservancy Council, Her Majesty's Stationery Office, London, 1977); Nature Conservancy Council, 'Reduction in the range of species related to habitat loss', from *Nature conservation and agriculture* (Nature Conservancy Council: Her Majesty's Stationery Office, London, 1977); Oerlemans, J. 'Generalised curves of ablation and accumulation' from R. A. Warwick, E. M. Barrows and T. M. L. Wigley (eds), *Climate and sea level change: observations, projections and implications* (Cambridge University Press, Cambridge, 1993); Oppenheimer, M. 'Cross section of an ice stream' from *Nature*, 393 (© Macmillan Publishers Ltd, 1998); Parker, A. G., Goudie, A. S., Anderson, D. E., Robinson, M. A. and Bonsall, C. 'Relations between factors influencing the mid-Holocene

- elm decline' from *Progress in physical geography*, 26, 2002; Pereira, H. C. 'The increase of water yield after clear-felling a forest: a unique confirmation from the Coweeta catchment in North Carolina', from *Land use and water resources in temperate and tropical climates* (Cambridge University Press, Cambridge, 1973); Rapp, A., Le Houerou, H. N. and Lundholm, B. 'Desert encroachment in the northern Sudan 1958–75, as represented by the position of the boundary between sub-desert scrub and grassland in the desert', from *Ecological bulletin*, 24, 1976; Rapp, A. 'Relation between spacing of wells and over-grazing', from *A review of desertization in Africa – water, vegetation and man* (Secretariat for International Ecology, Stockholm, Report no 1, 1974); Roberts, N. 'The human colonization of Ice-Age earth', from *The Holocene: an environmental history* (Blackwell Publishers, Oxford, 1989); Schwartz, M. W., Porter, D. J., Randall, J. M. and Lyons, K. G. 'Number of non-indigenous plant species by date as reported in botanical treatments of the California flora', from *Sierra Nevada Ecosystems project: final report for Congress Vol. II*, Davis: University of California, 1996; Shiklomanov, A. I. 'Changes in annual runoff in the CIS due to human activity during 1936–2000', from J. C. Rodda (ed.), *Facets of hydrology II* (copyright © 1985 John Wiley & Sons, Inc., reprinted by permission of John Wiley & Sons Inc.); Shiklomanov, A. I. 'Some major schemes proposed for large-scale inter-basin water transfers', from J. C. Rodda (ed.), *Facets of hydrology II* (copyright © 1985 John Wiley & Sons, Inc., reprinted by permission of John Wiley & Sons Inc.); Spate, O. H. K. and Learmonth, A. T. A. 'The Madurai–Ramanthapuram tank country in south India', from *India and Pakistan* (Methuen, London, 1967); Spencer, J. E. and Thomas, W. L. 'The diffusion of mining and smelting in the Old World', from *Introducing cultural geography*, 2nd edn (copyright © 1978 John Wiley & Sons, Inc., reprinted by permission of John Wiley & Sons, Inc.); Strandberg, C. H. 'Biological concentration occurs when relatively indestructible substances (DDT for example) are ingested by lesser organisms at the base of the food pyramid', from G. H. Smith (ed.), *Conservation of natural resources*, 4th edn (copyright © 1971 John Wiley & Sons, Inc., reprinted by permission of John Wiley & Sons, Inc.); Titus, J. G. 'Overwash: natural response of undeveloped barrier islands to sea level rise' from *Coastal management*, 18, 1990; Trimble, S. W. 'Changes in the evolution of fluvial landscapes in the Piedmont of Georgia, USA in response to land-use change between 1700 and 1970', from *Man-induced soil erosion on the southern Piedmont* (Soil Conservation Society of America, © Soil Conservation Society of America, 1974); Viles, H. A. 'Conceptual model of the impact of effective precipitation' from *Journal of nature conservation*, 11, 2003; Vinnikov, K. Y. 'Observed decrease of Northern Hemisphere sea ice extent' from *Science*, 286, 1999; US Geological Survey, 'Historical sediment and water discharge trends for the Colorado river', H. E. Schwarz, J. Emel, W. J. Dickens, P. Rogers and J. Thompson (eds), 'Water quality and flows', from B. L. Turner, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Matthews and W. B. Meyer (eds), *The Earth as transformed by human action* (Cambridge University Press, Cambridge, 1991); Wallwork, K. L. 'Subsidence in the salt area of mid-Cheshire, England, in 1954', from *Subsidence in the mid-Cheshire industrial area*, *Geographical journal*, 122, 1956; Watson, A. 'The distribution of pits and ponds in a portion of north-western England', from 'The origin and distribution of closed depressions in south-west Lancashire and north-west Cheshire', unpublished BA dissertation, University of Oxford; Wilkinson, W. B. and Brassington, F. C. 'Groundwater levels in the London area', from R. A. Downing and W. B. Wilkinson (eds), *Applied groundwater hydrology – a British perspective* (Clarendon Press, Oxford, 1991, by permission of Oxford University Press); Wolfe, S. A. 'Dune mobility for various stations' from *Journal of arid environments*, 36, 1997; Woo, M. K., Lewkowicz, A. G. and Rouse, W. R. 'Ground settlement in response to a thickening of the active layer' from *Physical geography*, 13, 1992; Wooster, W. S. 'Decrease in the salinity of the Great Bitter Lake, Egypt, resulting from the intrusion of fresher water by way of the Suez Canal', from *The ocean and man*, *Scientific American*, 221, 1969; Ziswiler, V. 'The former and present distribution of the bison in North America', from J. Illies (ed.), *Introduction of zoogeography* (Macmillan, London, 1974); Ziswiler, V. 'Time series of animal extinctions since the seventeenth century, in relation to the human population increase', figure (b) from *The earth and human affairs* (National Academy of Sciences, 1972).
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