1 INTRODUCTION

The development of ideas

To what extent have humans transformed their natural environment? This is a crucial question that intrigued the eighteenth century French natural historian, Count Buffon. He can be regarded as the first Western scientist to be concerned directly and intimately with the human impact on the natural environment (Glacken, 1963, 1967). He contrasted the appearance of inhabited and uninhabited lands: the anciently inhabited countries have few woods, lakes or marshes, but they have many heaths and scrub; their mountains are bare, and their soils are less fertile because they lack the organic matter which woods, felled in inhabited countries, supply, and the herbs are browsed. Buffon was also much interested in the **domestication** of plants and animals – one of the major transformations in nature brought about by human actions.

Studies of the torrents of the French and Austrian Alps, undertaken in the late eighteenth and early nineteenth centuries, deepened immeasurably the realization of human capacity to change the environment. Fabre and Surell studied the flooding, siltation, erosion and division of watercourses brought about by **deforestation** in the Alps. Similarly de Saussure showed that Alpine lakes had suffered a lowering of water levels in recent times because of deforestation. In Venezuela, 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, and the cultivation of indigo were among the causes of the gradual drying up of the basin.

Comparable observations were made by the French rural economist, Boussingault (1845). He returned to Lake Valencia some 25 years after von 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. (p. 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 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* (see e.g., Lyell, 1875), largely as a result of his experiences in the USA, where recent deforestation in Georgia and Alabama had produced numerous ravines of impressive size.

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'):

Man's necessities and enjoyments have been the cause of great changes in the animal creation, and his destructive propensity of still greater. Animals are intended for our use, and field-sports are advantageous by encouraging a daring and active spirit in young men; but the utter destruction of some races in order to protect those destined for his pleasure, is too selfish, and cruelty is unpardonable: but the ignorant are often cruel. 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**: 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 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 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 such as 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).

Marsh, however, was not totally pessimistic about the future role of humankind or entirely unimpressed by positive human achievements (1965: 43–4):

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 . . .

Reclus (1873), one of the most prominent French geographers of his generation, and an important influence in the USA, also 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). He warned rather darkly (p. 523) that 'in a spot where the country is disfigured, and where all the grace of poetry has disappeared from the landscape, imagination dies out, and the mind is impoverished; a spirit of routine and servility takes possession of the soul, and leads it on to torpor and death'. Reclus (1871) also displayed a concern with the relationship between forests, torrents and sedimentation.

In 1904 Friedrich coined the term 'Raubwirtschaft', which can be translated as economic plunder, robber economy or, more simply, devastation. This concept has been extremely influential but is open to criticism. 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 by Sauer (1938) and 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. 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 (Speth, 1977), 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 cultural landscape. The clearing of woodland (Darby, 1956; Williams, 1989, 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 past three 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 e.g., Manners and Mikesell, 1974; Wagner, 1974; Cooke and Reeves, 1976; Gregory and Walling, 1979; Simmons, 1979; Tivy and O'Hare, 1981; Turner et al., 1990; Bell and Walker, 1992; Middleton, 1995; Meyer, 1996; Mannion, 1997, 2002).

Concerns about the human impact have become central to many disciplines and to the public, particularly since the early 1970s, when a range of major developments in the literature and in legislation have taken place (Table 1.1). The concepts of **global change** or global environmental change have developed. These phrases are much used, but seldom rigorously defined. Wide use of the term global change seems to have emerged in the 1970s but in that period was used principally, although 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. The geocentric meaning of global change can be seen in the development of the International Geosphere–Biosphere Program: a Study of Global Change (IBGP). 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'.

Table 1.1 Some environmental milestones

1864	George Perkins Marsh, *Man and nature*
1892	John Muir founds Sierra Club in USA
1935	Establishment of Soil Conservation Service in USA
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
1971	Greenpeace established
1971	Ramsar Treaty on International Wetlands
1972	United Nations Environmental Program (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 (International Union for the Conservation of Nature and Natural Resources) World Conservation Strategy
1985	British Antarctic Survey finds ozone hole over Antarctic
1986	International Geosphere Biosphere Program (IGBP)
1986	Chernobyl nuclear disaster
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)
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 Program on Global Environmental Change
1997	Kyoto Protocol on greenhouse gas emissions
2001	Amsterdam Declaration
2002	Johannesburg Earth Summit

The term 'global environmental change' has in many senses come to be used synonymously with the more geocentric use of 'global change'. Its validity and wide currency were recognized when *Global environmental change* was established in 1990 as

> an international journal that addresses the human ecological and public policy dimensions of the environmental

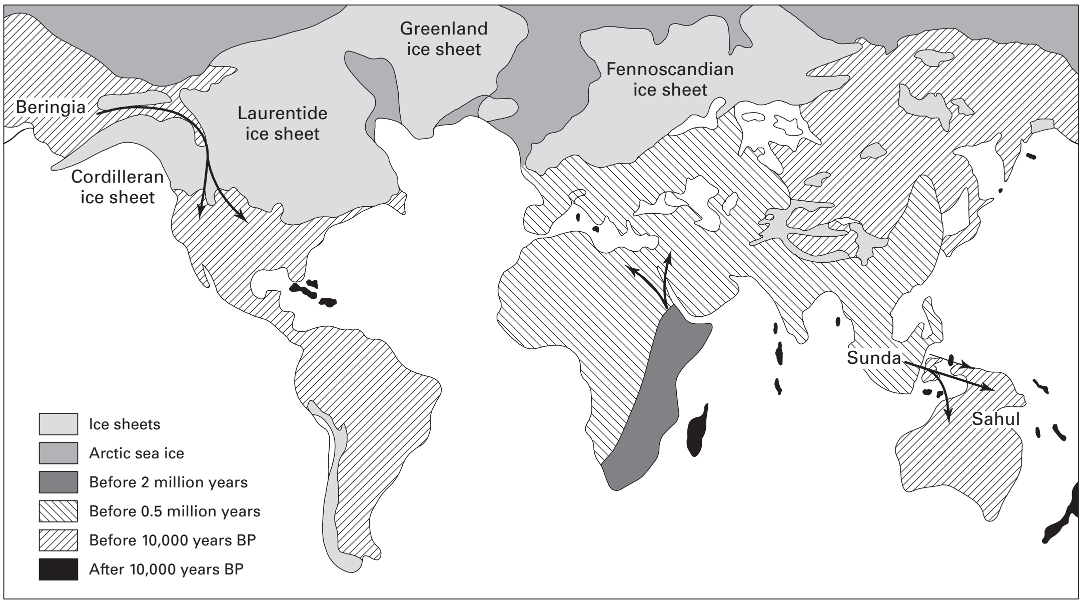

Figure 1.1 The human colonization of Ice Age Earth (after Roberts, 1989, figure 3.7).

processes which are threatening the sustainability of life of Earth. Topics include, but are not limited to, deforestation, desertification, soil degradation, species extinction, sea-level rise, acid precipitation, destruction of the ozone layer, atmospheric warming/cooling, nuclear winter, the emergence of new technological hazards, and the worsening effects of natural disasters.

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 Earth is a single system. Earth system science has emerged in response to this realization (see Steffen et al., 2004).

The huge increase in interest in the study of the human impact on the environment and of global change has not been without its 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. In this book, I take a long-term perspective and seek to show the changes that humankind has caused to a wide spectrum of environmental phenomena.

The development of human population and stages of cultural development

Some six or so million years ago, primitive human precursors or **hominids** appear in the fossil record (Wood, 2002). However, the first recognizable human, *Homo habilis*, evolved about 2.4 million years ago, more or less at the time that the ice ages were developing in mid-latitudes. The oldest remains have been found either in sediments from the Rift Valleys of East Africa, or in cave deposits in South Africa. Since that time the human population has spread over virtually the entire land surface of the planet (Oppenheimer, 2003) (Figure 1.1). *Homo* may have reached Asia by around two million years ago (Larick and Ciochan, 1996) and Europe not much later. In Britain the earliest fossil evidence, from Boxgrove, is from around half a million years ago. Modern humans, *Homo sapiens*, appeared in Africa around 160,000 years ago (Crow, 2002, Stringer, 2003; White et al., 2003).

Table 1.2 gives data on recent views of the dates for the arrival of humans in selected areas. Some of these dates are controversial, and this is especially true of Australia, where they range from *c.* 40,000 years to as much as 150,000 years (Kirkpatrick, 1994: 28–30). There

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	Champion et al. (1984)	c. 1,600,000 but most post-350,000
Britain	Roberts et al. (1995)	c. 500,000
Japan	Ikawa-Smith (1982)	c. 50,000
New Guinea	Bulmer (1982)	c. 50,000
Australia	Bowler et al. (2003)	c. 40,000–50,000
North America	Irving (1985)	15,000–40,000
South America	Guidon and Delibrias (1986)	32,000
Peru	Keefer et al. (1998)	12,500–12,700
Ireland	Edwards (1985)	9000
Caribbean	Morgan and Woods (1986)	4500
Polynesia	Kirch (1982)	2000
Madagascar	Battistini and Verin (1972)	c. AD 500
New Zealand	Green (1975)	AD 700–800

is also considerable uncertainty about the dates for humans arriving in the Americas. Many authorities have argued that the first colonizers of North America, equipped with so-called Clovis spears, arrived via the Bering landbridge from Asia around 12,000 years ago. However, some earlier dates exist for South America and these perhaps imply an earlier phase of colonization (Dillehay, 2003).

There are at least three interpretations of global population trends over the past two to three million years (Whitmore et al., 1990). The first, described as the 'arithmetic-exponential' view, sees the history of the global population as a two-stage phenomenon: the first stage is one of slow growth, while the second stage, related to the industrial revolution, displays a staggering acceleration in growth rates. The second view, described as 'logarithmic-logistic', sees the past million years or so in terms of three revolutions – the tool, agricultural and industrial revolutions. In this view, humans have increased the carrying capacity of Earth at least three times. There is also a third view, described as 'arithmetic-logistic', which sees the global population history over the past 12,000 years as a set of three cycles: the 'primary cycle', the 'medieval cycle' and the 'modernization cycle'; these three alternative models are presented graphically in Figure 1.2.

Estimates of population levels in the early stages of human development are difficult to make with any degree of certainty (Figure 1.3a). Before the agricultural 'revolution' some 10,000 years ago, human groups lived by hunting and gathering in parts of the world where this was possible. At that time the world population may have been of the order of five million people (Ehrlich et al., 1977: 182) and large areas would only recently have witnessed human migration. The Americas and Australia, for example, were probably virtually uninhabited until about 11,000 and 40,000 years ago respectively.

The agricultural revolution probably enabled an expansion of the total human population to about 200 million by the time of Christ, and 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 1000 million by AD 1850, 2000 million by AD 1930 and 4000 million by AD 1975. The figure had reached over 6000 million by the end of the millennium. Victory over malaria, smallpox, cholera and other diseases has been responsible for 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 sixfold between 1850 and 1950) 2.73%. The global annual growth in population over the past decade has been around 80 million people (Figure 1.3b).

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 collapsed, wars occurred, disease struck and **habitats** 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 consequences were legion.

Clearly, this growth of the human population of Earth is in itself likely to be a highly important cause of the transformation of nature. Of no lesser importance,

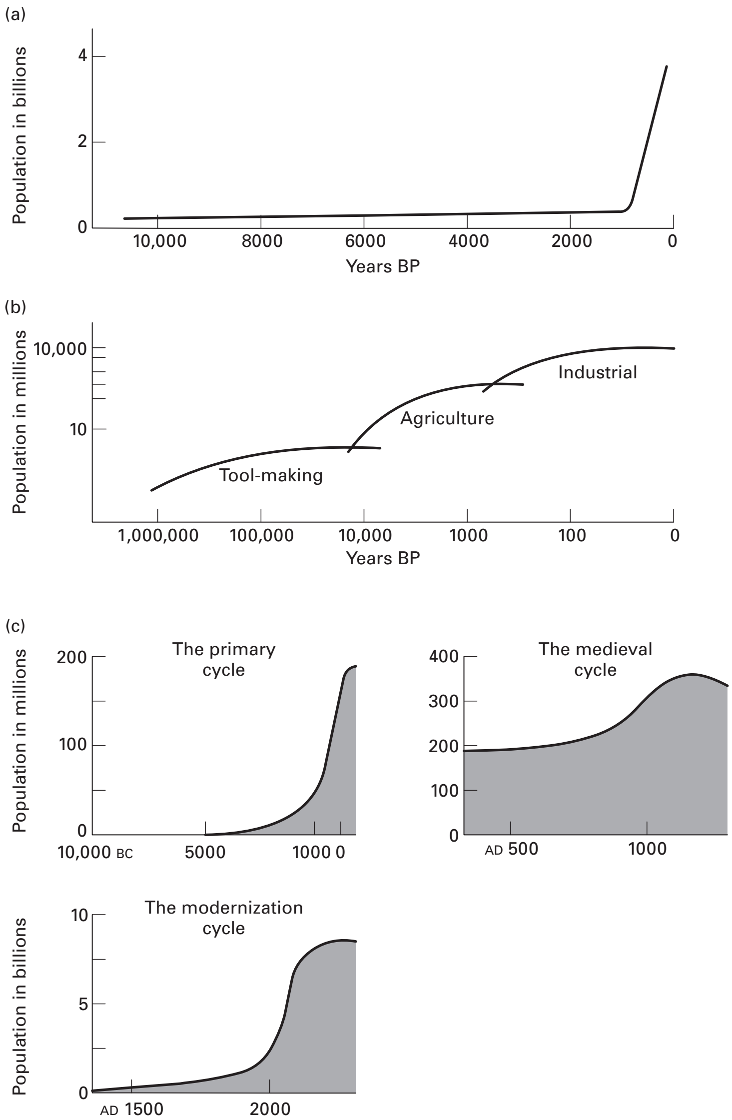

Figure 1.2 Three interpretations of global population trends over the millennia (billion = thousand million): (a) the arithmetic-exponential; (b) the logarithmic-logistic; (c) the arithmetic-logistic (after Whitmore et al., 1990, figure 2.1).

however, has been the growth and development of culture and technology. Sears (1957: 51) has put the power of humankind into the context of other species:

> Man's unique power to manipulate things and accumulate experience presently enabled him to break through the barriers of temperature, aridity, space, seas and mountains that have always restricted other species to specific habitats within a limited range. With the cultural devices of fire, clothing, shelter, and tools he was able to do what no other organism could do without changing its original character. Cultural change was, for the first time, substituted for biological evolution as a means of adapting an organism to new habitats in a widening range that eventually came to include the whole earth.

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).

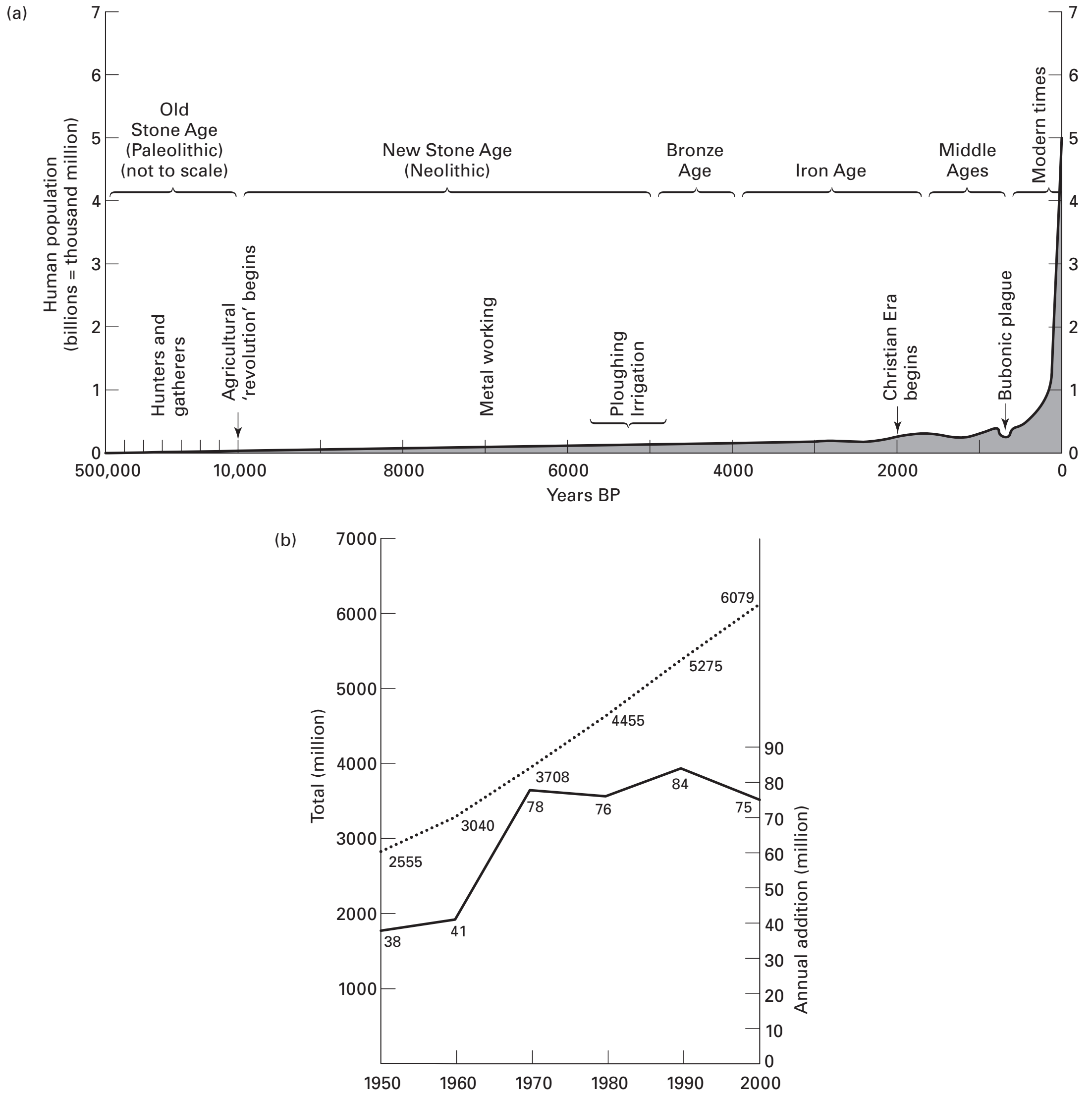

Figure 1.3 (a) The growth of human numbers for the past half million years (after Ehrlich et al., 1977, figure 5.2). (b) Annual growth of population since 1950.

The variables *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 (see e.g., Simon, 1981, 1996). 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 one 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. Three main phases will form the basis of this 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. These developments are treated in much greater depth by Ponting (1991) and Simmons (1996).

Hunting and gathering

The definition of 'human' is something of a problem, not least because, as is the case with all existing organisms, new forms tend to emerge by perceptible degrees from antecedent ones. Moreover, the fossil evidence is scarce, fragmentary and can rarely be dated with precision. Although it is probably justifiable to separate the hominids from the great apes on the basis of their assumption of an upright posture, it is much less justifiable or possible to distinguish on purely zoological grounds between those hominids that remained pre-human and those that attained human status. To qualify as a human, a hominid must demonstrate cultural development: the systematic manufacture of implements as an aid to manipulating the environment.

The oldest records of human activity and technology, pebble tools (crude stone tools which consist of a pebble with one end chipped into a rough cutting edge), have been found with human bone remains in various parts of Africa (Gosden, 2003). For example, at Lake Turkana in northern Kenya, and the Omo Valley in southern Ethiopia, a tool-bearing bed of volcanic material called tuff has been dated by isotopic means at about 2.6 million years old, another from Gona in the northeast of Ethiopia at about 2.5 million years old (Semaw et al., 1997), while another bed at the Olduvai Gorge in Tanzania has been dated by similar means at 1.75 million years. Indeed, these very early tools are generally termed 'Oldowan'.

As the Stone Age progressed the tools became more sophisticated, varied and effective. Greater exploitation of plant and animal resources became feasible. Stone may not, however, have been the only material used. Sticks and animal bones, the preservation of which is 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 Paleolithic Age, for ladders, fire, pigment (charcoal), the drying of wood and digging sticks. Tyldesley and Bahn (1983: 59) go so far as to suggest that 'The Palaeolithic might more accurately be termed the "Palaeoxylic" or "Old Wood Age".'

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

Another feature of early society that seems to have distinguished humans from the surviving non-human primates was their seemingly omnivorous diet. Biological materials recovered from settlements in many different parts of the world indicate that in the Paleolithic Age humans secured a wide range of animal meats, whereas the great apes, although not averse to an occasional taste of animal food, are predominately vegetarian. One consequence of enlarging the range of their diet was that, in the long run, humans

Figure 1.4 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.

were able to explore a much wider range of environment (G. Clark, 1977: 19). 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, but they never designate or describe objects.

At an early stage humans discovered the use of fire (Figure 1.4). This, as we shall see (Chapter 2), is a major agent by which humans have influenced their environment. The date at which fire was first deliberately employed is a matter of ongoing controversy (Bogucki, 1999: 51–54; Caldararo, 2002). It may have been employed very early in East Africa, where Gowlett et al. (1981) have claimed to find evidence for deliberate manipulation of fire from over 1.4 million years ago. However, it is not until after around 400,000 years ago that evidence for the association between human and fire becomes compelling. Nonetheless, 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 goes 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 Chapter 3) 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 that had either died natural deaths or been killed by carnivores such as 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% have lived as hunters and gatherers, about 6% 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 1.5 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.

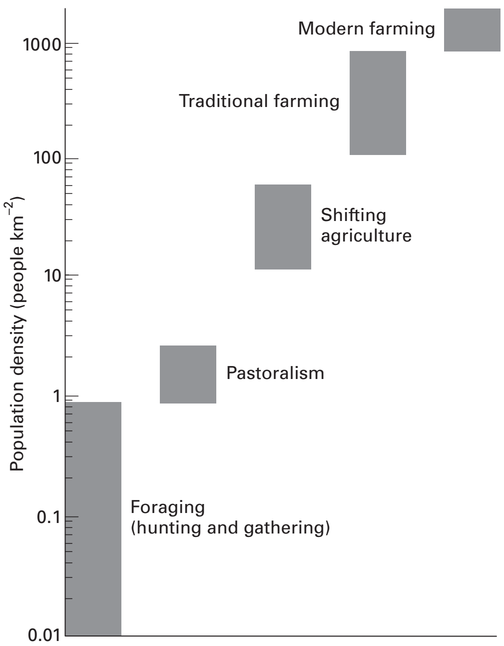

Figure 1.5 Comparison of carrying capacities of foraging, pastoralist, and agricultural societies.

Humans as cultivators, keepers, and metal workers

It is possible to identify some key stages of economic development that have taken place since the end of the Pleistocene (Table 1.3). First, around the beginning of the Holocene, about 10,000 years ago, humans started in various parts of the world 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 (1998). 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). As a consequence we see shortly thereafter, notably in the Middle East, the establishment of the first major settlements – towns. So long as man had

> to subsist on the game animals, birds and fish he could catch and trap, the insects and eggs he could collect and the foliage, roots, fruits and seeds he could gather, he was limited in the kind of social life he could develop; as a rule he could only live in small groups, which gave small scope for specialization and the subdivision of labour, and in the course of a year he would have to move over extensive tracts of country, shifting his habitation so that he could tap the natural resources of successive areas. It is hardly to be wondered at that among communities whose energies were almost entirely absorbed by the mere business of keeping alive, technology remained at a low ebb. (Clark, 1962: 76)

Although it is now recognized that some hunters and gathers had considerable leisure, 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 (1936) and others. Indeed, Isaac (1970) has termed domestication ‘the single most important intervention man had made in his environment’; and Harris (1996) has termed 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’.

A distinction can be drawn between cultivation and domestication. Whereas cultivation involves deliberate sowing or other management, and entails plants that 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. Domesticated plants are thus necessarily cultivated plants, but cultivated plants may or may not be domesticated. For example, the first plantations of *Hevea* rubber and quinine in the Far East were established from seed that had been collected from the wild in South America. Thus at this stage in their history these crops were cultivated but not yet domesticated.

The origin of agriculture remains controversial (Harris, 1996). 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 labor or milk until they were tamed – tamed perhaps for ritual sacrifice in connection with lunar goddess cults (the great curved horns being

Table 1.3 Five stages of economic development. Source: adapted from Simmons (1993: 2–3)

Economic stage	*Dates and characteristics*
Hunting–gathering and early agriculture	Domestication first fully established in southwestern 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 AD 1800 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.* AD 1800 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

the reason for the association). Another major theory was that domestication was produced by crowding, possibly brought on by a combination of climatic deterioration (alleged post-glacial progressive desiccation) and population growth. Such pressure may have forced communities to intensify their methods of food production. Current paleoclimatological 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), a geographer, believed that plant domestication was initiated in Southeast 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) who 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 center 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.

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 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). This might be construed to suggest that developments in one area triggered experiments with local plant materials in others. 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 1.6).

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

Center	*Dates (000 years BP)*	*Plant*
Mesoamerica	10.7–9.8	Squash-pumpkin
	9.0	Bottle gourd
Near East	10.0–9.3	Emmer wheat
		Two-rowed barley
	9.8–9.6	Einkorn wheat
		Pea
		Lentil
Far East	8.0–7.0	Broomcorn millet
		Rice
		Gourd
		Water chestnut
Andes	9.4–8.0	Chile pepper
		Common bean
		Ullucu
		White potato
		Squash and gourd

The locations and dates for domestication of some important domestic animals are shown in Figure 1.7.

The Near East, and in particular the Fertile Crescent, was especially important for both plant and animal domestication (Lev-Yadun et al., 2000; Zohary and Hopf, 2000), and wild progenitors were numerous in the area, including those of wheat, barley, lentils, peas, sheep, goats, cows, and pigs – a list that includes what are still the most valuable crops and livestock of the modern world (Diamond, 2002).

One highly important development in agriculture, because of its rapid and early effects on environment, was irrigation (Figure 1.8) and the adoption of riverine agriculture. This came rather later than domestication. 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 years ago (Butzer, 1976), although it is possible that irrigation in Iraq started even earlier.

A major difference has existed in the development of agriculture in the Old and New Worlds; in the New World there were few counterparts to the range of domesticated animals which were an integral part of Old World systems (Sherratt, 1981). A further critical difference was that in the Old World the secondary applications of domesticated animals were explored. The plow was particularly important in this process (Figure 1.9) – 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 fibers afforded, for the first time, a commodity that 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.

This secondary utilization of animals therefore had radical effects, and the change took place over quite a short period. The plow was invented some 5000 years ago, and was used in Mesopotamia, Assyria and Egypt. The remains of plow marks have also been found beneath a burial mound at South Street, Avebury in

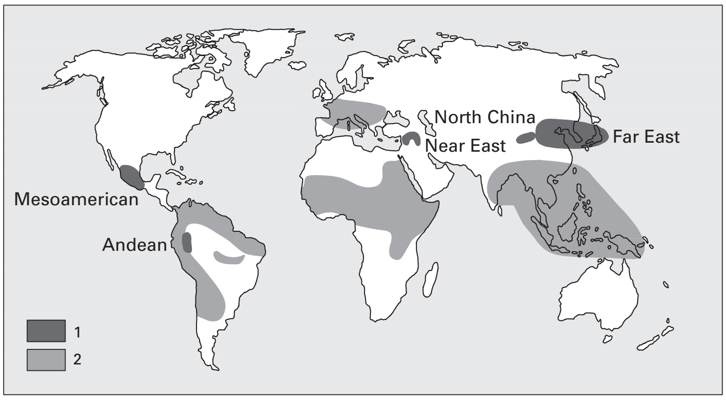

Figure 1.6 Major areas of domestication of plants identified by various workers. (1) The prime centers in which a number of plants were domesticated and which then diffused outwards into neighboring regions. (2) Broader regions in which plant domestication occurred widely and which may have received their first domesticated plants from the prime centers.

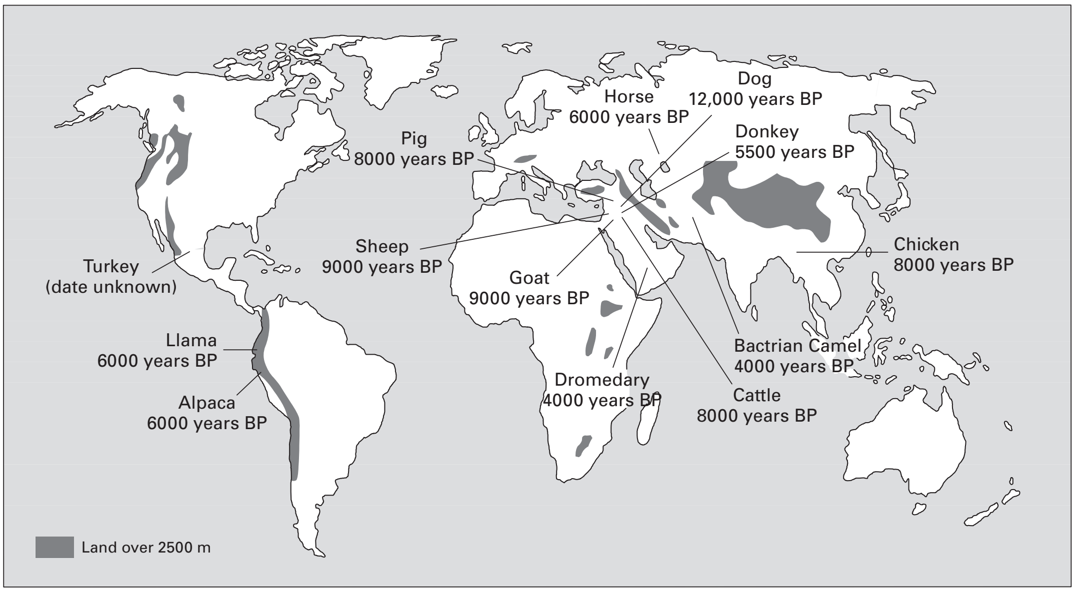

Figure 1.7 The places of origin, with approximate dates, for the most common domesticated animals.

Figure 1.8 Irrigation using animal power, as here in Rajasthan, India, is an example of the use of domesticated stock to change the environment.

England, dated at around 3000 BC, and ever since that time have been a dominant feature of the English landscape (Taylor, 1975). 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 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), while 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 (see Mannion, 1995). Pastoralists have had many major effects – for example, on soil erosion – though Passmore (1974: 12) believed that nomadic pastoralists are probably more conscious than agriculturists that they share the earth with other living things. Agriculturists, 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 plowing and seeding the grasslands, farmers have eliminated a hundred species of native prairie herbs and grasses, which they replace with pure

Figure 1.9 The development of plows provided humans with the ability to transform soils. This simple type is in Pakistan.

stands of wheat, corn or alfalfa. This simplification may reduce stability in the ecosystem (but see Chapter 13, section on 'The susceptibility to change'). Indeed, on a world basis (see Harlan, 1976) such simplification is evident. Whereas people once enjoyed a highly varied diet, and have used for food several thousand species of plants and several hundred species of animals, with domestication their sources are greatly reduced. 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. Simmonds (1976) provides an excellent account of the history of most of the major crops produced by human society.

Table 1.5 Estimated changes in the areas of the major land cover types between pre-agricultural times and the present*. Source: from J. T. Matthews (personal communication), in Meyer and Turner (1994). With permission of Cambridge University Press

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 kilometers.

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. Even in the past three hundred years the areas of cropland and pasture have increased by around five to sixfold (Goldewijk, 2001). It is possible (Ruddiman, 2003) that Holocene deforestation and land-cover change modified global climates by releasing carbon dioxide into the atmosphere.

One further development in human cultural and technological life that was to increase human power was the mining of ores and the smelting of metals. Neolithic cultures used native copper from the eighth millennium BC onwards, but evidence for its smelting occurs at Catal Hüyük in Turkey from the sixth millennium BC. The spread of metal working into other areas was rapid, particularly in the second half of the fifth millennium (Muhly, 1997) (Figure 1.10), 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 late third millennium BC. Metalworking required enormous amounts of wood and so led to deforestation.

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

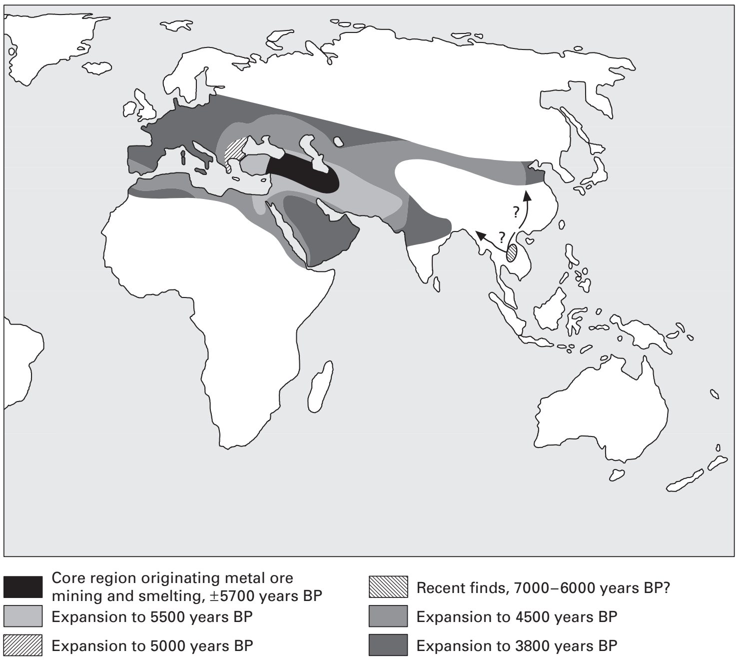

Figure 1.10 The diffusion of mining and smelting in the Old World (after Spencer and Thomas, 1978, figure 4.4).

Table 1.6 Environmental impacts of mineral extraction. Source: Young (1992, table 5)

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 sulfur 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 sulfur compounds) and metal contamination of lakes, streams, and groundwater
Smelting/refining	Air pollution (substances emitted can include sulfur 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)

amount of material moved by the mining industry globally is probably at least 28 billion tonnes – about 1.7 times the estimated amount of sediment carried each year by the world's rivers (Young, 1992). 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).

Modern industrial and urban civilizations

In ancient times, certain cities had 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, at its fall in 146 BC, had 700,000 (Thirgood, 1981). Such cities would have already exercised a considerable influence on their environs, but this influence was never as extensive as that of the past 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.

Figure 1.11 Urbanization (and, in particular, the growth of large conurbations such as Toronto in Canada) is an increasingly important phenomenon. Urbanization causes and accelerates a whole suite of environmental problems.

Table 1.7 World's urban agglomerations of ten million or more inhabitants, estimated 1999

City and country	*Includes*	*Population*
Tokyo, Japan	Yokohama, Kawasaki	34,200,000
New York, USA	Newark, Patterson	20,150,000
São Paulo, Brazil		19,750,000
Seoul, South Korea	Inchon, Songnam	19,350,000
Mexico City, Mexico	Nezahualcoyotl, Ecatepec de Morelos	18,000,000
Osaka, Japan	Kobe, Kyoto	17,700,000
Bombay (Mumbai), India	Kalyan, Thane, Ulhasnagar	17,200,000
Los Angeles, USA	Riverside, Anaheim	15,950,000
Cairo, Egypt	El Giza	13,950,000
Moscow, Russia		13,200,000
Buenos Aires, Argentina	San Justo, La Plata	13,100,000
Manila, Philippines	Quezon City, Caloocan	13,000,000
Calcutta (Kolkata), India	Haora	12,650,000
Lagos, Nigeria		12,450,000
Jakarta, Indonesia		12,100,000
Karachi, Pakistan		11,800,000
London, England		11,750,000
Shanghai, China		11,600,000
Rio de Janeiro, Brazil		11,450,000
Delhi, India		11,100,000
Tehran, Iran	Karaj	10,150,000
Paris, France		10,050,000

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 1.11), and it is now recognized that large cities have their own environmental problems (Cooke et al., 1982), and environmental effects (Douglas, 1983). As Table 1.7 shows, the world now has some enormous urban agglomerations. These, in turn, have large **ecological footprints**.

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

Modern science, technology, and industry have also been applied to agriculture, and in recent decades some spectacular progress has been made through, for example, the use of fertilizers and the selective breeding of plants and animals.

The twentieth century was a time of extraordinary change (McNeill, 2003). Human population increased from 1.5 to 6 billion, the world's economy increased fifteenfold, the world's energy use increased thirteen to fourteenfold, freshwater use increased ninefold, and the irrigated area by fivefold. In the hundred centuries from the dawn of agriculture to 1900, McNeill calculates that humanity only used about two-thirds as much energy (most of it from biomass) as it used in 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.

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

Table 1.8 Some indicators of change in the global economy from 1950–2000

World indicator	*1950*	*2000*	*Change* (× n)
Grain production (million tons)	631	1863	2.95
Meat production (million tons)	44	232	5.27
Coal consumption (million tons of oil equivalent)	1074	2217	2.06
Oil consumption (million tons)	470	3519	7.49
Natural gas consumption (million tons of oil equivalent)	171	2158	12.62
Car production (million)	8.0	41.1	5.14
Bike production (million)	11	104	9.45
Human population (million)	2555	6079	2.38

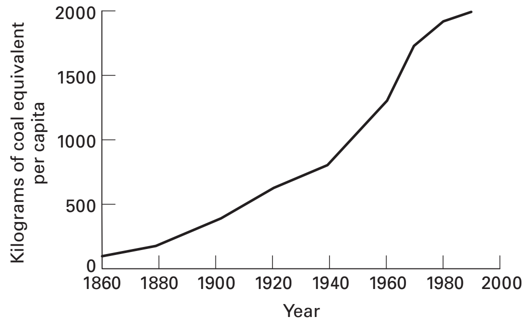

Figure 1.12 World per capita energy consumption since 1860, based on data from the United Nations.

(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. Second, 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 (dichlorodiphenyltrichloroethane), lead and sulfates are found at the poles, far removed from the industrial societies that produced them. This is one aspect of increasing globalization. Third, the complexity, magnitude, and frequency of impacts are probably increasing; for instance, massive modern dams such as at Aswan in Egypt and the Three Gorges Dam in China have 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 1.8). Energy resources are being developed at an ever increasing rate, giving humans enormous power to transform the environment. One index of this is world commercial energy consumption, which trebled in size between the 1950s and 1980. Figure 1.12 shows worldwide energy consumption since 1860 on a per capita basis. Nonetheless, it is important to recognize that there are huge differences in the likely environmental impacts of different economies in different parts of the world. As Table 1.9 indicates, 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).

Modern technologies have immense power output. A pioneer steam engine in AD 1800 might rate at 8–16 kW. Modern railway diesels top 3.5 MW, and a large aero engine 60 MW. Figure 1.13 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

Table 1.9 Comparing people's average consumption in Canada, USA, India, and the world. Source: Wackernagel and Rees (1995)

Consumption per person in 1991	*Canada*	*USA*	*India*	*World*
CO_2 emission (tonnes per year)	15.2	19.5	0.81	4.2
Purchasing power ($US)	19,320	22,130	1150	3800
Vehicles per 100 persons	46	57	0.2	10
Paper consumption (kg year^{-1})	247	317	2	44
Fossil energy use (GJ year^{-1})	250 (234)	287	5	56
Freshwater withdrawal (m^3 year^{-1})	1688	1868	612	644
Ecological footprint* (hectares per person)	4.3	5.1	0.4	1.8

*An ecological footprint is an accounting tool for ecological resources in which various categories of human consumption are translated into areas of productive land required to provide resources and assimilate waste products. It is thus a measure of how sustainable the lifestyles of different population groups are.

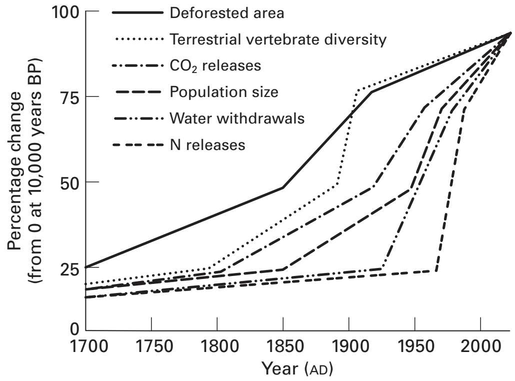

Figure 1.13 Percentage change (from assumed zero human impact at 10,000 years BP) of selected human impacts on the environment.

was taken to be 0% for 10,000 years ago (before the present = 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, and Carpenter (2001) examines the issue of whether civil engineering projects are environmentally sustainable.

Likewise, we can see stages in the pollution history of Earth. Mieck (1990), for instance, has identified a sequence of changes in the nature and causes of pollution: *pollution microbienne* or *pollution bacterielle*, caused by bacteria living and developing in decaying and putrefying materials and stagnant water associated with settlements of growing size; *pollution artisanale*, associated with small-scale craft industries such as tanneries, potteries, and other workshops carrying out various rather disagreeable tasks, including soap manufacture, bone burning, and glue-making; *pollution industrielle*, involving large-scale and pervasive pollution over major centers of industrial activity, particularly from the early nineteenth century in areas such as the Ruhr and the English 'Black Country'; *pollution fondamentale*, in which whole regions are affected by pollution, as with the desiccation and subsequent salination of the Aral Sea area; *pollution foncière*, in which vast quantities of chemicals are deliberately applied to the land as fertilizers and biocides; and finally, *pollution accidentale*, in which major accidents can cause pollution which is neither foreseen nor calculable (e.g., the Chernobyl nuclear disaster).

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 change, 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

Table 1.10 Types of global environmental change. Source: from Turner et al. (1990, table 1)

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

Earth system science and recognize the complex interactions that take place at a multitude of scales on our planet (Steffen et al., 2004).

We can conclude this introductory chapter by quoting from Kates et al. (1991: 1):

> Most of the change of the past 300 years has been at the hands of humankind, intentionally or otherwise. Our ever-growing role in this continuing metamorphosis has itself essentially changed. Transformation has escalated through time, and in some instances the scales of change have shifted from the locale and region to the earth as a whole. Whereas humankind once acted primarily upon the visible 'faces' or 'states' of the earth, such as forest cover, we are now also altering the fundamental flows of chemicals and energy that sustain life on the only inhabited planet we know.

Points for review

What have been the main stages in the development of ideas about the human impact on the environment?

How have human population levels changed over the past few millions of years?

To what extent did early humans change their environment?

What have been the main changes in the environment wrought by humans over the past 300 years?

What do you think is meant by the term Earth system science?

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.

Freedman, B., 1995, *Environmental ecology*, 2nd edn. San Diego: Academic Press. An enormously impressive and wide-ranging study with a strong ecological emphasis.

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. (ed.), 2002, *Encyclopedia of global change*. New York: Oxford University Press. A multi-author, two-volume compilation.

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

Kemp, D. D., 2004, *Exploring environmental issues: an integrated approach*. London: Routledge. A balanced, accessible, and comprehensive analysis of many environmental issues.

Mannion, A. M., 2002, *Dynamic world: land-cover and land-use change*. London: Hodder Arnold. A new and comprehensive study of the important role that land use plays in land transformation.

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., 2003, *The global casino*. London: Edward Arnold. The third edition of an introductory text, by a geographer, which is well illustrated and clearly written.

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

Pickering, K. T. and Owen, L. A., 1997, *Global environmental issues* (2nd edn.) London: Routledge. A well illustrated survey.

Ponting, C., 1991, *A green history of the world*. London: Penguin. An engaging and informative treatment of how humans have transformed Earth through time.

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 Earth, from an essentially historical perspective.

Simmons, I. G., 1997, *Humanity and environment: a cultural ecology*. A broad account of some major themes relating to humans and the environment.

State of the Environment Advisory Council, 1996, *Australia State of the Environment 1996*. Collingword, Australia: CSIRO Publishing. A large compendium which discusses major environmental issues in the context of Australia.

Steffen, W. and 10 others, 2004, *Global change and the Earth system*. Berlin: Springer-Verlag. 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 very good analysis of global and regional changes over the past 300 years.

13 CONCLUSION

The power of nonindustrial and pre-industrial civilizations

It has become apparent that Marsh was correct over a century ago to express his cogently argued views of the importance of human agency in environmental change. Since his time the impact that humans have had on the environment has increased, as has our awareness of this impact. There has been 'a screeching acceleration of so many processes that bring ecological change' (McNeill, 2000: 4). However, it is worth making the point here that, although much of the concern expressed about the undesirable effects humans have tends to focus on the role played by sophisticated industrial societies, this should not blind us to the fact that many highly significant environmental changes were and are being achieved by nonindustrial societies.

In recent years it has become apparent that fire, in particular, enabled early societies to alter vegetation substantially, so that plant assemblages that were once thought to be natural climatic climaxes may in reality be in part anthropogenic fire climaxes. This applies to many areas of both savanna and mid-latitude grassland (see p. 39). Such alteration of natural vegetation has been shown to re-date the arrival of European settlers in the Americas (Denevan, 1992), New Zealand, and elsewhere. The effects of fire may have been compounded by the use of the stone axe and by the grazing effects of domestic animals. In turn the removal and modification of vegetation would have led to adjustment in fauna. It is also apparent that soil erosion resulting from vegetation removal has a long history and that it was regarded as a threat by the classical authors.

Recent studies (see p. 50) tend to suggest that some of the major environmental changes in highland Britain and similar parts of western Europe that were once explained by climatic changes can be explained more effectively by the activities of Mesolithic and Neolithic peoples. This applies, for example, to the decline in the numbers of certain plants in the pollen record and to the development of peat bogs and podzolization (see p. 103). Even soil salinization started at an early date because of the adoption of irrigation practices in arid areas, and its effects on crop yields were noted in Iraq more than 4000 years ago (see p. 102). Similarly (see p. 84) there is an increasing body of evidence that the hunting practices of early civilization may have caused great changes in the world's megafauna as early as 11,000 years ago.

In spite of the increasing pace of world industrialization and urbanization, it is plowing and pastoralism which are responsible for many of our most serious environmental problems and which are still causing some of our most widespread changes in the landscape. Thus, soil erosion brought about by agriculture is, it can be argued, a more serious pollutant of the world's waters than is industry: many of the habitat changes which so affect wild animals are brought about through agricultural expansion (see p. 79); and soil salinization and desertification can be regarded as two of the most serious problems facing the human race. Land-use changes, such as the conversion of forests to fields, may be as effective in causing anthropogenic changes in climate as the more celebrated burning of fossil fuels and emission of industrial aerosols into the atmosphere. The liberation of CO_2 in the atmosphere through agricultural expansion, changes in surface albedo values, and the production of dust, are all major ways in which agriculture may modify world climates. Perhaps most remarkably of all, humans, who only represent roughly 0.5% of the total heterotroph biomass on Earth, appropriate for their use something around one-third of the total amount of net primary production on land (Imhoff et al., 2004).

The proliferation of impacts

A further point we can make is that, with developments in technology, the number of ways in which humans are affecting the environment is proliferating. It is these recent changes, because of the uncertainty which surrounds them and the limited amount of experience we have of their potential effects, which have caused greatest concern. Thus it is only since the Second World War, for example, that humans have had nuclear reactors for electricity generation, that they have used powerful pesticides such as DDT (dichlorodiphenyltrichloroethane), and that they have sent supersonic aircraft into the stratosphere. Likewise, it is only since around the turn of the century that the world's oil resources have been extensively exploited, that chemical fertilizers have become widely used, and that the internal combustion engine has revolutionized the scale and speed of transport and communications.

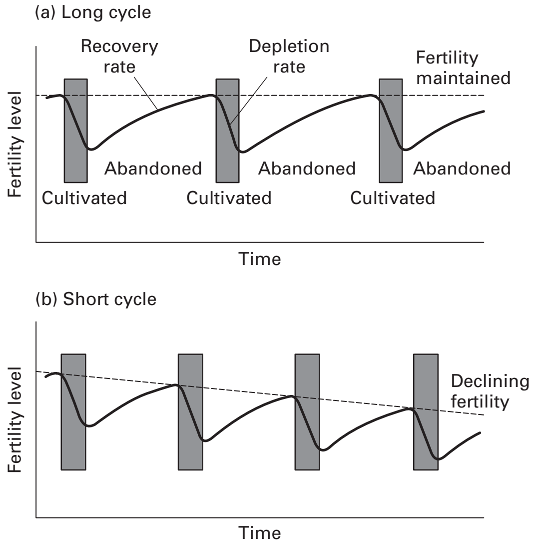

Figure 13.1 Land rotation and population density. The relationship of soil fertility cycles to cycles of slash-and-burn agriculture: (a) fertility levels are maintained under the long cycles characteristic of low-density populations; (b) fertility levels are declining under the shorter cycles characteristic of increasing population density. Notice that in both diagrams the curves of both depletion and recovery have the same slope (after Haggett, 1979, figure 8.4).

Above all, however, the complexity, frequency, and magnitude of impacts are increasing, partly because of steeply rising population levels and partly because of a general increase in *per capita* consumption. Thus some traditional methods of land use, such as shifting agriculture (see p. 36) and nomadism, which have been thought to sustain some sort of environmental equilibrium, seem to break down and to cause environmental deterioration when population pressures exceed a particular threshold. This is illustrated for shifting agriculture systems by Figure 13.1, which shows the relationship of soil fertility levels to cycles of slash-and-burn agriculture. Fertility can be maintained (Figure 13.1a) under the long cycles characteristic of low-density populations. However, as population levels increase, the cycles necessarily become shorter, and soil fertility levels are not maintained, thereby imposing greater stresses on the land (Figure 13.1b).

Figure 13.2 The impact of recreation pressures is well displayed at a prehistoric hill-fort, Badbury Rings, Dorset, England. Pedestrians and motorcyclists have caused severe erosion of the ramparts.

At the other end of the spectrum, increasing incomes, leisure, and ease of communication have generated a stronger demand for recreation and tourism in the developed nations (Figure 13.2). These have created additional environmental problems (see p. 62), especially in coastal and mountain areas. Some of the environmental consequences of recreation, which are reviewed at length by Liddle (1997), can be listed as follows:

1 desecration of cave formations by speleologists;
2 trampling by human feet leading to soil compaction;
3 nutrient additions at campsites by people and their pets;
4 decrease in soil temperatures because of snow compaction by snowmobiles;
5 footpath erosion and off-road vehicle erosion;
6 dune reactivation by trampling;
7 vegetation change due to trampling and collecting;
8 creating of new habitats by cutting trails and clearing campsites;
9 pollution of lakes and inland waterways by gasoline discharge from outboard motors and by human waste;
10 creation of game reserves and protection of ancient domestic breeds;
11 disturbance of wildlife by proximity of persons and by hunting, fishing, and shooting;
12 conservation of woodland for pheasant shooting.

Likewise, it is apparent when considering the range of possible impacts of one major type of industrial development that they are significant. As Table 13.1 indicates, the exploitation of an oilfield and all the activities that it involves (e.g., pipelines, new roads, refineries, drilling, etc.) have a wide range of likely effects on land, air, water, and organisms.

Conversely, if one takes one ecosystem type as an example – the coral reef – one can see the diversity of stresses to which it is now being exposed (Figure 13.3) as a result of a whole range of different human activities, which include global warming, increased sedimentation and pollution from river runoff, and overharvesting of fish and other organisms (Bellwood et al., 2004).

A very substantial amount of change has been achieved in recent decades. Table 13.2, based on the work of Kates et al. (1990), attempts to make quantitative comparisons of the human impact on ten 'component indicators of the biosphere'. For each component they defined total net change clearly induced by humans to be 0% for 10,000 years ago and 100% for 1985. They estimated dates by which each component had reached successive quartiles (i.e., 5, 50 and 75%) of its 1985 total change. 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.

Are changes reversible?

It is evident that while humans have imposed many undesirable and often unexpected changes on the environment, they often have the capacity to modify the rate of such changes or to reverse them. There are cases where this is not possible: once soil has been eroded from an area it cannot be restored; once a plant or animal has become extinct it cannot be brought back; and once a laterite iron pan has become established it is difficult to destroy.

However, through the work of George Perkins Marsh and others, people became aware that many of the changes that had been set in train needed to be reversed or reduced in degree. Sometimes this has simply involved discontinuing a practice which has proved undesirable (such as the cavalier use of DDT or CFCs), or replacing it with another which is less detrimental

Table 13.1 Qualitative environmental impacts of mineral industries with particular reference to an oilfield. Source: Denisova (1977: 650, table 2)

Facility	*Direction of the impact and reaction to the environment*			
	Land	*Air*	*Water*	*Biocenosis*
Well	Alienation of land surface Extraction of oil associated gas, groundwater Pollution by crude oil, refined products, drilling mud Disturbance of internal structure of soil and subsoil Destruction of soil	Pollution by associated gas and volatile hydrocarbons, products of combustion	Withdrawal of surface water and groundwater Pollution by crude oil and refined products, salination of freshwater Disturbance of water balance of both subsurface and surface waters	Pollution by crude oil and refined products Disturbance and destruction over a limited surface area
Pipeline	Alienation of land Accidental oil spills Disturbance of landforms and internal structure of soil and subsoil	Pollution by volatile hydrocarbons	Disturbance and destruction over limited surface area	
Motor roads	Alienation of land Pollution by oil products Disturbance of landforms and internal structure of soil and subsoil	Pollution by combustion products, volatile hydrocarbons, sulfur dioxide, nitrogen oxides	Pollution by combustion products Disturbances and destruction over limited surface area	
Collection point	Alienation of land Pollution by crude oil and refined products (spills) Disturbance of internal structure of soil and subsoil	Pollution by volatile hydrocarbons	Disturbance and destruction over limited surface area	

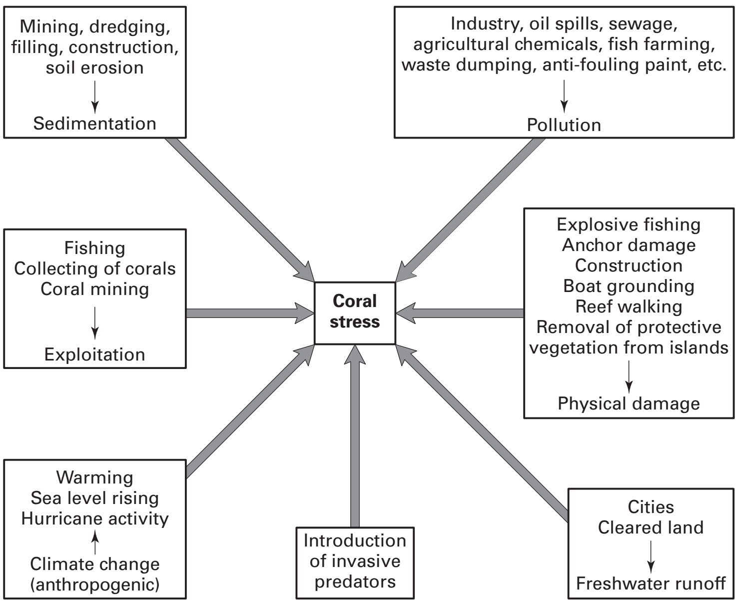

Figure 13.3 Some causes of anthropogenic stress on coral reef ecosystems.

Table 13.2 Chronologies of human-induced transformations. Source: from Kates et al. (1990, table 1.3).
(a) Quartiles of change from 10,000 BC to mid-1980s

Form of transformation	*Dates of quartiles*		
	25%	*50%*	*75%*
Deforested area	1700	1850	1915
Terrestrial vertebrate diversity	1790	1880	1910
Water withdrawals	1925	1955	1975
Population size	1850	1950	1970
Carbon releases	1815	1920	1960
Sulfur releases	1940	1960	1970
Phosphorus releases	1955	1975	1980
Nitrogen releases	1970	1975	1980
Lead releases	1920	1950	1965
Carbon tetrachloride production	1950	1960	1970

(b) Percentage change by time of Marsh and Princeton symposium

Form of transformation	*Percentage change*	
	1860	*1950*
Deforested area	50	90
Terrestrial vertebrate diversity	25–50	75–100
Water withdrawals	15	40
Population size	30	50
Carbon releases	30	65
Sulfur releases	5	40
Phosphorus releases	< 1	20
Nitrogen releases	< 1	5
Lead releases	5	50
Carbon tetrachloride production	0	25

in its effects. Often, however, specific measures have been taken which have involved deliberate decisions of management and conservation. Denson (1970), for example, outlines a sophisticated six-stage model for wildlife conservation:

1 immediate physical protection from humans and from changes in the environment;
2 educational efforts to awaken the public to the need for protection and to gain acceptance of protective measures;
3 life-history studies of the species to determine their habitat requirements and the causes of their population decline;
4 dispersion of the stock to prevent loss of the species by disease or by a chance event such as fire;
5 captive breeding of the species to assure higher survival of young, to aid research, and to reduce the chances of catastrophic loss;
6 habitat restoration or rehabilitation when this is necessary before introducing the species.

Many conservation measures have been successful, while others have created as many problems as they were intended to solve. This applies, for example, to certain schemes for the reduction of coast erosion. On balance, however, there has been notable progress in dealing with such problems as acid rain in Europe, and the depletion of stratospheric ozone. Many governments, though not all, have signed up to the Kyoto Protocol in an attempt to reduce greenhouse gas emissions.

The concern with preservation and conservation has been longstanding, with many important landmarks. Interest has grown dramatically in recent years. Lowe (1983) has identified four stages in the history of British nature conservation:

1 the natural history/humanitarian period	(1830–90)
2 the preservation period	(1870–1940)
3 the scientific period	(1910–70)
4 the popular/political period	(1960–present)

The first of these stages was rooted in a strong enthusiasm for natural history, and the crusade against cruelty to animals. Although many Victorian naturalists were avid collectors, numerous clubs were established to study nature and some of them sought to preserve species to make them available for observation. As we shall see, certain acts were introduced at this time to protect birds. During the preservationist period, there was the formation of a spate of societies devoted to preserving open land and its associated wildlife (e.g., the National Trust, 1894; and the Council for the Preservation of Rural England, 1926). There was a growing sense of vulnerability of wildlife and landscapes to urban and industrial expansion and geographers such as Vaughan Cornish (see Goudie, 1972b) campaigned for the creation of national parks and the preservation of scenery, made possible through the National Parks and Access to Countryside Act of

1949. From the First World War onwards ecological research developed, and there arose an increasing understanding of ecological relationships. Scientists pressed for the regulation of habitats and species, and the Nature Conservancy Council was established in 1949. In the 1960s and the years that followed popular interest in conservation and widespread media attention first developed. This was partly generated by pollution incidents (such as the wrecks of the *Torrey Canyon* and *Amoco Cadiz*), and a gathering sense of impending environmental doom, generated by such persuasive books as Rachel Carson's *Silent Spring.* Ecology became a political issue in various European nations, including the UK. In many countries major developments in land use, construction, and industrialization now have to be preceded by the production of an Environmental Impact Assessment, and the European Union has introduced measures such as the Water Framework Directive (2000) and the Landfill Directive to improve the ecological status of water resources.

Thus in some countries, and in connection with particular species, conservation and protection have had a long and sometimes successful impact. In Britain, for example, the Wild Birds Protection Act dates back to 1880, and the Sea Birds Protection Act even further to 1869. The various acts have been modified and augmented over the years to outlaw egg-collecting, pole-trapping, plumage importation, and the capture or possession of a range of species. The effectiveness of the different acts can be measured in real terms. Over the past 60 years no species have been lost as British breeding birds due to lack of protection – the only major loss has been the Kentish plover, which was in any case on the edge of its range. Perhaps more importantly, several species have successfully recolonized Britain, the most celebrated being the avocet and the osprey. Today both are firmly established, together with other species lost in the nineteenth century: the black-tailed godwit, the goshawk, and the bittern. Also as a result of protection the red kites of Wales have not only survived but also increased in number, and the peregrine falcon maintains its largest numbers in Europe outside Spain.

One further ground which gives some basis for hope that humans soon may be reconciled with the environment is that there are some signs of a widespread shift in public attitudes to nature and the environment. These changing social values, combined with scientific facts, influence political action. This point of view, which acts as an antidote for some of the more pessimistic views of the world's future, was elegantly presented by Ashby (1978). He contended that the rudiments of a healthy environmental ethic are developing, and explained (pp. 84–5)

> Its premise is that respect for nature is more moral than lack of respect for nature. Its logic is to put the Teesdale Sandwort . . . into the same category of value as a piece of Ming porcelain, the Yosemite Valley in the same category as Chartres Cathedral: a Suffolk landscape in the same category as a painting of the landscape by Constable. Its justification for preserving these and similar things is that they are unique, or irreplaceable, or simply part of the fabric of nature, just as Chartres and the painting by Constable are part of the fabric of civilisation; also that we do not understand how they have acquired their durability and what all the consequences would be if we destroy them.

Although there may be considerable controversy surrounding the precise criteria that can be used to select and manage sites that are particularly worthy of conservation (Goldsmith, 1983), there are nonetheless many motives behind the increasing desire to protect species and landscapes. These can be listed under the following general headings:

1 *The ethical.* It is asserted that wild species have a right to coexist with us on our planet, and that we have no right to exterminate them. Nature, it is maintained, is not simply there for humans to transform and modify as they please for their own utilitarian ends.
2 *The scientific*. We know very little about our surrounding environments, including, for example, the rich insect faunas of the tropical rain forest; therefore such environments should be preserved for future scientific study.
3 *The aesthetic.* Plants and animals, together with landscapes, may be beautiful and so enrich the life of humans.
4 *The need to maintain genetic diversity*. By protecting species we maintain the species diversity upon which future plant- and animal-breeding work will depend. Once genes have been lost (see Chapter 2, section on 'The change in genetic and species diversity') they cannot be replaced.

5 *Environmental stability*. It is argued that in general the more diverse an ecosystem is, the more checks and balances there are to maintain stability. Thus environments that have been greatly simplified by humans may be inherently unstable, and prone to disease, etc.
6 *Recreational*. Preserved habitats and landscapes have enormous recreational value, and in the case of some game reserves and natural parks may have economic value as well (e.g., the safari industry of East Africa).
7 *Economic*. Many of the species in the world are still little known, and there is the possibility that we have great storehouses of plants and animals, which, when knowledge improves, may become useful economic resources.
8 *Future generations*. One of the prime arguments for conservation, whether of beautiful countryside, rare species, soil, or mineral resources, is that future generations (and possibly ourselves later in life) will require them, and may think badly of a generation that has squandered them.
9 *Unintended impacts*. As we have seen so often in this book, profligate or unwise actions can lead to side-effects and consequences that may be disadvantageous to humans.
10 *Spiritual imperatives*. This includes a belief in the need for environmental stewardship.

Some of these arguments are more utilitarian than others (e.g., 4, 5, 6, 7 and 9), and some may be subject to doubt – it could, for example, be argued that future generations will have technology to use new resources and may not need some of those we regard as essential – but overall they provide a broadly based platform for the conservation ideal (Myers, 1979).

The susceptibility to change

Ecosystems respond in different ways to the human impact, and some are more vulnerable to human perturbation than others (Kasperson et al., 1995). It has often been thought, for example, that complex ecosystems are more stable than simple ones. Thus in Clements' Theory of Succession the tendency towards community stabilization was ascribed in part to an increasing level of integration of community functions. As Goodman (1975: 238) has expressed it:

> In general the predisposition to expect greater stability of complex systems was probably a combined legacy of eighteenth century theories of political economics, aesthetically and perhaps religiously motivated attraction to the belief that the wondrous variety of nature must have some purpose in an orderly work, and ageless folkwisdom regarding eggs and baskets.

Indeed, as Murdoch (1975) has pointed out, it makes good intuitive sense that a system with many links, or 'multiple fail-safes', is more stable than one with few links or feedback loops. As an example, if a type of herbivore is attacked by several predatory species, the loss of any one of these species will be less likely to allow the herbivore to erupt or explode in numbers than if only one predator species were present and that single predator type disappeared. The basic idea therefore is that diverse groups of species are more stable because complementary species compensate for one another if one species suffers severe declines (Doak and Marvier, 2003). A diverse ecosystem will have a variety of species that help to insure it against a range of environmental upsets (Naeem, 2002).

Various other arguments have been marshaled to support the idea that great diversity and complexity affords greater ability to minimize the magnitude, duration, and irreversibility of changes brought about by some external perturbation such as human activity (Noy-Meir, 1974). It has been stated that natural systems, which are generally more diverse than artificial systems such as crops or laboratory populations, are also more stable. Likewise, the tropical rain forest has been thought of as more diverse and more stable than less complex temperate communities, while simple Arctic ecosystems of oceanic islands have always appeared highly vulnerable to disturbance brought about by anthropogenic plant and animal introductions (see p. 54).

However, considerable doubt has been expressed as to whether the classic concept of the causal linkage between diversity/complexity and stability is entirely valid (see, e.g., Hurd et al., 1971). Murdoch (1975) indicated that there is not convincing field evidence that diverse natural communities are generally more stable than simple ones. He cited various papers which show that fluctuations of microtine rodents (lemmings, field voles, etc.) are as violent in relatively complex temperate zone ecosystems as they are in the less complex Arctic zone ecosystems. This was supported by Goodman (1975: 239) who wrote:

> As for the apparent stability of tropical biota, that could well be an illusion attributable to insufficient study of bewilderingly complex assemblages in which many species are so poorly represented in samples of feasible size that even considerable fluctuations might go undetected. Indeed, there are countervailing anecdotes regarding ecological instability in the tropics, such as recent reports on an insect virtually defoliating the wild Brazil-nut trees in Bolivia and of monkeys succumbing in large numbers to epidemics.

He went on to add: 'There is growing awareness of the surprising susceptibility of the rain forest ecosystems to man-made perturbation.' This is a point of view supported by May (1979) and discussed by Hill (1975). Hill pointed out that a very high species diversity is frequently associated with areas which have relatively constant physical environmental conditions over the course of a year and a series of years. The rain forest may be construed to be such an environment, and one where this constancy has allowed the presence of many specialized species, each pursuing a narrow range of activities. It has been argued that because of the high degree of specialization, the indigenous species have a limited ability to recover from major stresses caused by human intervention.

Goodman (1975) has also queried the sufficiency of the argument in its reference to the apparent instability of island ecosystems, suggesting that islands, being evolutionary backwaters and dead-ends, may accumulate species that are especially susceptible to competitive or exploitative displacement. In this case, lack of diversity may not necessarily be the sole or prime cause of instability.

The apparent instability of agricultural compared with natural communities is also often attributed to lack of diversity (see p. 62), and indeed modern agriculture does involve significant ecosystem simplification. However, such instability as there is may not, once again, necessarily result from simplification. Other factors could promote instability: agricultural communities are disrupted, even destroyed, more frequently and more massively as part of the cultivation process than those natural systems we tend to think of as stable; the component species of natural systems are co-evolved (co-adapted), and this is not usually true of agricultural communities. As Murdoch (1975: 799) suggests, it may be that:

> Natural systems are more stable than crop systems because their interacting species have had a long shared evolutionary history. In contrast with these natural communities the dominant plant species of a crop system is thrust into an often alien landscape . . . the crops have undergone radical selection in breeding programs, often losing their genetic defense mechanisms.

Thus the idea that complex natural ecosystems will be less susceptible to human interference and that simple artificial ecosystems will inevitably be unstable are not necessarily tenable. Nonetheless, it is apparent that there are differences in susceptibility between different ecosystem types, and these differences may result from factors other than the degree of diversity and complexity (Cairns and Dickson, 1977).

Some systems tend to be *vulnerable*. Lakes, for example, are natural traps and sinks and are thus more vulnerable to the effect of disadvantageous inputs than are rivers (which are continually receiving new inputs) or oceans (which are so much larger). Other systems display the property of *elasticity* – the ability to recover from damage. This may be because nearby epicenters exist to provide organisms to reinvade a damaged system. Small, isolated systems will often tend to possess low elasticity (see p. 88). Two of the most important properties, however, are *resilience* (being a measure of the number of times a system can recover after stress), and *inertia* (the ability to resist displacement of structural and functional characteristics).

Two systems which display resilience and inertia are deserts and estuaries. In both cases their indigenous organisms are highly accustomed to variable environmental conditions. Thus most desert fauna and flora evolved in an environment where the normal pattern is one of more or less random alternations of short favorable periods and long stress periods. They have pre-adapted resilience (Noy-Meir, 1974) so that they can tolerate extreme conditions, have the ability for rapid recovery, have various delay and trigger mechanisms (in the case of plants), and have flexible and opportunistic eating habits (in the case beasts). Estuaries, on the other hand, although the subject of increasing human pressures, also display some resilience. The vigor of their water circulation continuously and endogenously renews the supply of water, food, larvae, etc.; this aids recovery. Also, many species have biological characteristics that provide special advantages in estuarine survival. These characteristics usually protect the species against the natural violence of estuaries and are often helpful in resisting external forces such as humans.

The relationship between biodiversity and ecosystem stability continues to be a hot topic in ecology (Loreau et al., 2002; Kareiva and Levin, 2003). Some studies continue to throw doubt upon any simple relationship between biodiversity and stability (e.g., Pfisterer and Schmid, 2002), but there is perhaps an emerging consensus that diversity is crucial to ecosystem operation (McCann, 2000). As Loreau et al. (2001: 807) write,

> There is consensus that at least some minimum number of species is essential for ecosystem functioning under constant conditions and that a larger number of species is probably essential for maintaining the stability of ecosystem processes in changing environments.

Human influence or nature?

From many of the examples given in this book it is apparent that in many cases of environmental change it is impossible to state, without risk of contradiction, that people rather than nature are responsible. Most systems are complex and human agency is but one component of them, so that many human actions can lead to end-products that are intrinsically similar to those that may be produced by natural forces. How to distinguish between human-induced perturbations and ill-defined natural oscillations is a crucial question when considering issues such as coral reef degradation (Sapp, 1999). It is a case of equifinality, whereby different processes can lead to basically similar results. Humans are not always responsible for some of the changes with which they are credited. This book has given many examples of this problem and a selection is presented in Table 13.3. Deciphering the cause is often a ticklish problem, given the intricate interdependence of different components of ecosystems, the frequency and complexity of environmental changes, and the varying relaxation times that different ecosystem components may have when subject to a new impulse. This problem plainly does not apply to the

Table 13.3 Human influence or nature? Some examples, with page references to this book where applicable

Change	*Causes*		
	Natural	*Anthropogenic*	*Page reference*
Late Pleistocene animal extinction	Climate	Hunting	84
Death of savanna trees	Soil salinization through climatically induced groundwater rise	Overgrazing	–
Desertification of semi-arid areas	Climatic change	Overgrazing, etc.	42
Holocene peat-bog development in highland Britain	Climatic change and progressive soil deterioration	Deforestation and plowing	103
Holocene elm and linden decline	Climatic change	Feeding and stalling of animals	51
Tree encroachment into alpine pastures in USA	Temperature amelioration	Cessation of burning	–
Gully development	Climatic change	Land-use change	171
Late twentieth-century climatic warming	Changes in solar emission and volcanic activity	CO_2-generated greenhouse effect	196
Increasing coast recession	Rising sea level	Disruption of sediment supply	185
Increasing coastal flood risk	Rising sea level, natural subsidence	Pumping of aquifers creating subsidence	168
Increasing river flood intensity	Higher intensity rainfall	Creation of drainage ditches	134
Ground collapse	Karstic process	Dewatering by overpumping	157
Forest decline	Drought	Air, soil, and water pollution	59

same extent to changes that have been brought about deliberately and knowingly by humans, but it does apply to the many cases where humans may have initiated change inadvertently and unintentionally.

This fundamental difficulty means that environmental impact statements of any kind are extremely difficult to make. As we have seen, humans have been living on the earth and modifying it in different degrees for several millions of years, so that it is problematic to reconstruct any picture of the environment before human intervention. We seldom have any clear baseline against which to measure changes brought about by human society. Moreover, even without human interference, the environment would be in a perpetual state of flux on a great many different timescales. In addition, there are spatial and temporal discontinuities between cause and effect. For example, erosion in one locality may lead to deposition in another, while destruction of key elements of an animal's habitat may lead to population declines throughout its range. Likewise, in a time context, a considerable interval may elapse before the full implications of an activity are apparent. Also, because of the complex interaction between different components of different environmental systems and subsystems, it is almost impossible to measure total environmental impact. For example, changes in soil may lead to changes in vegetation, which in turn may trigger changes in water quality and in animal populations. Primary impacts give rise to a myriad of successive repercussions throughout ecosystems, which may be impracticable to trace and monitor. Quantitative cause-and-effect relationships can seldom be established.

Into the unknown

During the 1980s and 1990s the full significance of possible future environmental changes has become apparent, and national governments and international institutions have begun to ponder whether the world is entering a spasm of unparalleled humanly induced modification. For example, Steffen et al. (2004) have suggested that Earth is currently operating in a no-analogue state. They remark (p. 262):

> In terms of key environmental parameters, the Earth System has recently moved well outside the range of the natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented.

Likewise, the Amsterdam Declaration of 2001 pointed to the role of thresholds and surprises (see Steffen et al., 2004, p. 298):

> Global change cannot be understood in terms of a simple cause-effect paradigm. Human-driven changes cause multiple effects that cascade through the Earth System in complex ways. These effects interact with each other and with local- and regional-scale changes in multidimensional patterns that are difficult to understand and even more difficult to predict. Surprises abound.
>
> Earth System dynamics are characterized by critical thresholds and abrupt changes. Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants.

Our models and predictions are still highly inadequate, and there are great ranges in some of the values we give for such crucial changes as sea-level rise and global climatic warming, but the balance of scientific argument favors the view that change will occur and that change will be substantial. Some of the changes may be advantageous for humans or for particular ecosystems; others will be extremely disadvantageous.

It is clear that many environmental problems are interrelated and transboundary in scope so that integrated approaches and international cooperation are required. Environmental issues and environmental solutions have become globalized (Steffen et al., 2004, p. 290).

Some environments will change very substantially during the twenty-first century in response to a rise of land-use changes and climatic changes, with some predictions suggesting that the world's grasslands and Mediterranean biomes being particularly impacted (Sala et al., 2000). Marine ecosystems will also be impacted and Jenkins (2003: 1176) suggests that by 2050: 'If present trends . . . continue, the world's marine ecosystems in 2050 will look very different from today's, large species, and particularly top predators, will be by and large extremely scarce and some will have disappeared entirely . . .' Human populations will increase, and will probably be greater by 2 to 4 billion people by 2050 (Cohen, 2003).

But all change, if it is rapid and of a great magnitude, is likely to create uncertainties and instabilities. The study of future events will not only become a major concern for the environmental sciences but will also become a major concern for economists, sociologists, lawyers, and political scientists. George Perkins Marsh was a lawyer and politician, but it is only now, over a century since he wrote *Man and nature*, that the wisdom, perspicacity, and prescience of his ideas have begun to be given the praise and attention they deserve.

Points for review

Why has there been a 'screeching acceleration' in the twentieth century of so many processes that bring ecological change?

How may adverse environmental changes be reversed?

Why should one conserve nature?

In the context of ecosystems, what do you understand by such terms as 'stability', 'resilience', 'elasticity', and 'inertia'?

Why is it often difficult to disentangle natural and anthropogenic causes of environmental changes?

Guide to reading

Liddle, M., 1997, *Recreation ecology*. London: Chapman and Hall. An excellent review of the multiple ways in which recreation and tourism have an impact on the environment.

O'Riordan, T. (ed.), 1995, *Environmental science for environmental management*. Harlow: Longman Scientific. A multi-author guide to managing environmental change.

Roberts, N. (ed.), 1994, *The changing global environment*. Oxford: Blackwell. A good collection of case studies with a wide perspective.

Simon, J. L. (ed.), 1995, *The state of humanity*. Oxford: Blackwell. A multi-author work with an optimistic message.

Simon, J. L., 1996, *The ultimate resource 2*. Princeton: Princeton University Press. A view that the state of the world is improving.

Steffen, W. and 10 others, 2004, *Global change and the earth system*. Berlin: Springer. Chapter 6 of this multi-author volume addresses ways of global management for global sustainability.

Turner, B. L. (ed.), 1990, *The Earth as transformed by human action*. Cambridge: Cambridge University Press. A magnificent study of change in the past 300 years.