Chapter 1

The Living Planet

"Man is but earth 'Tis true', but earth is the centre."
John Donne, LXXX Sermons, 1640.

1.1. Life on Earth

Earth, the third planet from the sun, was formed some 4.6 billion years ago [1,2]. The first simple life forms appeared a billion years later and, despite suffering five major extinctions since then, the oceans and landmasses now teem with a huge diversity of animals and plants [3]. From space an obvious sign of life is the seasonal variation of photosynthesis that causes the colours of the continents to change with the great burst of growth of deciduous plants in springtime and the fall of leaves in autumn. A more sophisticated observer might see that the infrared radiation emitted by Earth shows gaps where absorptions by atmospheric water, methane, ozone and carbon dioxide occur as seen in Fig. 1.1 [4]. In contrast, the infrared radiation from Earth's apparently lifeless neighbours, Venus and Mars, the second and fourth planets from the sun, shows a large gap due to absorption by atmospheric carbon dioxide alone. Water is essential to all known forms of life and the presence of ozone indicates that oxygen, from which it is produced by solar radiation, is also present in Earth's atmosphere. Oxygen is produced by cyanobacteria, algae and green plants and is essential to the life of air breathing animals [5]. Conversely, methane is produced from dead animal and plant tissue by anaerobic bacteria that shun oxygen. Thus, the infrared absorptions due to water, ozone and methane may be viewed as the signature of life written large in Earth's atmosphere, a signature eagerly sought by those seeking life on other planets [6]. Meanwhile, humanity signals its presence with a barrage of microwave and radio transmissions and city lights sprinkled across the night side of Earth [7]. However, as population grows and demands for resources increase, a question mark hangs over humanity's tenancy of the planet on which some one hundred billion humans have so far lived [8]. Earth now faces a challenge to the resilience of its biological environment and habitability of a magnitude never before presented by a living species. It is the nature and possible consequences of this challenge that are explored in this book.

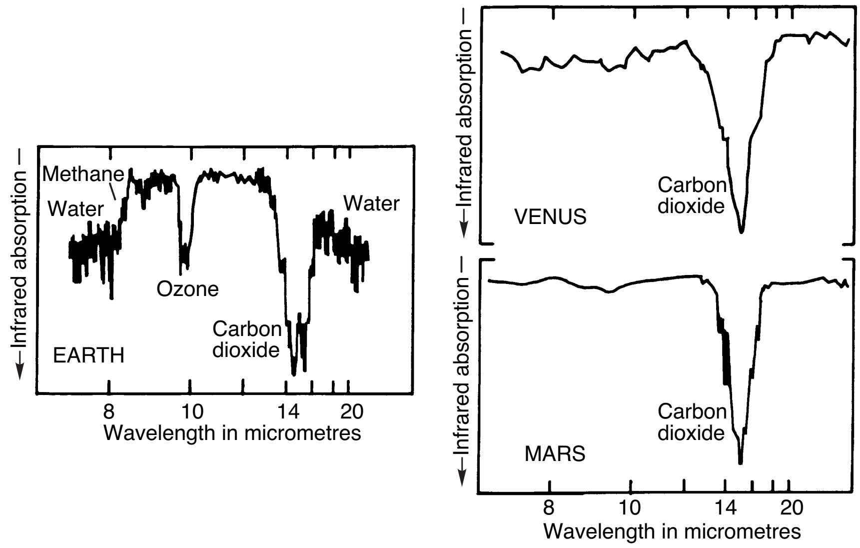

Fig. 1.1. The absorption of infrared radiation emitted by Earth, Venus and Mars by carbon dioxide in their atmospheres. The additional infrared absorptions by water, methane and ozone in Earth's atmosphere indicate the presence of life. Adapted from [4].

1.2. Life's Vicissitudes

A plethora of animal and plant species have appeared on Earth only to be either much diminished or to disappear altogether in five great extinctions [9]. Of all the species that have lived almost all have vanished. The Late Ordovician extinction saw the demise of eighty-five percent of all species 440 million years ago and was followed by the loss of eighty percent of species in the Late Devonian extinction 365 million years ago. The largest extinction, the Permian-Triassic, occurred 250 million years ago with the loss of ninety-six percent of species only to be followed by the loss of seventy-six percent of species 205 million years ago in the Late Triassic extinction. These great extinctions took place over tens of thousands to a million years. They appear to have been caused by asteroid impacts, volcanic eruptions and interrelated changes in climate, sea levels and atmospheric composition that occurred as the continents slowly drifted to their present positions.

The Cretaceous-Tertiary extinction occurred sixty-five million years ago with the loss of eighty percent of all living species including the dinosaurs [10]. This has been attributed to a large asteroid striking Earth at Chicxulub on the coast of the Yucatàn peninsula of Mexico. After the initial massive destruction caused by the impact which may have triggered major volcanic eruptions, the debris, smoke and dust that filled Earth's atmosphere greatly reduced the sunlight reaching the surface and caused a global cooling and reduction in photosynthesis. This was probably followed by a substantial global warming caused by the loading of the atmosphere with carbon dioxide and water from vaporization of carbonate rocks and ocean water caused by the heat of the impact. While these events would have made life very difficult, a 2004 study suggests that this asteroid impact occurred some 300,000 years before the Cretaceous-Tertiary extinction began and that a series of later asteroid impacts may have caused the extinction [11]. However, such is the tenacity of life that the demise of one set of species has invariably been accompanied by the rise of new species. Today, of all of Earth's estimated 100 million or so living species, ranging from single cell organisms to advanced plant and animals, only about 1.5 million have been described [12,13].

Of these multitudinous lifeforms, humans are now dominant and with the birth of Adnan Nevic in Sarajevo on 12 October 1999 the United Nations formally recognized that the human population had reached six billion [14]. This population has arisen from a few thousand African progenitors of some 200,000 years ago and thrives in the warm Holocene epoch that has lasted almost 12,000 years since the retreat of the great ice sheets of the last Ice Age [15]. So large is this population that there remains no part of Earth that has not been changed to some extent as a consequence [16,17]. However, the record of past extinctions holds a salutary message for humanity, a young species by comparison with other species that have inhabited Earth such as the dinosaurs that were dominant for 165 million years. Humans are at once the most intelligent, inventive and, both wittingly and unwittingly, destructive species that Earth has yet seen. It is this last characteristic that is responsible for a sixth great species extinction now underway [18,19]. This holds a great danger for it is possible that a combination of the destruction of complete ecosystems, or biomes, an imbalance in the biological diversity, or biodiversity, of species and a decline in the populations of individual species in the environment may become so great that humanity's future is jeopardized. This could arise through an overwhelming of biological recycling systems, a failure of food supply and the spread of disease. Fortunately, a growing awareness that humanity has become the custodian of the environment shows signs of leading to a more perceptive approach to the health of the planet.

1.3. A New Realization

The slow realization that humanity has a global stewardship role has an interesting history. Humans have always possessed a lively curiosity that was probably a major stimulus for their spread to all of the habitable continents during their nomadic phase. Once largely settled, they retained an urge to explore. Thus, in relatively recent times humans spread across the Pacific to settle the myriad islands of Melanesia, Micronesia, Oceania and Polynesia [20]. The Arabs and Chinese explored the southern oceans in pursuit of trade and the Europeans circumnavigated Earth and settled in lands far from their places of birth. Because of the slowness of their vessels a feeling of the vastness of the oceans and the planet was implanted in the minds of these seafarers and was passed on to humanity at large. However, this was to change slowly from the late nineteenth and early twentieth centuries with the advent of flight by balloon and aircraft that led to a shrinking perception of the size of the planet.

The next major step came with the launch of the first satellite, Sputnik 1, on 4 October 1957, that heralded the beginning of the space age and had millions watching the night sky to marvel at this small artificial moon regularly traversing its Earth orbit [21,22]. Shortly afterwards, on 3 November 1957, Sputnik 2 took the first of Earth's inhabitants, the dog Laika, into orbit. A few years later, on 12 April 1961, Yuri Gagarin in the spacecraft Vostok became the first man to orbit Earth during the Cold War driven space race between the Soviet Union and the United States [23]. The next immense step came with the Apollo 11 mission and the landing on the moon of the first man, Neil Armstrong, on 20 July 1969, who memorably said as he stepped onto the lunar surface: "One small step for (a) man, one giant leap for mankind" [24]. Remarkable as this achievement and subsequent lunar landings were technologically, it is probable that the pictures of Earth from the moon that they provided generated the greatest impact. For the first time all humanity could see Earth as a magnificent translucent blue planet on which are traced the outlines of continents, oceans, rivers and mountain ranges partially covered by clouds suspended in a surprisingly thin envelope of air. This now familiar picture of Earth against the blackness and immensity of space has reinforced a global awareness of the smallness of the planet and the fragility of its habitability.

This raises the question as to whether humanity is intelligent and capable enough to maintain Earth in a sufficiently healthy state to sustain the generations to come [25]. In seeking an answer to this question a wide range of issues is explored in this book. This chapter begins the exploration through a brief examination of the demands placed on Earth by humanity and the perceptions and understandings that were slowly reached in the twentieth century. The chapters that follow contain more detailed considerations of the pressures of population growth, the basic necessities of water and food, a remarkable new understanding of biology, the ever present possibility of disease, the seemingly insatiable demand for energy, and human induced global atmospheric changes and the consequent beginning of climate change.

1.4. Humanity's Footprint

As a walker on a sandy seashore leaves footprints to be washed away by the incoming tide, so humanity leaves ecological footprints on the environment, but so large have they become that nature's regenerative capacity is no longer able to wash them away. And yet for most of humanity these footprints are made unknowingly in seeking to satisfy everyday needs and aspirations. Few would relish being accused of despoiling Earth, yet this despoliation has accelerated with population growth and expectations of higher living standards. The point has now been reached were humanity's impact threatens to impose a decline in the quality of life and possibly to render some now habitable parts of Earth close to uninhabitable because of either land degradation or flooding or both.

Such a dismal prognosis is not new but, probably just in time, an increasing global awareness of the problem may restore a balance between humanity's demands and Earth's regenerative capacity. The nature of the problem is shown by a 1999 study of the ecological footprint of the people of the county of Malmöhus in southern Sweden that is a microcosm of the highly demanding developed world and is illustrated by Fig. 1.2 [26]. The size of this footprint was established by comparing the resources consumed and the waste produced by the people of Malmöhus with the ability of the county's environment to absorb these demands and to completely regenerate while reserving a minimum of twelve percent of the county's area to preserve the biodiversity of nature [27]. In other

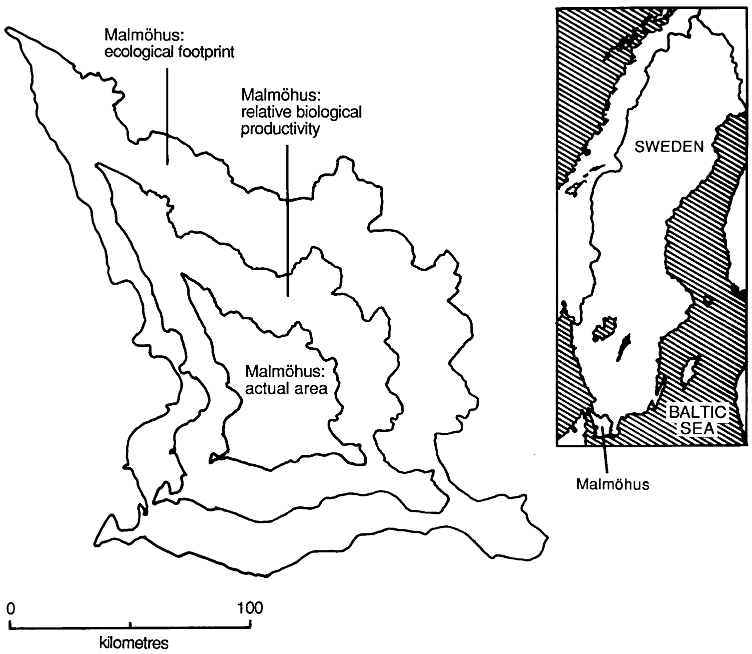

Fig. 1.2. The county of Malmöhus showing its actual area, its biologically productive area on the basis of average global productivity, and its ecological footprint in terms of the consumption and waste production of its population. Adapted from [26].

words, it is an assessment of the ability of Malmöhus to sustain the lifestyle of its people while retaining its animal and plant inhabitants in a healthy state. The footprint includes the consumption of energy, food, clothing and other requirements of the people of Malmöhus and the waste they produce. This waste is mainly carbon dioxide to be absorbed by the growth of permanent forests [28], and nitrates and phosphates from sewerage and agricultural fertilizer runoff to be filtered by wetlands and assimilated by plants and microorganisms that protect fresh water supplies and aquatic ecologies [29]. It also takes into account the balance between imported and exported consumables and the waste produced from them and so incorporates the use of land and ocean beyond Malmöhus' borders.

Malmöhus is fortunate as the 1.2 hectares of available productive land per person are so biologically productive that they are equivalent to 3.4 hectares of land of globally averaged productivity. When twelve percent of this is set aside for maintaining biodiversity, 3.0 hectares of land of globally averaged productivity are available to each person in Malmöhus. However, the Swedish ecological footprint is 7.2 hectares of land of globally averaged productivity so that land elsewhere has to make up the difference of 4.2 hectares for each person in Malmöhus. This difference represents the ecological deficit for Malmöhus as is illustrated in Fig. 1.2. Fortunately for Swedes, 8.2 hectares of land of globally averaged productivity per person are available in Sweden after subtracting twelve percent to preserve biological diversity. However, if every nation adopted the 1997 Swedish lifestyle the capacity of Earth would be exceeded threefold.

Ecological footprint calculations are almost certainly on the low side as accounting for the effect of every human activity on the environment is probably unachievable. Even so, such calculations invariably show the ecological footprints of most nations to be greatly overtaxing the environment's capacity to regenerate as is seen from the selection of nations in Fig. 1.3 [30]. Thus, in 1997 the average Canadian used 7.0 hectares of globally average productive land and 0.7 of a hectare of productive ocean to give a total of 7.7 hectares per person. This compared with an available biological capacity of 9.6 hectares per person to sustain the Canadian lifestyle. By the same calculation, an American required 10.3 hectares whereas there were only 6.7 hectares available per person in the United States that as a consequence had an ecological deficit of 3.6 hectares per person. In contrast, an Indian had a much smaller ecological footprint of 0.8 hectares per person and yet India could provide only 0.5 hectares for each of its people and had an ecological deficit of 0.3 hectares. This compared with an average footprint of 2.8 hectares per person for Earth's entire population in 1997, whereas only 2.0 hectares were available so that there was an ecological deficit of 0.8 hectares per person. Generally, the larger the ecological footprint per person the higher is the standard of living of the nation and its gross domestic product. Thus, Fig. 1.3 largely reflects the relative wealth of nations. Clearly, Earth is ecologically overstretched and as the developing nations seek to attain the living standards of the developed nations and population grows this overstretching will increase unless humanity becomes less demanding and far more efficient at using Earth's resources.

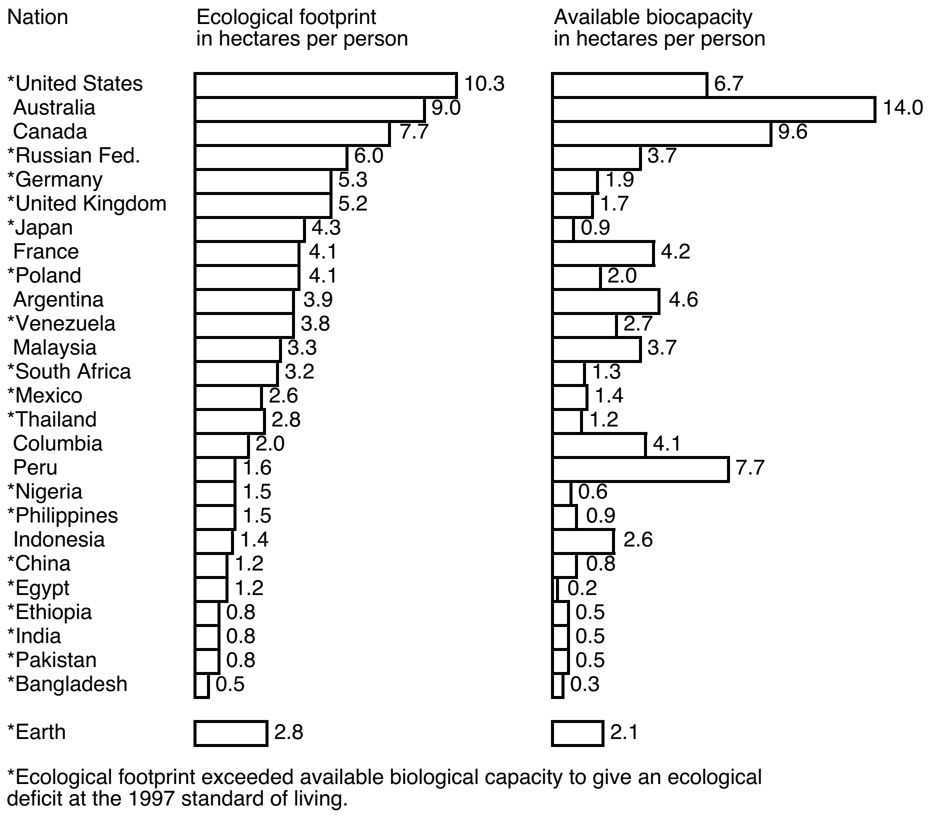

Fig. 1.3. The ecological footprints and available biological capacity for a selection of nations. Data from [30].

When the 1997 ecological footprint per person is multiplied by a nation's population a national ecological footprint is obtained as shown in Fig. 1.4 for five of each of the more populous developed and developing nations that together used 46.2 percent of Earth's biological capacity. Thus, the United States and China used the largest portions and Japan used eight times the portion taken by Bangladesh despite having a similar population.

Another assessment of humanity's impact was gained from a 2004 estimate that about twenty percent of the amount of annual plant growth, and through it animal growth, on land and referred to as net primary production was consumed by humans as food and materials [31]. There was a great variation in this consumption from close to zero in sparsely inhabited regions to over 30,000 percent in large urban areas. On a regional basis, Africa consumed 12.40 percent, East Asia, 63.25 percent, South and Central Asia, 80.39 percent, Western Europe, 72.22 percent, North America, 23.69 percent and South and Central America, 6.09 percent. Average consumption per person in the developed nations was almost twice that of the developing nations where eighty-three percent of the population lived. Should the per person consumption of the latter nations rise to match those of the former, global consumption would rise to thirty-five percent of Earth's net primary production on land.

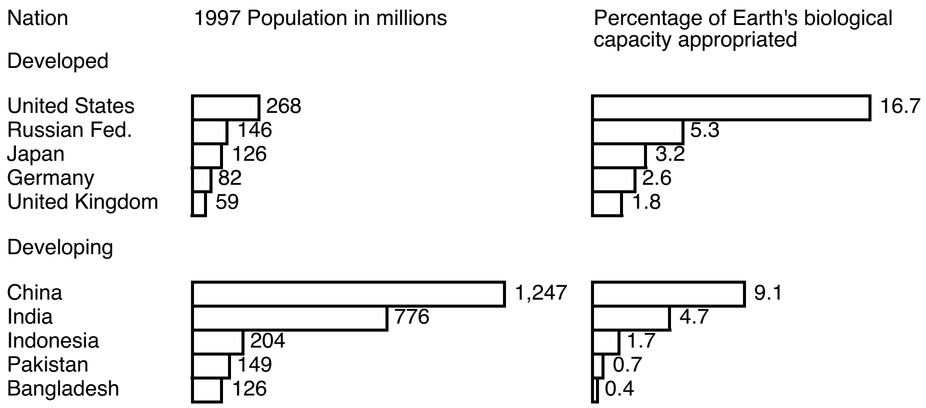

Fig. 1.4. The 1997 appropriations of Earth's biological capacity by ten nations [30].

1.5. Economics and the Environment

Despite humanity's dependency on the life supporting services that the environment performs, these services are generally undervalued because they have always been present and it is assumed that they will continue to be so. Briefly stated, these services include the regulation of climate, the recycling of the nutrients and materials that sustain living organisms, the recycling of fresh water, soil protection, crop pollination and pest control amongst others, and yet these are generally assumed to be "free". Although all of humanity's everyday and economic activities are dependent on these services, economic considerations seldom include them [12,32]. One estimate of the monetary value of these services is gained from the massive and somewhat controversial

Biosphere 2 experiment set up in 1991 in the Sonoran Desert of Arizona to support eight people for two years [33]. This large self-sustaining and closed environment contained some 4,000 plant and animal species in tropical rainforest, marsh, desert, cropland and oceanic ecosystems. Its source of power was sunlight and electricity that drove pumps, sensors, scrubbers and cooling systems to maintain habitability. It cost US$150 million to run for two years that averaged to US$9 million per person for a year. To provide similarly for a six billion human population at this rate would cost US$54 thousand trillion annually, or about 3,000 times Earth's 1997 gross domestic product, an impossibly high figure. Obviously this is an extreme example as such complete life support systems would only become necessary in the event of a total environmental breakdown, a distant possibility that fortunately there still appears to be time to avoid. Evidence that humanity is awakening to such a possibility may be drawn from the internationally enforced prohibitions of the use of the ozone depleting chlorofluorocarbons, or CFCs [34], and the increasingly stringent international sanctions practiced and proposed against global warming carbon dioxide emissions [35,36].

Until quite recently, economists tended not to overtly count the value of environmental assets among a nation's wealth [37]. As a result rivers, aquifers, forests, cropland, fisheries and other natural assets could be exploited beyond their regenerative ability without the consequential impoverishment appearing explicitly in national accounts. In the last decades of the twentieth century that saw the widespread adoption of market economics as the management model for national and international affairs, change arrived slowly with the first attempts to place monetary value on environmental assets. Such valuation is inevitably complex and may vary greatly depending on the perceptions and ambitions of the valuer. Nevertheless, a full valuation of environmental assets is essential if further impoverishment of Earth's biological capacity is to be avoided [38].

In 1997, a detailed attempt to cost the global value of services provided by the environment arrived at the huge value of US$33 trillion that compared with Earth's gross domestic product of US$18 trillion [39]. This assessment subdivided the environment into eight parts, or ecosystems, leaving others uncosted as shown in Fig. 1.5. Inevitably, this analysis has drawn considerable comment and some criticism [40]. Even so, it provides an important new element in the intensifying global argument between those proposing economic development and those opposing it on environmental grounds that often include aesthetically and ethically based assessments that are difficult to quantify in economic terms [18,41]. Nevertheless, it seems likely that the type of injudicious developments of the past, that when fully costed lost more for humanity than they gained, will be increasingly resisted both on environmental and economic grounds.

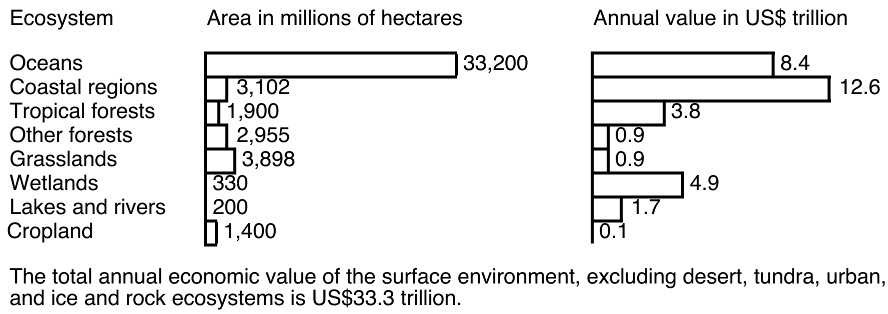

Fig. 1.5. The estimated monetary value of Earth's environment. There is some uncertainty in the range of upper and lower limits in the estimations of the averaged value shown for each ecosystem. For the entire environment, this range was estimated to be US$16-54 trillion with an average value of US$33.3 trillion in 1997 [39].

While estimation of the monetary value of the services provided by the environment as shown in Fig. 1.5 is a major step forward, the practical realization of this worth requires a sophisticated approach. This was shown by the city of New York that draws much of its water from the Catskill Mountains [42]. Until the early 1990s water purification by microorganisms, root systems, and sedimentation in the catchment area cleansed water to the levels required for urban supply. However, gradually increasing levels of sewerage, fertilizers and pesticides in the catchment caused water quality to deteriorate to an unacceptable level. As a consequence, New York was faced with either building a purification plant at a cost of US$6-8 billion with annual running costs of US$300 million, or restoring the Catskill water catchment by buying land in and around it and subsidizing the improvement and building of local sewerage treatment farms at a cost of US$1-1.5 billion. The latter course of action was chosen with an expectation that major savings would accrue. Similar realizations of the economic and environmental advantages of biological water purification have resulted in either the restoration or construction of hundreds of wetlands for this purpose in Europe, North America and elsewhere [43].

As awareness of the environmental damage often caused by commerce and industry grows so does regulation to reduce such damage. In time, this will inevitably lead to companies either having to include in the cost of their products a component to repair the environmental damage the manufacture and use of their products might cause, or to pay taxes to repair such damage, or a combination of these environmental protection measures. This is already the case for acid rain-causing sulfur dioxide in developed nations where the acidity of rain has fallen as a result [44,45]. Accompanying such changes are likely to be accelerating changes in consumer choice made either on the economic grounds of the increasing cost of environmentally damaging products or on the basis of choosing to protect the environment.

1.6. Changing Earth

Most of humanity has seen wilderness cleared for agricultural use, forests felled for timber, suburbs encroaching onto farmland and other changes in the landscape. Frequently accompanied by a decrease in wildlife, these changes in the environment are the most immediately obvious ones that humanity has wrought as population and economic activity have increased. However, in the latter decades of the twentieth century and at the beginning of the twenty-first century, it is probable that the more subtly detectable depletion of the ozone layer and increasing levels of carbon dioxide in the atmosphere and their consequences have been the most publicly discussed of humanity's impacts on Earth. In particular, the issue of global warming has attracted great attention [35,36].

Evidence that Earth is warming has come from a range of sources as exemplified by underground temperatures measured from 616 boreholes on every continent except Antarctica [46]. This study shows that Earth has slowly warmed by about 1^{o}C over the past 500 years with the greatest increase in the rate of warming occurring in the twentieth century. This coincides with the increased carbon dioxide content of the atmosphere, caused by fossil fuel burning, cement production and land clearing, retaining increasing amounts of

Earth's infrared radiation in an enhanced greenhouse effect. Other studies that deduce the increase in Earth's temperature by a range of methods show that the twentieth century was the warmest over the past 400 to 1,000 years with its last decade being particularly warm [47].

While the eleven year solar cycle causes variations in the amount of sunlight reaching Earth, as does the ash and smoke from volcanic eruptions, there appear to be no natural phenomena that can completely account for the rise in Earth's temperature during the twentieth century. As ice sheets and glaciers melt and water expands with rising temperature as the oceans warm, flooding of low lying land is inevitable together with climate changes due to the increased warmth of the atmosphere and the greater amount of water vapour that it retains [48,49]. These potential changes have greatly focused public and governmental attention on humanity's effects on Earth particularly among the sixty percent of humanity that lives in low lying coastal areas.

While the present level of public funding of environmental research and protection is unprecedented, concern about environmental issues is not a recent thing. Human induced environmental degradation began thousands of years ago as evidenced by some of the stark landscape of modern Greece where grazing, tree felling and arable farming destabilized soil on hillsides led to extensive erosion [50]. Aristotle commented on the conversion of the Argive marshes to agricultural use and fertile land around Mycenae becoming dry and barren [51]:

> "In the time of the Trojan wars the Argive was marshy and could only support a small population, whereas the land of Mycenae was in good condition (and for this reason Mycenae was the superior). But now the opposite is the case ... the land of Mycenae has become ... dry and barren, while Argive land that was formerly barren has now become fruitful. Now the same process that has taken place in this small district must be supposed to be going on over whole countries and on a large scale."

The origins of the particularly strong concern about humanity's impact on Earth in the western developed nations at the end of the twentieth century can be traced back to the seventeenth and eighteenth centuries when European nations became alarmed at the environmental effects of their exploitation of newly colonized lands. As a consequence they sought to conserve large tracts of their new possessions by establishing forest and other reserves in places as far apart as Africa, Australia, India, Mauritius, North America, Southeast Asia and the West Indies [52].

Sometimes an individual can powerfully focus attention on an environmental issue. This was the case in 1962 when Rachel Carson's book, Silent Spring, drew attention to the disappearance of songbirds in many regions of the United States because of the use of DDT (dichlorodiphenyltrichloroethane) and other organochlorine insecticides [53]. These insecticides were intended to protect crops from insect pests but had the effect of destroying most insects, be they pest, spectator or benefactor, and thereby diminishing the food supplies for songbirds. Subsequently, it was found that the accumulation of pesticides in raptors at the top of the food chain, such as eagles, hawks and kestrels, caused the shells of their eggs to become thin and break in the nest with a consequent decline in successful breeding. While the benefits of the use of organochlorine insecticides were substantial in terms of crop protection and controlling mosquitoes, flies and lice that spread malaria, typhus and other diseases, their persistence in the environment inevitably caused them to enter the wildlife and human food chain. As a consequence their use in the developed world is now greatly restricted and their use by developing nations is much decreased.

Nevertheless, great environmental changes have occurred because of population increase and the concomitant demands on resources and the accompanying land clearing, forestry, grazing, urbanization, mining, trawling, dredging and related activities. The recycling of carbon, nitrogen, phosphorus and sulfur between air, water and soil, and plants and animals has been changed through fossil fuel burning and the use of agricultural fertilizers. And these activities have caused the loss of animals and plants through habitat changes, agriculture and fishing practices and the release of chemicals into the environment [19,53-55].

1.7. An Ecological Accounting

Almost three quarters of Earth's habitable land are either partially or totally dominated by humanity leaving a quarter available as wilderness according to a 1994 report as shown in Fig. 1.6 [56]. Of the total area of the continents some 162.1 million square kilometres, a little over half, is undisturbed by humans. But this includes uninhabitable rocky, desert and ice covered land that supports little life. Europe is the most human dominated habitable continent while Australasia and South America are the least dominated. Within this global picture enormous variability occurs among countries. This is exemplified by the contrast between the United Kingdom, where almost all land is habitable and less than one percent is undisturbed by humans, and Australia where only twenty percent of land is habitable and is human dominated, the remainder being either desert or arid scrub. However, even in the sparsely populated areas humanity has left its mark as is discussed below.

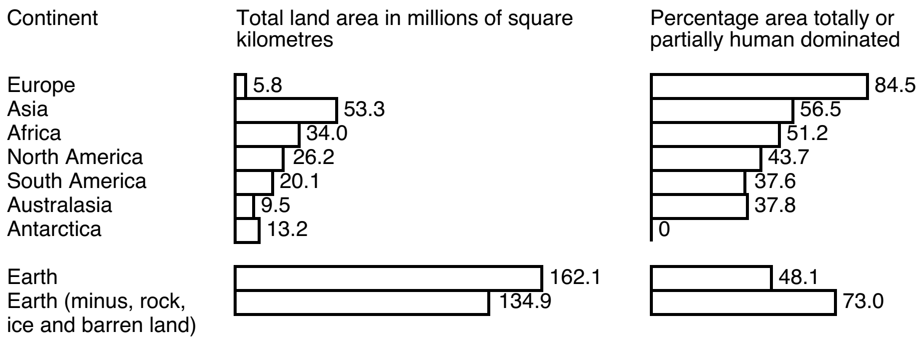

Fig. 1.6. The total area of the continents and the percentage areas under total or partially human domination in 1994. Data from [56].

The study of Earth and its animals and plants has been a human interest for thousands of years. However, as population has grown the regions of Earth unaffected by human activities have become vanishingly small and the opportunities to study a pristine part of nature have all but disappeared. This has induced a gradual change in attitude towards the concept of managing the planet, notably among ecologists. Richard Gallagher and Betsy Carpenter succinctly expressed this changing attitude in their introduction to a special report entitled

"Human-Dominated Ecosystems" in the 25 July 1997 issue of the journal Science [57] where they wrote:

> "Ecologists traditionally have sought to study pristine ecosystems to try to get at the workings of nature without the confounding influence of human activity. But that approach is collapsing in the wake of scientists' realization that there are no places left on Earth that don't fall under humanity's shadow. Furthermore, many scientists now believe that eventually all ecosystems will have to be managed to one extent or another, and, to do this well, managers will need sound advice."

Almost eight years earlier another journal, Scientific American, devoted an entire issue to the subject of "Managing Planet Earth" that examined the prospects for sustainable development of Earth's finite resources and fragile environment [58]. Thus, although Fig. 1.6 shows that 51.9 percent of Earth's land area is not directly disturbed by humanity, it is not insulated from the increasing levels of carbon dioxide, methane, oxides of nitrogen and sulfur, and a variety of other gases generated by human activities that are steadily changing the atmosphere. Nor is there protection from water and wind borne contaminants. Nevertheless, the relatively undisturbed areas of Earth provide refuge for much wildlife including seasonal migratory insects and birds that find themselves increasingly at risk as they either migrate to or traverse the human dominated land around them [59].

A more specific catalogue of the changes effected by humanity, largely since the beginning of the twentieth century, appears in Fig. 1.7. Humanity's impact on the atmosphere through increases in carbon dioxide and methane levels and decreases in stratospheric ozone levels changes has a global reach [60-62]. As population has grown the total area of land in agricultural use increased 466 percent from 1700 to 1980 and was accompanied by a clearing of forty percent of tropical forests [63]. While the rate of this increase slowed from 1960 onwards, food production increased dramatically through the introduction of high yielding crops and an intensification of use of pesticides and fertilizers in the "Green Revolution" [64]. The extent of industrial nitrogen fixation to produce nitrogenous fertilizers now exceeds the amount of nitrogen fixed biologically and by lightening.

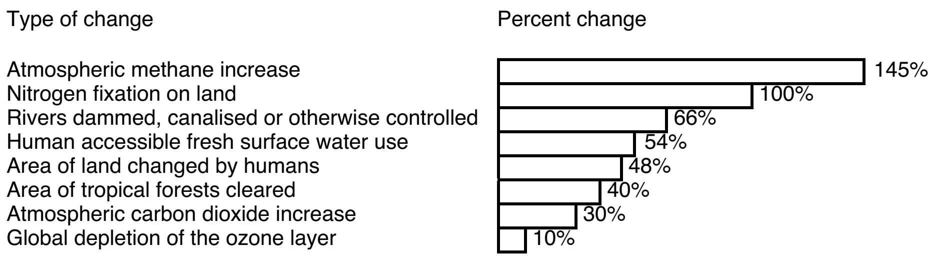

Fig. 1.7. Human induced global changes in the environment. Based on [17,59-66].

Without the greatly increased use of nitrogenous fertilizers and the corresponding increase in the productivity of cropland, some 1.5 billion people would have insufficient food to live [65]. However, the drainage of excess fertilizers into rivers, lakes and oceans, frequently leads to excessive algal and plant growth that unbalances aquatic systems with deleterious consequences. Humanity now uses at least fifty-four percent of accessible fresh water [66] and in an effort to conserve this vital resource, to generate electricity and to prevent flooding, the flow of many of Earth's major rivers is controlled through dams, levees and similar constructions. As a consequence, some major rivers such as the Colorado, Ganges and Nile now deliver very little water to the ocean. While this selection of global changes is not comprehensive it does show that the domination of the environment by humanity is massive.

1.8. Biodiversity: How Many and How Much?

The great variety, or biodiversity, of life on Earth, exists at three levels. The first level is the ecosystem, or biome, such as coral reefs, rainforests, savannahs and deserts where the most biologically prolific and abundant are generally the most vulnerable to human impact. The second level contains all of the species such as bacteria, algae, insects, birds, fish, humans, shrubs and trees that make up the biome, and the third level consists of the diversity of genes in the genome of each species. Biodiversity has probably reached one of its highest levels ever, but unfortunately understanding and knowledge of biodiversity is inadequate at the very time when concern about humanity's impact on biodiversity is increasing.

While estimates of the number of living species are as high as 100 million of which 1.5 million or so have been identified, it might be thought that all of the large living species would be known by now, but even this is probably not so. A new species of large mammal was discovered on average every three years in the last half of the twentieth century and a new large marine animal every five years [67]. Occasionally, new trees were discovered as exemplified by the Wollemi pine, *Wollemia nobilis*, in Australia in 1994 [68]. Across the whole spectrum of life about 300 new species were found each day. Some of these newly found species exist under extreme conditions as exemplified by invertebrate species living in the superheated water of deep ocean hydrothermal vents [69] and the SLiMEs (subsurface lithoautotropic microbial ecosystems), communities of bacteria and fungi that live up to three kilometres beneath the surface in the pores of igneous rock [70].

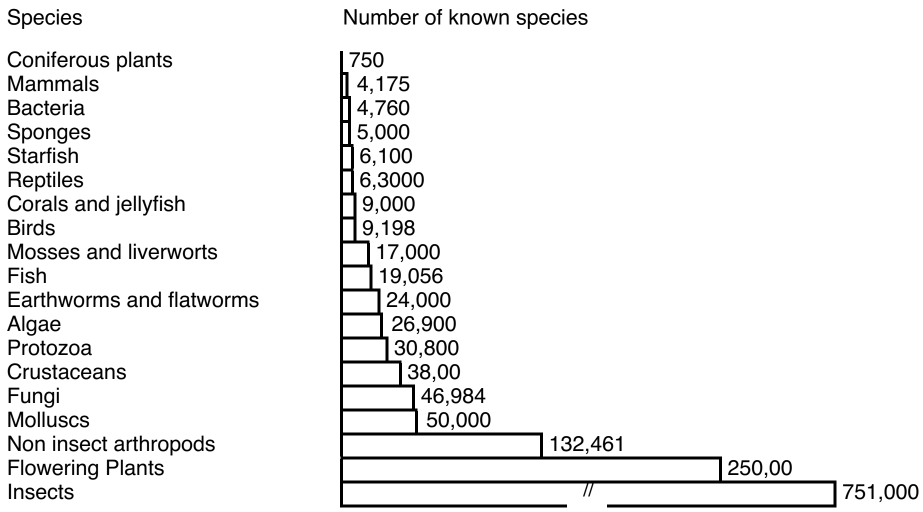

Fig. 1.8. The broadly classified species and the number identified by 1990 to give a total of 1,436,662 [72].

Generally, humanity is more aware of the larger animals and plants because of their visibility and usually expresses more concern about their conservation than for that of beetles, fungi and microorganisms. However, it is insects that make up one half of all known living species while the 4,000 or so mammals represent only a quarter of a percent as Fig. 1.8 shows [71,72]. Although the variety of animals greatly outweighs that of plants, it is plants that make up the vastly larger part of the mass of living tissue. It is also plants that through photosynthesis and recycling carbon dioxide, oxygen, nitrogen, phosphorus, sulfur and water, in collaboration with soil bacteria and fungi, integrate life into the colossal recyclings, or biogeochemical cycles, that support animal and plant life.

The size of this process is seen from the huge reservoir of carbon contained in plants and animals shown in Fig. 1.9 [73]. The rainforests are by far the most biologically productive biomes, which explains the growing concern accompanying their depletion. Roughly one tenth of the carbon in the biomes is recycled annually through photosynthesis and plant growth totals about sixty billion tonnes as seen in Fig. 1.10 [74]. This plant growth represents the

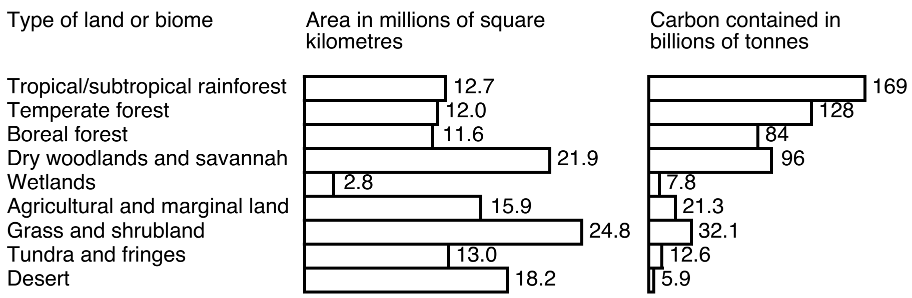

Fig. 1.9. The amounts of carbon stored in the animals and plants of the different types of biomes total 556.7 billion tonnes. The amount of carbon stored in kilograms per square metre ranges from 13.5 through 10.5, 7.2, 4.4, 2.7, 1.4, 1.4, 0.97 to 0.32 as the figure is descended from the prolific life of the rainforests to the sparseness of the deserts. Data from [73].

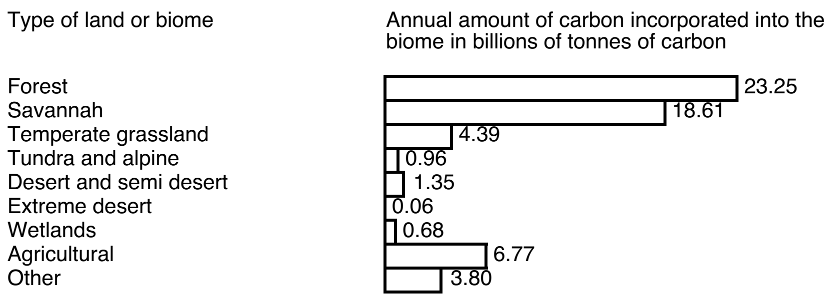

Fig. 1.10. The annual amount of carbon incorporated into living tissue in a variety of land types through photosynthesis and plant growth totals 59.86 billion tonnes according to [74].

difference between the amount of carbon assimilated through photosynthesis and the amount released through respiration and is approximately matched by the amount of carbon released through decay as discussed in section 8.4. A single rainforest tree pumps some 10,000 tonnes, or cubic metres, of water into the atmosphere over a hundred year lifespan [18]. While the huge magnitudes of the quantities listed in Figs. 1.9 and 1.10 are very impressive, so is humanity's capacity to greatly alter a biome and thereby its vital recycling role.

1.9. The Sixth Extinction: The Loss of Biomes

Earth is presently undergoing a major loss of biodiversity that is often referred to as a sixth extinction by analogy to the five great species extinctions preceding it [19,75]. This loss began thousands of years ago as humans became sufficiently organized to dominate and change their environment. With the growth of this organization the loss of biodiversity accelerated to reach an extraordinary level at the beginning of the twenty-first century. Humanity is now so dominant that the destruction of small biomes such as wetlands through drainage and mangrove swamps by dredging is commonplace. However, some of the biomes now threatened are so large that their destruction may cause substantial local, and possibly global, climate change as exemplified by the huge Indonesian rainforest fires of 1997.

In August to December 1997, a great smoke cloud spread over much of Southeast Asia presaging the greatest ever air pollution disaster caused by humanity as shown in Fig. 1.11. This arose through a conjunction of the need to accommodate and feed an Indonesian population growing by three million people a year, a desire to increase gross domestic product, a prolonged drought resulting from the El Niño climatic phenomenon and the burning of tens of thousands of square kilometres of rainforest [76]. The resulting smoke cloud reduced visibility to 100 metres and less, enveloped most of Indonesia, all of Malaysia, Singapore and Brunei and the southern tip of Thailand from mid August to December 1997, and caused at least 100,000 people to become ill. The loss of wildlife was colossal.

This disaster was preceded by largely avoidable and extensive forest fires in 1983, 1991 and 1994 in Indonesia when El Niño induced droughts occurred. The imminence of an El Niño event, and the consequent onset of drought in

Indonesia, was forecast from observations of variations in ocean temperatures across the Pacific early in 1997. Yet, despite the obvious danger, fires were

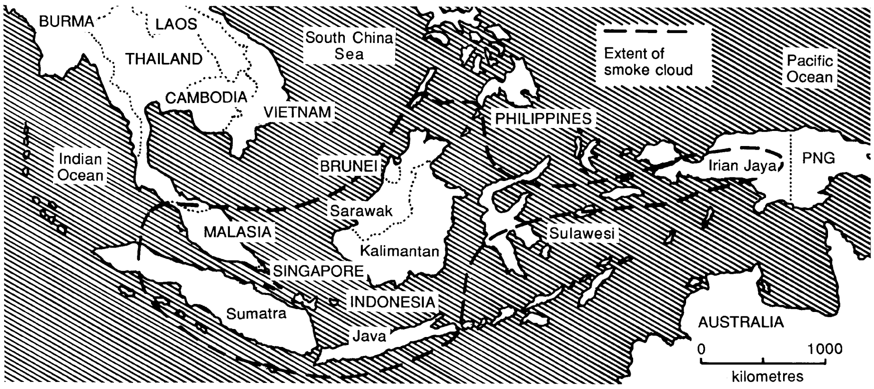

Fig. 1.11. The burning rainforests of Irian Jaya, Java, Kalimantan, Sulawesi and Sumatra generated a huge smoke cloud that thickly cloaked most of Indonesia, all of Malaysia and Brunei and the southern tip of Thailand from mid August to December 1997.

deliberately lit by forestry and plantation companies to clear vast tracts of land through burning to make way for rice paddies and oil palm plantations after they had cleared the valuable timber from the forests. Slash and burn peasant farmers added greatly to the fires that rapidly spread out of control in the drought conditions of 1997. The combination of the cavalier attitudes of the 175 Indonesian and Malaysian forestry companies mainly responsible for the fires with the worst drought in Indonesia for fifty years brought on the predictable disaster [77]. In October 1997, and only after great pressure from governments of nearby nations and wider international pressure, the Indonesian government belatedly withdrew the licenses of twenty-nine forestry and plantation companies who had flouted the weakly enforced environmental laws. It is estimated that in six months the burning forests and peat bogs released one billion tonnes of carbon, or 3.7 billion tonnes of carbon dioxide, into the atmosphere. This compared with the 3.3 billion tonnes of carbon dioxide released by Western Europe annually through fossil fuel burning.

While the Indonesian fires were burning, the American NOAA-12 satellite detected more than 24,000 fires burning in the Amazonian rainforests of Brazil in August and September, some of which spread into Columbia. It is estimated that the 1997 rate of global deforestation was at least 20,000 square kilometres a year, the highest rate since 1988 that was preceded by accelerating and massive deforestation in Amazonia from 1970 onwards. And the burning and deforestation are continuing [78-80]. By 1983, of the 24,500,000 square kilometres of tropical rainforests and seasonal forests that once existed only some 10,000,000 square kilometres remained [81]. About 8,000,000 square kilometres had been converted to agricultural use, 3,000,000 square kilometres to slash and burn agriculture and 3,500,000 square kilometres to pasture. Apart from the loss of the huge forest transpiration that pumps colossal amounts of water into the atmosphere and thereby greatly influences climate and rainfall, it appears that the smoke generated by forest fires causes clouds to form smaller water droplets that are too small to fall as rain and so reduce rainfall in smoke affected areas [82]. This may have contributed to the decrease in tropical rainfall over the last one hundred years.

1.10. The Sixth Extinction: The Loss of Species

The common saying "Dead as a dodo" is a reflection of humanity's acceptance of responsibility for the extinction of other inhabitants of Earth such as the dodo, a flightless bird last seen in Mauritius in the 1670s [52]. Other well-known extinctions are those of the great auk (1844), Steller's sea cow (1768), the sea mink (1880) and the West Indian monk seal (1952) [83]. These are but a few examples of recent species losses whose origins may be traced back thousands of years as humans spread across the continents taking with them fire, exotic animals and plants that supported their hunting and developing agricultural skills and forced other life into retreat [84]. In the Americas fifty-seven large animal species, including mammoths, mastodons, elephants, giant sloths, lions, sabre toothed tigers and glyptodonts, disappeared between ten and twelve thousand years ago and similar losses occurred in Africa, Asia and Europe. In New Zealand half of all the giant bird and insect species were extinct a few hundred years after the Maoris' arrival. In Australia fifty giant marsupials, including giant kangaroos, and animals resembling tapirs, ground sloths, lions, dogs and rhinoceros, were seemingly destroyed by the aborigines during their 50,000 years occupation of the island continent. Globally, about twenty percent of all bird species have disappeared in an extinction that started thousands of years ago as humans hunted the large and easily caught flightless birds. Since 1800, of about 9,600 bird species, seventy-five have become extinct and 1,100 face extinction [85]. Of about 4,300 mammals, sixty have become extinct and 650 face extinction, and of about 4,700 reptiles, twenty have become extinct and 210 face extinction.

These extinctions are symptomatic of the constant drive to increase food supply depleting animal populations either through hunting or habitat destruction. Slowly, humanity is becoming aware of the self-destructive aspects of this process as shown by the rising concern about the relatively recent depletion of fisheries that at one time were thought to be inexhaustible [54]. Although providing about fifteen percent of animal protein for human consumption, few fisheries are now operating at a sustainable level. Directly connected to some of this decline is the global destruction of fifty percent of mangrove swamps that act as fish nurseries and provide coast protection. The loss of the latter capacity is held responsible for increased flooding and loss of life during coastal cyclones [86]. Land clearance and logging have put ten percent of trees, some 8,750 species, at risk of extinction that compares with eleven percent of bird species at risk of extinction, a coincidence that suggests a strong link between loss of habitat and loss of wildlife [87]. There are some bright spots where conservation has saved species from extinction, usually involving large animals. This is exemplified by the biggest of all species, the whale that had become severely depleted by commercial hunting [88]. Starting in the 1970s, most nations banned whale hunting to conserve the species and, although some types of whale may have become extinct, the populations of several members of the whale family have increased to the point where their future appears assured. Some land animals have also been brought back from the verge of extinction, as in the case of the California condor [89], but generally such successes are having only a small effect on the general tide of extinction.

The total recorded loss of species since 1600 is 724, with sixty being lost between 1900 and 1950. This compares with an estimated natural loss rate of one animal and one plant species every 100 to 1000 years. Both the recorded and estimated natural rates of loss of species are small when compared with current extinction rates estimated to be several thousands annually [19]. The reason for this is that the method of estimating this very high species loss rate is not based on definite identification of species lost, most of them small and unnoticed by the casual onlooker, but instead is calculated on the lost of habitat as wilderness is cleared. The tropical rainforests are thought to contain at least sixty percent of Earth's animal and plant species [77,90]. As a consequence concern about the loss of biodiversity heightened with the great acceleration in the clearing of these forests to the point where they covered less than half of their original area by the end of the twentieth century. It is estimated that if the rainforests are reduced to less than ten percent of their original area, as may occur, some 65,000 species, animal and plant, large and small, will be lost [91]. Comparisons of such estimates with the disappearance of species in the fossil record suggest that extinction rates at the end of the twentieth century could be at least 10,000 times greater than the natural loss rate [92]. The fossil record suggests that after past great extinctions it has taken up to ten million years for biodiversity to fully recover, and the same may well be the case for the current human induced extinction quite apart from its impact on future evolutionary patterns [93-95].

Apart from the uncertainty about the number of species that exist, there is also considerable uncertainty about how many of a particular species exists. In some cases these numbers are very small as exemplified by the single known examples of the trees *Diospyros angulata* (Mauritius), *Carpinus putoensis* (China) and *Holmskioldia gigas* (Tanzania) and the three or four examples of *Hibiscus clayi* (Hawaii), *Scalesia atracyloides* (Galapagos Islands) and *Ilex khasiana* (India) [87]. Many large mammals are at risk of extinction because their populations have been greatly reduced and are subject to increasing human competition for living space. This is typified by the three hundred mountain gorillas living in the 330 square kilometre Bwindi Impenetrable Forest rainforest reserve in Uganda that represent half of the remaining population of mountain gorillas [96]. Elsewhere in Africa, the great ape populations are being decimated by hunting and Ebola infection [97]. Another example comes from the ocean where leatherback turtles face extinction as a consequence of being inadvertently caught during commercial fishing [98]. Thus, while 1,367 leatherback females nested at one of their nesting beaches, Playa Grande in Costa Rica, in 1988-89, this number fell steadily until only 117 nested in 1998-1999, and a further fall to fifty was predicted for 2003-2004. In complete contrast, twelve million roundworms, 46,000 small earthworms and their relatives, and a similar number of insects and mites have been found to live under a square metre of Danish pasture [18]. A gram of fertile agricultural soil is capable of supporting over 2.5 million bacteria, 400,000 fungi, 50,000 algae and 30,000 protozoa.

Twenty-five areas, covering twelve percent of Earth's landmasses and spread over every continent except Antarctica, are impressively rich in plant and animal species and have been termed biodiversity hotspots [99]. In 1995, more than 1.1 billion people lived in these areas with an average population density of seventy-three people per square kilometre that compared with an average global population density of forty-two people per square kilometre when ice and rock covered land was excluded. As population grows, so pressure increases on the animals and plants of these biodiversity hotspots, as is the case in the other inhabited areas. It was for this reason that in 1992, at the United Nations Conference on Environment and Development in Rio de Janeiro, over a hundred nations signed the Convention on Biological Diversity to set aside areas to conserve biodiversity [100].

It may be argued that as intensive agriculture, aquaculture and forestry concentrate on those animals and plants that provide for humanity's needs, the loss of other species is inevitable and need not affect humanity's future. However, such an argument is untenable as it neglects the underpinning of the food supply. This is the breeding of extremely productive crops and domestic animals from wild species in parallel with technology that frees the bulk of the population of the developed nations from food production to pursue the myriad other activities that characterize sophisticated societies. At present sixty percent of humanity's food is directly derived from just three crops, maize, rice and wheat that are produced in a massive monocultural agricultural system and were first bred from wild species some 10,000 years ago. The 1997 global wheat crop covered an area of 250 million hectares with at least 500 trillion individual plants [93]. However, during a long breeding program to produce the high yielding modern strains that coincided with the destruction of much of the natural environment with increase in population, many of the wild progenitors of agricultural wheat and other wheat strains have been lost [101].

The narrowness of the genetic origins of major food crops is shown by almost all of the hard red winter wheat varieties grown in the United States originating from only two varieties from Poland and Russia [101]. Almost all soybeans grown in the United States originated from a dozen strains found in a small area of northeast China [102]. Such genetic narrowness places humanity in a vulnerable situation as monocultures are particularly susceptible to the spread of disease because of the closeness of identical plants over extensive areas. This is not a speculative assertion as was shown by the great potato famine in Ireland in the late nineteenth century that arose because of the spread of potato blight from field to field to produce widespread starvation and destitution [103]. It was a number of such disasters that led to the setting up of seed banks to preserve genetic diversity in agriculturally important crops and their progenitors [102].

Unfortunately, seed banks, reserves and similar stratagems cannot protect the vast majority of plant species from which great benefit for humanity flows and from which yet to be discovered benefit may flow. Thus, digitalis, morphine and quinine are directly derived from large plants and the first antibiotic, penicillin, was extracted from a mould [18]. Cyclosporin, now widely used to suppress the immune system and prevent organ transplant rejection, is derived from a similar source, as is gliotoxin that promises applications similar to those of cyclosporin. Humanity has to become reconciled with a dependence on biodiversity for the Earth's habitability and incorporate its protection into everyday agricultural and other activities.

Almost perversely, as this largely unwitting experiment with Earth's biodiversity has been occurring, a deep understanding of biodiversity at the molecular level developed during the twentieth century that appears set to have a substantial effect on humanity, and thereby Earth, in diverse ways in the twenty-first century. This understanding is based on the double helical molecule deoxyribonucleic acid, DNA, that contains the genome of each living organism and its genetic code. As other species and their genomes are disappearing, humanity celebrated the publication of the near complete sequence of the human genome in 2004 that promises to lead to the prevention and cure of previously intractable diseases and increases in the human lifespan [104]. Similarly a growing understanding of the genomics of plants and animals has already resulted in genetically engineered new plants and animals, the production of which, while the subject of much debate, may result in considerable benefit to humanity [105]. This "new biology" is explored in more detail in Chapter 5.

1.11. The Human Condition

Great as is humanity's dominance of Earth, and impressive as were the advances in scientific endeavour and the benefits arising from them during the twentieth century, the beginning of the twenty-first century finds the major part of humanity still preoccupied with gaining sustenance and shelter and the avoidance of disease and death. This is despite life expectancy in the developed nations becoming unprecedently long. Globally a million or so people die each week while about 2.5 million are born, many of whom soon join the ranks of the dying through war, famine and disease, especially in sub-Saharan Africa.

Humans have a unique ability to threaten their own survival through systematic war. The twentieth century saw the most technologically advanced nations engage in the First and Second World Wars of 1914-1918 and 1939-1945 that were hugely destructive of life and economically devastating. During the Cold War of the latter part of the twentieth century, the possibility of global nuclear war posed the greatest ever threat to humanity's tenancy of Earth. At its height every human was threatened with a nuclear equivalent of three tonnes of the high explosive trinitrotoluene, TNT [106]. It is probable that the fear of the awesome destructive power of nuclear weaponry acted as the dominant deterrent to a major conflict between the massively armed Cold War opponents. Fortunately, the threat of global nuclear war has receded and nuclear armouries are now much reduced. Nevertheless, conventional wars, large and small, continue to be waged as a testimony to human aggressiveness.

Devastating as war is, famine and disease claimed far more lives during the twentieth century and are likely to do so in the twenty-first century. The major diseases leading to death globally are diseases that infrequently lead to death in the developed world. The exception is the new disease, autoimmune deficiency syndrome, AIDS, that is associated with the human immune deficiency virus, HIV, that lowers the body's ability to resist disease. The 1996 World Health Report of the World Health Organization listed the ten diseases with the biggest death toll in 1995 as shown in Fig. 1.12 [107]. The vast majority of the seventeen million deaths from these diseases occurred among the children of developing nations and compared with a total global death toll of fifty-two million.

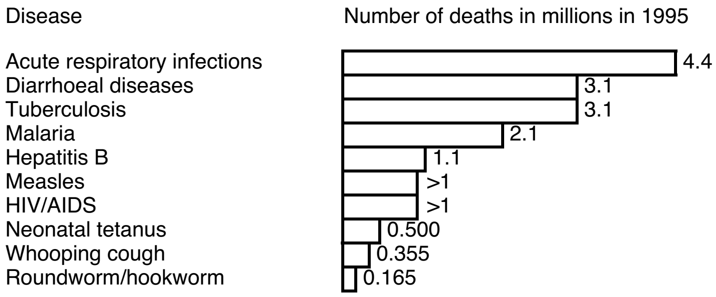

Fig. 1.12. The ten biggest killer infectious diseases in 1995 according to the World Health Organization [107].

By 1998, HIV/AIDS had become the major cause of death in sub-Saharan Africa with an annual death toll of 2.2 million that compared with 200,000 lives lost in all of the African conflicts in that year, and 23.3 million people were infected that compared with a global total of 33.4 million [108]. So devastating is the impact of HIV/AIDS on economic, social and political stability in sub-Saharan Africa that in January 2000, the United Nations Security Council declared the pandemic a threat to world stability. However, by the end of 2004 the global total of HIV/AIDS sufferers had risen to 39.4 million of which 25.4 million were in sub-Saharan Africa [109]. Some 3.1 million people died of HIV/AIDS in 2004 and there were 4.9 million new infections of which 3.1 million were in sub-Saharan Africa, 890,000 in South and Southeast Asia, 290,000 in East Asia, 240,000 in South and Central America, and 210,000 in Eastern Europe and Central Asia. Given the large populations of these regions, they could soon rival sub-Saharan Africa in the total number of infections, the global peak of which appears to be years away.

1.12. Natural Disasters

Earth is a restless planet and every so often natural occurrences such as extreme weather events or movement of tectonic plates either directly or indirectly result in disaster. So great can be the loss of life and economic activity from such disasters that the last decade of the twentieth century was declared the Decade for Natural Disaster Reduction by the United Nations [110]. The hazards specifically considered were earthquakes, windstorms, tsunamis, floods, landslides, volcanic eruptions, wildfires, grasshopper and locust infestations, and drought and desertification. To gain an idea of the magnitude that such disasters can assume several examples are now briefly discussed.

On 15 June 1991, the six centuries dormant Philippines volcano, Pinatubo, erupted spectacularly [111]. This, the largest volcanic eruption of the twentieth century, is variously estimated to have ejected four to eight cubic kilometres of dust and ash and twenty million tonnes of sulfur dioxide into the atmosphere, much of it entering the stratosphere. The immediate effect was to smother a huge tract of the surrounding countryside in metres thick layers of dust and ash that collapsed buildings, choked water courses and displaced hundreds of thousands of people from farms and villages. As the eruption rumbled on, much of the dust and sulfur dioxide was washed out of the atmosphere by rain. However, in the stratosphere, far above the rainstorms, the fine dust, together with a sulfuric acid aerosol arising from reaction of sulfur dioxide with atmospheric moisture, formed a girdle around Earth above the equator that reflected sunlight back into space to cause a slight global cooling. While the effect of the dust decreased rapidly as it fell back to the surface, the cooling effect of the sulfuric acid aerosol lessened more gradually over three or so years as it slowly re-entered the lower atmosphere. On the ground in the immediate vicinity of Pinatubo, that was still rumbling in 1995, great viscous streams of magma, or lahars, continued to flow from the caldera. Although the loss of life was small, the loss of livelihood was enormous. Unlike the situation with Pinatubo, often many people die in volcanic eruptions and it is thought that 274,443 people died in a variety of ways as a consequence of 304 volcanic eruptions during the sixteenth to twentieth centuries [112]

Early in the morning of 17 January 1995, an earthquake measuring 6.9-7.2 on the Richter scale struck the Japanese harbour city of Kobe killing over 6,000 people and rendering 310,000 homeless as it destroyed freeways and water, gas and electricity supplies [113]. This earthquake was Japan's second most devastating after the 1923 Tokyo earthquake that killed 142,000 people. Japan continuously experiences earth tremors because it lies close to the junction of the Philippine and Eurasian tectonic plates that grind against each other along with the jostling of all of the other tectonic plates that make up Earth's surface [1]. Every so often this produces a major earthquake to which cities at the edge of tectonic plates are particularly vulnerable. Thus, on the eastern side of the Pacific

Ocean, Los Angeles and San Francisco frequently experience tremors as the Pacific plate grinds against the North American plate along the San Andreas fault [114]. Similar movements occur elsewhere, as exemplified by that along the North Anatolian fault line that resulted in a 7.4 Richter scale earthquake and the loss of more than 15,000 lives in the Turkish city of Izmit on the morning of 17 August 1999 [115]. This was followed by the 8 Richter scale Bhuj-Anjar-Bhachau earthquake in western India that took 30,000 lives on the morning of 26 January 2001, and another earthquake at Bam in Iran took 50,000 lives on the morning of 26 December 2003 [116,117].

Earthquakes are hazards whose danger can be lessened by building to withstand their force, recognizing of early warning signs and having well prepared emergency services. Even so, the huge waves, or tsunamis, caused by earthquakes beneath the ocean can strike with little warning, as was the case in Papua New Guinea in the evening 17 July 1998 [118]. There, a 7.1 Richter scale earthquake thirty kilometres offshore produced a series of waves in rapid succession, some up to fifteen metres high. These completely overwhelmed the low lying coastal villages of Sissano, Arop, Warapu and others taking more than 2,200 lives and obliterating not only houses, but also stripping most vegetation from the coastline. Tsunamis are much more powerful than the surface waves generated by storms because they reach to the ocean floor and carry huge volumes of water with them on fronts of hundreds of kilometres at up to 800 kilometres an hour over thousands of kilometres. Although tsunamis may be scarcely noticed in the deep ocean, their effect as they pile up on a shoreline is devastating.

Most tsunamis occur in the Pacific Ocean, ten of which took more than 4,000 lives from 1990 to 2000. Tragically, this familiarity with tsunamis proved no preparation for the huge tsunami that killed some 300,000 people living in Indian Ocean coastal areas on 26 December 2004 [119]. Jostling between the Indian and Burma tectonic plates caused a 9.3 Richter scale earthquake that caused some parts of the seafloor to drop by 2.5 metres and other parts to rise five metres over an area of 25,000 square kilometres 200 kilometres west of Sumatra. This generated a fast moving half metre high wave 100 kilometres wide that piled up on the coast of the Indonesian province of Aceh to produce fifteen metre high waves that took at least 230,000 lives with further heavy loss of life in India, Sri

Lanka, Thailand, Myanmar (Burma) and the Maldives. So massive was the tsunami that it killed many on the eastern side of the Indian Ocean in Somalia and other East African nations. In addition to the huge loss of life and property damage of many US$ billion, complete ecosystems were stripped away in low lying areas such that restoration and re-establishment of livelihoods will take decades to achieve. If an early warning ocean floor tsunami sensor system had been in place in the Indian Ocean, similar to that in the Pacific Ocean, it is probable that the loss of life would have been much less. Tragically, the tsunami was followed on 28 March 2005 by a magnitude 8.7 Richter scale earthquake on the seabed close to the December earthquake and a further 2,000 lives were lost on the island of Nias [120].

On 29 October 1998, a weakening hurricane, Mitch, swept in from the Caribbean to bring high winds and torrential rain to most of Honduras and large parts of Nicaragua, El Salvador and Guatemala [121]. Entire villages were obliterated by surging streams, rivers of mud and landslides to leave up to 24,000 people dead or missing and causing damage in excess of US$5 billion. Over 600 millimetres of rain fell in the Honduran mountains in a single day. This, combined with the extensive land clearance for cattle grazing that accelerated water runoff and destabilized the soil, made major flooding, huge soil erosion and landslides inevitable. In the wake of Mitch, the sodden countryside was ideal for the proliferation of water borne diseases such as cholera of which there were more than 30,000 cases. Diseases transmitted by mosquitoes, that thrive under such waterlogged conditions, resulted in more than 30,000 cases of malaria and more than a thousand cases of dengue fever. This is a typical pattern of extreme weather and land clearing combining to produce disasters large and small. Extensive clearance of rainforest by farmers and loggers in Brazil, Indonesia and Thailand, areas also subject to torrential rain, can be expected to cause losses of life and homes similar to those experienced in Central America.

A very large extreme weather death toll arose when a cyclone struck Bangladesh on the night of 29 April 1991 [122]. Winds in excess of 225 kilometres per hour whipped up seven metre waves in the Bay of Bengal and spread devastation and flooding in coastal regions to kill more than 130,000 and injure over 450,000. More than 850,000 houses were destroyed, 440,000 cattle drowned and 63,000 hectares of crops were lost.

1.13. Unnatural Disasters

Humanity is quite capable of generating its own disasters that show signs of becoming bigger and more deadly as the scale of technology grows. The worst industrial accident to date occurred in India just after midnight on 3 December 1984 when forty tonnes of highly toxic methyl isocyanate escaped from the Union Carbide pesticide plant in Bhopal [123]. The vaporized chemical enveloped a wide area killing over 2,800 people and injuring some 200,000 others, many seriously and many permanently. This provides an example of multiple aspects of human aspirations leading to unforeseen and tragic consequences. Here the manufacture of pesticides to protect crops to feed a burgeoning population of a developing nation seeking to industrialize, perhaps without adequate safeguards to control a major chemical plant operated by a large multinational company seeking to increase its global market share, resulted in a chain of events leading to disaster.

However, developed nations are not immune to such disasters that may present themselves in a variety of forms. Although seldom costly in human life, an all too frequent accident is the spillage of huge quantities of oil from stricken tankers into the ocean and usually onto coastlines with consequent great loss of wildlife and the destruction of fisheries. One of the biggest such spills was that from the super tanker Exxon Valdez that ran aground in Prince William Sound in Alaska on 24 March 1989 spilling forty-two thousand cubic metres of crude oil into the ocean and onto the surrounding coastline [124]. While no human lives were lost through the spill, the large loss of fish, birds, marine mammals and plankton constituted an extensive and long lasting damaging effect on the ecology of Prince William Sound and the rich fishing industry that it supported.

In the early morning of 26 April 1986, the worst ever nuclear accident occurred at Chernobyl in Ukraine [125]. The inappropriate operation of an obsolete RBKN nuclear reactor resulted in a massive explosion, reactor core meltdown and the spread of a large cloud of radioactive fission products over most of Europe and Scandinavia within a few days. Within a few weeks, radioactive fallout was detected as far afield as Japan and the United States. The release of radioactivity was 200 times greater than that produced by the nuclear weapons dropped on Hiroshima and Nagasaki combined [106].

Although the immediate death toll from the explosion was small, several thousand people died from radiation sickness and related diseases in the ten years following the explosion according to some estimates. Many of these deaths occurred among the large numbers of people drafted into the reactor site and environs in an attempt to stop the release of huge amounts of radioactive material that belched from the crippled reactor for ten days and to collect and bury radioactive debris. More deaths also occurred among the populations of Ukraine, Belarus and Russia closest to Chernobyl where millions were exposed to fallout. A thirty kilometre radius zone around Chernobyl became so radioactive that the 135,000 people living in it were evacuated immediately and are unlikely to be allowed to return in the foreseeable future. Since then many more have been evacuated from other contaminated areas to bring the total to more than 200,000 evacuees.

Twenty major radioactive fission and decay products were in the vast radioactive cloud emitted by the reactor. Among them were iodine-131 with a half-life of eight days, cesium-134 and cesium-137 with half-lives of two and thirty years, respectively, strontium-90 with a half-life of thirty years, and several isotopes of plutonium with half-lives varying from thirteen to 24,3600 years. Apart from the deaths from radiation sickness, the most obvious health effect of this contamination was that the incidence of thyroid cancer in children in Gomel in Belarus became much greater than normal. This was caused by radiation damage from iodine-131 that accumulates in the thyroid gland. An increased rate of sperm and foetal abnormalities in the Chernobyl region was also attributed to the accident.

In the immediate aftermath of the accident, contaminated agricultural produce in Austria, Belarus, Finland, Georgia, Germany, Hungary, Norway, Poland, Russia, Sweden, Ukraine and the United Kingdom had to be destroyed, and restrictions on agricultural produce still applied in 2000 even in some of the more distant countries. Water from the Chernobyl area drains into the Pripyat, a tributary of the Dnieper that flows into the Black Sea, and spreads the longer lived radioactive contamination further afield.

These three accidents stemmed largely from humanity seeking to supply its basic needs of sustenance and energy and to increase living standards. This activity is unlikely to diminish in the twenty-first century and, given that very often such activities are carried out at the minimum safeguard level thought necessary, it seems inevitable that similar accidents will occur in the future. The effects of natural and unnatural disasters are placed in perspective in Fig. 1.13 that shows the size of areas affected and the time for the environment to recover [126,127]. At first sight it seems a little odd that intensive agriculture should be identified as an unnatural disaster. However, such agriculture can lead to loss of soil fertility and soil loss through erosion, both of which result in reduced crop yield and sometimes in crop failure, quite apart from loss of biodiversity. Often intensive agriculture leads to further problems in the form of soil salinization through excessive irrigation, and eutrophication of inland and coastal waters as a result of fertilizer runoff. The magnitude of the nuclear accident shown in Fig. 1.13 is based on Chernobyl. The asteroid and comet impact magnitude shows an envelope that incorporates the Tunguska impact of 1804 and larger impacts that humanity would survive, but does not extend to the magnitude of the Yucàtan impact of sixty-five million years ago that humanity would survive with great difficulty [10,11].

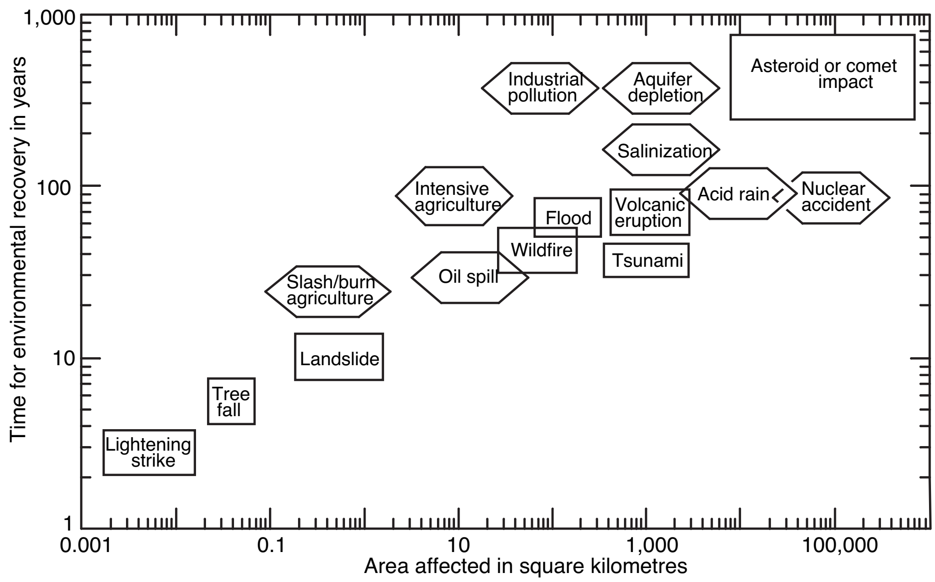

Fig. 1.13. The approximate variation of the area affected and the time for environmental recovery characterizing a selection of natural and human caused environmental impacts represented by rectangles and lozenges, respectively. Constructed from Chernobyl data and those in references [10,11,126].

1.14. Challenged Earth

While Earth could be said to be challenged by humanity to continue to provide the underpinnings of life, the reality is that it is humanity that faces many challenges to maintain Earth as a beautiful and hospitable planet for the generations to come. While inexorable geological and climate changes will occur as Earth continues along its planetary evolution most such changes are likely to be slow on the human timescale and therefore fairly readily adjusted to as long as the Holocene epoch persists. The challenge is to ensure that events are not precipitated that damage Earth's habitability to the point where humanity's existence becomes marginal, possibly to the point of extinction. Should this occur, Earth will still appear as a magnificent blue planet, but something extraordinary will have been either much diminished or lost, humanity, the highest known form of life, and with it much of its companion animal and plant life. Fortunately, it is probable that humanity is sufficiently intelligent and resilient to avoid such a catastrophe. Even so, some of the challenges are massive as exemplified by those posed by the sheer size of the human population and its growth as discussed in Chapter 2.

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