Environmental change and disease
The Lloyd Roberts lecture 1994

This article is based on a lecture given at the Royal College of Physicians on 29 March 1994 by Sir Crispin Tickell, The Warden, Green College at the Radcliffe Observatory, Oxford.

Life is delightfully defined in the Concise Oxford dictionary [1] as 'a state of ceaseless change and functional activity peculiar to organized matter, and especially to the portion of it constituting an animal or plant before death'. As a part of that state of ceaseless change, and perhaps uniquely as observers of it, our little animal species usually forgets, if it ever knew, the limitless interdependence of organisms within a system of life which thinly covers the surface of our planet like the bloom of an apple.

I want to begin with that interdependence—that interconnectedness—of organisms which constitute life. A happy phrase, much used in a different sense by early philosophers of natural history was 'the great chain of being'. This chain stretches in two ways: the vertical one of species and clades (or suites of species over time); and the horizontal one of habitats and the ecosystem of life within them. In both directions the system is in constant movement and change. In this lecture I will concentrate on the horizontal chain. Our own little animal species is an assemblage of species: from the mitochondria, once independent, in every human cell, to the billions of bacteria in and on and around us, without which we could not exist. Likewise our species is part of a wider ecosystem of plants and animals in a web of life of almost infinite complexity. We are both composed of organisms and joined to organisms. As Darwin once wrote:

'We cannot fathom the marvellous complexity of an organic being. But...each living creature must be looked at as a microcosm—a little universe, formed of a host of self-propagating organisms, inconceivably minute, and as numerous as the stars in heaven.' [2]

The interconnectedness is unstable. Stability in biology would be like stability in physics: death in one case, inertia in the other. The prime characteristic of life is dynamism. The links in the chain of being are always changing, and the chain itself can change the direction of its coils. Yet the system holds amazingly firm. Only the great cataclysms in the history of the earth—the collapse of 90% of marine organisms at the end of Permian times 250 million years ago, or the more famous crash which brought the dominance of the dinosaurs to an end 65 million years ago—challenged the system itself. If the system, with our ancestors the shrews, had not survived, we would not be here today.

But within the system the twin forces of competition and cooperation, skewed from time to time by mutation, are intense. Doctors are perhaps more aware of the first than the second. In Alice's adventures in Wonderland [3], Alice asked the Red Queen why, if she ran so fast, she never seemed to arrive anywhere.

'A slow sort of country!' said the Queen. 'Now here, you see, it takes all the running you can do to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!'

The so-called Red Queen effect is evident throughout biology. We have to run—or change—to stay where we are. We are in a war to the death with those of our parasites—from worms to bacteria to viruses—for whom our bodies are natural targets. The physical causes of premature death are rarely physical. As has recently been well written by Matt Ridley:

'When a tree falls in the forest, it has normally been weakened by a fungus. When a herring meets its end, it is usually in the mouth of a bigger fish or a net. What killed your ancestors two centuries or more ago? Smallpox, tuberculosis, influenza, pneumonia, plague, scarlet fever, diarrhoea. Starvation or accidents may have weakened people, but infection killed them. A few of the wealthiest ones died of old age, or cancer, or heart attacks, but not many. The great war of 1914 to 1918 killed 25 million people in four years. The influenza epidemic that followed it killed 25 million in four months... Europe was laid waste by measles after AD 165, by smallpox after AD 251, by bubonic plague after 1448, by syphilis after 1492, by tuberculosis after 1800.'

Parasites may also have played a key role in the evolution of sex. Fungi, bacteria and viruses break into human cells or sabotage their genetic machinery. To do so they use protein molecules to bind themselves to other molecules on the cell surface. If they are not to break in by opening the lock, the host is wise to change the lock combination. Genetic mixing through sexual reproduction in each generation represents a constant changing of the combination.

Every creature is thus in a perpetual arms race.
Because parasites can reproduce so quickly, they can normally outpace their hosts. According to one study [5] the AIDS retrovirus has changed its make-up more in 10 years than humans have in 10 million. No wonder that humans have evolved so rich an array of resistance genes, some more effective than others, and most needing time to adapt to the latest parasitic ingenuity.

It is all but impossible to distinguish changes arising from within the system from changes brought about by environmental and other pressures from outside. Modification of the natural environment is a prime factor in evolution. It is happening all the time. Indeed the behaviour of living organisms—whether beavers in the forest or algae drawing carbon out of the atmosphere—makes a major contribution. But such change usually takes place slowly over centuries or even millennia. Most organisms and the ecosystems of which they are part have time to adapt or migrate. Some may be able to do so easily because it is within their normal repertoire. Because of the repercussive effects of all change, neither the organisms nor the ecosystems will be quite the same as when the process began. Other organisms will not be so robust. They can be saved by a lucky mutation; or they may go the way of 99.9% of all species that have ever lived, and become extinct.

**Climate change**

Of all the outside agents forcing evolution into new courses, none is more important than climate change. Climate changes all the time. It seems to have ridden a slow roller coaster for the past 60 million years. It warmed gradually until about 53 million years ago, reaching a peak that brought crocodiles to northern Canada; and then it entered a long, undulating downward slide towards the ice age world of the past few million years. We are living in one of the brief warm periods in the recent history of the earth. For the last two and a half million years there has been a broad 100,000 year rhythm, with over 20 glacial periods interspersed with 10,000 to 15,000 year interglacials. Even the last relatively stable 10,000 years have shown important variations. For example, during the hypsithermal, about 6,000 years ago, the average temperature was about 1.5°C more than it is today. Sea levels were a little higher. Cooler conditions then set in and did not reverse until around 2,000 years ago. The early Middle Ages were the warmest in recent memory. But in the little ice age between the 14th and 18th centuries, temperatures were between 1 and 2°C below those of today. There were also wide regional variations, and we still know relatively little about corresponding events in the southern hemisphere.

These changes, big and small, had profound effects on life. They advantaged some species and ecosystems and disadvantaged others. In our own case they must have contributed to the emergence of humans adapted to Ice Age Europe—the Neanderthals—and also to the more recent rise and fall in human numbers a few centuries ago. The benign conditions of the 11th and 12th centuries AD led to a big increase in food production and population, while the downturn at the end of the 15th century led to shorter growing seasons, social disruption, weakening of human health, and conditions conducive to the spread of bubonic plague.

**Human-induced change**

Within the broad picture of natural change there is clear evidence of human-induced or anthropogenic change. But until the industrial revolution, the effects of human activities were local, or at worst regional, rather than global. All the great civilisations of the past have cleared land for cultivation, introduced plants and animals from elsewhere, and caused long lasting change. The eastern and southern shores of the Mediterranean were once relatively well watered forested country: their conversion to grain growing areas for the Roman Empire and its successors contributed to its current deterioration into semi-desert. Mesopotamia was a flourishing civilisation 5,000 years ago. Initially wheat was grown as the staple food but irrigation caused the soil to become more saline. The more salt tolerant barley had to be grown instead. Deforestation nearby caused the water table to rise and enhance salt accumulation in the surface soil, while the resultant increased run-off caused soil erosion and silting of the irrigation system. Around 3,500 years ago the build up of salt and silt overwhelmed the agricultural heartland and contributed to social breakdown.

During the last three or four decades, it has become apparent not only that this change is occurring at an alarming rate, but that some of the change may be irreversible on any human time-scale. Degradation of the quality of land, water and atmosphere, together with a reduction in biodiversity may drastically diminish our capacity to adapt to or mitigate the effects of environmental change.

The prime engine of the recent dizzy-making changes is the industrial revolution. On the one hand there has been a huge growth in human population, on the other there has been an equally huge growth in consumption of the world’s resources, both factors combining to overload the carrying capacity of the earth’s natural systems.

In broad terms there were around 10 million people at the end of the Ice Age, 1 billion in the lifetime of Thomas Malthus, 2 billion in 1930, and around 5.6 billion now; short of catastrophe there will be around 8.5 billion in 2025. At the same time there has been a still steeper growth in urban populations, with all that implies for the resources surrounding cities and the living conditions within cities. In 1950, 29% of the world’s population was urban, in 1990 it was nearer 50%, and by 2025 it may be around 60%. An observer
from outer space, with a device for speeding up time, would see steadily increasing brown patches like freckles on the green and blue surface of the earth.

The most significant land use change has not been the spread of brick, stone, concrete and urban sprawl but an acceleration of the destruction of forests worldwide and declining fertility of soils. The UN Environment Programme has recently published its 1993–4 Environmental Data Report [6] which shows that 17% of the world’s soil has been degraded by human activity. Enough productive topsoil to cover the whole of France washes away or degrades beyond reasonable use every year. Forest destruction, with accompanying loss of species, is on a scale to change the whole global ecosystem.

Fresh water is a particular problem. The global demand for water doubled between 1940 and 1980, and is expected to double again by the year 2000. Rivers, lakes and underground aquifers show widespread signs of degradation, pollution and depletion even as human demands on water resources rise inexorably. Many countries already suffer severe shortages and droughts. Competition for water was a prime source of conflict in the past, and will be in the future: for example over the Nile, which flows through nine states, each with its own interests and demands; over the Euphrates and the Jordan which nourish Turkey, Syria, Iraq, Jordan and Israel; and over the Colorado, now no more than a sickly salty stream when it finally reaches the sea.

Then there are the direct effects of industrialisation: pollution and recent accidents have demonstrated the international character of industrial hazards. Within the vast land mass of the former Soviet Union, some 16% (or 1,382,000 square miles) was recently judged an ecological disaster area by the Academy of Sciences. Chemical accidents may be limited in their effects, but disposal of chemical wastes is a worldwide problem. Nuclear war could damage the world as a whole but even nuclear accidents are serious enough: the fallout from Chernobyl was some fifty times that of Hiroshima. More insidious but more real for the ordinary citizen is the growing problem of waste disposal. No part of the world is now exempt from the wastes produced by industrial activity.

Next comes the atmosphere. Acid precipitation is a problem for those down wind of industry; but it is essentially local in character and can be solved if there is political will to solve it. Depletion of the stratospheric ozone layer is more serious. The miracle molecules so useful as refrigerants, deodorants, fire extinguishers, and so on have been depleting the protective screen which prevents short wave ultraviolet radiation reaching the surface of the earth, and damaging the genetic material of living beings. Damage to the human metabolism may seem alarming to us, but the more fundamental problem could be the effects on other organisms.

Global warming through enhancing the natural—and indispensable—greenhouse effect could affect every aspect of human society. The main conclusions of the Intergovernmental Panel on Climate Change of 1990 [7], partially updated in 1992 [8], represented a broad scientific consensus. There will be a complete update next year. On the assumption that we continue to pump carbon dioxide, methane and nitrous oxide into the atmosphere, there could be a rise of global mean temperature of around 1.0°C by 2025, and around 3.0°C by the end of that century. Compare this with a drop of around 5.0°C during the last glacial episode. There has already been a rise of up to 0.6°C over the last hundred years. There would also be a continuing rise of sea levels, caused partly by thermal expansion and partly by melting snow and ice at the poles. A rise of half a metre by the end of the next century would greatly affect the proportion of people living along shores or estuaries.

These figures may seem small, but the results could be very different in different places. To judge from recent—somewhat controversial—evidence from ice-cores taken from Greenland, it could precipitate instability as seems to have been the case some 120,000 years ago. Weather patterns could change drastically, with rain coming where it hardly came before, and droughts coming where there was previously ample rainfall. According to the Intergovernmental Panel’s first report in 1990, changes will be greater than have occurred naturally in the last ten thousand years, and the rise in sea level will be three to six times faster than in the last one hundred years. Major uncertainties remain, but they are more about the magnitude and geographical distribution of change than about change itself.

Environmental change: local and global aspects

Thus environmental change falls into two broad and in some instances overlapping categories. The first consists of environmental effects of a local, sometimes ephemeral, usually human-induced character such as air, soil and water pollution, the cumulative effects of which are increasingly important. The second category concerns environmental effects of global, long-lasting, partly natural, partly human-made character such as climate change and changes in the land surface of the earth.

Local level changes and human health

Study of the impacts of environmental change on human health has traditionally been concerned with the first category: the toxic effects of conventional pollutants studied at a local level. But the lack of scientific evidence has so far made it difficult to establish causal relationships. There are several possible reasons: a relatively small number of cases to work on; inaccurate measure of exposure; and a large number of confounding variables. Some widely used substances such
as lead and furans have become so widespread that it is virtually impossible to detect an unexposed population, while the long latency associated with low doses hinders detection.

For example, dioxin is a highly toxic and carcinogenic substance in the laboratory. Until only last year it was thought that there had been no significant increases in cancer mortality as a result of the release of large amounts into the environment after the accident in Seveso in Italy in 1976. However, recent work has shown an upturn in the incidence of cancers among the Seveso population living in the second most contaminated area. Such people were nearly three times more likely to develop liver cancer; while women were 5.3 times more likely to develop a form of myeloma; and among men some cancers of the blood were 5.7 times more likely. These results were not found among the population of the most polluted area as those concerned moved immediately after the accident, so their exposure to the chemical was short.

Despite these difficulties there have been numerous instances of direct toxicological effects. For example, in eastern Massachusetts an excess of childhood leukaemia was detected where a hundred tonnes of cadmium and equivalent amounts of lead and arsenic had been deposited. There was also a two- to three-fold increase in the risk of astrocytoma in cranberry farmers and residents near to pesticide spraying, while an estimated quarter of a million people in industrial countries die each year from pesticide poisoning.

Pollution in the Great Lakes of North America from the discharge of toxic wastes by industry has been linked to a spread in breast cancer, a significant drop in the male sperm count, and an increased number of children with learning and behavioural problems.

A particularly bad case is the fate of the people of Musilova in the southern Urals. For more than four decades they have been exposed to radiation from the Mayak nuclear reprocessing and waste plant just 30 km upriver. This was the Soviet Union’s main centre for the production of nuclear weapons, and it poured a cocktail of radioactive elements into the Techa river as a result of both deliberate and accidental releases. Among many wide-ranging effects, half of the population is said to be sterile and a third of the babies born have some physical disorder or defect. At least five chronic diseases such as heart disease, high blood pressure, arthritis and asthma affect 96% of the population. There has been a doubling in the rate of leukaemia, a quadrupling in the incidence of skin cancer, and most women are anaemic. Even people only 25 years old suffer from chronic fatigue and memory lapses.

Many of these local toxicological effects are becoming more widespread. There is also evidence of pollutants interacting and facilitating each other’s effects. Government research has shown that 19 million people a year in Britain are exposed to air pollution levels in excess of international guidelines as a result of the growth in industry and traffic [9]. Sulphur dioxide accumulates on particles to produce acid aerosols which are respiratory irritants. Fine particulates that come mostly from the exhaust pipes of cars, lorries and buses are of particular concern. They account for around 60,000 deaths in the US and 10,000 deaths in Britain every year. People with the highest risk of dying are those with pneumonia, chronic heart and lung disease. Carbon monoxide deprives the body of haemoglobin causing drowsiness and headaches, slowing thought and reflexes and increasing pressure in the heart. Nitrogen oxides increase susceptibility to viral illnesses, irritate lung tissue and increase the risk of bronchitis and pneumonia. Low-level ozone has the ability to increase epithelial permeability and aggravates asthma and bronchitis. It also affects normally healthy adults, causing coughing, eye, nose and throat irritation and headaches.

Allergic diseases are also increasing. Asthma is the only treatable chronic illness that is becoming more prevalent in industrial countries. Its annual prevalence in Britain doubled between 1956 and 1982, and the incidence among children has doubled over the past decade.

Another example is hay fever. The annual prevalence quadrupled between 1956 and 1982. Today it is so common that television and the press provide us with pollen counts during the summer months. Compare this with the situation in the 19th century when hay fever was so uncommon that it took John Bostock nine years to collect 28 cases for his second article on this new phenomenon. City dwellers apparently suffer more than people living in the country. Clearly people are affected not by one source but by a combination of pollutants. It may be that the growth of industry and the subsequent increase in atmospheric pollution has led to chronic chemical damage to the nasal mucosa thus facilitating the entry of allergens.

An immediate difficulty in trying to determine the severity of environmental change of this kind is that it is new in recorded experience. But in the case of ozone depletion, we can use epidemiological data about the incidence of human skin cancers and ocular cataracts and relate them to geographical variations in exposure to ultraviolet radiation.

Non-melanoma skin cancers provide the most firmly established link. The incidence of non-melanoma skin cancers becomes strongly non-linear once ozone loss gets above a threshold of 5%. Thus a 10% reduction of ozone could lead to a 24% increase while a 50% loss could lead to quadrupling. The 25% loss predicted for northern Europe in 2005, even if ozone depleting chemicals are phased out by 1996, could result in a doubling of the incidence of non-melanoma skin cancer. Rates of melanoma and other skin cancers have doubled in Australia over the past 10 years where about 60% of the population can expect to experience at least one episode of skin cancer up to the age of 75.
The equivalent figure for malignant melanoma is 1.8%. High cumulative levels of ultraviolet exposure significantly increase the risk of eye disease, most notably cataracts, while its effect on the immune system is well known but not yet well characterised. Immunosuppression and the resultant predisposition to infection may turn out to be the most important consequence of ozone depletion for humans.

Direct impacts on human health of increased temperatures resulting from climate change are those associated with acute heat stress such as cardiovascular disturbances, altered fluid balance, fainting and salt depletion, disturbed sleep patterns and increased irritability. An extreme heatwave in 1980 caused an eight-fold increase in heat related deaths in the southern parts of the US.

Effects of this kind are dangerous, but in most cases fall into the realm of the known and the manageable. We do not have to cause pollution of this kind, and in the shorter or longer run we can at least theoretically reduce or eliminate it. We can also adapt to it. But this is not necessarily so with the wider and more complex changes precipitated by pressure on ecosystems, and in particular the micro-organisms within them.

Global changes and human health

The interconnectedness of life is unstable: a small change in one place can have big effects in another. Life may be inherently robust within certain limits, but relationships between organisms seem to pass between relatively long periods of order and relatively short periods of chaos, followed by re-establishment of relative order. Two critical elements in precipitating change are variations in temperature and moisture. Together or separately they can alter the weaponry in the perpetual arms race between organisms. As a species we suffer from the enormous handicap that we cannot react to change as fast as the vast populations of parasites with whom we have our being.

The initial impact of climate change is at the margins of current distributions of disease. The limit of the distribution of yellow fever is defined by the 10°C isotherm while that of malaria is defined by the 16°C isotherm. Any warming of the climate is likely to shift these further into temperate regions and to higher altitudes. In addition, seasonal movements of the isotherms may be larger than the annual mean represented by these lines. It is much less certain that the diseases will eventually be as prevalent in the newly invaded areas as elsewhere. Obviously, temperature is not the only factor involved. Rainfall patterns and the resultant humidity and amounts of static water in an area are critical factors in the breeding of many vectors such as mosquitoes. A study of malaria epidemics on the high plateau of Madagascar [10] with its cold, dry season showed that they were associated with large permanent water sources; whereas in the lowlands higher temperatures meant that the larvae could complete their development in more ephemeral rainwater sources, resulting in a broader distribution of the disease.

Observed warming has been largest in the northern hemisphere winter. This may allow certain species to winter in areas that were previously too cold for year round survival. In Egypt, water snails lose their schistosome infections during winter, but if winter temperatures were to increase, infection could spread throughout the year. Some bacteria, fungi and viruses might find that warmer seas allowed them to spread colonies over larger regions, thus expanding the range of exposure to such diseases as cholera and schistosomiasis.

The rapid and easy movement of people from one continent to another gives all diseases access to new environments. For example, alarm bells are ringing over the spread of an apparently new potential carrier of yellow fever known as the Asian tiger mosquito Aedes albopictus. In 1985 it travelled from Japan to the southern US in a shipment of used tyres. It is now abundant in the US and Brazil and seems to be spreading to Latin America. Experiments show that it can easily pick up and transmit viruses including dengue and yellow fever. Currently the small bodies of water that collect in tree holes during California’s cool, wet season remain below the 11°C threshold required for larval development but in some places the water temperature now approaches it.

Habitat destruction may cause changes in the behaviour of vectors that switch attention away from diminishing populations of natural hosts and begin to use humans as a source of blood and other nutrients. Deforestation is a particular culprit. The bugs which carry Chagas’ disease originally lived in the dry forest of Central and Southern America, but the destruction of these forests led to a change of preferred habitat of the vector, Triatoma infestans, from rabbit burrows to thatched houses, with the result that the incidence of Chagas’ disease has increased among the human population. Certain species of sandflies, the carriers of Leishmania, used to feeding on forest animals, have adapted to feeding on humans, while in some cases deforestation has created new habitats for Anopheles mosquitoes and resulted in malaria epidemics in South America.

The links between climate and disease are illustrated by the incidence of vector-borne diseases associated with the climatic extremes of temperature and moisture induced by the El Niño Southern Oscillation. This is a periodic shift in the circulation of the trade winds over the Pacific that affects global weather and ocean currents. For example, infrequent but severe epidemics of Australian encephalitis occur in temperate south-east Australia between January and May, and are associated with the high rainfall and severe flooding associated with the El Niño phenomenon.

During an exceptionally hot, rainy period in northern Australia in 1992 there were four epidemics of Ross River fever, an arbovirus infection usually con-
fined to the northernmost parts of the Northern Territory. The same year the population of the Pacific coast of Central and South America was struck by cholera. The bacillus had hibernated and been harboured by algae, plankton, fish, molluscs, crustacea, emerging when the conditions associated with the El Niño event brought warmth and nutrients.

The re-emergence of diseases such as cholera, dengue and other viral fevers can be traced to changes in land use and the growth of cities. Large cities are a recent unplanned experiment in human ecology. Seventy-five per cent of cities of more than five million people are in poor countries. Until recently the average level of health has usually been better in cities than in rural areas but this is unlikely to continue. In these cities 25% of people have no access to safe water, and 40% have no access to sanitation. Children brought up in these circumstances have 40 times the mortality of children. As in Europe until the last century, infectious diseases thrive in urban populations. The frequency of contact, the density of the population and the concentration of infective and susceptible people promote the transmission of disease. Diarrhoeal diseases account for a high proportion of illnesses and morbidity, while a high proportion of the population in poor settlements will be debilitated by intestinal worms. Many disease vectors live, breed or feed in urban areas where there is poor drainage and inadequate provision for garbage collection, sanitation and piped water. By completing their life-cycle in a matter of days such vectors as the Anopheles and Aedes mosquitoes can breed in standing water, as in the pots used for storing water, the small pools that collect in discarded cans and tyres, even discarded bottle tops or water filled footprints.

There is a further point of importance for the future. Much urban growth in poor countries results from immigration from depressed rural economies or collapsed and degraded agricultural land. This steady stream of people moving into a city from different areas will import a whole variety of pathogens. The effects of sea-level rise could increase the numbers of these environmental refugees from the currently estimated 10 to 12 million to many orders of magnitude more. This in turn would have profound social and economic effects within and between states. Social breakdown is a well known breeder of disease.

Nor should we forget the myriad other species on which we depend. The regional impact of climate change on agriculture is impossible to predict, given our lack of knowledge of the interaction between temperature, rainfall and soil moisture, droughts, floods, cyclones and plant diseases. At the same time an estimated 7% of the world’s two billion hectares of arable land was rendered unproductive during the 1980s, and some other intensively farmed land may be approaching exhaustion. The gains in productivity achieved by the green revolution relied on high yielding grain varieties which had been bred in the laboratory and required good soils, accessible groundwater, irrigation and fertilisers.

Outside forces are also taking a toll on agriculture. Air pollution has already reduced US crop production by 5 to 10% according to US government estimates. It is probably having a still worse effect in Eastern Europe and in China. Little work has been done on the effects of air pollution on plant diseases but there are many field observations of increases in the incidence of crop pathogens related to air pollution. One laboratory study has shown that sulphur dioxide and nitrogen dioxide enhance the performance of aphids.

The direct health impacts of ozone may be small compared with the effects on the biota in food chains. Of more than 200 species and strains of plants screened for tolerance to ultraviolet radiation, about two-thirds were found to be sensitive. Food crops including peas, beans, melons, cabbage and mustard were particularly so. Perhaps more worrying are the adverse effects on the phytoplankton that form the very base of the aquatic food web and the most important single group of primary producers.

There may be great possibilities for biotechnology, but we should be cautious. Modern agricultural techniques have led to an excessive dependence on a few miracle strains of even fewer plants and animals. It is absurd that out of some 80,000 edible plants, we eat only a few hundreds. These hundreds have spread to all parts of the earth, including environments to which they are not suited. Only three species—maize, rice and wheat—supply almost 60% of the calories and protein that humans derive from plants. Meanwhile the wild relatives of these strains are often lost when natural habitat is converted for other land uses. Without a large natural genetic reservoir, we make our food supplies vulnerable to disease as the Irish potato growers in the last century learned to their cost. Plant breeders rely on this genetic reservoir to develop new strains able to withstand pests, disease and unfavourable environmental conditions.

Wild plants are also a bountiful source of medicines. More than three-quarters of the population in poor countries depends on plant-based drugs, while in industrialised ones about a quarter of prescription drugs contain at least one compound that is or once came from higher plants. So far only 10% or less of flowering plants have been tested, but there have been some outstanding successes. Substances derived from the rosy periwinkle of Madagascar proved effective against childhood leukaemia and Hodgkin’s disease, and the bark of a rare Pacific yew yielded drugs for use against ovariain cancer. Many forest primates eat specific plants when they become sick and chemical examination has revealed potentially important new drugs for treating parasitic helminthic infestations.

As Paul and Anne Ehrlich have written, ‘We not only sprang from other life ourselves, we are completely dependent on it to maintain the habitability of this planet’ [11]. In short, we need a congenial world in
which to live. At present we take as cost-free a broadly regular climatic system with ecosystems, terrestrial and marine to match. We rely on forests and vegetation to produce soil and hold it together; to regulate our water supplies by preserving catchment basins, recharging groundwater and buffering extreme conditions. We also rely upon soils to be fertile and to absorb and break down pollutants.

There is no conceivable substitute for these natural services, and so far there has been no permanent shortage of such commodities as fertile land, clean water, clean air or the supply of genetic resources. Yet with the scale of environmental change we are witnessing today, we cannot continue to assume that this natural bounty will continue. Those systems which are already under stress or close to their climate limits are likely to experience the greatest difficulty in adapting to climate change.

The risks to population health caused by global environmental changes of this kind are qualitatively different from those due to the direct-acting toxicity of conventional pollutants. These risks arise from the impairment of the biosphere’s natural systems and need to be understood within an ecological framework. In my view we need a new approach to epidemiology: one that relates a population and its health to the environment’s carrying capacity. Is there a sustainable human carrying capacity of our planet? Obviously any answer must be subjective. It depends substantially on diet and distribution. An attempt has been made by the World Hunger Programme at Brown University [12]. Those concerned estimate that, in terms of 1992 food supply and supposing an even distribution of food, the earth could support 6.3 billion people (115% of current population) on a basic diet; 4.2 billion (77% of current population) on an improved diet; and 3.2 billion (55% of current population) on a full healthy diet.

So we are already around the limits of wherever we want to fix them. Sooner or later nature will take care of us, one way or another: some ways are more disagreeable than others. We only have to look at the fate of other species which overreached themselves, although none has done what we have done to the environment. Let me leave you with a final thought which comes from a recent book by Roger Lewin on complexity theory:

‘Run a thin stream of sand onto a round plate. A pile steadily builds, soon reaching the edge. The initially low pile now gets higher and higher, until suddenly more sand may trigger a small avalanche, and then a bigger one, avalanches of all sizes. The sand pile, when it can take no additional sand, represents the system poised at the critical state. And the avalanches of all size ranges, provoked by disturbance of the same magnitude of disturbance (another grain of sand), represent the power law distribution of response: the signature of a system that has got itself to the critical state. Got itself, perhaps to the edge of chaos’ [13].

Who knows?

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Address for correspondence: Sir Crispin Tickell, The Warden, Green College at the Radcliffe Observatory, Woodstock Road, Oxford OX2 6HG.