Human frontiers, environments and disease

Past patterns, uncertain futures

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Disease patterns in human biohistory

We are living through an unprecedented transformation in the pattern of human health, disease and death. There have been many great episodes of pestilence and famine in local populations over the ages, but there has been nothing as global and rapid as the change in the profile of human disease and longevity over the past century or so. For hundreds of thousands of years as hunter-gatherers, and subsequently in agrarian societies, our predecessors had an average life expectancy of approximately 25–30 years. Most of them died from infectious disease, and many died of malnutrition, starvation or physical trauma. A large proportion died in early childhood. Today, for the world as a whole, average life expectancy is approaching the biblical 'three score years and ten', and in some rich countries it has reached 80 years.

Two immediate questions arise. What has caused this radical shift in health profile? Can future health gains be shared more evenly around the world? During the 1990s, the combined burden of premature death and chronic or disabling disease was about four times greater, per 1,000 persons, in sub-Saharan Africa than in the Western world.[1] An even more important question looms in a world that is undergoing rapid social and environmental change: can those gains in population health be sustained? To answer the second and third questions we will need to answer the first question.

Over the past two centuries human ecology has been transformed, albeit very unevenly between rich and poor regions. Little more than a century ago, in Manchester, England, half of all young children died before age five. Subsequently, in much of the world, food supplies, housing, water quality and sanitation have improved; ideas of personal and domestic hygiene and of family planning have spread; and workplaces have become safer. Literacy has increased and social modernisation has occurred. Various public health and medical interventions have arisen: anaesthesia and antiseptic surgery in the second half of the nineteenth century, followed by vaccination, contraception, antibiotics, pesticides and oral rehydration therapy for diarrhoeal disease. Death rates in early childhood, particularly from infectious diseases, have declined markedly, first in Western countries from around mid-nineteenth century and then in low-income countries from the 1920s onwards. Maternal deaths in childbirth have declined. Deaths from adult infectious disease, particularly from tuberculosis, have receded.

As more people survive to older age, and as patterns of living, consuming and environmental exposures change, so noncommunicable diseases such as coronary heart disease, diabetes and cancer have come to dominate. Low-income countries are following in the footsteps of the rich countries (Figure 1.1). An epidemic of obesity now looms in rich countries and in urban middle-class populations elsewhere – even as a similar proportion of the world population continues to be underfed and hungry. The world's three leading causes of disease burden (comprising premature death and disabling disease) in the early 1990s, as assessed by the World Health Organization in 1996, were pneumonia, diarrhoeal disease and perinatal disorders.[1] The three conditions projected to take their place by 2020 were coronary heart disease, mental depression and road traffic accidents. Even so, the human immune-deficiency disease, HIV/AIDS, had moved rapidly into second position by 1999, after pneumonia.

Most of this transformation in population health has resulted from broad social changes, from radical shifts in human ecology. Even so, most health-related research continues to focus on specific behavioural, clinical and technological interventions. That, of course, is the style of mainstream science, which deals with discrete, measurable and manipulable units. It also reflects the difficulty we have in seeing the larger picture, in recognising that a population's profile of health and disease is essentially an expression of its social and physical environments. That is, it is an 'ecological' characteristic that reflects the population's collective experiences and way of life. In early 2000, Britain's Labour government announced a national initiative for the *prevention* of heart disease deaths. Along with a familiar 'quit smoking' campaign came an ill-conceived strategy that gave precedence to quicker treatment of heart attack cases (including placing life-saving defibrillators in public venues), training more heart surgeons and more effective prescribing of drugs. Little attention was given to modifying the nation's heart-unfriendly diet, or to changing transport systems and physical activity patterns in order to counter the rise in obesity and its associated metabolic disorders and high blood pressure. The 'Mediterranean diet' keeps heart disease rates low in Greece and Italy. The greater reliance on public transport, cycling and walking has slowed the rise of obesity in the Netherlands. British surgeons at the ready will achieve little in the way of actual prevention (but may, of course, win votes).

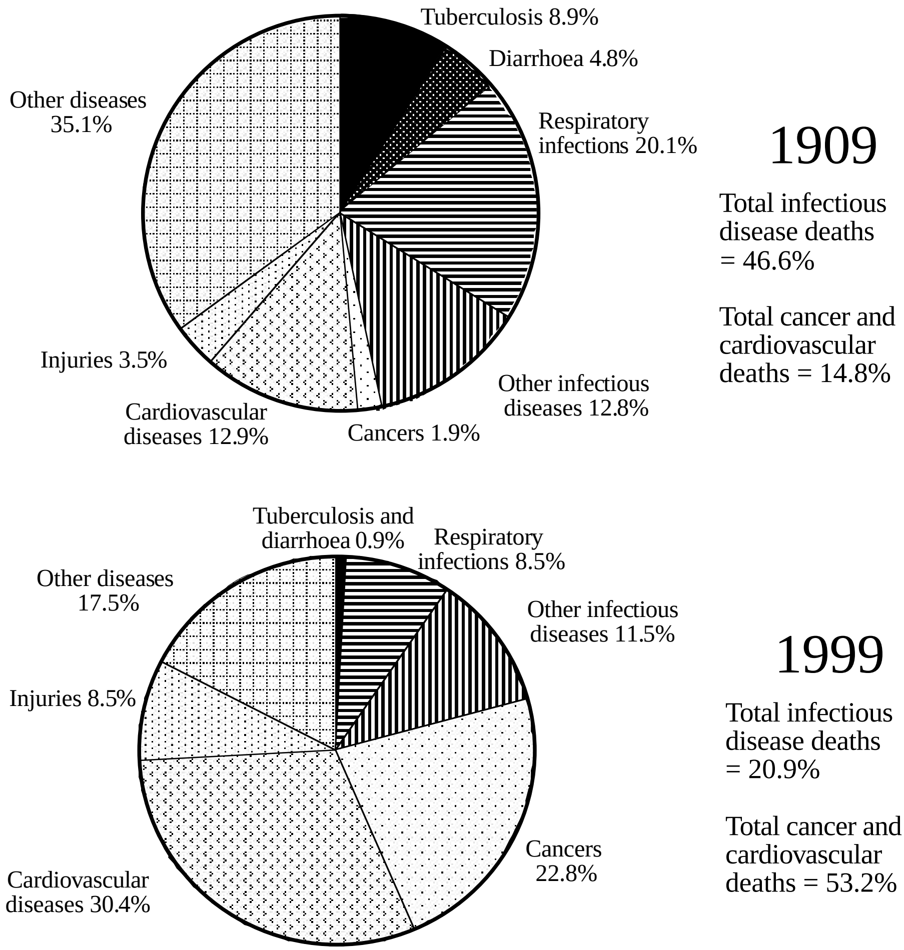

Figure 1.1 Change in the profile of causes of death in Chile between 1909 and 1999. Note the marked reduction in deaths from infectious diseases, and the rise in noncommunicable diseases, especially cardiovascular disease.

Our awareness of these larger influences on health and disease, reflecting the population's relationships with both the natural world and other populations and its own history and internal social structures, ought to have increased in recent years. Various recent developments have underscored this ecological dimension – including, for example, evidence of the health hazards of intensified food production, of the adverse impacts of increased climatic instability attributable to global warming, and of the many social and environmental influences on the emergence and spread of infectious diseases.

A grim reminder of the power of social change to alter patterns of population health comes from HIV/AIDS. Both the origins and the spread of this infectious disease, first identified in the early 1980s, reflect aspects of human ecology. These include: the initial contact with chimpanzee or monkey sources of a human-compatible strain of the ancestral simian virus, the amplified local spread in humans via rural–urban migration in Africa, long-distance dissemination via movements of tourists and military mercenaries, patterns of sexuality and intravenous drug use, and (especially in Africa) the roles of poverty, political denial and the subordination of women. HIV/AIDS may well become numerically the greatest epidemic scourge in human history. Currently there are 40 million infected persons; two-thirds of them are in Africa.

MEANWHILE, NEW large-scale influences on population health are emerging. The future patterns of disease will be much affected by the rapid increase in the proportion of older people, the worldwide process of urbanisation, gains (unequally shared) in affluence and its associated patterns of consumption, and new genetic technologies. The advent of unprecedented global environmental changes, especially human-induced climate change, stratospheric ozone depletion, biodiversity loss and the depletion of fertile soils and fresh water supplies, will have a range of adverse effects on human health. The prospects for human health are being further affected by the processes of globalisation, especially the liberalisation of production, trade and investment with its often inadvertent collateral damage to economic equity, social wellbeing, labour standards, environmental resources and human health.

Patterns of health and disease in the twenty-first century will differ greatly from those of previous centuries. In Western societies, deaths from infectious disease dominated in 1900 and those from heart disease and cancer dominated in 2000. What will dominate in 2100? We are entering a new phase of human ecology as we restructure our relationships with the natural world, convert the global village into a global supermarket, and accelerate the through-traffic of materials, money, people, microbes, information and ideas. The 1.5 billion humans of 1900 will have become 8–9 billion by 2050. We may yet face adversity and crisis as a result of unconstrained climate change and deterioration in the vitality of the planet. There is great uncertainty about these unfamiliar ‘futures’ – and, as yet, little experience in seeking effective international solutions.

Over the next few decades, life expectancies will probably continue their historically unprecedented rise, especially in low-income countries. However,

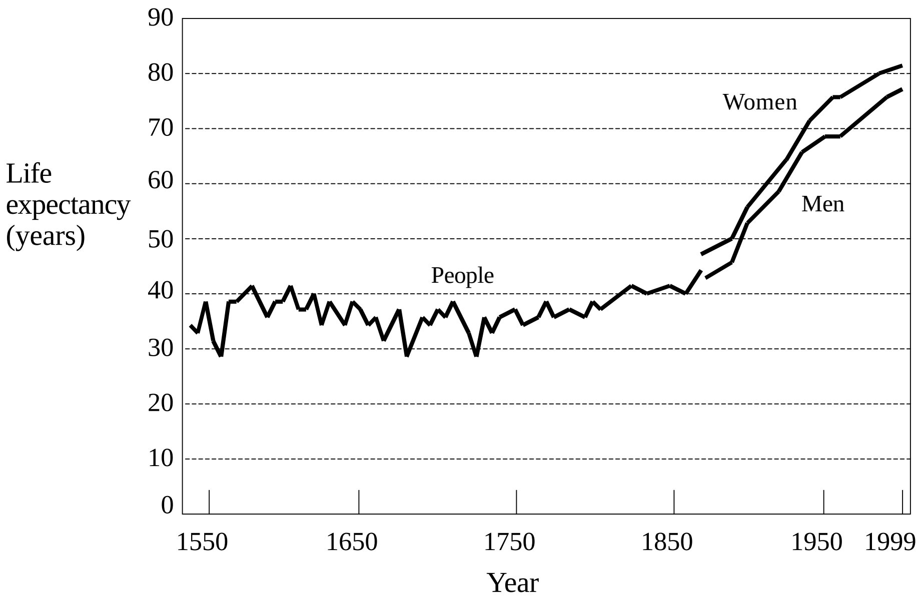

Figure 1.2 Gains in life expectancy in England and Wales over the past two centuries. Social, economic and climatic conditions deteriorated during the seventeenth century. From around 1750 there was a gradual rise in average life expectancy, accelerating after 1850. Much of that rise reflected the decline in infant and child deaths.

if the HIV/AIDS pandemic intensifies, then life expectancies will decline in afflicted countries as they have already done in many sub-Saharan African countries. Globally, the proportion of deaths from infectious diseases will halve from around one-third to one-sixth of total deaths, whereas the proportion due to coronary heart diseases, stroke, cancer and other noncommunicable adult diseases will rise from around one-half to three-quarters.[1] The proportion of deaths from injuries, too, will increase. Malnutrition and unsafe drinking water in the less-developed countries, along with indoor air pollution from cooking and heating in poor households, will remain major killers – even as cigarette smoking, alcohol consumption and dietary excesses cause increasing rates of adult disease and premature death. The burgeoning global tobacco epidemic killed at least 4 million people in 2000. By 2020 it will be killing 10 million per year – that is, about one in every three adult deaths.[1] Diabetes, currently afflicting around 4% of the world's adults, is becoming more prevalent as urban populations everywhere get older and fatter. The widespread decline in traditional family and social supports may contribute to mental depression becoming a major source of chronic health impairment within several decades.

In this changeable world surprising shifts in disease patterns may become more frequent. Life expectancy plummeted in Russia in the early 1990s as social structures and controls dissolved following the collapse of communism. Elsewhere during the 1990s, adult life expectancy fell by at least two years in around 10 other (non-African) countries, including Haiti, Ukraine, Moldova, North Korea and several countries of Central Asia. The newly named variant Creutzfeld-Jakob disease (human 'mad cow disease') appeared unexpectedly in Britain in the mid-1990s, and its future course remains ominously uncertain. For much of the past half-century we imagined that humankind's ancient foe, infectious disease, was in terminal retreat: antibiotics, pesticides, vaccinations, modern sanitation and environmental controls seemed like a winning hand. But then HIV/AIDS emerged and, by the year 2000, was killing over 2 million people annually. Cholera has extended its dominion over the past quarter-century, having embarked on its longest-ever pandemic. Tuberculosis, assisted by HIV, has rebounded. During that same period, the mosquito-borne diseases, malaria and dengue fever, have become resurgent.

So, it is appropriate to stand back from the details and ask big questions about the determinants of population health – and about the sustainability of human health across future generations. The great theme permeating that long-running story is the intimate relationship between environmental circumstances, social conditions, human biology and the occurrence of disease. It is an *ecological* story that reflects the shaping of both human biology and society by environment. It reflects the dependence of human population health upon stocks of natural resources, the functioning of ecosystems, and cohesive social relations.

Disease in history: seeking patterns

The historical record contains many spectacular one-off disease events. One thinks of the great killing epidemics of classical Athens and of Justinian Constantinople; the fourteenth-century Black Death; the Irish potato famine in the 1840s; and the 'Spanish influenza' pandemic that killed around 25 million people in 1918–19. The history of human disease is replete with anecdote and intrigue. Perhaps the Fall of Rome was hastened by lead-induced dementia in the ruling class who stored their wine in lead-lined vessels. The porphyria and resultant intermittent madness of Britain's King George III in the late eighteenth century helped precipitate the fiscal feud that caused the American War of Independence. Smallpox in the seventeenth and eighteenth centuries killed emperors in Japan and Burma and kings and queens in Europe. Beethoven's deafness may have been caused by a markedly raised blood lead concentration (as evidenced in preserved samples of his hair). The Battle of Waterloo may have turned upon Napoleon's haemorrhoids and his resultant sleeplessness.

But those are merely history's eye-catching headlines. The story runs much deeper. It is embedded in the long biological and social evolution of humans and their australopithecine ancestors over the past 5 million years. It is a story of genetic adaptations acquired by globally dispersing hunter-gatherer populations when confronted by unfamiliar local environments. Some of those genetically based traits affect the health of today's populations even though they may now live in environments free of the original hazard. Sickle-cell anaemia in African Americans who are no longer threatened by malaria, and skin cancer in fair-skinned Australians who no longer live under clouded northern European skies are two simple examples. The story is also embedded in human cultural evolution, particularly over the past 10,000 years since agriculture emerged, entailing changes in diet, patterns of infectious diseases, urban living, workplace hazards, and social inequalities. As the scale of human intervention in the natural environment has increased, depleting resources and disrupting ecosystems, so the plot has thickened further.

The scale of real interest, then, is not that of personal haemorrhoids or porphyria. Rather, it lies in the ebb and flow of diseases in whole populations. These are the deeper currents that signify changes in the ecological circumstances of human populations, and which have often affected the course of history. Consider how the warming and climatic instability that followed the end of the last ice age, around 15,000 years ago, induced landscape changes, species dispersals and regional food scarcity that eventually pressed many human groups into growing their own food and herding animals. Consider how the subsequent crowded early villages and towns acted as incubators for novel infectious diseases able to enter human populations from cohabiting animal sources. During the first millennium AD, the repeated ravaging of the Roman Empire and the vast Chinese Han Empire by imported epidemic diseases affected the political map of Eurasia. Later, following the devastating Black Death in Europe, the loss of faith in church and politics contributed to a new social fluidity, scepticism and individualism that potentiated the

Renaissance in Europe and the rise of post-Aristotelian empirical science. With Europe becoming expansionary in trade and conquest, the unwitting reinforcement of adventurous bands of Spanish conquistadors by deadly legions of measles, influenza and smallpox viruses facilitated the conquest of the vast and opulent civilisations of Central and South America. And so the story continues. During the past century, the profile of disease has changed radically, first in Western countries and now in the rest of the world.

We are transient participants in this great, unfinished adventure. Hominids have processed from humble australopithecine origins on the margins of the African savannah several million years ago to today's world, in which modern humans stand, mightily, centre-stage. Central to this unfinished story is the ever-changeable pattern of human health and disease, reflecting the shifts in human ecology and the extent to which our way of life is materially provident, socially equitable and ecologically sustainable. Historical anecdotes make fascinating reading, of course, but it is the larger story at the population level that will assist us to find a sustainable path to the future.

OUR PERCEPTIONS of the causes of disease have evolved rapidly over the past century. Earlier longstanding ideas of divine wrath, astrological conjunctions and non-specific miasmas were replaced in the late nineteenth century by the idea of specific casual agents. That idea arose particularly from the influential germ theory as propounded by Louis Pasteur and Robert Koch. It was reinforced by the elucidation of vitamin deficiency disorders and the identification of particular disease-inducing exposures in the workplace. As the science of genetics evolved; as neo-Darwinism arose in the early twentieth century from the blending of Darwin's theory of evolution with Mendel's theory of inheritance; and as Erwin Schrodinger and others plumbed the mysteries of the nature and origins of life itself, so by mid-twentieth century deeper questions were being asked about human biology and disease. These included questions about the biological ancestry of the human species, about human susceptibility or resistance to agents of disease, and about the social and environmental modulation of disease occurrence.

By the 1960s it became clear that high-income, urbanising populations in the West and Japan had substantially exchanged the ancient burden of infectious diseases for a new set of noncommunicable diseases of later adulthood. The overly simplistic assumption emerged that health and disease were mainly determined by personal behaviours and local environments.[2] With infectious disease seemingly under control and with modern energy-intensive agriculture yielding larger harvests, any sense of dependence on the wider environment had receded. Western epidemiologists led the way in demonstrating the health hazards to individuals of cigarette smoking, of excessive alcohol consumption, of diminished physical activity, and of acquiring high levels of blood pressure and blood cholesterol. Even so, there were other stirrings: there was new talk of 'human ecology', a growing awareness of the insidious hazards to species and ecosystems from DDT and other human-made organic chemicals,[3] accruing evidence of adverse respiratory effects from exposure to a range of urban air pollutants, and, in the 1970s, discussion about the 'limits to growth'.[4] During the 1980s, concerns over human-induced stratospheric ozone depletion and impending global climate change grew stronger. By century's end we could see more clearly that the sheer weight of the human enterprise was increasingly overloading, disrupting and depleting many of Earth's great biophysical systems. Here was a new, potentially serious dimension of risk to human well-being and health.

From this narrative we see that there are probable risks to population health whenever we exceed the capacity of the natural environment to stabilise, absorb, replenish or recycle. Intensifying the production of British beef by feeding cows recycled scraps of other cows, and thus violating nature's food chains, opened up a niche for an infectious agent. If global climate change intensifies the El Niño system, then droughts, tropical hurricanes and floods will increase in many regions. We can gain some perspective on likely future problems by considering some of the large-scale ecological experiences of past civilisations.

A polar bear for a bishop: carrying capacity and survival

The tragic story of Easter Island, one of the world's most remote specks of land in the south-east Pacific, encapsulates the dire consequences for humans of exceeding the natural environmental carrying capacity of a closed system.[5] Having settled the island in about 900 AD, the once thriving Polynesian population, the Rapanui, eventually denuded the island of forest. The trees were needed as rollers for transporting massive stone statues, the poker-faced *moai*, to their ocean lookout posts. Massive soil erosion ensued. Hence wooden canoes for fishing could no longer be built. From an estimated peak population of around 7,000 in the fifteenth century, numbers dwindled, conditions deteriorated, and warfare and cannibalism broke out. When Dutch explorers landed in 1722, there were fewer than 2,000 inhabitants – plus several hundred *moai*. By the nineteenth century, the survivors had dwindled to several hundreds.

A similar but less well known story comes from the other side of the world. The mysterious demise of the West Viking settlement in Greenland in the fourteenth century attests to the vulnerability of human societies to small shifts in environmental conditions if they are already living on the margins of viability. Which of the Four Horsemen of the Apocalypse bore down upon that remote settlement at the limits of European colonialism? Regional climate change, leading to malnutrition and culminating in acute famine, is the most likely.

Global temperatures began rising in the ninth century AD as the Medieval Warm period arrived. The Norse began to expand their settlements around the North Atlantic: from northern Scotland, to the Faroe, Shetland and Orkney Islands, to Iceland and, a hundred years later, to Greenland. The Norse colonisation of Greenland, established around 985 AD and eventually totalling about 4,000 persons, lasted for five centuries. The eastern settlement was initiated by the renegade viking Erik the Red.[6] With a real estate developer's flair and considerable poetic licence, Erik called the great ice-bound continent 'Greenland', to entice further settlers. There were indeed several grassy but treeless fjord-like havens around the south-western coastline. The eastern settlement was towards the southern tip of Greenland, four days sailing westwards from Iceland. The western settlement was 500 kilometres further up the west coast of Greenland, at Godthabsfjord. Each location had sufficient pasture for grazing and for the production of fodder for winter. It was difficult to grow cereals: the climate was cold and the soil was thin. The settlers got by with cows and sheep, along with some goats and pigs. The diet was supplemented with caribou, fish, seal, snow hare and some seasonal berries. Walrus ivory and polar bear skins were exported. Timber, iron nails and corn were imported.

Contemptuous of the primitive Inuit 'skraelings', whom they considered akin to trolls, the colonists learnt little about the wider possibilities for acquiring local foods. Had they, for example, adopted the Inuits' toggling harpoons, they could have hunted harp and ring seals all year round rather than just the harp seals during the warmer months. Indeed, compared to other contemporary Norse settlements in varied environments around Europe, the Greenland settlers displayed an unusual rigidity. They struggled to recreate a little Norseland with unchanged styles of clothing, housing and diet. Later, both the east and west settlements became more fervent in their religious practices. Christianity had only recently arrived in the Scandinavian region, after struggling northwards in Europe during the Dark Ages. The settlements paid their tithes to the Church in walrus tusks. The eastern settlement then petitioned the Norse king to send them a bishop in return for a live polar bear. Since bishops had become plentiful around the royal court in twelfth-century Norway, and since polar bears were a prestigious novelty, the deal was readily concluded. A stone cathedral with stained-glass windows was duly built. Its ruins remain there today. The bishop acceded to high office in the eastern settlement and assumed a large prime farming site for himself. Meanwhile, one presumes, the polar bear dined well in Norway.

In both Iceland and Greenland the settlers changed the landscape. Archaeologists have revealed that a loss of plant cover and extensive soil erosion occurred within several centuries, increasing the sensitivity of the area's pastures and cropland to climate variability. Computer simulations indicate that the western settlement was more vulnerable to the effects of temperature declines than the eastern settlement. Regional temperatures began falling during the fourteenth century and the climate deteriorated, as Europe's Little Ice Age emerged. Records from Iceland indicate an increase in sea-ice during the first half of the fourteenth century. The Inuit were moving south from above the Arctic Circle. The Greenland settlers were increasingly isolated, as sailing became more dangerous. A letter sent by the Pope took five years to be delivered. The western settlement perished mysteriously around 1350, and the larger eastern settlement vanished during the later 1400s.

The final collapse of the western settlement seems to have occurred abruptly. The zoo-archaeological analyses of the remains of animals and insects in association with human habitation are intriguing. In one of several well-preserved houseblocks there is chronologically layered evidence of inhabitants resorting to eating snow-hare and ptarmigan, of slaughtering lambs and young calves, and finally of eating the family dog. Meticulous study of the layers of preserved insects indicates that warm-loving faeces-feeding insects, long present in the inhabited houses, were abruptly succeeded by cold-dwelling carrion-feeding insects.[7] No human remains have been discovered. The fact that the front doors of the houses were left in place provides a clue since, in Norse culture, a family that was deliberately relocating would have at least taken the symbolically carved, spiritually significant, wooden doors with them. All the evidence thus suggests a rapid abandonment as food ran out, in late winter or early spring. Did they desperately board the boats and perish at sea?

Historians have not yet settled the matter. Did the climatic deterioration become irresistible by around 1350? Were there conflicts with the Inuit? Or was there a crippling decline in overseas trade as European consumers switched to high-quality ivory from African elephants in preference to walrus ivory? Recent analyses of Greenland ice-cores show that the extreme of cold in fourteenth-century Greenland occurred in 1349–56.[8] Although these were exactly the years when the Black Death reached Scotland and Scandinavia, there is no evidence of the bubonic plague having reached either Iceland or Greenland. On the other hand, the marked declines in harp seal and cod populations that occurred more recently in the region during the slight northern hemisphere cooling of 1950–75 indicate just how vulnerable the marine food yield would have been to the fourteenth century cooling. With the climate closing in on them, with their limited pastoral land degraded and with a limited repertoire of food sources, it seems likely that the balance of health, nutrition and survival was finally tipped against the West Vikings.

THE STORY of the West Vikings, like that of the Easter Islanders, may seem a rather extreme example. However, there are many other examples where human societies have pushed at the margins of environmental 'carrying capacity', leaving no buffering against the ever-present possibility of climatic-environmental reversals. An early example is the decimation of settlements along the River Nile 12,000 years ago as post-ice-age climatic fluctuations disrupted river flooding and vegetation patterns, causing violent inter-settlement conflict that is evident in fractured and shattered skeletal remains. Eight thousand years later a similar disaster occurred, when a prolonged drought brought the Old Kingdom of Egypt to its knees. The Pharaohs of the regrouped Middle Kingdom learnt a lesson, and took greater pains to defend agricultural Egypt against the vicissitudes of the Nile and its annual silt-bearing floods.[9]

After a thousand years of agricultural innovation and urban florescence the Mayan civilisation imploded early in the tenth century AD as a combination of global and regional climate cycles brought severe droughts to Central America. Several centuries later the pueblo-building Anasazi at the eastern fringe of the Colorado Plateau (Northwest New Mexico) disappeared as their tenuous water sources dried up.[9] For many centuries following the warmer and less populous Middle Ages, Europe suffered repeated acute famines during the Little Ice Age (approximately 1450–1850). The last great famines in Europe occurred in the nineteenth century.

These examples underscore the profound dependence of human wellbeing, health and survival upon environmental conditions and natural resources. Serious environmental disruption usually results in deprivation, disease or death typically mediated by pestilence, famine or conflict. Modern urban societies, both distant from and buffered from immediate exposures to most environmental changes, easily forget that a population's health depends crucially upon food supplies, fresh-water availability, local microbial ecology, reliable climatic patterns and shelter. Yet, as we shall see in later chapters, as urban populations expand and as the size of their 'ecological footprint' increases, so the risk increases of seriously exceeding Earth's aggregate carrying capacity.

The long story of human biological evolution, geographic dispersal and social development, and the associated patterns of health and disease, is a story of pushing back environmental limits. Non-human species must cope with local environmental vicissitudes by relying on their evolutionary endowment. Humans, however, have pushed back many environmental limits via spectacular cultural advances: tool-making, language, agriculture, animal husbandry, the harnessing of elemental energy, urban settlement, industrialisation, infection control, molecular biology and telecommunications. To support our growing numbers we have occupied more land and extracted more food and materials. Humankind now accounts for more than one-third of Earth's total photosynthetic product, either by direct and indirect consumption or by alienation of land.[10] Cultural evolution has thus hugely extended our control over diverse environments.

Within the past 80,000 years the anatomically modern species *Homo sapiens* has colonised non-polar habitats all around the world. This ability to migrate into new environments, buffered by cultural adaptation, has exposed human biology to various unfamiliar living conditions. This in turn has caused various genetic adaptations in body shape, skin colour and various metabolic capacities. Not suprisingly, some of these biological adaptations have had health consequences in recent times in populations that have, again, changed their place and style of living. Examples include fair-skinned Celts developing skin cancers in sun-drenched northern Australia, darker skinned South Asians developing vitamin D deficiency in less sunny northern Europe, and lactose-intolerant Asians discomforted by Western-style dairy foods.[11]

Over time, changes in human culture, social arrangements and, more generally, in human ecology have been the dominant influence on population disease profiles and survival. The drive to increase food supplies has frequently resulted in unintended changes in local ecosystems – changes that have usually then rebounded against human wellbeing. For example, when irrigated croplands turn salty, as happened in Mesopotamia 4,000 years ago, or when natural food supplies are over-harvested, then malnutrition and starvation occurs and civilisations may collapse. Inter-community warfare broke out among the Maori in New Zealand several centuries ago over the food pressures caused by wiping out the bonanza of large, flightless, edible moas within half a millennium after settlement.

These experiences tend to be the rule, not the exception. It is a characteristic of humans to seek to control and change the environment. We are what the ecologist Bill Rees calls 'patch disturbers'.[12] Our natural style as hunter-gatherers has been to exploit and deplete local patches, then move on to another. The size of the disrupted patch has increased over time. The early Australian Aborigines, from around 50,000 years ago, gradually transformed the landscape with 'firestick farming' and tropical forest burning which resulted in pine forests and rain-forest being replaced with eucalyptus trees and mallee scrub. Agriculture and forest manipulation by the North American native population extended over one-third of the continent by the fifteenth century. Today, however, the rate of human impact on the environment has increased dramatically and the biosphere is showing the strain.[13] Some types of environmental strain, such as stratospheric ozone depletion, human-induced climate change and accelerating widespread biodiversity losses, we have not previously encountered. We have, too, been careless with food-producing ecosystems on land and at sea, and their future capacity to feed several extra billion people is now in question. If the bruising environmental impact of 6-plus billion humans upon the biosphere persists, we can expect to encounter some larger-scale health setbacks in coming decades.

The ways in which these large-scale changes to our biophysical and social environments can affect patterns of health can best be understood within an ecological framework. First, though, we should try to define 'health'.

What is 'health'?

Defining 'health' is not much easier than defining 'time'. Health, in the non-human natural world, is no more than a means to an end; good biological functioning is a prerequisite to reproductive success. The level of biological functioning is a product of genes, life history and current environment. The genetically based component of reproductive performance is often referred to as Darwinian 'fitness': that is, the individual's innate capacity to contribute his/her particular genes to the population's next generation. In the human species, to complicate matters, reproductive capacity is modulated by cultural and socioeconomic influences. Reproductive 'fitness' is not necessarily the same thing as 'health'. The parental animal that instinctively sacrifices itself to defend its offspring, the bearers of its genes, suffers poor health (serious injury or death) but has high Darwinian fitness.[14] Conversely, a woman who avoids pregnancy may increase her personal health by avoiding the hazards of reproduction, but she reduces her Darwinian fitness. Nevertheless, throughout nature healthier individuals generally have better reproductive potential.[15]

Health can also be addressed as a collective property of a population. Indeed, this book is primarily about the determinants of patterns of health and disease in populations. Since healthy populations tend to out-perform, to out-compete, less healthy populations, let us also look briefly at the extent to which genetically based variation in Darwinian fitness can also be a property of groups. Within 'social' species such as bees, within-group cooperation can increase the average probability of survival and reproduction of individual members. As we shall see later, one particular selection pressure that probably favoured the evolution of the large human brain during the early Pleistocene was the need for greater cooperation in seeking food supplies, including the hunting of animals. A strain of early humans in which the 'cooperation' gene had become prevalent would function better as a group, and they would tend to out-reproduce other less cooperative strains. Nevertheless, much of the selection pressure in relation to that gene would have acted at the individual level: those individuals less able to participate in group activity would have been marginalised in the survival stakes. True group selection is unusual in nature: inter-individual variation yields much quicker changes in gene frequency than does inter-group variation.[16]

The notion of collective health can also be applied to whole ecosystems. Over the past decade the concept of 'ecosystem health' has been paid increasing attention by ecologists.[17] The attributes of ecosystems such as diversity, vigour, internal organisation and resilience are the criteria of healthy systems. Conversely, indices of 'ecological distress' or of reduced 'biological integrity' can help us identify ecosystems that are prone to decline or collapse.

Now, in humans, what is the relationship between good biological function and health? Nature, with its Darwinian agenda, may not be interested in how we feel or look – but we, via consciousness and culture, certainly are. We imbue 'health' with personal and social meaning. We aspire to health, wealth and wisdom, not just as functional means but as desirable ends. Nevertheless, in culturally diverse human societies the preferred form of health as an 'asset' may differ. René Dubos has pointed out that the state of human biological 'adaptedness' to the circumstances of an ancient agrarian society differed from that required by the nineteenth-century industrial revolution, and differs from that required in today's automated age.[18] When hunter-gatherers turned to agriculture, over the course of several thousand difficult years, the fossil record suggests that their health initially deteriorated. They experienced more food shortages and more nutritional deficiencies, their growth was stunted, dental decay and arthritic disease increased, and life expectancy declined a little. Yet, as we shall see in chapter 7, this agrarian transformation of human ecology allowed shorter birth spacing and hence an increase in fertility. Their reproductive 'fitness' thus increased, even as their health apparently decreased. Molecular genetic analyses of European populations show that Middle Eastern farming populations gradually expanded through Europe, overwhelming and replacing the slower-breeding hunter-gatherers.

The interplay between nature and culture, in humans, is well illustrated by the relationship between maternal health and reproductive success. In large-brained humans, the demands of fetal brain development draw upon the pregnant woman's nutritional reserves. Further, in order to enable passage of the large fetal brain, birth in humans occurs at a markedly 'premature' stage relative to non-human primates. Therefore, the adult woman in traditional society must continue to care for and breast-feed the helpless new-born baby for several years. Human reproduction and extended breast-feeding thus takes an unusually great toll on the woman's biological reserves. Traditional cultures have long understood that births need to be sufficiently spaced for a woman's 'vitality' to be preserved and replenished. Hence the wonderfully varied social taboos and within-marriage relations that different cultures use to modulate human conception. In some developing country settings, contraception is used much less to reduce the number of births than to space them. These practices affirm that the woman's health and vitality is both a means and an end – a biological means to successful reproduction and, therefore, a culturally reinforced end that is achieved by deliberate birth spacing.

There are, of course, no guarantees of good health in the natural world. The ceaseless interplay between competing species, groups and individuals; the ubiquity of infection; the vagaries of climate, environment and food supplies; and the presence of physical hazards – these all contribute to the relentless toll of disease, dysfunction and death throughout the plant and animal kingdoms. Nevertheless, within enlightened human society, we aspire to shared good health as an important social goal. Yet, there are inevitable differences in health status between individuals because of genetic susceptibilities and the occurrence of random events. Indeed, as René Dubos reminds us: 'The concept of perfect and positive health is a utopian creation of the human mind. It cannot become reality because man will never be so perfectly adapted to his environment that his life will not involve struggles, failures, and sufferings.'[19] While this utopian idea has inspirational value, he says, it can become a dangerous mirage if its unattainability is forgotten.

Birth, health, disease and death are part of the landscape of life. There are good times and bad times in the ongoing life of all populations as physical circumstances change, as disasters occur, and as natural environmental stocks increase and decline. The interplay between these stocks of resources and the flows of births and deaths determines the population's prospects. To survive, a population must be able to maintain its numbers across generations. To thrive and extend its range, it must be able to increase its numbers and expand into new territory. Expansion can be achieved either by occupying new terrain that meets that species' environmental requirements (of temperature, types of food, etc.) or by adapting to the new environment. Humans, with their omnivorous eating habits and brain-powered cultural ingenuity, are supremely adaptable. The ensuing chapters explore this story of *Homo sapiens* over many millennia as new frontiers have been encountered. But first we should clarify the notion of 'ecology' and its relevance to human health and disease.

Seeking an 'ecological' perspective

The word 'ecology' (from the Greek *oikos*, meaning household) was coined by the German biologist Ernest Haeckel in 1866. Ecology refers to the interconnected relationships between populations of plants and animals and between them and their natural environment. There is an emphasis on integration, interdependency, and feedback processes, all within a systems context. Ecological systems can be studied at different levels of organisation: individual organisms, populations, biotic communities, ecosystems, biomes, the biosphere and the ecosphere. The *biosphere* is that part of our planet where living organisms exist. At its limits it extends 10 kilometres above sea level and 10 kilometres below sea level. It is a thin and discontinuous film over Earth's surface, with a maximum thickness equivalent to no more than two-thousandths of the planet's diameter. The *ecosphere* consists of the biosphere and all of the inanimate systems and processes with which living things interact, such as the climate system, fresh water and oceans.

Ecology is the broadest and most inclusive of the natural sciences. The human dimension of ecology, says the *Oxford Dictionary*, encompasses 'humans' habits, modes of life, and relationships to their surroundings'. To understand the foundations of human ecology requires knowing something of the biological evolution of hominids, that branch of the primate family leading to the *Homo* genus. We must explore how hunter-gatherer social behaviour developed to maximise group wellbeing and survival, perhaps guided by natural selective forces that favoured cooperation and altruism. This perspective highlights the dependence of human groups and societies on the natural world, as the source of food, raw materials and of the many cleansing, recycling and stabilising 'services' of nature.[20] We can also understand from our ancestral past something of the foundations of childhood emotional and cognitive development, including children's fascination with domestic and caged animals, with tree-climbing, and the bedroom fear of nocturnal predators.

Part of the downside of Western science and culture has been the lost sense of human participation in and dependence upon nature. Ideas in Western culture, reaching back to Plato, have posited Man as the pinnacle of creation, the culmination of the Great Chain of Being, the centre of the universe. Ptolemaic astronomy maintained Earth's central position in a cosmos of theologically ordained perfect spheres, circles and epicircles. The corresponding centrality of humankind was essential to the Church's teaching and political power. The flowering of Late Renaissance science proclaimed the power of systematic observation, of reducing a complex real-world whole to researchable parts, of understanding the clockwork-like mechanisms of the world. The seventeenth-century views of Francis Bacon and René Descartes prevailed: empiricism, reductionism and material determinism would yield new understanding and control over nature. Here, at last, was the modern means of realising the Old Testament's exhortation: 'and God said unto them [Adam and Eve]: Be fruitful, and multiply, and replenish the earth, and subdue it; and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth.'[21]

In the realm of astronomy there were some particularly unsettling stirrings in the sixteenth and seventeenth centuries. Copernicus, Galileo and Kepler eroded the ecclesiastically endorsed view of the cosmos. They adduced evidence that the Earth circled the sun; the moon, viewed by telescope, was pockmarked; Jupiter had its own four moons; and planetary orbits were elipitical, not circular. Further crippling challenges to the dogma of a human-centred cosmos followed. Two centuries later, Darwin argued that we and other living creatures were not custom-built by a creator, but were the changeable products of an amoral and dispassionate process of natural selection. The human species was part of this continuing process of biological evolution, with no biblically certifiable birth-date and no guaranteed permanence. Then, early in the twentieth century, Freud (resurrecting a debate from classical Greek philosophy) queried the supremacy of individual free will and rationality.[22] The self-defining and executive decision-taking role of our 'ego', he said, is liable both to subversion by darker ancestral drives from the recesses of the mid-brain, the id, and to being overruled by the socially conditioned, higher-minded, superego.

We have therefore passed through the twentieth century knowing that our planet is but a peripheral speck in a vast and violent universe, that there is a certain serendipidity about the origins of the human species and an uncertain future for it, and that human rationality is beset by inner fears, urges, prejudices, inhibitions and the echoes of childhood. We have also learned of the unpredictable and complex nature of the world around us. Newtonian physics suffices to plan moon-shots and to help pedestrians avoid being hit by a bus, but Einstein, Bohr and Heisenberg have shown us the surprising relativities, non-linearities and uncertainties of the cosmic and atomic worlds. Today, we are gaining insights into the phenomena of chaos ('ordered disorder'), complexity, and the self-organising properties of the systems and assemblages of the natural world.[23] We are thus complementing the 'selfish gene' perspective with a clearer understanding that cooperative activity, at various scales and via the realisation of emergent properties, can confer survival advantage.

We are duly acquiring an ecological perspective on humankind within the world at large, as scientists engage increasingly in integrative types of thinking. Yet there is a novel tension in the contemporary situation. At the other extreme of scale, we are unlocking the secrets of life itself. For half a century we have understood the basic genetic code – the four-letter molecular alphabet that comprises four nucleotide bases (designated as A, T, G and C). These, in runs of several thousands, are arrayed on chromosomes as 'genes' – with each triplet of nucleotides coding for a specific amino acid. Each gene thus specifies the assembly of a particular protein (made up of amino acids), and those proteins then do the cell's metabolic work or act as messengers or hormones to influence other cells. We now have the laboratory tools to catalogue the entire genome of an organism. We have begun with yeasts, worms and fruit-flies. Humans, with around 35,000 genes, have approximately two orders of magnitude more genetic material than do protozoan yeast cells and invertebrate organisms. We have now catalogued the full genetic sequence of a 'standard human'. We may next learn to repair genes by correcting molecular 'spelling errors'. We can already transfer whole genes between totally dissimilar species – such as taking the anti-freeze gene from cold-water flounder fish and inserting it into the genome of strawberries to make them frost resistant. Expectantly but nervously, we stand on the brink of a 'post-genome' society in which we face the possibilities of therapeutic cloning, of as-yet-unimagined transgenic organisms, of purpose-built DNA vaccines, of genetic therapy, and of personalised genetic bar-coding that may facilitate a risk-minimising individual lifestyle.

These technological triumphs aside, we are still struggling to come to terms with humankind's place within the biosphere. The idea of 'ecology' remains a relatively novel perspective. Western culture has fostered the illusion of humans as being apart from nature, rather than being a part of nature. Darwin's more egalitarian and ecological view of the human species was readily applied by others to a frankly competitive view of human society. In the ruthless struggle for existence, they said, only the fittest individuals survive to breed. It was Herbert Spencer, not Darwin, who coined the phrase 'survival of the fittest': if nature is red in tooth and claw then 'fitness' in humans must entail conquest, dominance and hierarchical relations. Here were the origins of social Darwinism and of the eugenics movement. The concomitant values of these early twentieth-century ideas were elitist, not egalitarian; they were controlling, not participatory. It has taken us another hundred years to become serious about trying to understand human biology, culture, social relations, health and disease within an ecological framework.

ECOLOGY IS a way of observing and thinking about the complex natural world; it is integrative, not disaggregative. Three decades ago, Paul Shepard, the first academic to be appointed a professor of human ecology, wrote:

> Truly ecological thinking [has] an element of humility which is foreign to our thought, which moves us to silent wonder and glad affirmation. But it offers an essential factor, like a necessary vitamin, to all our engineering and social planning, to our poetry and understanding. There is only one ecology; not a human ecology on one hand and another for the subhuman . . . For us it means seeing the world mosaic from the human vantage without being man-fanatic. We must use it to confront the great philosophical problems of man – transience, meaning, and limitation – without fear.