1

Introduction

CHAPTER OVERVIEW

In this chapter the first issue that is addressed is the development of ideas over the last 300 years about the relationship between humans and their environment and in particular the development of ideas about how humans have changed their environment. The historical theme continues with a brief analysis of the changes that have taken place in human societies from prehistoric times onwards, culminating in the massive impacts that humans have achieved over the last three centuries and in particular during the so-called 'Great Acceleration' since the Second World War.

1.1 The Development of Ideas

To what extent have humans transformed their natural environment? This is a crucial question which became very important in the seventeenth and eighteenth centuries (Grove and Damodaran, 2006) as Western Europeans became aware of the ravages inflicted in the tropics by European overseas expansion. It was a theme that intrigued the eighteenth-century French natural historian, Count Buffon, in his colossal series, *L'Histoire Naturelle*. He can be regarded as the first Western scientist to be concerned directly and intimately with the human impact on the natural environment (Glacken, 1967). He contrasted the appearance of inhabited and uninhabited lands.

Studies of the torrents of the European Alps, undertaken in the late eighteenth and early nineteenth centuries, deepened immeasurably the realization of human capacity to change the environment. Jean-Antoine Fabre and Alexandre Surell studied the flooding, siltation, erosion, and division of watercourses brought about by deforestation in these mountains (Ford, 2016). Similarly Horace-Bénédict de Saussure showed that Alpine lakes had suffered a lowering of water levels in recent times because of deforestation. In Venezuela, Alexander von Humboldt concluded that the lake level of Lake Valencia in 1800 (the year of his visit) was lower than it had been in previous times, and that deforestation, the clearing of plains, irrigation, and the cultivation of indigo, were among the causes of the gradual drying up of the basin (Cushman, 2011). Comparable observations were made by the French rural economist, Jean-Baptiste Boussingault (1845). He returned to Lake Valencia some 25 years after Humboldt and noted that the lake was actually rising. He described this reversal to political and social upheavals following the granting of independence to the colonies of the erstwhile Spanish Empire. The freeing of slaves had led to a decline in agriculture, a reduction in the application of irrigation water, and the re-establishment of forest.

Boussingault also reported some pertinent hydrological observations that had been made on Ascension Island in the South Atlantic:

> In the Island of Ascension there was an excellent spring situated at the foot of a mountain originally covered with wood; the spring became scanty and dried up after the trees which covered the mountain had been felled. The loss of the spring was rightly ascribed to the cutting down of the timber. The mountain was therefore planted anew. A few years afterwards the spring reappeared by degrees, and by and by followed with its former abundance. (Boussingault, 1845: 685)

Charles Lyell, in his *Principles of Geology*, one of the most influential of all scientific works, referred to the human impact and recognized that tree-felling and drainage of lakes and marshes tended 'greatly to vary the state of the habitable surface'. Overall, however, he believed that the

Human Impact on the Natural Environment: Past, Present and Future, Eighth Edition. Andrew S. Goudie.

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forces exerted by people were insignificant in comparison with those exerted by nature:

> If all the nations of the earth should attempt to quarry away the lava which flowed from one eruption of the Icelandic volcanoes in 1783, and the two following years, and should attempt to consign it to the deepest abysses of the ocean they might toil for thousands of years before their task was accomplished. Yet the matter borne down by the Ganges and Burrampooter, in a single year, probably very much exceeds, in weight and volume, the mass of Icelandic lava produced by that great eruption. (Lyell, 1835: 197)

Lyell somewhat modified his views in later editions of the *Principles* (Lyell, 1875), largely as a result of his experiences in the United States, where recent deforestation in Georgia and Alabama had produced numerous ravines of impressive size (Figure 1.1).

One of the most important physical geographers to show concern with our theme was Mary Somerville (1858) (who clearly appreciated the unexpected results that occurred as man 'dextrously avails himself of the powers of nature to subdue nature'):

> A farmer sees the rook pecking a little of his grain, or digging at the roots of the springing corn, and poisons all his neighbourhood. A few years after he is surprised to find his crop destroyed by grubs. The works of the Creator are nicely balanced, and man cannot infringe his Laws with impunity. (Somerville, 1858: 493)

This is in effect a statement of one of the basic laws of ecology, much championed by Alexander von Humboldt (see Wulf, 2015): that everything is connected to everything else and that one cannot change just one thing in nature.

Considerable interest in conservation, climatic change, and extinctions arose amongst European colonialists who witnessed some of the consequences of Western-style economic development in tropical lands (Grove, 1997). However, the extent of human influence on the environment was not explored in detail and on the basis of sound data until George Perkins Marsh (Figure 1.2) published *Man and Nature* (1864), in which he dealt with human influence on the woods, the waters, and the sands. The following extract illustrates the breadth of his interests and the ramifying connections he identified between human actions and environmental changes:

> Vast forests have disappeared from mountain spurs and ridges; the vegetable earth accumulated beneath the trees by the decay of leaves and fallen trunks, the soil of the alpine pastures which skirted

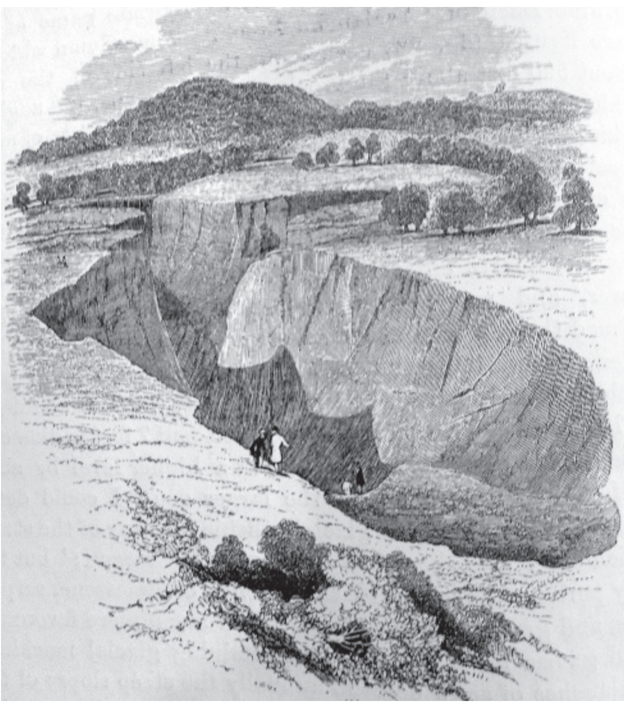

Figure 1.1 A newly formed ravine or gully that developed at Milledgeville, Georgia, USA, following deforestation. *Source:* Lyell (1875: 338).

Figure 1.2 George Perkins Marsh (1801–1882). *Source:* from the Library of Congress Prints and Photographic Division, Washington DC, http://loc.gov/pictures/resource/cwpbh.02223/ (accessed January 2018).

> and indented the woods, and the mould of the upland fields, are washed away; meadows, once fertilized by irrigation, are waste and unproductive, because the cisterns and reservoirs that supplied the ancient canals are broken, or the springs that fed them dried up; rivers famous in history and song have shrunk to humble brooklets; the willows that ornamented and protected the banks of lesser watercourses are gone, and the rivulets have ceased to exist as perennial currents, because the little water that finds its way into their old channels is evaporated by the droughts of summer, or absorbed by the parched earth, before it reaches the lowlands; the beds of the brooks have widened into broad expanses of pebbles and gravel, over which, though in the hot season passed dryshod, in winter sealike torrents thunder; the entrances of navigable streams are obstructed by sandbars, and harbours, once marts of an extensive commerce, are shoaled by the deposits of the rivers at whose mouths they lie; the elevation of the beds of estuaries, and the consequently diminished velocity of the streams which flow into them, have converted thousands of leagues of shallow sea and fertile lowland into unproductive and miasmatic morasses. (Marsh, 1965: 9)

More than a third of the book is concerned with 'the woods'; Marsh does not touch upon important themes like the modifications of mid-latitude grasslands, and he is much concerned with Western civilization. Nevertheless, employing an eloquent style and copious footnotes, Marsh, the versatile Vermonter, stands as a landmark in the study of environment (Thomas, 1956; Lowenthal, 2000, 2013).

Marsh, however, was not totally pessimistic about the future role of humankind or entirely unimpressed by positive human achievements:

> New forests have been planted; inundations of flowing streams restrained by heavy walls of masonry and other constructions; torrents compelled to aid, by depositing the slime with which they are charged, in filling up lowlands, and raising the level of morasses which their own overflows had created; ground submerged by the encroachment of the ocean, or exposed to be covered by its tides, has been rescued from its dominion by diking; swamps and even lakes have been drained, and their beds brought within the domain of agricultural industry; drifting coast dunes have been checked and made productive by plantation; sea and inland waters have been repeopled with fish, and even the sands of the Sahara have been fertilized by artesian fountains. These achievements are far more glorious than the proudest triumphs of war . . . (Marsh, 1965: 43–44)

Elisée Reclus (1873), an anarchist and one of the most prominent French geographers of his generation, was an important influence in the USA and recognized that the 'action of man may embellish the earth, but it may also disfigure it; according to the manner and social condition of any nation, it contributes either to the degradation or glorification of nature' (p. 522). Reclus (1871) also displayed a concern with the relationship between forests, torrents, and sedimentation.

In 1904 the German geographer Ernst Friedrich coined the term 'Raubwirtschaft', which can be translated as 'economic plunder', 'robber economy' or, more simply, 'devastation'. He believed that destructive exploitation of resources leads of necessity to foresight and to improvements, and that after an initial phase of ruthless exploitation and resulting deprivation human measures would, as in the old countries of Europe, result in conservation and improvement. This idea was opposed in the USA by Carl Sauer (1938) and Joe Russell Whitaker (1940), the latter pointing out that some soil erosion could well be irreversible (p. 157):

> It is surely impossible for anyone who is familiar with the eroded loessial lands of northwestern Mississippi, or the burned and scarred rock hills of north central Ontario, to accept so complacently the damage to resources involved in the process of colonization, or to be so certain that resource depletion is but the forerunner of conservation.

Nonetheless Friedrich's concept of robber economy was adopted and modified by the great French geographer, Jean Brunhes, in his *Human Geography* (1920). He recognized the interrelationships involved in anthropogenic environmental change (p. 332): 'Devastation always brings about, not a catastrophe, but a series of catastrophes, for in nature things are dependent one upon the other.' Moreover, Brunhes acknowledged that the 'essential facts' of human geography included 'Facts of Plant and Animal Conquest' and 'Facts of Destructive Exploitation'. At much the same time other significant studies were made of the same theme. Nathaniel Shaler of Harvard (*Man and the Earth*, 1912) was very much concerned with the destruction of mineral resources (a topic largely neglected by Marsh).

Sauer led an effective campaign against destructive exploitation, reintroduced Marsh to a wide public, recognized the ecological virtues of some so-called primitive peoples, concerned himself with the great theme of domestication, concentrated on the landscape changes that resulted from human action, and gave clear and far-sighted warnings about the need for conservation (Sauer, 1938: 494):

> We have accustomed ourselves to think of ever expanding productive capacity, of ever fresh spaces of the world to be filled with people, of ever new discoveries of kinds and sources of raw materials, of continuous technical progress operating indefinitely to solve problems of supply. We have lived so long in what we have regarded as an expanding world, that we reject in our contemporary theories of economics and of population the realities which contradict such views. Yet our modern expansion has been affected in large measure at the cost of an actual and permanent impoverishment of the world.

The theme of the human impact on the environment has, however, been central to some historical geographers studying the evolution of the landscape. The clearing of woodland (Darby, 1956; Williams, 2003), the domestication process (Sauer, 1952), the draining of marshlands (Williams, 1970), the introduction of alien plants and animals (McKnight, 1959), and the transformation of the landscape of North America (Whitney, 1994) are among some of the recurrent themes of a fine tradition of historical geography.

In 1956, some of these themes were explored in detail in a major symposium volume, *Man's Role in Changing the Face of the Earth* (Thomas, 1956). Kates et al. (1990: 4) write of it:

> *Man's role* seems at least to have anticipated the ecological movement of the 1960s, although direct links between the two have not been demonstrated. Its dispassionate, academic approach was certainly foreign to the style of the movement . . . Rather, *Man's role* appears to have exerted a much more subtle, and perhaps more lasting, influence as a reflective, broad-ranging and multidimensional work.

In the last five decades many geographers have contributed to, and been affected by, the phenomenon which is often called the environmental revolution or the ecological movement. The subject of the human impact on the environment, dealing as it does with such matters as environmental degradation, pollution, and desertification, has close links with these developments, and is once again a theme in many textbooks and research monographs in geography (see Turner et al., 1990; Meyer, 1996; Middleton, 2013).

Concerns about the human impact have become central to many other disciplines and to the public, particularly since the early 1970s, and a range of major developments in literature, legislation, and international debate have taken place (Table 1.1). The concepts of global change or global environmental change have developed. Wide use of the term 'global change' seems to have emerged in the 1970s but in that period was used principally, though by no means invariably, to refer to changes in international social, economic, and political systems (Price, 1989). It included such issues as proliferation of nuclear weapons, population growth, inflation and matters relating to international insecurity, and decreases in the quality of life. Since the early 1980s the concept of global change has taken on another meaning which is more geocentric in focus. This can be seen in the development of the International Geosphere-Biosphere Programme: A Study of Global Change. This was established in 1986 by the International Council of Scientific Unions, 'to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities'. The term 'global environmental change' has in many senses come to be used synonymously with the more geocentric use of 'global change'. As Castree (2015) has stressed, global change has become a major research thrust, and it can provide a major focus for a more integrated discipline of Geography (Goudie, 2017).

Table 1.1 Some environmental milestones.

1864	George Perkins Marsh, *Man and Nature*
1892	John Muir founds Sierra Club in USA
1903	President Theodore Roosevelt establishes a federally protected wildlife refuge at Pelican Island, Florida. The first of fifty-three wildlife sanctuaries he creates as president
1905	The Bureau of Forestry in the Department of Agriculture becomes the US Forest Service
1916	USA National Park Service established
1935	Establishment of Soil Conservation Service in USA
1949	USA National Trust for Historic Preservation created
1956	*Man's Role in Changing the Face of the Earth*
1961	Establishment of World Wildlife Fund
1962	Rachel Carson's *Silent Spring*
1969	Friends of the Earth established
1970	US Environmental Protection Agency created

Table 1.1 (Continued)

1971	Greenpeace established
1971	Ramsar Treaty on International Wetlands
1972	United Nations Environmental Programme (UNEP) established
1972	*Limits to Growth* published by Club of Rome
1973	Convention on International Trade in Endangered Species (CITES)
1974	F.S. Rowland and M. Molina warn about CFCs and ozone hole
1975	Worldwatch Institute established
1979	Convention on Long-Range Transboundary Air Pollution
1980	IUCN's World Conservation Strategy
1985	British Antarctic Survey finds ozone hole over Antarctic
1986	International Geosphere Biosphere Programmme (IGBP)
1987	World Commission on Environment and Development (Brundtland Commission). *Our Common Future*
1987	Montreal Protocol on substances that deplete the ozone layer
1988	Intergovernmental Panel on Climate Change (IPCC) established
1989	Global Environmental Facility
1992	Earth Summit in Rio and Agenda 21
1993	United Nations Commission on Sustainable Development
1994	United Nations Convention to Combat Desertification
1996	International Human Dimensions Programme on Global Environmental Change
1997	Kyoto Protocol on greenhouse gas emissions
2001	Amsterdam Declaration
2002	Johannesburg Earth Summit
2002	Introduction of the term 'Anthropocene'
2007	United Nations Bali Climate Change Conference
2010	United Nations Copenhagen Climate Change Conference
2010	Nagoya Biodiversity Summit and International Year of Biodiversity
2012	Rio + 20 United Nations Conference on Sustainable Development
2015	Paris Conference on Climate Change
2015	28th Meeting of the Parties to the Montreal Protocol to phase out HFCs
2015	China introduces Environmental Protection Law

In addition to the concept of global change, there is an increasing interest in the manner in which biogeochemical systems interact at a global scale, and an increasing appreciation of the fact that the Earth is a single system. Earth System Science has emerged in response to this realization (see Steffen et al., 2004). Earth System *Science*, a modern manifestation of Global Change which concentrates on modelling, treats the Earth as an integrated system and seeks a deeper understanding of the physical, chemical, biological, and human interactions that determine the past, current, and future states of the Earth's lithosphere, hydrosphere (including the cryosphere), biosphere, and atmosphere. While it has its antecedents in the work of people like Humboldt (see Wulf, 2015; Stott, 2016), it came into prominence in the last two decades of the twentieth century. It has emerged in response to (1) the realization that biogeochemical systems operate globally and (2) an increasing appreciation that Earth is a single system. It includes societal dimensions and the recognition that humanity plays an ever-increasing role in global change. It represents humans as internal components of the Earth system not just an external 'forcing agent'.

1.2 The Anthropocene

Early in this millennium, Crutzen and colleagues introduced the term 'Anthropocene' (e.g. Crutzen, 2002; Steffen et al., 2007; Röckstrom et al., 2009), as a name for a new epoch in Earth's history – an epoch when human activities have 'become so profound and pervasive that they rival, or exceed the great forces of Nature in influencing the functioning of the Earth System' (Steffen, 2010). In the last three hundred years, they suggest, we have moved from the Holocene into the Anthropocene. They identify three stages in the Anthropocene. Stage 1, which lasted from c. 1800 to 1945, they call 'The Industrial Era'. Stage 2, which extends from 1945 to c. 2015, they call 'The Great Acceleration', and Stage 3, which may perhaps now be starting, is a stage when people have become aware of the extent of the human impact and may thus start stewardship of the Earth System. Good reviews of the Anthropocene concept are provided by Castree (2014a, b, c).

However, it has been argued that the Anthropocene was initiated much more than three centuries ago. Indeed, one of the great debates surrounding the Anthropocene is when it started and whether it should be regarded as a formal stratigraphic unit with the same rank as the Holocene (Waters et al., 2016). Walker et al. (2015), for example, raise the possibility that the Anthropocene might be designated a unit of lesser rank, and hence could become a subdivision of the Holocene rather than an epoch in its own right. On the other hand, there are those who think the Anthropocene should replace the Holocene, which would become downgraded and reclassified as the final stage of the Pleistocene (Lewis and Maslin, 2015). Conversely, there are those who think the Anthropocene only started with the Industrial Revolution and that 1800 AD is a logical start date for the new epoch (Steffen et al, 2011; Zalasiewicz et al., 2011). At the other end of the spectrum, there are archaeologists (Balter, 2013), who believe that substantial human impacts go back considerably further. They have drawn attention to the deep history of widespread human impacts (Ellis et al. 2013a, b; Albert, 2015; Braje, 2015; Piperno et al., 2015). Smith and Zeder (2013) argued that the Anthropocene started at the Holocene/Pleistocene boundary (around 10,000 years ago), with the first domestication of plants and animals and the development of agriculture and pastoralism (see Section 1.5). Certini and Scalenghe (2011) preferred to place the lower boundary at around 2000 years ago when major civilizations flourished.

Foley et al. (2013) proposed the term 'palaeoanthropocene' for the period between the first signs of human impact and the start of the Industrial Revolution, whereas Glikson (2013) suggested a sub-division of the Anthropocene into three phases. He regarded the discovery of ignition of fire (see Section 2.3) as a turning point in biological evolution and termed it the Early Anthropocene. The onset of the Neolithic he referred to as the Middle Anthropocene, while the onset of the industrial age since about 1750 AD he called the Late Anthropocene. Ruddiman (2014) argued that early deforestation and agriculture caused large greenhouse gas (carbon dioxide and methane) emissions slightly later, but nevertheless quite early in the Holocene.

Lewis and Maslin (2015) reviewed the evidence for a 'golden spike' which might provide an incontrovertible, globally relevant mark in the sedimentary record for the start of the Anthropocene. They proposed that there were two candidates. The first of these is a dip in atmospheric CO_2 levels around 1610 as recorded in high-resolution Antarctic ice cores, while the second is a spike in ^{14}C concentrations in 1964 (associated with atom bomb testing prior to test bans coming into force) as recorded within tree-rings of a dated pine in Poland. The 1610 dip in CO_2 values, which they regarded as the most convincing golden spike, resulted from the arrival of Europeans in the Americas. This led to a large decline in the indigenous population, the accompanying near-cessation of farming, a reduction in fire use, and the regeneration of over 50 million hectares of forest, woody savanna, and grassland. This caused a carbon uptake by vegetation and soils and a reduction in atmospheric CO_2 levels. In similar vein, Rose (2015) postulated that a stratigraphic marker for the start of the Anthropocene was provided by spheroidal carbonaceous fly-ash particles (SCPs), which are by-products of industrial fossil-fuel combustion. He found that data from over 75 lake sediment records showed a global, synchronous, and dramatic increase in particle accumulation starting in c. 1950, driven by the increased demand for electricity and the introduction of fuel-oil combustion, in addition to coal, as a means to produce it. He argued that SCPs are morphologically distinct and, being solely human in origin, provide an unambiguous marker. In contrast, Gale and Hoare (2012) argued that the worldwide diachroneity of human impact makes it impossible to establish a single chronological datum for the start of the Anthropocene, and the validity of a search for these sorts of golden spike has been rejected by Hamilton (2015). Thus the controversy rumbles on, though a large number of earth and environmental scientists are now firm in their opinion that the Anthropocene Epoch can be so defined (Waters et al., 2016).

The huge increase in interest in the study of the human impact on the environment and of global change has not been without other great debates and controversies, and some have argued that environmentalists have overplayed their hand (see e.g. Lomborg's *The Skeptical Environmentalist*, 2001) and have exaggerated the amount of environmental harm that is being caused by human activities. There has also been much debate about whether or not the Anthropocene is an era for hope (a 'Good Anthropocene') or an era of impending disaster (a 'Bad Anthropocene') (see Dalby, 2016).

In this book, I take a long-term perspective and seek to show the changes that mankind has caused to a wide spectrum of environmental phenomena. The current fixation with global warming should not blind us to the importance of other aspects of global change, including deforestation, desertification, salinization, pollution, and the like (Slaymaker et al., 2009).

1.3 The Development of Human Population and Stages of Cultural Development

During the history of humans on Earth, there have been some key milestones in cultural and technical development (Goudie and Viles, 2016):

Years before present (log scale)	*Driving force*
100	The Great Acceleration Internal combustion engine Industrial revolution European colonization of Americas, Australia, etc.

1000	Peopling of New Zealand, Madagascar, Oceania, etc.
	The classical era
	Secondary products revolution
	Irrigation
	Metals and mining
	Settlements and urbanization
	Domestication, agriculture, land clearance
10,000	Pleistocene extinctions
	Peopling of Americas and Australia
	Dying out of Neanderthals
100,000	Modern humans
1,000,000	Use of fire and stone tool manufacture
	Arrival of *Homo*

Some six or so million years ago, primitive human precursors or hominids appear in the fossil record (Wood, 2002). The earliest remains of a small, bipedal hominim, *Sahelanthropus tchadensis*, have been found in Chad (Brunet el al., 2002). Studies in Turkana, Kenya, have recently identified evidence of early hominin tool-making activity at Lomekwi 3, a 3.3-million-year-old archaeological site (Harmand et al., 2015). The oldest remains of *Homo* have been found either in sediments from the rift valleys of East Africa (as in the Afar region of Ethiopia) (Villmoare et al., 2015) or in caves in South Africa. The first recognizable human, *Homo habilis,* evolved about 2.5–2.8 million years ago, more or less at the time that the Pleistocene ice ages were developing in mid-latitudes. Since that time the human population has spread over virtually the entire land surface of the planet (Oppenheimer, 2003) (Figure 1.3). *Homo* may have reached Asia by around two million years ago (Zhu et al., 2008b) and Europe not much later (Moncel, 2010). In southern Europe there are stone tools in Italy associated with *Homo* that date back to 1.3–1.7 Ma (Arzarello et al., 2007) and also in Spain (Carbonell et al., 2008). In north-west Europe and Britain the earliest dates for human occupation are >0.78 Ma (Parfitt et al., 2010). Modern humans, *Homo sapiens*, have generally been thought to have appeared in Africa around 160,000 years ago (Stringer, 2003; White et al., 2003), though an even earlier date of c. 300, 000 years is possible based on remains from Morocco (Richter et al., 2017). They then spread 'out of Africa' to other parts of the world.

Table 1.2 gives data on recent views of the dates for the arrival of humans in selected areas. The dates for Australia are controversial, and they range from c. 40,000 years to as much as 150,000 years, but with a date of c. 50,000 years ago being widely accepted (Balme, 2013; Clarkson et al., 2017; Veth et al., 2017). There is also

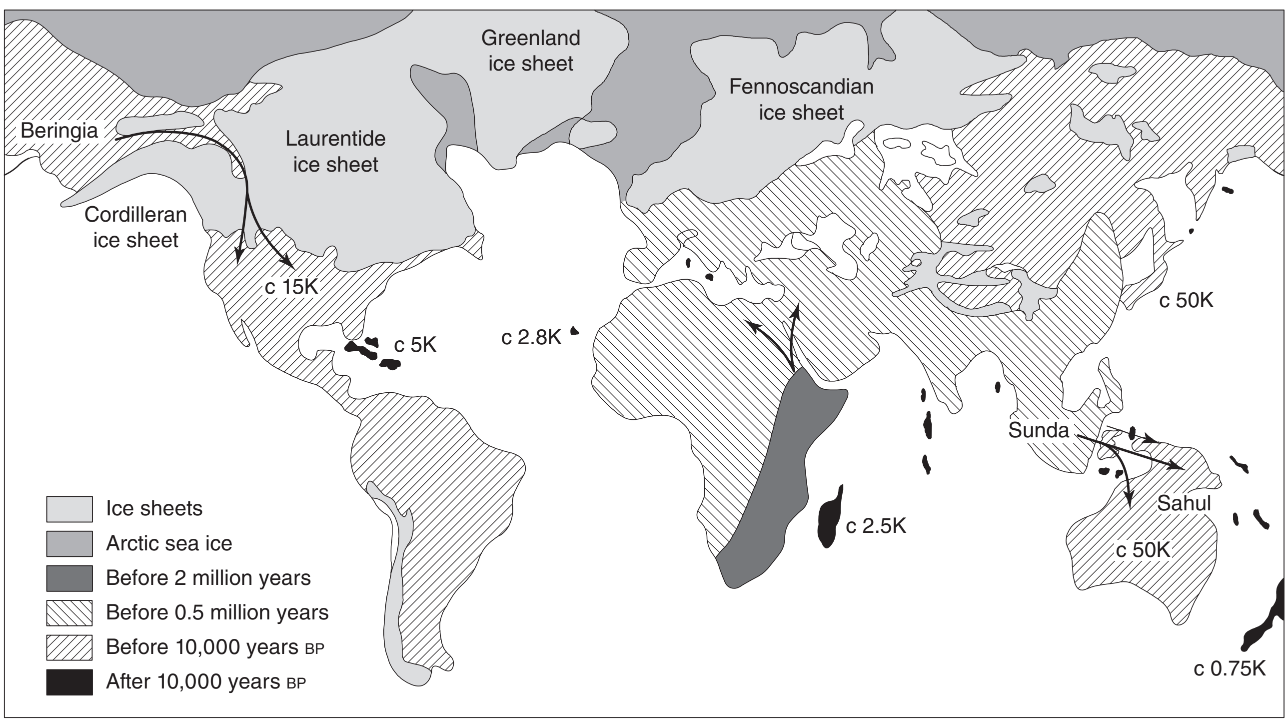

Figure 1.3 The human colonization of Ice Age Earth. Dates for some islands are given in thousands of years.

Table 1.2 Dates of human arrivals.

Area	Source	Date (years BP)
Africa	Klein (1983)	2,700,000–2,900,000
China	Huang et al. (1995)	1,900,000
Georgian Republic	Gabunia and Vekua (1995)	1,600,000–1,800,000
Java	Swisher et al. (1994)	1,800,000
Europe	Moncel (2010)	c. 1,500,000
Britain	Parfitt et al. (2010)	c. 790,000
Japan	Ikawa-Smith (1982)	c. 50,000
Australia	Geyer et al. (2017)	c. 65,000
North America	Goebel et al. (2008)	15,000
Peru	Keefer et al. (1998)	12,500–12,700
Ireland	Edwards (1985)	9,000
Taiwan	Rolett et al. (2010)	5000
Caribbean	Siegel et al. (2015)	5000
Balearic Islands	Burjachs et al. (2017)	4300
Remote Oceania	Matisoo-Smith (2015)	3000
Canary Islands	de Nascimento et al. (2015)	2800–2500
Polynesia	Kirch (1982)	2,000
Madagascar	Crowley (2010)	2500
New Zealand	Lowe (2008)	750

considerable uncertainty about the dates for humans arriving in the Americas (Goebel et al., 2008; Amick, 2016). Many authorities have argued that the first colonizers of North America, arrived via the Bering landbridge from Asia around 12,000 years ago. However, some earlier dates exist for the Yukon (Bourgeon et al., 2017), and Florida (Halligan et al., 2016), and these perhaps imply an earlier phase of colonization. Indeed, very recently, Holen et al. (2017) claim to have found evidence of human butchering of mastodon bones in southern California, dating back to as much as 130,000 years ago. The settlement of Oceania took place relatively late, with colonization of the western archipelagos of Micronesia and eastern Melanesia taking place at c. 3500–2800 BP, of central and eastern Micronesia at 2200–2000 BP, and of eastern and southern Polynesia at 1100–700 BP (Anderson, 2009).

Estimates of population levels in the early stages of human development (Figure 1.4a) are imprecise and uncertain. At the peak of the Last Glacial Maximum around 20,000 years ago, the population of the old world was possibly between about 2 and 8 million (Gautney and Holliday, 2015). Human population estimates for the Holocene are diverse and controversial (Boyle et al., 2011). The mid-Holocene value was between 5 and 24 million, the value at the end of the Roman period was c. 200 million, the late medieval value was between c. 400 and 500 million, and the value at the start of the Industrial Revolution was around 900–1000 million. The total has now passed 7000 million.

Before the agricultural 'revolution' some 10,000 years ago, human groups were hunters and gatherers. Population densities were low, and the optimum territory for a band of hunter-gatherers in the Middle Eastern woodland–parkland belt would have been 300–500 square kilometres, while in the drier regions it would have been 500–2000 square kilometres (Bar-Yosef, 1998). However, the agricultural revolution probably enabled an expansion of the total human population to 500 million by AD 1650. It is since that time, helped by the medical and industrial revolutions and developments in agriculture and colonization of new lands, that human population has exploded, reaching about 1,000 million by AD 1850, 2,000 million by AD 1930, and 4,000 million by AD 1974. Victories over various diseases (e.g. smallpox, cholera, malaria) have caused marked decreases in death-rates throughout the non-industrial world, but death-rate control has not in general been matched by birth control. Thus the annual population growth rate in the late 1980s in South Asia was 2.64%, Africa 2.66%, and Latin America (where population increased fourteenfold between 1850 and 2000), 2.73%. In the period from 2005–2010 these rates had slowed down substantially, with Latin America down to 1.2% and Africa to 2.2%. The global annual growth in population has over the last decade been around 75–77 million people (Figure 1.4b).

The history of the human impact, however, has not been a simple process of increasing change in response to linear population growth over time, for in specific places at specific times there have been periods of reversal in population growth and ecological change as cultures have collapsed, wars occurred, diseases struck, and habitats been abandoned. Denevan (1992), for example, has pointed to the decline of Native American populations in the new world following European entry into the Americas. This created what was 'probably the greatest demographic disaster ever'. The overall population of the Western Hemisphere in 1750 was perhaps less than a third of what it may have been in 1492, and the ecological and atmospheric consequences were legion (see Section 1.2). It is certainly dangerous to think that in all places the human impact has shown a continually increasing trajectory, for there are many examples of ravages in one era being followed by phases of restoration, recovery, and stability in another. Trimble

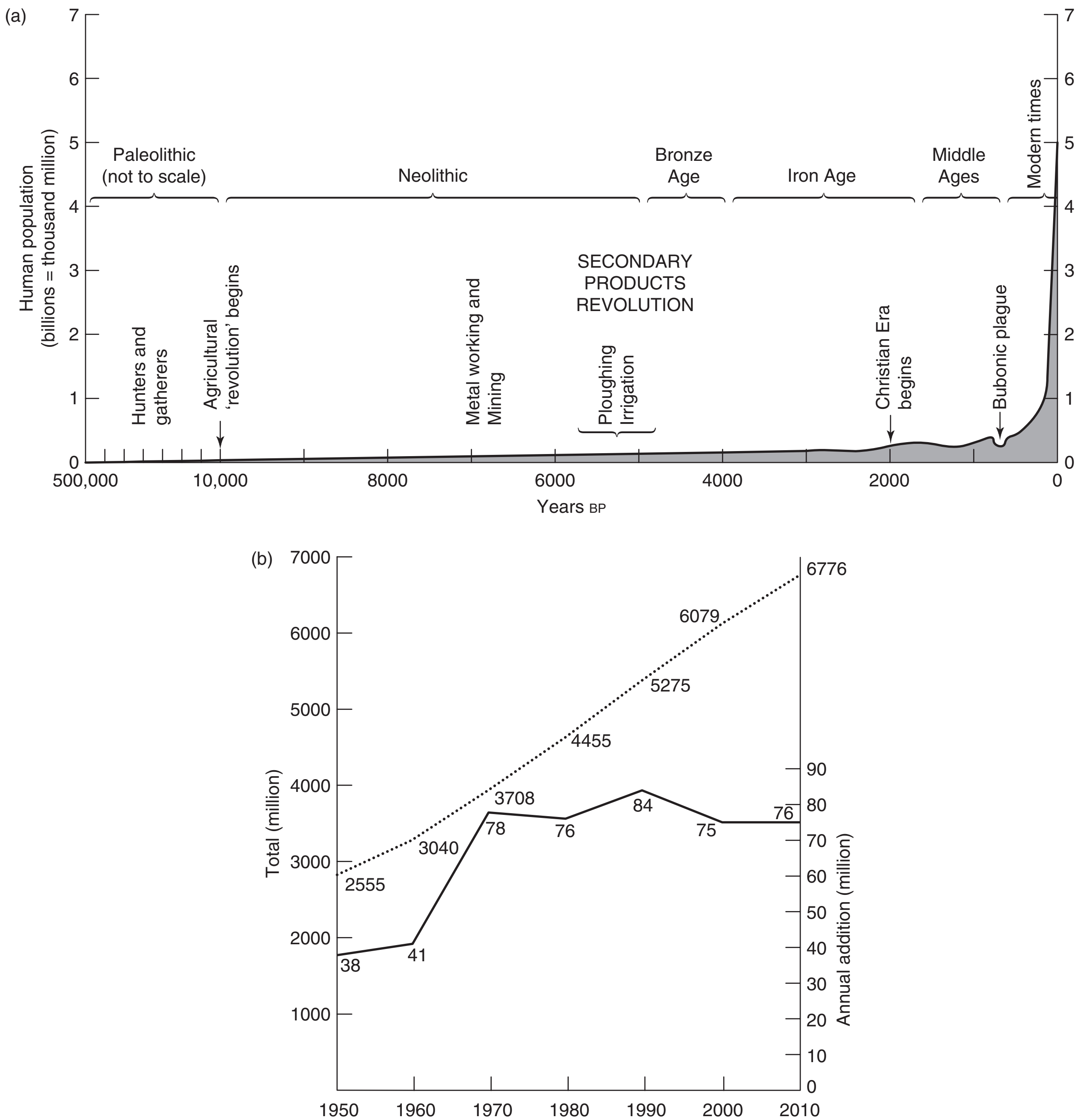

Figure 1.4 (a) The growth of human numbers for the past half million years. *Source:* adapted from Ehrlich et al. (1977: figure 5.2). (b) Annual growth of world population since 1950. *Source:* based on UN data.

(2013) demonstrates this in the context of the land use and land degradation history in the American Midwest.

The evolving impact of humans on the environment has often been expressed in terms of a simple equation:

$$I = P\ A\ T$$

where I is the amount of pressure or impact that humans apply on the environment, P is the number of people, A is the affluence (or the demand on resources per person), and T is a technological factor (the power that humans can exert through technological change). P, A, and T have been seen by some as 'the three horsemen of the environmental apocalypse' (Meyer, 1996: 24). There may be considerable truth in the equation and in that sentiment; but as Meyer points out, the formula cannot be applied in too mechanistic a way. The 'cornucopia view', indeed, sees population not as the ultimate depleter of resources but as itself the ultimate resource capable of causing change for the better. There are cases where strong population growth has appeared to lead to a reduction in environmental degradation (Tiffen et al., 1994). Likewise, there is debate about whether it is poverty or affluence that creates deterioration in the environment. On the other hand many poor countries have severe environmental problems and do not have the resources to clear them up, whereas affluent countries do. Conversely it can be argued that affluent countries have plundered and fouled less fortunate countries, and that it would be environmentally catastrophic if all countries used resources at the rate that the rich countries do. Similarly, it would be naïve to see all technologies as malign, or indeed benign. Technology can be a factor either of mitigation and improvement or of damage. Sometimes it is the problem (as when ozone depletion has been caused by a new technology – the use of chlorofluorocarbons) and sometimes it can be the solution (as when renewable energy sources replace the burning of polluting lignite in power stations).

In addition to the three factors of population, affluence, and technology, environmental changes also depend on variations in the way in which different societies are organized and in their economic and social structures (see Meyer, 1996: 39–49 for an elaboration of this theme). For example, the way in which land is owned is a crucial issue. The controls of environmental changes caused by the human impact are thus complex and in many cases contentious, but all the factors discussed play a role of some sort, at some places, and at some times.

We now turn to a consideration of the major cultural and technical developments that have taken place during the past two to three million years. Takács-Sánta (2004) argued that there have been six major transformations in the history of the human transformation of the environment: the use of fire, the development of language, the birth of agriculture, the development of cities and states, European conquests since the fifteenth century AD, and the Technological-Scientific Revolution, with the emergence of fossil fuels as primary energy sources. In this book, three main phases will form the basis of the analysis: the phase of hunting and gathering; the phase of plant cultivation, animal keeping and metal working; and the phase of modern urban and industrial society, culminating in the Great Acceleration. These developments are treated in much greater depth by Simmons (1996) and Ponting (2007).

1.4 Hunting and Gathering

The supposed uniqueness of humans as tool makers has been seen as false because of recent studies which have shown that wild monkeys are capable of flaking stone tools (Proffitt et al., 2016). Nonetheless, the oldest records of human activity and technology are pebble tools which consist of a pebble with one end chipped into a rough cutting edge. At Dikika in Ethiopia there is evidence for stone-tool-assisted consumption of meat at 3.42–3.24 Ma (McPherron et al., 2010). At Lake Turkana in northern Kenya, and the Omo Valley in southern Ethiopia, a tool-bearing bed of volcanic material has been dated by isotopic means at about 2.6 million years old, another from Gona in the north-east of Ethiopia at about 2.5 million years old (Semaw et al., 1997), while another bed at the Olduvai Gorge in Tanzania (Figure 1.5) has been dated by similar means at 1.75 million years. Indeed, these very early tools are generally termed 'Oldowan'.

Figure 1.5 The Olduvai Gorge in Tanzania – one of the great sites for the investigation of early man (ASG).

As the Stone Age progressed the tools became more sophisticated, varied, and effective, and Figure 1.6 shows some beautiful Palaeolithic hand axes from Olorgesailie in East Africa. Greater exploitation of plant and animal resources became feasible. Stone may not, however,

Figure 1.6 A cluster of Palaeolithic hand axes from Olorgesailie in East Africa (ASG).

have been the only material used. Sticks and animal bones, the preservation of which are less likely than stone, are among the first objects that may have been used as implements, although the sophisticated utilization of antler and bone as materials for weapons and implements appears to have developed surprisingly late in pre-history. There is certainly a great deal of evidence for the use of wood throughout the Palaeolithic Age and by modern and hunter-gatherer communities, for ladders, fire, pigment (charcoal), the drying of wood, and digging sticks. Tyldesley and Bahn (1983: 59) went so far as to suggest that 'The Palaeolithic might more accurately be termed the "Palaeoxylic" or "Old Wood Age", and experiments have shown the efficiency of wooden hunting tools in comparison with ones made of stone' (Waguespack et al., 2009).

The building of shelters and the use of clothing became a permanent feature of human life as the Palaeolithic period progressed, and permitted habitation in areas where the climate was otherwise not congenial. European sites from the Mousterian of the Middle Palaeolithic have revealed the presence of purposefully made dwellings as well as caves, and by the Upper Palaeolithic more complex shelters were in use, allowing people to live even in the tundra lands of Central Europe and Russia.

Another feature of early society which seems to have distinguished humans from the surviving non-human primates was their seemingly omnivorous diet. Whereas the great apes, though not averse to an occasional taste of animal food, are predominately vegetarian, our Palaeolithic ancestors, including *Homo sapiens*, lived as hunter-gatherers, eating wild animal-source foods (lean meats, internal organs, bone marrow, but no dairy) and uncultivated plant-source foods (mostly fruits, vegetables, and nuts). One consequence of enlarging the range of their diet was that, in the long run, humans were able to explore a much wider range of environments. Another major difference that set humankind above the beasts was the development of communicative skills such as speech. Until hominids had developed words as symbols, the possibility of transmitting, and so accumulating, culture hardly existed. Animals can express and communicate emotions, never designate or describe objects.

Very early on in their history humans started using fire (Glikson, 2013; Bowman, 2014; Albert, 2015) (Figure 1.7). This, as we shall see (Sections 2.3–2.6), is a major agent by which humans have influenced their environment (Kinoshita et al., 2016). The date at which it was first deliberately employed is a matter of ongoing controversy (Caldararo, 2002; Gowlett, 2016). In South Africa, Beaumont (2011) and Berna et al. (2012) found some traces of repeated burning events from Acheulean

Figure 1.7 Fire was one of the first and most powerful tools of environmental transformation employed by humans. The high grasslands of southern Africa may owe much of their character to regular burning, as shown here in Swaziland (ASG).

cave sediments dating back to more than a million years ago. In East Africa, Gowlett et al. (1981) claimed to find evidence for deliberate manipulation of fire from over 1.4 million years ago. In Murcia, Spain, there is evidence for use of fire in the early Palaeolithic between c. 780,000 and 980,000 years ago (Rhodes et al., 2016). After c. 400,000 years ago (i.e. in the Middle Pleistocene) evidence for the association between humans and fire becomes compelling (Shimelmitz et al., 2014).

It is apparent from many parts of the world that even small hunter-gatherer populations can cause great environmental changes through the use of fire (Lightfoot and Cuthrell, 2015). As Pyne (1982: 3) has written:

> It is among man's oldest tools, the first product of the natural world he learned to domesticate. Unlike floods, hurricanes or windstorms, fire can be initiated by man; it can be combated hand to hand, dissipated, buried, or 'herded' in ways unthinkable for floods or tornadoes.

He went on to stress the implications that fire had for subsequent human cultural evolution (p. 4):

> It was fire as much as social organisation and stone tools that enabled early big game hunters to encircle the globe and to begin the extermination of selected species. It was fire that assisted hunting and gathering societies to harvest insects, small game and edible plants; that encouraged the spread of agriculture outside the flood plains by allowing for rapid landclearing, ready fertilization, the selection of food grains, the primitive herding of grazing animals that led to domestication, and the expansion of pasture and grasslands against climate gradients; and that, housed in machinery,

powered the prime movers of the industrial revolution.

Overall, compared with later stages of cultural development, early hunters and gatherers had neither the numbers nor the technological skills to have a very substantial effect on the environment. Besides the effects of fire, early cultures may have caused some diffusion of seeds and nuts, and through hunting activities (see Section 3.7) may have had some dramatic effects on animal populations, causing the extinction of many great mammals (the so-called 'Pleistocene overkill'). Locally some eutrophication may have occurred, and around some archaeological sites phosphate and nitrate levels may be sufficiently raised to make them an indicator of habitation to archaeologists today (Holliday, 2004). Equally, although we often assume that early humans were active and effective hunters, they may well have been dedicated scavengers of carcasses of animals which had either died natural deaths or been killed by carnivores like lion.

It is salutary to remember, however, just how significant this stage of our human cultural evolution has been. As Lee and DeVore (1968: 3) wrote:

> Of the estimated 80,000,000,000 men who have ever lived out a life span on earth, over 90 per cent have lived as hunters and gatherers, about 6 per cent have lived by agriculture and the remaining few per cent have lived in industrial societies. To date, the hunting way of life has been the most successful and persistent adaptation man has ever achieved.

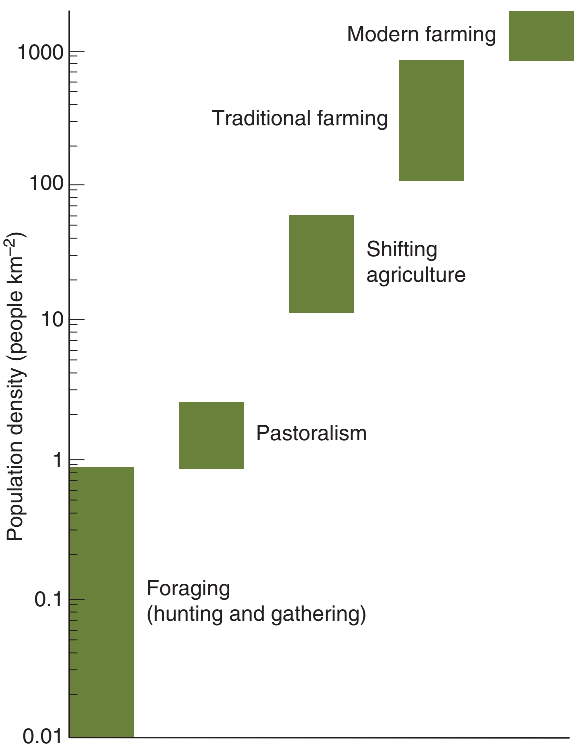

Figure 1.8 Comparison of carrying capacities of foraging, pastoralist, and agricultural societies.

Figure 1.8 indicates the very low population densities of hunter/gatherer/scavenger groups in comparison with those that were possible after the development of pastoralism and agriculture.

1.5 Humans as Cultivators and Keepers

Humans have been foragers rather than farmers for around 95% of their history, but during the end of the Pleistocene major changes were afoot. It is possible to identify some key stages of economic development that have taken place since then (Table 1.3). For example around 14,000–15,000 years ago, in the Middle Eastern region, now consisting of Jordan, Syria, Israel, Palestine, and Lebanon, the hunting folk – the Natufians – in addition to their hunting, began to build permanent houses of stone and wood, they buried their dead in and around them with elaborate rituals, gathered in communities of up to several hundred people, ground up wild cereals with pestles and mortars, and made tools and art objects from animal bones (Bar-Yosef, 1998; Barker, 2006; Balter, 2010). Then, round the beginning of the Holocene, about 10,000 years ago, the Natufians and other groups in various other parts of the world began to domesticate rather than to gather food plants and to keep, rather than just hunt, animals. This phase of human cultural development is well reviewed in Roberts (2014). By taking up farming and domesticating food plants, they reduced enormously the space required for sustaining each individual by a factor of the order of 500 at least (Sears, 1957: 54) and population densities could thus become progressively greater (Figure 1.9). As a consequence we see shortly thereafter, notably in the Middle East, the establishment of the first major settlements – towns.

It is now recognized that some hunters and gathers had considerable leisure and did not need to develop agriculture to avoid drudgery and starvation. Moreover, some believe that the mobile hunter-gatherer lifestyle was far more attractive than a sedentary one, which creates problems of refuse disposal, hygiene, and social conflict (Mithen, 2007). However, there is no doubt that through the controlled breeding of animals and plants humans were able to develop a more reliable and readily expandable source of food and thereby create a solid and secure basis for cultural advance, an advance which included civilization and the 'urban revolution' of Childe

Table 1.3 Five stages of economic development.

Economic stage	Dates and characteristics
Hunting-gathering and early agriculture	Domestication first fully established in south-western Asia around 7500 BC; hunter-gatherers persisted in diminishing numbers until today. Hunter-gatherers generally manipulate the environment less than later cultures, and adapt closely to environmental conditions
Riverine civilizations	Great irrigation-based economies lasting from c. 4000 BC to 1st century AD in places such as the Nile Valley and Mesopotamia. Technology developed to attempt to free civilizations from some of the constraints of a dry season
Agricultural empires	From 500 BC to around 1800 AD a number of city-dominated empires existed, often affecting large areas of the globe. Technology (e.g. terracing and selective breeding) developed to help overcome environmental barriers to increased production
The Atlantic-industrial era	From c. 1800 AD to today a belt of cities from Chicago to Beirut, and around the Asian shores to Tokyo, form an economic core area based primarily on fossil fuel use. Societies have increasingly divorced themselves from the natural environment, through air conditioning for example. These societies have also had major impacts on the environment
The Pacific-global era	Since the 1960s there has been a shifting emphasis to the Pacific Basin as the primary focus of the global economy, accompanied by globalization of communications and the growth of multinational corporations

Source: adapted from Simmons (1993: 2–3).

Figure 1.9 The growth of towns and cities was a major factor in the transformation of the environment. This image is of the Citadel in Aleppo, Syria. Aleppo is an ancient metropolis, and one of the oldest continuously inhabited cities in the world; it may have been inhabited since the 6th millennium BCE (ASG).

(1936) and others. Indeed, Isaac (1970) termed domestication 'the single most important intervention man had made in his environment'; and Harris (1996) regarded the transition from foraging to farming as 'the most fateful change in the human career'. Diamond (2002) termed it 'the most momentous change in Holocene human history', while Mithen (2007: 705) has said that 'The origins of farming is the defining event of human history – the one turning point that has resulted in modern humans having a quite different type of lifestyle and cognition to all other animals and past types of humans'.

A distinction can be drawn between cultivation and domestication. Whereas cultivation involves deliberate sowing or other management, and entails plants which do not necessarily differ genetically from wild populations of the same species, domestication results in genetic change brought about through conscious or unconscious human selection. This creates plants that differ morphologically from their wild relatives and which may be dependent on humans for their survival.

The origin of agriculture remains controversial (Scarre, 2005; Barker, 2006; Barker and Goucher, 2015). Some early workers saw agriculture as a divine gift to humankind, while others thought that animals were domesticated for religious reasons. They argued that it would have been improbable that humans could have predicted the usefulness of domestic cattle before they were actually domesticated. Wild cattle are large, fierce beasts, and no one could have foreseen their utility for labour or milk until they were tamed – tamed perhaps for ritual sacrifice in connection with lunar goddess cults (the great curved horns being the reason for the association). Another major theory – the demographic hypothesis – was that domestication was produced by crowding, possibly brought on by a combination of climatic deterioration (alleged post-Glacial progressive desiccation) and population growth. Gordon Childe's 'oasis propinquity hypothesis' held that increasing desiccation brought wild animals and plants into ever closer relationships, from which symbiosis and ultimately domestication emerged (Renfrew, 2006). Such pressure, may have forced communities to intensify their methods of food production. Current palaeo-climatological research tends not to support this interpretation, but that is not to say that other severe climatic changes could not have played a role (Sherratt, 1997).

Sauer (1952) believed that plant domestication was initiated in South-East Asia by fishing folk, who found that lacustrine and riverine resources would underwrite a stable economy and a sedentary or semi-sedentary life style. He surmises that the initial domesticates would be multi-purpose plants set around small fishing villages to provide such items as starch foods, substances for toughening nets and lines and making them water-resistant, and drugs and poisons. He suggested that 'food production was one and perhaps not the most important reason for bringing plants under cultivation'.

Yet another model was advanced by Jacobs (1969) which turned certain more traditional models upside down. Instead of following the classic pattern whereby farming leads to village which leads to town which leads to civilization, she proposed that one could be a hunter-gatherer and live in a town or city, and that agriculture originated in and around such cities rather than in the countryside. Her argument suggests that even in primitive hunter-gatherer societies particularly valuable commodities such as fine stones, pigments, and shells could create and sustain a trading centre which would possibly become large and stable. Food would be exchanged for goods, but natural produce brought any distance would have to be durable, so meat would be transported on the hoof for example, but not all the animals would be consumed immediately; some would be herded together and might breed. This might be the start of domestication. Indeed, settlements may have been a cause of agriculture rather than a consequence (Watkins, 2010).

Another hypothesis – the feasting hypothesis – is based on the idea that in many societies, those wishing to achieve rank and status do so by throwing feasts. The adoption of cultivation and the husbanding of domestic animals made it possible for ambitious individuals to produce increasing amounts of food which would give them an advantage in social competition (Hayden, 1995). It is also possible that as humans developed art and equipment to process plants, they developed new ideas and saw cultivation and domestication as a means of social prestige (Mithen, 2007). In other words, the origins of agriculture 10,000 years ago may perhaps be explained by a fundamental change in the way in which the human mind conceived of nature.

The process of domestication and cultivation was also once considered a revolutionary system of land procurement that had evolved in only one or two hearths and diffused over the face of the earth, replacing the older hunter-gathering systems by stimulus diffusion. It was felt that the deliberate rearing of plants and animals for food was a discovery or invention so radical and complex that it could have developed only once (or possibly twice) – the so-called 'Eureka model'. In reality, however, the domestication of plants occurred at approximately the same time in widely separated areas (Table 1.4). As Barker (2006: 412) has written:

> probably many more societies than commonly envisaged, in all parts of the world, started to engage in different kinds of animal and/or plant husbandry at or soon after the transition to the Holocene – in South-West Asia, South Asia, East Asia, Island South-East Asia, several parts of the Americas, and North Africa (and who knows when in tropical West Africa?). Independent of one another (at the regional scale, that is) and in many different ways, very many societies arrived at solutions to living in the transformed landscapes they were encountering which we can recognize as the beginnings of systematic husbandry.

Table 1.4 Dates which indicate that there may have been some synchroneity of plant domestication in different centres.

Centre	Dates (000 years BP)	Plant
Mesoamerica	10.7–9.8 9.0	Squash-pumpkin
		Bottle gourd
		Maize
Near East	11.0–9.3	Fig tree
		Emmer wheat
		Two-rowed barley
		Einkorn wheat
		Pea
		Lentil
		Flax
Far East	11.0–7.0	Broomcorn millet
		Rice
		Gourd
		Water chestnut
Andes	9.4–8.0	Chilli pepper
		Common bean
		Ullucu
		White potato
		Squash and gourd

So, the balance of botanical and archaeological evidence seems to suggest that humans started experimenting with domestication and cultivation of different plants at different times in different parts of the world (Figure 1.10) (Mithen, 2007; Fuller et al., 2014; Larson et al., 2014). It has been argued that domestication of plants can be divided into three stages: (i) *gathering*, in which people gathered annual plants from wild stands; (ii) *cultivation*, in which wild plant genotypes were systematically sown in fields of choice; and (iii) *domestication*, in which mutant plants with desirable characteristics were raised (Weiss et al., 2006). Cultivation is the essential stage, as the repetitive cycle of sowing, collecting, and sowing of wild plants which it involves gives rise to genotype accumulation that leads on to domestication.

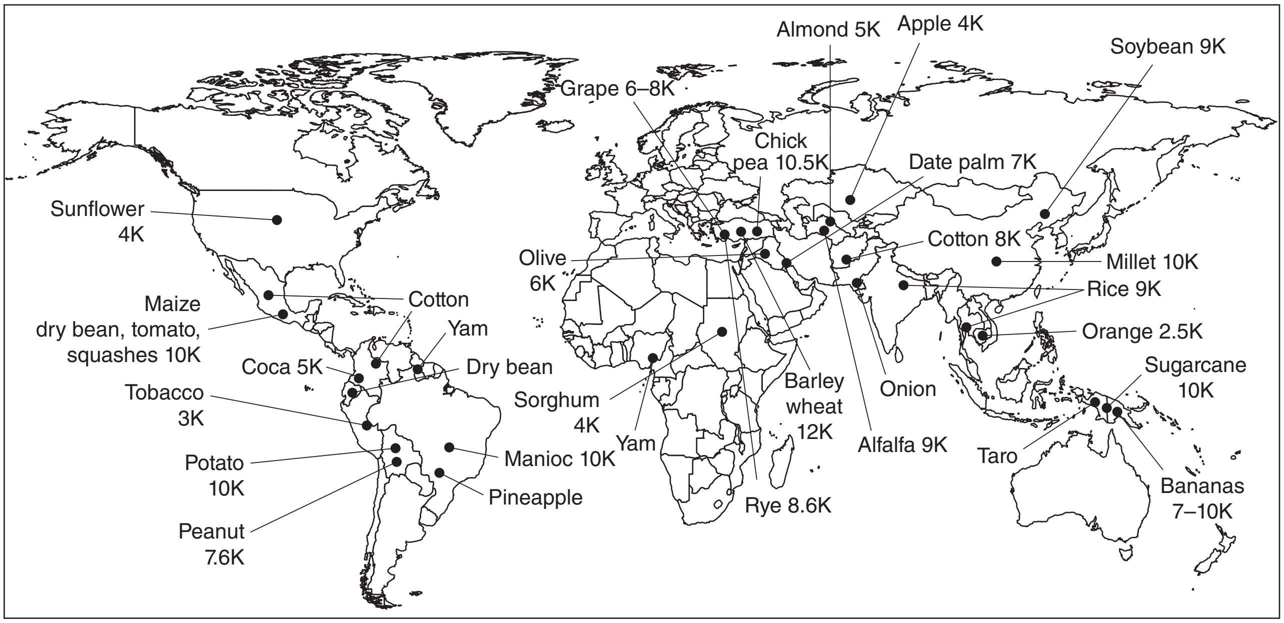

Figure 1.10 A map of the centres of origin for selected crops with details of the dates of their domestication.

The dates for the first evidence of domestication tend to have become earlier in recent years, and the first steps towards domestication of crops in the eastern Mediterranean lands and the so called 'Hilly Flanks' of the Middle East may have taken place around 12,000 BP (Before Present) (Zeder, 2008; Özkan et al., 2011). The so-called founder crops were three cereals (emmer wheat, einkorn wheat, and barley), four types of pulse, and flax. Flax (*Linum usitatissimum*), although it may have initially been domesticated as a source of oil, represents the earliest known domesticated fibre (linen) in the archaeological record. It was domesticated from 'pale flax' (*Linum bienne*), a wild plant which grows across south-west Asia, north Africa, western and southern Europe. The grape was also domesticated in the Middle East at c. 6000–8000 BP (Myles et al., 2011) and the date palm was domesticated in southern Mesopotamia around 7000 BP (Tengberg, 2012). With regard to olives, although early exploitation and use of wild olive trees (namely oleasters) has been documented since the Neolithic from the Near East to Spain, it is usually accepted that the domestication of the olive tree began in the north-east Levant approximately 6000 years ago (Besnard et al., 2013). Nonetheless, recent syntheses of sites of plant domestication on a global basis (Meyer et al., 2012) have shown the importance of such centres as China, South-East Asia, and the Americas (Dillehay et al., 2007; Pickersgill, 2007). The earliest domestication of rice occurred in China (though the exact locations are a matter of debate) after c. 9000 BP (Liu et al., 2007; Fuller et al., 2009), while evidence for cotton domestication occurs in Baluchistan (Pakistan) at c. 8000 BP (Moulherat et al., 2002). The domestication of millet in China has been extended back to 10,000 BP (Lu et al., 2009). In Mesoamerica maize, beans, squashes, and the potatoes may have been domesticated as early as 10,000–9000 BP (Zizumbo-Villarreal and Colunga-García Marín, 2010; Ovchinnikova et al., 2011).

The locations and dates for domestication of some important domestic animals are shown in Figure 1.11. Note that the domestication of sheep, goats, pigs, and cattle took place in the Near East and neighbouring areas round about 10,500–9000 BP, with the cat following shortly thereafter (Driscoll et al., 2009). However, the animal that was first domesticated, probably because of its utility for hunting, was the dog, *Canis familiaris*, which was probably domesticated by c. 16,000 BP (Galibert et al., 2011), possibly in southern China (Pang et al., 2009), Central Asia (Shannon et al., 2015), or in Western Eurasia (Frantz et al., 2016). The horse was first domesticated in the steppes of Kazakhstan at c. 5500 BP (Outram et al., 2009), while the chicken was domesticated at several centres in south and South-East Asia (Tixier-Boichard et al., 2011), including the Indus Valley and China (Liu et al., 2006). The donkey was domesticated from the wild ass in north-east Africa and possibly Yemen about 5000 BP (Kimura et al., 2011; Rosenbom et al., 2015), and the water buffalo was domesticated during the Neolithic in various regions in south and eastern Asia (Yang et al., 2008). The pig may have been independently domesticated not only in the Middle East but also in China (Amills, 2011). The domestication of

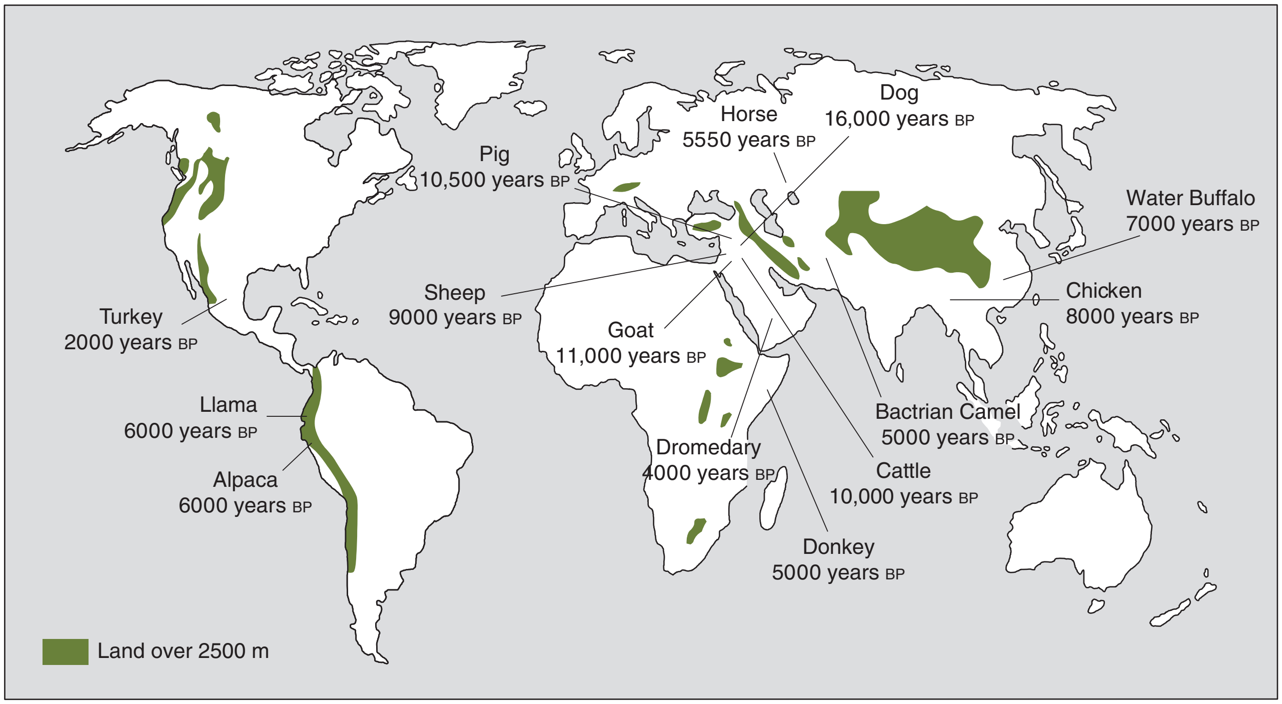

Figure 1.11 The places of origin, with approximate dates, for the most common domesticated animals.

the dromedary camel took place rather late in human history, most likely at the transition between three and four thousand BP (Orlando, 2016), while the wild bactrian camel, whose range extended from the great bend of the Yellow River in north-western China through Mongolia to central Kazakhstan, may have been domesticated about 5000 BP (Ji et al., 2009).

There are various pathways by which animal domestication occurred (Larson and Fuller, 2014). One is the *Commensal Pathway*. This does not begin with intentional action on the part of people to bring wild animals into their camps. Instead, as people manipulated their immediate surroundings, different populations of wild animals would have been attracted to elements of the human niche, including human food waste and/or smaller animals that were also attracted to the refuse. Examples of these animals include dogs, cats, pigeons, and guinea pigs. A second pathway is the *Prey Pathway*. Each step along the trajectory, from wild prey to game management, to herd management, to directed breeding, may have been guided by a desire to increase the supply of a resource that had been diminished by hunting. This applied particularly to larger meat-providing animals, such as sheep, goats, and cattle. A third pathway is the *Directed Pathway*. This was the only pathway that began with a deliberate objective to domesticate a species. Species, such as donkeys and camels, were deliberately brought into the human niche for reasons such as their utility as sources of transport.

It was the Near East, and in particular the Hilly Flanks, that was especially important for both plant and animal domestication (Bar-Yosef, 1998; Abbo et al., 2010; Zohary et al., 2012). Wild progenitors were numerous in the area, including those of wheat, barley, flax, lentils, olives, peas, sheep, goats, cows, and pigs – a list that includes what are still the most valuable crops and livestock of the modern world (Diamond, 1997, 2002; Morris, 2010).

An important and slightly later development in agriculture was irrigation (Figure 1.12) and the adoption of

Figure 1.12 Irrigation using animal power, as here in Rajasthan, India, is an example of the use of domesticated stock to change the environment (ASG).

riverine agriculture. Amongst the earliest evidence of artificial irrigation is the mace-head of the Egyptian Scorpion King which shows one of the last pre-dynastic kings ceremonially cutting an irrigation ditch around 5050 BP (Butzer, 1976), although it is possible that irrigation at Sumer in Iraq started even earlier. Irrigation in the American south-west may date back 3000 years (Damp et al., 2002). There are problems of establishing dates for the inception of irrigation in Mesopotamia and elsewhere in the Middle East, but their scale has increased over the last 3000 years (Wilkinson and Rayne, 2010).

A major difference has existed in the development of agriculture in the Old and New Worlds; in the latter there were few counterparts to the range of domesticated animals which were an integral part of the former (Sherratt, 1981). A further critical difference was that in the Old World the secondary applications of domesticated animals were explored. This has been termed 'The Secondary Products Revolution' (Greenfield, 2010). The plough was particularly important in this process (Figure 1.13) – the first application of animal power to the mechanization of agriculture. Closely connected to this was the use of the cart, which both permitted more intensive farming and enabled the transportation of its products. Furthermore, the development of textiles from animal fibres afforded, for the first time, a commodity which could be produced for exchange in areas where arable farming was not the optimal form of land use. Finally, the use of animal milk provided a means whereby large herds could use marginal or exhausted land, encouraging the development of the pastoral sector with transhumance or nomadism. Organic residues preserved in pottery vessels have provided direct evidence for early milk use in the Neolithic period in the Near East and south-eastern Europe, North Africa, Denmark, and the British Isles, and have demonstrated the early production of cheese (Dunne et al., 2012; Salque et al., 2013).

This Secondary Products Revolution therefore had radical effects, and the change took place over quite a short period. The plough was invented some 5000 years ago, and was used in Mesopotamia, Assyria, and Egypt. The wheeled cart was first produced in the Near East in the fourth millennium BC, and rapidly spread from there to both Europe and India (Figure 1.14) during the course of the third millennium. The development of other means of transport preceded the wheel. Sledge-runners found in Scandinavian bogs have been dated to the Mesolithic period (Cole, 1970: 42).

The origins of seafaring are difficult to establish. On the one hand by c. 800,000 years ago, people seem to have crossed a deep water strait between Bali and Lombok in South-East Asia, and humans crossed a 100 kilometre-wide strait to reach Australia by c. 50,000

Figure 1.13 The development of ploughs provided humans with the ability to transform soils. This simple type is in Pakistan (ASG).

Figure 1.14 In the Secondary Products Revolution, cattle, such as these in Haryana, India, were used as beasts of burden, for pulling ploughs, and as a source of products such as leather (ASG).

years ago (Broodbank, 2006; Erlandson 2010; Balme, 2013). However, in the Mediterranean world there is very little firm evidence of any maritime activity until the late Pleistocene (Knapp, 2010) and this is also the time when humans may have navigated down the coast of the Americas (Erlandson et al., 2011). Neolithic people undertook a 130 kilometre open sea voyage to reach Taiwan by c. 5000 years ago (Rolett et al., 2011). Indeed, by the Neolithic era humans had developed boats, floats, and rafts that were able to cross to Mediterranean islands and sail the Irish Sea. Dugout canoes could hardly have been common before polished stone axes and adzes came into general use during Neolithic times, although some paddle and canoe remains are recorded from Mesolithic sites in northern Europe. The middens of the hunter-fishers of the Danish Neolithic contain bones of deep-sea fish such as cod, showing that these people certainly had seaworthy craft with which to exploit ocean resources.

Both the domestication of animals and the cultivation of plants have been among the most significant causes of the human impact. Pastoralists have had many major effects – for example, on soil erosion – and nomadic pastoralists are probably more conscious than agriculturalists that they share the earth with other living things. That said, heavily grazed lands tend to have considerably lower infiltration capacities than those found in ungrazed lands and this can change the nature and density of vegetation cover, thereby affecting erosion rates, including wind erosion (Aubault et al., 2015).

Agriculturalists, on the other hand, deliberately transform nature in a sense which nomadic pastoralists do not. Their main role has been to simplify the world's ecosystems. Thus in the prairies of North America, by ploughing and seeding the grasslands, farmers have eliminated a hundred species of native prairie herbs and grasses, which they replace with pure stands of wheat, corn, or alfalfa. On a world basis (see Harlan, 1976) such simplification is evident. For example, today four crops (wheat, rice, maize, and potatoes) at the head of the list of food supplies contribute more tonnage to the world total than the next twenty-six crops combined. This simplification may reduce the stability of ecosystems (but see Section 13.6).

The spread of agriculture has transformed land cover at a global scale. As Table 1.5 shows, there have been great changes in the area covered by particular biomes since pre-agricultural times. It is possible (Ruddiman, 2014) that mid-Holocene deforestation and land-cover change, including rice irrigation in China, modified global climates by releasing carbon dioxide and methane into the atmosphere, and by altering albedo (He et al., 2014). Even in the last three hundred years the areas of cropland and pasture have increased by around five- to sixfold (Goldewijk, 2001).

1.6 Mining and Metals

One further development in human cultural and technological life, which was to increase human power, was the mining of ores and the smelting of metals (Roberts et al., 2009). Neolithic cultures used native copper from the eighth millennium BC onwards, but evidence for its smelting occurs at Catal Hüyük in Turkey and in Jordan from the sixth millennium BC (Grattan et al., 2007) and in Serbia from the fifth millennium BC (Radivojević et al., 2010). The spread of metal working into other areas was rapid particularly in the second half of the fifth millennium (Muhly, 1997) and by 2500 BC bronze products were in use from Britain in the west to northern China in the east. The smelting of iron ores may date back to the

Table 1.5 Estimated changes in the areas of the major land cover types between pre-agricultural times and the present.*

Land cover type	Pre-agricultural area	Present area	Percent change
Total forest	46.8	39.3	−16.0
Tropical forest	12.8	12.3	−3.9
Other forest	34.0	27.0	−20.6
Woodland	9.7	7.9	−18.6
Shrubland	16.2	14.8	−8.6
Grassland	34.0	27.4	−19.4
Tundra	7.4	7.4	0.0
Desert	15.9	15.6	−1.9
Cultivation	0.0	17.6	+1760.0

* Figures are given in millions of square kilometres.
Source: from J.T. Matthews (personal communication), in Meyer and Turner (1994). With permission of Cambridge University Press.

late third millennium BC. Metal working required enormous amounts of wood and so led to deforestation and erosion, as in parts of China (Li et al., 2011) and Africa (Lupo et al., 2015). It also caused contamination of sediments as early as the mid-Holocene (Grattan et al., 2016). Metallurgy was also invented independently in the Andean area (Peru and Bolivia), with the use of gold starting about 4000 years ago and of copper about two thousand years ago (Serneels, 2017).

In recent decades fossil-fuelled machinery has allowed mining activity to expand to such a degree that in terms of the amount of material moved its effects are reputed to rival the natural processes of erosion. Taking overburden into account, the total amount of material moved by the mining industry globally was estimated by Young (1992) as at least 28 billion tonnes – about 1.7 times the estimated amount of sediment carried each year by the world's rivers. However, the rate at which many major minerals are being mined is steadily increasing. This can be illustrated by the statistics for iron ore. In 1974 the world figure was c. 900 million tonnes. By 2012 this figure had risen to 3000 million tonnes, an increase of more than three times. The comparable figures for coal are 3000 million tonnes in 1974, and 7924 million tonnes in 2012, an increase of 2.6 times (http://www.bgs.ac.uk/mineralsuk/statistics/home.html, accessed December 2017). In China, there has been a huge increase in the production of aggregates for cement manufacture, and China is currently using more cement in three years than the USA used in the whole of the twentieth century (https://www.washingtonpost.com/news/wonk/wp/2015/03/24/how-china-used-more-cement-in-3-years-than-the-u-s-did-in-the-entire-20th-century/?utm_term=.60b7f8d7219a, accessed December 2017). The environmental impacts of mineral extraction are diverse but extensive, and relate not only to the process of excavation and removal, but also to the processes of mineral concentration, smelting, and refining (Table 1.6). For instance, in mining areas, increased weathering leads to increased export of ions in stream flows. This is the case in the Appalachian coal mining area of the eastern USA. Here excess overburden from mountain-top mining is disposed of in constructed fills in small valleys adjacent to the mining site. Leachate from these increases the downstream concentrations of major ions (Lindberg et al., 2011; Griffith et al., 2012; Hopkins et al., 2013a). In areas with underground mining, acidic metal-rich mine drainage can develop as a result of accelerated oxidation of iron pyrite (FeS_2) and other sulphidic minerals resulting from the exposure of these minerals to both oxygen and water, as a consequence of the mining and processing of metal ores and coals (Raymond and Oh, 2009). Mining also had an impact on stream sediments and channel forms, as is evident for gold mining areas in Australia (Lawrence et al., 2016).

Table 1.6 Environmental impacts of mineral extraction.

Activity	Potential impacts
Excavation and ore removal	• Destruction of plant and animal habitat, human settlements, and other features (surface mining) • Land subsidence (underground mining) • Increased erosion: silting of lakes and streams • Waste generation (overburden) • Acid drainage (if ore or overburden contain sulphur compounds) and metal contamination of lakes, streams, and groundwater
Ore concentration	• Waste generation (tailings) • Organic chemical contamination (tailings often contain residues of chemicals used in concentrators) • Acid drainage (if ore contains sulphur compounds) and metal contamination of lakes, streams, and groundwater
Smelting/ refining	• Air pollution (substances emitted can include sulphur dioxide, arsenic, lead, cadmium, and other toxic substances • Waste generation (slag) • Impacts of producing energy (most of the energy used in extracting minerals goes into smelting and refining)

Source: Young (1992: table 5). Reproduced with permission of Worldwatch Institute.

1.7 Modern Industrial and Urban Civilizations

Although humans may have constructed modest communal settlements before the adoption of domestication (Watkins, 2010), it was within a few thousand years of the uptake of cereal agriculture that people began to gather into ever-larger settlements (cities) and into more institutionalized social formations (states). After around 6000 BP cities developed in the basins of the Tigris and Euphrates, and more followed by c. 5000 BP elsewhere in the Middle East (Figure 1.9), in the coastal Mediterranean, the Nile Valley, the Indus plain, and coastal Peru. Subsequently, cities evolved which had considerable human populations. It has been estimated that Nineveh may have had a population of 700,000, that Augustan Rome may have had a population of around one million, and that Carthage (Figure 1.15a), at its fall in 146 BC, had 700,000 (Thirgood, 1981). Another large city of the Roman Empire was Leptis Magna in modern-day Libya (Figure 1.15b). Such cities would have already exercised a considerable influence on their environs, but this influence was never as extensive as that of the last

(a)

(b)

Figure 1.15 (a) Carthage, in northern Tunisia, was one of the great cities of the ancient world, while in Libya (b) the Romans also built the city of Leptis Magna (ASG).

Figure 1.16 Urbanization (and, in particular, the growth of large conurbations such as Kuwait) is an increasingly important phenomenon. Urbanization causes and accelerates a whole suite of environmental problems (ASG).

few centuries; for the modern era, especially since the late seventeenth century, has witnessed the transformation of, or revolution in, culture and technology – the development of major industries. This, like domestication, has reduced the space required to sustain each individual and has increased the intensity with which resources are utilized.

Modern science and modern medicine have compounded these effects, leading to accelerating population increase even in non-industrial societies. Urbanization has gone on apace (Figure 1.16), and it is now recognized that large cities have their own environmental problems (Cooke et al., 1982) and environmental effects (Douglas, 1983). Cities can be conceived of as landforms, with special landforming processes, including concrete speleothem formation and sinkhole collapse (Dixon et al., 2017). Urban ecology, a transdisciplinary enterprise that integrates ecological, geographical, planning, and social sciences (Wu, 2014) has become a major research area (Douglas and James, 2014). Urban areas are hubs for people, infrastructure, and commerce, requiring extensive resources and putting intense pressure on the environment. They account for about 60% of all residential water use, 75% of energy use, 80% of the wood used for industrial purposes, and 80% of human greenhouse gas emissions. As Haase et al. (2014: 414) remark, 'Understanding how urban ecosystems work, how they change, and what limits their performance can add to the understanding of ecosystem change and governance in an ever more human-dominated world'. As Table 1.7 shows, the world now has some enormous urban agglomerations. By 2015 there were over 500 urban areas with a population greater than 1 million, and 12 with a population over 20 million. The urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960 (http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/, accessed December 2017).

Cities, in turn, have large ecological footprints. They suck in resources and materials and export vast amounts of waste, so that it is now possible to use such terms as 'urban hydrology', 'urban ecology', and 'urban geomorphology' (Gurnell et al., 2007). In China, new urban areas are being created by removing mountaintops, as is the case with New Lanzhou City. Cities have their own range of internal environmental impacts and characteristics, and these are referred to elsewhere in this book (Table 1.8) and some of their wildlife impacts are discussed by Goddard et al. (2010) and Aronson et al. (2014).

Another major development was the perfecting of sea-going ships in the sixteenth and seventeenth centuries. This was part of our industrial and economic transformation, and was the time when mainly self-contained but developing regions of the world coalesced so that the ecumene became to all intents and purposes

Table 1.7 World's urban agglomerations of ten million or more inhabitants in 2016.

Agglomeration	Country	Population
1 Guangzhou	China	47,700,000
2 Tokyo	Japan	39,500,000
3 Shanghai	China	30,900,000
4 Jakarta	Indonesia	28,100,000
5 Delhi	India	26,400,000
6 Seoul	South Korea	24,400,000
7 Karachi	Pakistan	24,300,000
8 Manila	Philippines	23,300,000
9 Mumbai	India	23,200,000
10 Mexico City	Mexico	22,100,000
11 New York	United States	22,000,000
12 São Paulo	Brazil	21,800,000
13 Beijing	China	21,100,000
14 Osaka	Japan	17,800,000
15 Dhaka	Bangladesh	17,600,000
15 Los Angeles	United States	17,600,000
17 Lagos	Nigeria	17,100,000
18 Krung Thep	Thailand	16,900,000
18 Moskva	Russia	16,900,000
20 Al-Qāhirah (Cairo)	Egypt	16,800,000
21 Kolkata	India	16,000,000
21 Buenos Aires	Argentina	15,800,000
23 London	United Kingdom	14,400,000
24 Istanbul	Turkey	14,300,000
25 Tehran	Iran	13,700,000
26 Johannesburg	South Africa	13,400,000
27 Rio de Janeiro	Brazil	12,700,000
28 Paris	France	12,400,000
29 Tianjin	China	11,400,000
30 Kinshasa	Democratic Republic of the Congo	10,600,000
31 Bengaluru	India	10,576,167
32 Chennai	India	10,400,000
33 Nagoya	Japan	10,300,000
34 Lahore	Pakistan	10,200,000
35 Xiamen	China	10,000,000

continuous. The invention of the steam engine in the late eighteenth century, and the internal combustion engine in the late nineteenth century, massively increased human access to energy and lessened dependence on animals, wind, and water. The number

Table 1.8 Urban environments.

Phenomenon	Discussion in this book (section)
Accelerated salinization	4.3
Areas of land reclamation and offshore islands	6.3
Biodiversity	3.3
Channelisation and burying of streams	6.8
Ground levelling for airports, etc.	6.2
Ground subsidence caused by fluid extraction	6.4
Groundwater augmentation and extraction	5.5
Increased sediment loads during construction	4.26
Landslides produced by building on slopes	6.12
Pits produced by excavation of building materials	6.2
Pollution of air	2.19 and 7.14
Pollution of soil (e.g. by heavy metals)	4.18
Pollution of water	5.6
Runoff generation and floods from storm drains,	
sewers & impermeable surfaces	5.3.6
Soil transformation (compaction, addition of rubble,	
loss of organics, etc.)	4.14
Sulphation and other forms of weathering	6.12
Urban animals	3.3
Urban heat island effect	7.11
Waste dumps and landfill	6.3

of tractors in the world as a whole increased from 0.3 million in 1920 to over 26 million in 2000 (McNeill, 2000: table 7.2). The invention of the gasoline-powered chainsaw, especially after 1950, was another important development. This cutting-edge technology allowed humans to fell trees 100 or 1000 times faster than with axes (McNeill, 2000: 307).

1.8 The Great Acceleration

The twentieth century was a time of extraordinary change (McNeill and Engelke, 2016). The human population soared from 1.5 to 6 billion, the world's economy increased fifteenfold, the world's energy use thirteen to fourteenfold, freshwater use ninefold, and the irrigated area fivefold. In the hundred centuries from the dawn of agriculture to 1900, McNeill (2003) calculated that humanity only used about two-thirds as much energy (most of it from biomass) that it used it the twentieth century. Indeed, he argued that humankind used more energy in the twentieth century than in all preceding human history put together. In addition he suggests that the seas surrendered more fish in the twentieth century than in all previous centuries, and that the forest and woodland area shrank by about 20%, accounting for perhaps half the net deforestation in world history. This is also a topic that has been discussed by Waters et al. (2016), who draw attention to the rapid development in the use of artificial materials. For example, the manufacture of new organic polymers (plastics), which were initially developed in the early years of the twentieth century, rapidly grew from the 1950s to an annual production of around 380 Tg by 2015 (Geyer et al., 2017). Likewise, concrete, which the Romans invented, has become the primary building material since the Second World War. The period from 1995 to 2015 accounts for more than half of the 500,000 Tg of concrete ever produced, and may be equivalent to around 1 kg m^{-2}.

One measure of the extent of the human impact is the human appropriation of net primary production (HANPP) as a percentage of the total amount of net primary productivity (NPP) generated on land. There is a considerable range of estimates of HANPP as a percentage of NPP, but Imhoff et al. (2004) give a global figure of around 20%, but also point to great differences between the continents, with values ranging from c. 6.1% for Latin America to 80.4% for south-central Asia. Humans have appropriated a large amount of the world's biomass for their own use and Smil (2011) has estimated that through harvesting, deforestation, and conversion of grasslands and wetlands, humans have reduced the stock of global terrestrial plant mass by as much as 45% in the last 2000 years, with a third of this being achieved in the twentieth century.

To conclude, we can recognize certain trends in human manipulation of the environment which have taken place in the modern era. The first of these is that the ways in which humans are affecting the environment are proliferating, so that we now live on what some people have argued is a human-dominated planet (Vitousek et al., 1997). For example, nearly all the powerful pesticides post-date the Second World War, and the same applies to the construction of nuclear reactors. Secondly, environmental issues that were once locally confined have become regional or even global problems. An instance of this is the way in which substances such as DDT, lead, and sulphates are found at the poles, far removed from the industrial societies that produced them. This is one aspect of increasing globalization. Thirdly, the complexity, magnitude, and frequency of impacts are probably increasing; for instance, a massive modern dam like that at Aswan in Egypt (opened in 1970) or the Three Gorges Dam in China (opened in 2003) has very different impacts from a small Roman one. Finally, compounding the effects of rapidly expanding populations is a general increase in per capita consumption and environmental impact (Myers and Kent, 2003) (Table 1.9). Energy resources are being developed at an ever-increasing rate, giving humans enormous power to transform the environment, not least in China (see Section 13.4). Increasing amounts of energy are also being harvested from hydropower schemes, which require the construction of major dams (Zarfl et al., 2015), the consequences of which for river flow and sediment trapping are very major. At least 3700 dams, each with a capacity of more than 1 megawatts, are currently either planned or under construction, primarily in countries with emerging economies. Particular concern has been expressed about the potential impacts of rampant dam construction across the Amazon basin, especially on its floodplains and the oceanic waters into which it flows (Latrubesse et al., 2017).

Table 1.9a Some indicators of change in the global economy from 1950–2015.

World indicator	1950	2005	Change(xn)	2015	Change (xn)
Grain production (million tonnes)	631	2008	3.18	2473	3.92
Meat production (million tonnes)	44	264	6.0	259	5.88
Coal consumption (million tonnes of oil equivalent)	1074	2597	2.42	3839	3.57
Oil consumption (million tonnes)	470	3861	8.21	4331	9.21
Natural gas consumption (million tonnes of oil equivalent)	171	2512	14.69		–
Car production (million)	8.0	46	5.75	91	11.38
Bike production (million)	11	124	11.27		–
Human population (million)	2555	6469	2.53	7349	2.88

Table 1.9b Scale of changes between 1890s and 1990s (modified and updated from McNeill, 2005: tables 1 and 2).

Indicator	Increase (x)
Freshwater use	9
Marine fish catch	35
Cropland	2
Irrigated area	5
Pasture area	1.8
Carbon dioxide emissions	17
Sulphur dioxide emissions	13
Lead emissions	8
Cattle population	4
Goat population	5
Pig population	9
World industrial output	40
World energy use	13
Coal production	7
Urban population	13
World economy	14

Figure 1.17a shows worldwide energy consumption since 1860 on a per capita basis, while Figures 1.17b and c show energy consumption since 1965 in terms of sources and regions. It is important to recognize, however, that there are huge differences in the likely environmental impacts of different economies in different parts of the world. The environmental impact, as measured by the so-called ecological footprint, is twelve times greater, for example, for the average American than for the average Indian (Wackernagel and Rees, 1995). On a global basis, our ecological footprint, according to the 2010 WWF *Living Planet Report*, doubled between 1961 and 2007.

Modern technologies have immense power output. A pioneer steam engine in AD 1800 might rate at 8–16 kilowatts. Modern railway diesels top 3.5 megawatts, and a large aero engine 70 megawatts. Figure 1.18 shows how the human impact on six 'component indicators of the biosphere' has increased over time. This graph is based on work by Kates et al. (1990). Each component indicator was taken to be 0% for 10,000 BP) and 100% for 1985. They then estimated the dates by which each component had reached successive quartiles (that is, 25, 50, and 75%) of its total change at 1985. They believe that about half of the components have changed more in the single generation since 1950 than in the whole of human history before that date. McNeill (2000) provides an exceptionally fine picture of all the changes in the environment that humans achieved in the twentieth century, while Steffen et al.

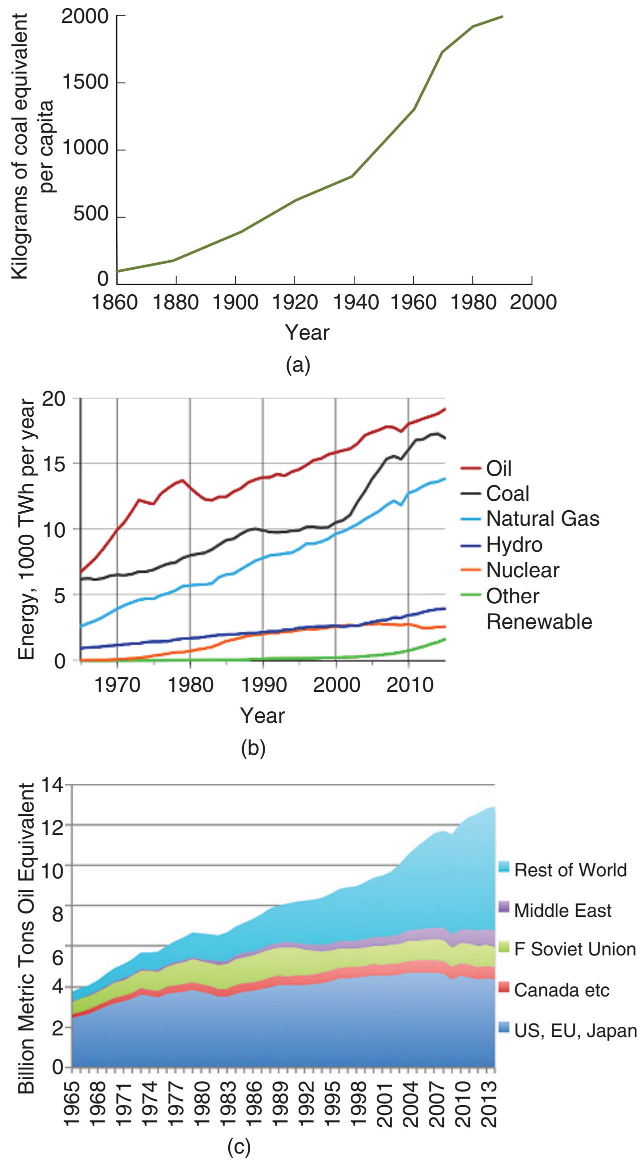

Figure 1.17 (a) World energy consumption since 1860, based on data from the United Nations. (b) World energy consumption since 1965 showing the role of different sources. (c) World energy consumption by part of world, based on data from BP Statistical Review of World Energy, 2015. *Source:* https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf (accessed January 2018).

(2015) show the trends of various socio-economic and environmental indicators from 1750 onwards, illustrating the dramatic changes during what supporters of the Anthropocene concept call the 'Great Acceleration'.

Humans now play a very substantial role in major biogeochemical cycling, including the nitrogen cycle. For example, human activities now convert more N_2 from the atmosphere into reactive forms than all of the Earth's

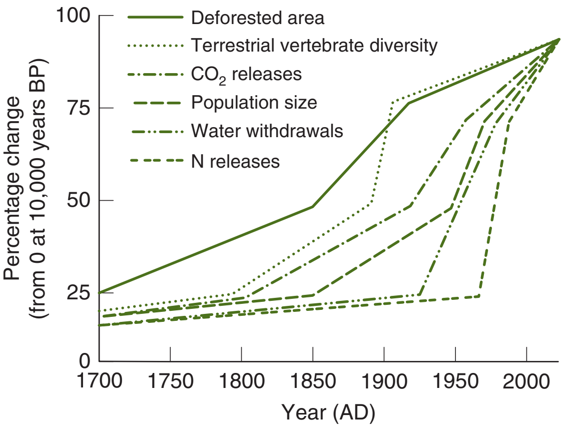

Figure 1.18 Percentage change (from assumed zero human impact at 10,000 BP) of selected human impacts on the environment.

Table 1.10 Types of global environmental change.

Type	Characteristic	Examples
Systemic	Direct impact on globally functioning system	(a) Industrial and land use emissions of 'greenhouse' gases (b) Industrial and consumer emissions of ozone-depleting gases (c) Land cover changes in albedo
Cumulative	Impact through worldwide distribution of change	(a) Groundwater pollution and depletion (b) Species depletion/genetic alteration (biodiversity)
	Impact through magnitude of change (share of global resource)	(a) Deforestation (b) Industrial toxic pollutants (c) Soil depletion on prime agricultural lands

Source: from Turner et al. (1990: table 1). Reproduced with permission of Elsevier.

terrestrial processes combined (Galloway et al., 2008; Rockström et al., 2009). This is achieved through four processes: industrial fixation of N_2 to ammonia, agricultural fixation of N_2 via cultivation of leguminous crops, fossil-fuel combustion, and biomass burning. Much of this reactive N_2 eventually ends up in the environment, polluting waterways and coastal zones, and changing the species composition of grasslands (Stevens et al., 2015). Atmospheric deposition of N has been reported to have negative impacts on a range of European habitats, including acid grasslands and steppes. It has the potential to enrich the N content of soils, resulting in increased plant growth and hence competition for light. Reductions in biodiversity can result (Stevens et al., 2010; Zhang et al., 2014).

Above all, as a result of the escalating trajectory of environmental transformation it is now possible to talk about *global* environmental change. There are two components to this (Turner et al., 1990): systemic global change and cumulative global change. In the systemic meaning, 'global' refers to the spatial scale of operation and comprises such issues as global changes in climate brought about by atmospheric pollution. This is a topic discussed at length in Chapters 7–12. In the cumulative meaning, 'global' refers to the areal or substantive accumulation of localized change, and a change is seen to be 'global' if it occurs on a worldwide scale, or represents a significant fraction of the total environmental phenomenon or global resource. Both types of change are closely intertwined. For example, the burning of vegetation can lead to systemic change through such mechanisms as carbon dioxide release and albedo modification, and to cumulative change through its impact on soil and biotic diversity (Table 1.10). It is for this reason that we now talk of Earth System Science and recognize the complex interactions that take place at a multitude of scales on our planet (Steffen et al., 2004) (see also Section 13.3).

1.9 Methods of Study

A range of techniques has been employed in trying to establish the timing and the extent of the human impact on the environment and to try and disentangle human and natural drivers of change. These include analyzing evidence from cores from lakes (Mills et al., 2017), ice cores (Barbante et al., 2017) bogs and the like, which can give a long-term, often well-dated, high-resolution picture of environmental change which, when compared with data on potential drivers of change, can be used to identify the human roles (e.g. O'Hara et al., 1993). Among these analyses are those of pollen, which can be used to identify, *inter alia*, vegetation change and the introduction of domesticated crops (Rösch and Lechterbeck, 2016), those of diatoms (Smol and Stoermer, 2010) which can be used to infer changes in water pH and of acid rain, and those of ostracods (Jones et al., 2015), which are especially useful for investigating changes in lacustrine environments. Faecal remains, including spherulites, may mark the introduction of grazing by domestic stock (Henry et al., 2017). Palaeosols with a distinct human signature may also be utilized (e.g. Beach et al., 2015). Related to this is the presence of anthropogenic materials, such as artefacts, coal, fly ash, slag, human-generated isotopes, or pottery, in sedimentary sequences (e.g. Tang et al., 2015; Grimley et al., 2017). Also important has been the collection of historical and archival material (Trimble and Cooke, 1991; Trimble, 2008b), including old ground photographs of, for example, vegetation type (Brusca et al., 2013), glaciers, gullies, soil erosion, debris flows, and arroyos (Cerney, 2010; Webb et al., 2010; Frankl et al., 2011), and the use of sequential maps and remotely sensed images (e.g. Bakoariniaina et al., 2006). The study of sequences of air photographs has particular value (Micheletti et al., 2015). In recent years several technological developments have led to enhanced resolution and coverage of datasets on, for example, topography and its change over time, which allow an unprecedented insight into the changing face of the Earth and the human imprints upon it. Equally, long-term monitoring, when it exists, can indicate the timing and scale of landscape changes (Burt, 1994) and of phenomena such as water pollution, ozone depletion, and soil erosion. We have learnt much about the state of the biosphere from long-term censuses of, for example, common bird species. Numerical modelling is an increasingly important approach to understanding of systems behaviour and the prediction of possible future changes (e.g. Nearing et al., 2005), with, for example, GCMs (Global Circulation Models) being vital for creating future climatic scenarios. As discussed in Section 8.1, such models are not without limitations. In the area of hydrology, literally hundreds of studies have employed SWAT (Soil & Water Assessment Tool), which is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds (Douglas-Mankin et al., 2010).

Guide to Reading

Baker, A.R.H. (2003) *Geography and History, Bridging the Divide.* Cambridge: Cambridge University Press. Chapter 3 contains a valuable and perceptive discussion of environmental geographies and histories.

Barker, G. (2006) *The Agricultural Revolution in Prehistory: Why Did Foragers Become Farmers?* Cambridge: Cambridge University Press. An impressive assessment at a global scale of what drove foragers to become farmers near the transition to the Holocene.

Barker, G. and Goucher, C. (eds) (2015) *The Cambridge World History: Volume 2, A World with Agriculture, 12,000 BCE–500 CE*. Cambridge: Cambridge University Press. A major compilation on the history of agriculture, which includes discussions of domestication, pastoralism, etc.

Cuff, D.J. and Goudie, A.S. (eds) (2009) *The Oxford Companion to Global Change.* New York: Oxford University Press. A multi-author encyclopedia of global change.

Diamond, J. (1997) *Guns, Germs and Steel*. London: Chatto and Windus. A lively review of human history over the last 13,000 years.

Douglas, I. and James, P. (2014) *Urban Ecology: An Introduction*. London: Routledge. A wide-ranging discussion of the multiple impacts that urbanization has had.

Goudie, A.S. (ed.) (1997) *The Human Impact Reader: Readings and Case Studies*. Oxford: Blackwell. A collection of key papers on many of the themes discussed in this book.

Goudie, A.S. and Viles, H. (1997) *The Earth Transformed*. Oxford: Blackwell. An introductory treatment of the human impact, with many case studies.

Goudie, A.S. and Viles, H.A. (2016) *Geomorphology in the Anthropocene*. Cambridge: Cambridge University Press. A discussion of the Anthropocene concept and the ways in which the geomorphological environment has changed.

Govorushko, S.M. (2011) *Natural Processes and Human Impacts*. Heidelberg: Springer. A highly comprehensive and well-illustrated survey.

Meyer, W.B. (1996) *Human Impact on the Earth.* Cambridge: Cambridge University Press. A good point of entry to the literature that brims over with thought-provoking epigrams.

Middleton, N.J. (2013) *The Global Casino.* London: Routledge. The fifth edition of an outstanding introductory text by a geographer, which is well illustrated and clearly written.

Morris, I. (2010) *Why the West Rules – For Now*. London: Profile Books. A massive survey of the patterns of development since prehistory and how they have varied in the west and the east.

Oppenheimer, S. (2002) *Out of Eden: Peopling of the World.* London: Constable. A very accessible account of human development in prehistory.

Ponting, C. (2007) *A New Green History of the World*. London: Penguin. The second edition of an engaging and informative treatment of how humans have transformed the Earth through time.

Scarre, C. (ed.) (2005) *The Human Past: World History and The Development of Human Societies.* London: Thames & Hudson. A splendid account of current ideas about the evolution of humans and human societies.

Simmons, I.G. (1996) *Changing the Face of the Earth: Culture, Environment and History* (2nd edn).

Oxford: Blackwell. A characteristically amusing and perceptive review of many facets of the role of humans in transforming the Earth, from an essentially historical perspective.

Simmons, I.G. (1997) *Humanity and Environment: A Cultural Ecology.* Harlow: Longman. A broad account of some major themes relating to humans and the environment.

Steffen, W. and 10 others (2004) *Global Change and the Earth System.* Berlin: Springer. A multi-author, high-level, Earth System Science-based overview of environmental change at a global scale.

Turner, B.L. II (ed.) (1990) *The Earth as Transformed by Human Action.* Cambridge: Cambridge University Press. A great analysis of global and regional changes over the past 300 years.