

## Science, the Natural World and Public Opinion: Are We in Crisis?

**Editor's Introduction** | For the majority of humanity, the quality of life is better now than it ever has been in history. But that will change as we use up the planet's natural riches, as species go extinct, as populations continue to grow and as resources become scarce. In this feature, based on the prestigious 2001 Annual Science Lecture that he gave at The Natural History Museum, Lord Robert May draws on his wealth of knowledge and experience to present a highly personal and compelling analysis of our current situation and possibilities for the future.

My theme is not original: it is that we are living in the best of times and the worst of times. We are living at a really singular time. It is the best of times in a quite concrete sense, while the worst of times aspect is more a thin end of the wedge. It could be argued that ours is a good time to be here, getting many of the advantages of our understanding of the external world, without having yet inherited many of the unintended adverse consequences.

I will elaborate my 'best of times, worst of times' claim, then move on to describe aspects of this theme that are appropriate for The Natural History Museum. These aspects focus on questions about biological diversity and the threats it faces. I will end, with less confidence in the precision of what I say, with some of my opinions about what the social, political and ethical dimensions of the questions posed by the earlier part of the lecture are: Why should we care? What is the cost of effective action? What are some of the problems, even if we all agreed that we cared and we were willing to pay the cost?

We live, in very specifically measurable ways, in what is the best of times. Take the simplest measurements--human health and life expectancy. [Table 1](#) shows a typical survivorship curve for hunter-gatherers, about 30,000 years ago. This shows the probability that an individual will survive to 10, 20, 60 and 70 years. It looks like the survivorship curve for a typical bird species; an individual is roughly equally likely to die in any year of their life, but a bit more likely to die at the beginning.

[Table 2](#) shows the survivorship curves for human populations about 30 years ago. The top curve represents Sweden, a typical developed world country. Once born, an individual has a very good chance of living until 70 years old and often more. The lower curve, which is not all that different from the hunter-gatherers, represents a typical developing country (Tanzania) about 30 years ago.

Fifty years ago, the average life expectancy of the average inhabitant on this planet, at birth, was 46 years. Today it is 64 years. Fifty years ago, the gap in life expectancy at birth between the developed world and the developing world was 26 years. Today, it is a still shameful, but much lower, 12 years. That huge increase in average life expectancy, from 46 to 64 years, is partly because the developed world does better now, but, more importantly, because the developing world does better, with lower infant mortality and better survival rates at every age. In the developed world, not only do we live longer but variance in life expectancy has dramatically decreased. Various factors have contributed to this:

**Agriculture:** In the developed world, food has never been more abundant, more diverse and cheaper. Over the past 35 years, as a result of the Green Revolution, which was based on a better understanding of how the natural world works, food production has doubled. This food has been produced on only 10 percent more land and, during that time, the world population has increased by 60 percent. So today there is 25 percent more food available per person than there was 35 years ago. The problem of feeding everyone adequately today is a problem of equitable distribution, but it would be wrong to say it is *simply* a problem of equitable distribution. That problem has been with us from the dawn of agriculture, 10,000 years ago, and it is as difficult and refractory today as it was then. Although, as a result of the Green Revolution, we could feed all today's population adequately were things better distributed, we could not be feeding today's population with

yesterday's agriculture.

**Table 3**, from the Office of the UK Statistician, is a breakdown of how, on average, disposable income in the UK is spent. Food and non-alcoholic drink ranks second, but consumes, on average, only 16 percent of disposable income of the average family in the UK.

**Energy:** Today, almost everything we do is subsidised by external energy sources. Globally, the average citizen (developed and developing world averaged together) consumes 14 times the amount of energy needed for basic metabolic requirements. There are, however, huge variations from country to country.

Globally, 90 percent of this energy comes from the burning of fossil fuel. Nuclear fuel is a distant second, and renewable energy sources represent only a small fraction.

In the developed world we use that energy every day, for household devices, for travel, for shopping, for pre-prepared meals.

But each of these improvements has a flip-side.

**Health:** The consequence of the better health that we enjoy, differentially in the developed and developing world, is a still-accelerating population growth. When we were roving bands of hunter-gatherers, the population on Earth numbered between 5 and 20 million, half the population of Great Britain today, or less. Since that time population size has grown slowly and jerkily with the invention of agriculture, the creation of cities and the beginnings of the Industrial Revolution. Around 1880 the Earth's population hit the first billion. It took half a century to double and 40 years to double again, to 4 billion in 1970. Today it's over 6 billion. Growth rates in the 1970s were around 2 percent per annum. Today they have slowed to about 1.4 percent per annum, but we are still committed to massive population growth. Even if we were to move overnight to replacement-size families, the momentum of people already born, growing up and replacing themselves, comes close to doubling the world population. The impact of all those additional people, year on year, is differentially amplified in different places, and their activities have knock-on effects that have other adverse, unintended consequences.

**Agriculture:** Food production has doubled in the past 35 years on only 10 percent more land. This was achieved by roughly doubling the amount of irrigated land and by multiplying the input of nitrogen fertilisers by a factor of about seven. There are already signs that those gains are beginning to level off. But looking only 20 years ahead, we're committed to feeding 7.7 billion people, about half of them in cities. This requires the doubling of the output produced by the Green Revolution over the next 20 to 30 years. If this is done along the lines of the Green Revolution, it would require two or three times the amount of nitrogen fertiliser and another doubling of the amount of irrigated land. We already use, one way or another, 50 percent of the world's freshwater supplies. By 2025, 50 countries, with roughly half the world's population, will be experiencing a water deficit.

Round the world last year, from the poles across the great steppes of the temperate zone to the tropical forests, more than half the atoms of nitrogen and phosphorus that were incorporated into green plant material came from fertilisers subsidised by fossil fuel energy and not from the natural bio-geochemical processes that built the biosphere as a place where life can flourish.

We humans sequestered, directly or indirectly, to our use, between a quarter and a half of all the green plant material produced on Earth last year. Never before in the history of life on Earth has one species had such a lock on the consumption of primary productivity.

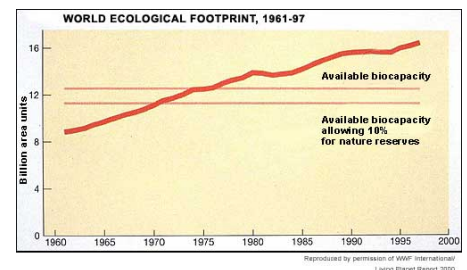
**Energy:** In 2001, President Bush 'shared with us' his personal distrust of the science of climate change. In response to that, 17 of the world's major academies, including representatives from China, India, Mexico, Brazil and Australia, issued a statement that the work of the

Intergovernmental Panel on Climate Change (IPCC) represents the consensus of the international scientific community on climate change science. Despite increasing consensus on the science underpinning the predictions of global climate change, doubts have been expressed recently about the need to mitigate the risks posed by this. The academies do not consider such doubts justified.

The statement goes on to say that there will always be a degree of uncertainty, but these academies further support the current informed assessment that it is at least 90 percent certain that temperatures will continue to rise. The average global surface temperature is projected to increase somewhere between 1.5 and 6°C above 1990 levels over the course of this century. For those living in colder climates it might sound attractive, but I assure you it sounds a lot less attractive the more you look into the details.

The drivers of climate change are the input of greenhouse gases; the primary greenhouse gas is carbon dioxide. This comes from the burning of fossil fuels, which provides 90 percent of our energy subsidy sources. The ultimate drivers are a mixture of population growth, multiplied by the impact of source consumption, multiplied by the efficiency of the energy generation. All of those factors are very uneven.

This year, the United Kingdom's net population will grow by about 120 new people. Those people, on average, will input more carbon dioxide into the atmosphere than the roughly 2.4 million people added to Bangladesh. So it's quite tricky to say who is to praise and who is to blame.



The graph above is a necessarily imprecise analysis, made by WWF, that asks: 'With the different current patterns of consumption around the world, what footprint has *Homo sapiens* stamped on the Earth over the last few decades in terms of the sustainable area needed to support current levels of consumption?' This is shown against a baseline of what the Earth can sustainably support, with and without setting a bit aside for preserving other creatures, indicating that we went past break-even some time in the 1970s.

The components are varied and greenhouse gases form a fair chunk of them (see Table 5).

And the footprint, of course, varies hugely from country to country (see Table 6). The vertical axis measures the average footprint per capita in different regions: North America, Western Europe, Central and Eastern Europe, Latin America, Asia/Pacific and Africa. The horizontal axis measures the number of people. So the total impact--total footprint--is demonstrated by the area of the graph.

There are many fascinating paradoxes to be teased out: of countries with patterns of high consumption that, however, are less than their country can support, and countries with pathetically low patterns of consumption that, however, are larger than their impoverished country, burdened with too many people, can support. One approach that draws some of these themes together is to look at the patterns of agriculture in the developed world over a sweep of time.

When we were hunter-gatherers, we obeyed an ill-understood ecological generalisation: that we spent about a tenth of a calorie of energy to harvest a calorie of food. That very general rule holds true for bass, bumblebees, certain kinds of protozoa and hunter-gatherers. The way agriculture worked in developed countries 100 years ago, a calorie of energy was spent for each calorie of food put on the table. Food production was subsidised by fossil fuel energy. Across the developed



The biggest mammal society has about 10,000, as does the Botanical Society. And there is no UK society to express affection for nematodes.

So, when we turn to ask how many species of plants and animals and fungi do we currently share the world with, the answer is we don't know. Credible estimates range from as low as 3 million, twice the number recorded, to as high as 100 million or more, although I personally believe that the real number is somewhere between 5 and 10 million.

When we consider the rate at which we are losing species, it is similarly difficult to say. WWF has produced indices based on observations of the creatures that live in forests, documenting patterns against an arbitrary baseline year of moderate, but statistically really very significant, decline (see [Table 9](#)). Their earlier index was based on loss of habitat; we've lost about half of the world's pre-agricultural habitat and are slowly reducing the remainder. If the scale is measured in centuries, we are reducing wild habitat at an alarming rate.

Freshwater species are really taking a hammering, and that can be broken down by region (see [Table 10](#)). Marine species also don't do well, again varying by region (see [Table 11](#)). In summary, if a kind of living planet index is considered, (see [Table 12](#)), indexed by the health of populations, the news is not good--although it is not dramatically bad. By the time today's children are middle-aged not all the world's species will have gone, or even half or, in my opinion, a quarter. But species are disappearing at a rate that, compared with the rate of the past record of life on Earth, is extraordinarily rapid.

A corner of the Bronx Zoo contains a set of tombstones of species that have gone extinct in recent years. Every one of them is a bird or a mammal. Indeed, essentially every organism used in the WWF statistics is a vertebrate (mainly birds and mammals, fish, and the odd reptile or amphibian). If you turn to the numbers of documented certified extinctions collected, they run to about one bird or mammal species a year over the past century. Of the vastly more numerous insects, only 73 would have been entitled to a tiny tombstone. But those 73 form a fairly odd set of insects. Of the 73, 42 are Hawaiian drosophila or fruit flies. Of the others, they are all from islands except seven from the United States and one from Germany. Not a single recorded extinct insect comes from the tropics.

One way of approaching the problem of how little we know is to ask roughly how long do species live in the fossil record, from their appearance to their extinction? The answer is hugely variable, within a group and among groups. Sometimes species survive a few hundred thousand years, sometimes hundreds of millions. But characteristically, their life spans range from one to ten million years. An analysis of the statistic that, on average, one mammal or bird will go extinct each year from a group of 10,000 species, indicates that the expected lifetime of the average bird or mammal species--one of 10,000 playing Russian roulette with a gun of 10,000 chambers with one bullet in it each year--is about 10,000 years. This is 100 to 1,000 times less than the average over the 600 million year sweep of the fossil record. It is an imprecise estimate, but it has physics-like precision compared to estimates that compound our ignorance of numbers of species with wild extrapolations of ecological rules that correlate habitat with species abundance.

Our knowledge of the future is even less precise. Four different lines of argument, which I will not elaborate here, tend to converge in suggesting a further ten-fold acceleration. This does not mean that we might see a dramatic disappearance of half of all the world's species in the next few years. But we are looking at an acceleration that is in the same ballpark as the five episodes of mass extinction that the Earth has seen, characterised, for example, by the end of the age of dinosaurs (see [Table 13](#)).

We are standing on the breaking tip of the sixth great wave of extinction in the history of life on Earth, and it differs from the previous five in that it is not external, environmental events that are causing it. The cause is the sequestration of resources, more than a quarter to a half of all primary

productivity, by a single species. The consequence is habitat destruction, exploitation, alien movements of species to new places and extinction. One by one are winking out the lights.

Why should we care about this? There are three categories of argument, and none is necessarily compelling. The first is a narrowly utilitarian argument which contends that species that share the world with us today, in all their variety and with all the genetic novelties embodied in them, are the raw stuff of tomorrow's biotechnological revolution. Setting aside the ethical status of that argument and seeing it as just an argument of convenience, I still think it's shaky, because I believe tomorrow's biotechnology, tomorrow's drugs, tomorrow's novelties, will ultimately be built from the molecules up, as we learn, more and more, to read the book that codes the molecular machinery of life.

The second argument may be called broadly utilitarian. It claims that the oxygen-rich biosphere, Jim Lovelock's Gaia, was actually self-assembled. It was self-constructed by living organisms and we do not sufficiently understand the structure and the function of eco-systems to know how much they can be simplified and still deliver the services we depend on. Cleaning the water, cleaning the air and pollinating crops are a set of services that, a slightly lunatic but nonetheless fascinating and important--although hugely imprecise--calculation suggests, add up to more than the conventionally calculated global GDP of \$30 trillion. One of the great founders of the ethics of conservation biology, Aldo Leopold, said: 'The first rule of intelligent tinkering is to keep all the pieces.' But I believe that we could live in a hugely impoverished world, and be clever enough to keep ourselves flourishing in it. It would be the world of the cult movie *Blade Runner*.

The third and final argument asks: is that a world you want to live in? This, to my mind, more compelling argument, set out in the first paragraph of the UK's previous Conservative government's White Paper on the environment and re-affirmed by the current Labour government, says: 'For this government the first consideration is the ethical imperative of stewardship.' But although that *is* compelling, to be compelled one needs to be enjoying the privileged luxury of the developed world. That argument would be a lot less compelling if you were struggling to feed your fifth child in a dirt-poor environment.

We currently spend about \$6 billion a year conserving other creatures, but it would cost at least \$30 billion a year to do a better job and to properly compensate and engage the people in the regions in which we're trying to conserve things. To do a really good job of greening agriculture--in the way that certain subsidies are designed to encourage farmers in the EU, not always successfully--would cost more like \$300 billion a year, which is 1 percent of the conventional global GDP of \$30 trillion. I do not think that that is a forbidding cost, but politically it is a hugely difficult cost to accomplish. The reason for that is simple, and it is very difficult to see the way through it. All the problems I've discussed are, in many senses, tomorrow's problems. They are problems whose outlines are clear and whose growing impact is ineluctable if we fail to act now, and yet real disturbance from them lies decades, or in some cases centuries, in the future.

The timescale for *really* serious losses of biological diversity, I believe, should be measured in centuries and, at best, in 50-year bites. The timescale for feeding the world's population as it grows, the most pressing of these problems, is a problem in decades. However, local exceptions--such as the conflicts in Rwanda--were, arguably, ultimately driven by the first clear indication of fights over land. Conflicts in the Middle East, vastly more complicated than simply fights over water, also feature land as a serious component. Climate change, which is really going to cause the flooding of oceanic islands and major economic dislocations in the agriculture and other aspects of certain countries, is 50 to 100 years ahead. On the other hand, the timescale for action, and for that action to be felt, is often equally slow. The carbon dioxide that went into the atmosphere this year has characteristic residence times of a century, and the global warming that has occurred in the last decade will continue to heat the oceans and cause them to rise for a couple of centuries. So that even if we could, overnight, go back to pre-industrial levels of carbon dioxide

input, it would be more than a century before we came back to the 1900s levels of greenhouse gases and the balance that thus existed. In short, we're dealing with processes that grow exponentially or, worse, nonlinearly, where small actions today are much more important than bigger actions later. For all the huge inadequacy of Kyoto's targets against what we ultimately need to do, it is immensely important to have done it to get the train moving out of the station. So, we are faced with a conundrum: the things that will really impact on people are as yet seemingly distant, but for all that seeming distance, what we do today is absolutely crucial because it will amplify and have a much greater effect than big things we do later on. And that must be sold in communities of humans that, like other animals, have no evolutionary experience of acting today on behalf of a distant future.

If The Natural History Museum is a secular temple to any one individual, which it is not, then I would say it is a secular temple to Charles Darwin. Along with Alfred Russel Wallace, Darwin recognised as unsolved a huge problem, which was how, within the theory of natural selection, the evolution of co-operative or altruistic behaviour, where individuals subjugate their own interests to the collective good of a group, could be explained. You might think it is simple, that the explanation lies in the collective benefit to the group outweighing the advantage to the individual. But natural selection acts ruthlessly and mindlessly to favour the behaviour that leaves the individual more descendants. And the person who joins the co-operative group, gains the benefit but cheats by not paying the penalties of co-operation, will leave more descendants. That is a classic, as yet not fully solved, problem of evolutionary biology. In our societies we have laws, covenants and political processes that bind us, but they grew out of roots of co-operative behaviour that is still paradoxical to us and of which we still have no fundamental understanding. Yet what we are asking is to take these creaky and ill-understood mechanisms that we manage to use to bind ourselves, and commit ourselves to collective actions and purge ourselves of, or punish, or exclude, cheats. We're asked to apply these, to give up things, not just for our collective benefit today, but for the benefit of a sometimes distant future. Frankly, I think that this is an enormously difficult problem and, unfortunately, most of the evidence points my way.

To supply a fanciful, rather than a pessimistic ending, I could ask how many inhabited planets may there be in the galaxy, in the universe. It is highly improbable that there is only one and there might be many. An interesting question is: would the course life takes on these different planets produce the dilemma we are in here? Would it produce one species that communicates so effectively that each individual member can be the active possessor of the accumulated wisdom of its past history and its present technology, so that it asserts such mastery over the planet that it explodes out of control and wrecks the planet? Or are there other evolutionary courses, in which the ill-understood evolution of altruistic and co-operative behaviour takes a different trajectory? The choice between a fanciful ending or a pessimistic ending is yours.

## **Books:**

Title: Stability and Complexity in Model Ecosystems

Format: Paperback

Author: May, Robert M.

Date: 01-MAR-01

ISBN: 0691088616

Title: Extinction Rates

Format: Paperback

Author: Lawton, John H.; May, Robert M.

Date: 01-FEB-95

ISBN: 019854829X