The Winners of the Blue Planet Prize

2001

2001

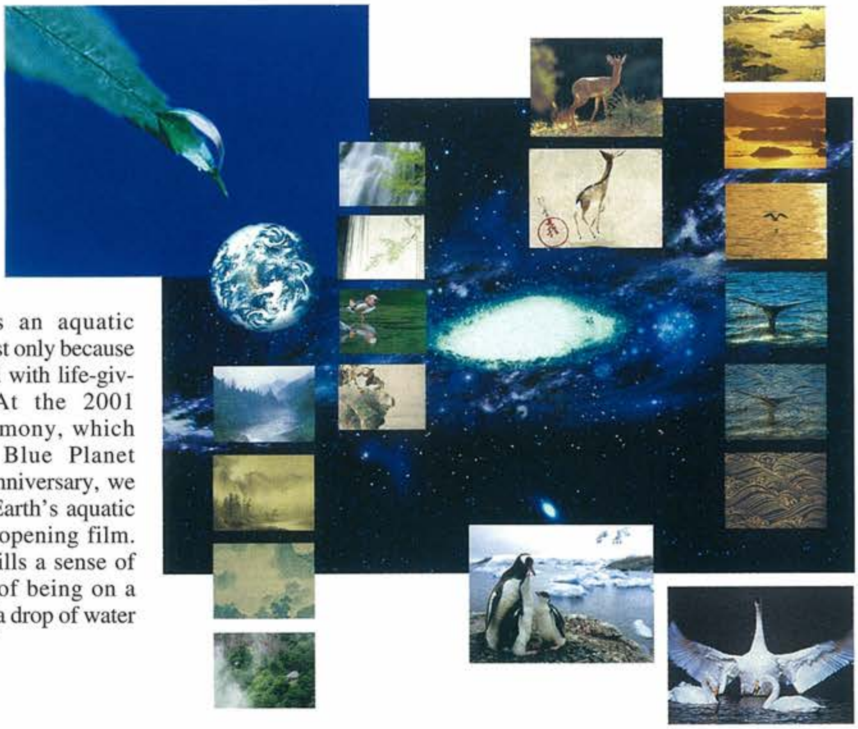
Blue Planet Prize

Lord (Robert) May of Oxford (Australia)

President of the Royal Society of London

Dr. Norman Myers (U.K.)

Honorary Visiting Fellow, Green College, Oxford University

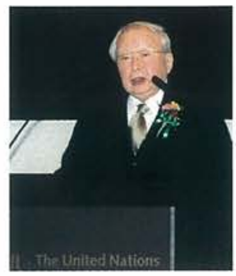


The Earth is an aquatic planet. We exist only because we are blessed with life-giving water. At the 2001 Awards Ceremony, which marked the Blue Planet Prize's 10th anniversary, we explored the Earth's aquatic nature in the opening film. This film instills a sense of appreciation of being on a planet that is "a drop of water in the galaxy."

His Imperial Highness Prince Akishino congratulates the laureates.

His Imperial Highness Prince Akishino at the ceremony.

Dr. Jiro Kondo, chairman of the Selection Committee, describes the Blue Planet Prize selection process.



The prizewinners receive their trophies and certificates of merit from Foundation Chairman Hiromichi Seya.

Lord (Robert) May of Oxford

Dr. Norman Myers

The Blue Planet Prize Commemorative Lectures.

John McCarthy, Ambassador of Australia to Japan (left), and Stephen Gomersall, Ambassador of the United Kingdom to Japan (right), congratulate the laureates.

Lord (Robert) May of Oxford

President of the Royal Society of London

Education and Academic and Professional Activities

1936	Born in January in Australia.
1956	B. Sc., University of Sydney.
1959	Ph.D., Theoretical Physics, University of Sydney.
1959-1961	Researcher, Harvard University, U.S.A.
1962-1972	Professor, Physics, University of Sydney.
1973-1988	Professor, Biology, Princeton University.
1979	Fellow, Royal Society of London.
1980	Weldon Memorial Prize, Oxford University.
1984	MacArthur Award.
1988-1995	Professor, Imperial College and Oxford University, United Kingdom.
1991	Linnean Medal, Linnean Society.
1991	Overseas Member, Australian Academy of Sciences.
1992	Inaugural Christian Marsh Prize.
1992	Foreign Member, U.S. National Academy of Science.
1995	Frink Medal, Zoological Society.
1995-2000	Chief Scientific Advisor, Government of the United Kingdom.
1996	Crafoord Prize in Biosciences, Royal Swedish Academy of Sciences.
1998	Balzan Prize awarded by the President of Italy.
2000—	President, Royal Society of London.

After pursuing research in theoretical physics at the University of Sydney, Lord (Robert) May of Oxford shifted his focus to mathematical biology. He achieved a solid record of noteworthy accomplishments at Princeton University in the United States before coming to his present post at Oxford University, where he is active as an influential, world-leading academic.

Applying mathematical concepts to biology, he studied the stability of animal populations in 1973, and discovered for the first time that when you increase the number of species, even in complex animal societies, or add more interactions between species, the probability of the system becoming less stable was greater. Furthermore, he uncovered the fact that unidimensional nonlinear differential equations often exhibit dynamic states similar to those of animal populations, and founded the new field of "chaotic dynamics" in biology.

Lord May drew attention to the fact that if we wish to manage ecosystems—for example, if we wish to estimate the impact of human fishing on fishing grounds—that we must pay attention to the characteristic changes in the populations. He also investigated how AIDS, which was transmitted to a different species as a result of environmental change, spreads, utilizing a combination of simplified analytical models and computer simulations to provide the data required to formulate preventative strategies.

In 1995, Lord May was appointed Chief Scientific Advisor to the British Government and Head of the Office of Science and Technology, and was honored in 2000 with election as President of the Royal Society of London. From these elite positions, he continues to counsel for ecological preservation and action to curb various urgent environmental problems.

Essay

Biological Diversity in a Crowded World: Past, Present, and Likely Future

Lord (Robert) May of Oxford

February 2002

How much do we know about the diversity of organisms on our planet? First, estimates of the number of distinct species of plants, animals and fungi (eukaryotes) that have been named and recorded—a simple, factual question, like how many books in the library catalogue—range from 1.4 million to 1.8 million. Second, estimates of the total number of species present on Earth today range over more than an order-of-magnitude, from a low of around 3 million, to a high of 30 million or possibly much more. And third, we have even less idea of the rates at which species may currently be going extinct as a result of habitat destruction, introduced aliens, overexploitation and other consequences of human population growth.

Numbers of Species Today

The systematic naming and recording of species began relatively recently with Linneaus' canonical work, which in 1758 recognised some 9,000 species. Today, the total number of living species named and recorded is around 1.7 to 1.8 million. Amazingly, no centralised catalogue exists. Around one million of these are insects, of which an estimated 400,000 are beetles. And of these beetles, an estimated 40% are known from only one collecting site, and sometimes from only one specimen. So it is not surprising that there is a problem with synonymy (the same species unwittingly recorded under different names by different researchers). Known rates of synonymy run, on average, around 20%. Recent mathematical studies, however, suggest that if these rates are the ones we know, the true rates are likely to be higher (Solow *et al*, 1995). My estimate is that we may have named and recorded around 1.5 million species (May, 2000), but this number could be 10% higher or lower. To this total, we are adding around 13,000 new species each year. But at the same time, we are resolving synonymies, so that the net addition is around 10,000 new species each year (Hammond, 1995).

Some groups are much better known than others, reflecting patterns in the taxonomic workforce, which derive from intellectual fashions rather than analytic assessments of priorities. Bird and mammal species are comparatively well documented; even though three to five new bird species and around 10 new mammal species are found each year, such numbers are small fractions of the totals recorded in these classes (approximately 10,000 species of birds and 4,000 of mammals). The roughly 270,000 recorded species of vascular plants probably represent 90% or so of the true total. But comprehensive explorations of invertebrate groups in previously-unstudied places—tropical canopy insects; deep-sea benthic macrofauna; fungi—typically find 20% to 50%, or even more, of the species are new to science. Taxonomists are distributed roughly evenly between vertebrates, plants and invertebrates. But there are roughly 10 plant species for each vertebrate animal species, and conservative estimates suggest around 100 insect species for each vertebrate one. Thus, current patterns of knowledge reflect the fact that the average vertebrate species receives 10 times more taxonomic effort than the average plant species, and 100 times more than the average invertebrate (Gaston and May, 1992). This is a bad way to run a business.

The true total number of living species is very uncertain. My guesstimate is in the range 5 to 15 million with a favoured figure of perhaps 7 million (May, 2000). Dramatically higher numbers have been proposed: 30-million insects on the basis of studies of beetles in tropical canopies; tens of millions of benthic invertebrates on the basis of a deep-shelf transect off the northeastern U.S.A.; 1.5-million fungi on the basis of scaling up the species ratio of fungi to vascular plants in Britain; and others. I am sceptical of all these estimates, but a true total anywhere in the range 3 to 100 million could turn out to be correct. The fact that reasonable estimates vary so widely says a lot about how little we know.

Uuderstanding Diversity

The lack of systematic compilations of information about recorded species, much less about the true species totals, greatly impedes our understanding of the causes of biological diversity and of the likely consequences of its impending reduction.

Various patterns—some more general than others—have been tentatively documented. None are fully understood (May, 1990, 1999; Wilson, 1992; Lawton, 1995).

(1) For most groups of organisms, there is a marked "latitudinal species diversity gradient." This is particularly notable for tree species, where the enormous diversity of tropical forests gives way to the almost monospecific conifer forests of northerly latitudes.

(2) Other things being equal, there is a relation between a region's area and the number of species found in it. A tenfold reduction in area (as when a reserve is established and its surroundings modified) roughly halves the number of species; more generally, $S=cA^z$, where the constant c varies from group to group, and the exponent z is usually in the range 0.2 to 0.3.

(3) There are broad trends in the relative abundances of species within a community or ecosystem. In old-established communities, these patterns of species relative abundance tend to be more even (often described by a subset of lognormal distributions) than those for early successional or highly disturbed situations. These "canonical" lognormal patterns can be interpreted as arising from the multiplicative interplay of many ecological and evolutionary factors, and the observed species-area relations can be derived from them (under the additional assumption that total numbers of

individuals scale roughly linearly with area).

(4) The numbers of species in different categories of physical size vary systematically. For terrestrial animals, a decrease by a factor 10 in characteristic linear dimensions (or equivalently, a factor 1,000 in mass) roughly results in 100 times more species. This rough rule holds down to size categories around a few millimetres; species numbers fall away below this. What are the ecological or evolutionary origins of this rough rule, which holds true over four or more orders-of-magnitude in characteristic lengths of animals on land and roughly similarly in the sea (Fenchel, 1993). To what extent—and why—is the breakdown in this rule at small sizes real, and to what extent may it be a consequence of less knowledge about smaller things?

(5) Patterns in the relations between the body sizes and the geographical ranges of species are only just beginning to receive systematic attention. It is possible that geographical ranges are typically more extensive for relatively large organisms and for microorganisms (protozoa and below) than for mid-size organisms (insects). If true, such patterns, which are entwined with the species-size effects of (4), are relevant, amongst other things, to possible range modifications associated with climate change.

Extinction Rates

The history of life on Earth, written in the fossil record over the past 600-million years since the Cambrian explosion in the diversity of multicellular organisms, is one of broadly increasing diversity, albeit with many fluctuations and punctuated by episodes of mass extinction. As reviewed in more detail elsewhere (Sepkoski, 1992; May, 2000), the average lifespan of a species in the fossil record, from origination to extinction, is typically a few million years (that is, of the order 10^6 to 10^7 years). There is, however, much variation both within and among groups, and some groups have lifespans significantly longer or shorter than this. Comparing this few-million-year average lifespan with the 600-million-year fossil record span, we might estimate that 1% to 2% of all species ever to have lived are with us today. But, allowing for the fluctuating but steady—very roughly linear—average growth in species diversity since the Cambrian, a better estimate might be 2% to 4%. And if we recognise that most of today's species are terrestrial invertebrates (mainly insects), whose patterns of diversification began around 450-million years ago and whose average lifespan may be characteristically longer than 10-million years, it could be that today's species represent more like 5%, or conceivably even 10%, of those ever to have graced our planet.

Over the past century, rigorously documented extinctions in well-studied groups—primarily birds and mammals—have run around one species per year. Because tropical species typically receive less attention, true extinction rates of birds and mammals are undoubtedly higher. But even one per year among the roughly 14,000 species of birds and mammals translates to expected species' lifetimes, based on documented recent extinction rates, of around 10^4 years. Although seemingly long, this is shorter by a factor of order 10^{-2} to 10^{-3} than the background average lifespan of 10^6 to 10^7 years seen in the fossil record. That is, recent extinction rates in well-documented groups have run one-hundred to one-thousand times faster than the average background rates.

Looking toward the immediate future, four different approaches to estimating impending rates of extinction suggest species' life expectancies of around a few hundred to one-thousand years. One of these approaches is based on the above-mentioned species-area relations, coupled with assessments of current rates of tropical deforestation or other habitat loss (if tropical forests are being lost at the rate of 1% to 2% each year, the species-area relation implies this commits 0.25% to 0.5% of their species to extinction, which inverts to a rough estimate of species' lifetimes of roughly 200-400 years). Two other methods are based in different ways on the International Union for the Conservation of Nature's (IUCN) current catalogue of "endangered" or "vulnerable" species. As reviewed elsewhere (May *et al*, 1995), one of these estimates the average rate at which species in better-studied groups (birds, mammals and palm trees) are climbing the ladder of IUCN categories of endangerment. This suggests expected species' lifetimes in the range 100 to 800 years in these groups. A more precise variant of this approach uses species-by-species assessments of extinction probability distributions as functions of time. Using 10 vertebrate groups (3, 4, 3 orders or families of reptiles, birds and mammals, respectively), Mace (1994) estimates average species' lifetimes in the range 100 to 1,000 years, and mainly in the 300- to 400-year range for mammals and birds. The fourth method uses models for branching processes in phylogenetic trees, along with recent data for bird and mammal orders, to project average times to extinction within bird and mammal orders (McKinney, 1998). Under a range of assumptions about branching processes, these models suggest species' lifetimes again of the order of a few hundred years (characteristically shorter for mammals than birds). Thus, all four of these methods, each of which is unreliable in its own distinctive way, agree in suggesting a further shortening of expected species' lifetimes to around 10^2 to 10^3 years.

Such figures correspond to likely extinction rates of a factor of ten thousand, give or take at most an order of magnitude, above background over the next century or so. This represents a sixth great wave of extinction, fully comparable with the Big Five mass extinctions of the geological past, but different in that it results from the activities of a single other species rather than from external environmental changes.

As we face this future, we must ask: does it matter more if we lose 25% of all mammal species than if we lose 25% of the vastly more numerous insect species? Or does it matter equally? Or less? There is need not only for more taxonomic information, but also for a "calculus of biodiversity" based on this information. Such a calculus should, ideally, quantify the taxonomic uniqueness, or amount of independent evolutionary history, inherent in individual species (Vane-Wright et al, 1991; Nee and May, 1997). I would like to see such quantification, along with more explicit recognition of constraining political, economic and social realities, replace emotion in assigning conservation priorities and places on the Ark (although emotional elements should, certainly, also be part of such a quantification). For further review and remarks on this topic, see May *et al* (1995).

Why Value Biological Diversity?

One argument for the preservation of biological diversity is narrowly utilitarian. It correctly emphasises the benefits already derived from natural products, such as foods, medicines and so on. Currently, 25% of the drugs on the shelves in the pharmacy derive from a mere 120 species of plants. But, throughout the world, the traditional medicines of native peoples make use of around 25,000 species of plants (about 10% of the total number of plant species). We have much to learn. More generally, as our understanding of the natural world advances, both at the level of new species and at the level of the molecular machinery from which all organisms are self-assembled, the planet's genetic diversity is increasingly the raw stuff from which our future can be constructed. It seems a pity to be burning the books before we can read them, and before we can create wealth from the recipes on their pages.

Another class of arguments is more diffusely utilitarian. The interactions between biological and physical processes created and maintain the earth's biosphere as a place where life can flourish. With impending changes in climate caused by the increasing scale of human activity, we should be worried about reductions in biological diversity, at least until we understand its role in maintaining the planet's life support systems. The first rule of intelligent tinkering is to keep all the pieces.

For me, however, a third class of argument is the most compelling. It is clearly set out by the U.K. Government in *This Common Inheritance* (HMSO, 1990, ch 1.14). It is "the ethical imperative of stewardship ... we have a moral duty to look after our planet and hand it on in good order to future generations." This argument is, however, easier to sustain for those privileged to live in affluent developed countries. Were I struggling to feed my fifth child in abject poverty in some areas of the developing world, I suspect I would find this ethical argument less compelling.

Conclusion

The previous century has seen more advances in our understanding of the natural world than has all previous human history. We have applied this scientific understanding to improve lives in both developed and developing countries. We are, however, now beginning to realise some of the unintended adverse consequences of well-intentioned actions. Arguably the most significant is accelerating loss of biological diversity. What happens to our world, and to us and the creatures we share the world with, in the future depends on the actions we take now. As a new century dawns, our greatest challenge remains to ensure that necessary increases in global productivity are achieved in a sustainable and environmentally friendly way.

I believe these are matters of concern for all of us. But effective action must be based on good scientific understanding of the underlying causes, and likely consequences, of loss of biological diversity.

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Lecture

Biological Diversity: Causes, Consequences, and Conservation

Lord (Robert) May of Oxford

Introduction

I am honoured to receive the 2001 Blue Planet Prize. Also I am very aware that I receive this prize as a symbolic representative of the large community of scientists, who in recent years have greatly advanced our understanding of the causes and consequences of biological diversity, and of growing threats to it. I especially commend the Asahi Glass Foundation for establishing this Prize in recognition of the importance of environmental and conservation science.

Properly to understand how today's rich and varied plant and animal life came to be here, we need to answer underlying ecological questions. How does the structure of the web of interactions among species affect communities' ability to recover from disturbance or to resist invasion? What factors determine the observed variety of patterns of species abundance, of commonness and rarity? More generally, what determines species numbers in different places? Above all, what are the various causes of observed extinctions, and to what extent are extinction rates currently accelerating? In what follows, I will sketch answers to some of these questions, and also will indicate remaining areas of uncertainty.

Structure of Ecosystems

Earlier Ideas. Around 1970, the conventional wisdom—set out in textbooks, following the work of the pioneering ecologists, Charles Elton and Evelyn Hutchinson—was that "complex" communities (those with more species and/or richer webs of connections among them) were more "stable" (better able to resist or recover from disturbance, human-created or natural). Comparing mathematical models for ecological communities with few species against the corresponding models with many species, I showed there could be no such simple and general rule; all things being equal, complex systems are likely to be more dynamically fragile. This and other related work was drawn together in the monograph *Stability and Complexity in Model Ecosystems* (1973, with a second edition in 1974). In 2001, Princeton University Press reissued this book, with introductory "retrospective thoughts," in its *Landmarks in Biology* series.

Ecosystem Stability and Complexity. I believe this work helped to refocus the agenda for studies of the structure and function of ecosystems. For one thing, we have become more careful about distinguishing the productivity of a community of interacting plants and animals, as a whole, from the productivity and fluctuations in the individual populations that constitute the community. Recent studies by Tilman *et al* (1996, 1998), Naeem and Li (1997) and others tend to bear out my earlier suggestions that increasing complexity or diversity, in the sense of a larger number of constituent species in the community (larger "species richness"), tends to make for greater stability in total productivity, but that individual species are liable to greater fluctuations in abundance in such communities. For another thing, it has become clear that increasing numbers of interactions among species in a foodweb (increasing "connectance") does not automatically enhance ability to resist disturbance; instead, current efforts seek to understand the special kinds of interconnectedness among subsets of species that reconcile complexity with stability in particular ecosystems (McCann *et al*, 1998).

A Contemporary Synthesis? More broadly, my own view is that, over evolutionary time, ecosystems are in tension between two opposing forces. On the one hand, evolution tends to favour every opportunity, every niche, being exploited, making for increasing diversity over time. On the other hand, more species-rich communities in general are more dynamically fragile, tending to set limits to diversification. In relatively environmentally predictable settings, such as tropical rainforests or some coral reefs, the trade-off between these two countervailing pressures is set at a point corresponding to more species-rich communities. In harsher and less predictable environments, such as boreal forests or estuaries, the trade-off results in relatively simpler communities. In both cases, the set point is determined by the acceptable average degree of fluctuation in individual populations, which is broadly similar—over the long run—in all cases. As noted above, this cuts across the earlier conventional wisdom, but seems increasingly in accord with observations about levels of fluctuation in tropical communities, and in various field experiments.

Patterns in the Distribution and Abundance of Species

Species Relative Abundance. There are broad trends in the relative abundances of species within a community or ecosystem. In old-established communities, these patterns of species relative abundance tend to be more even (often described by a subset of lognormal distributions) than those for early successional or highly disturbed situations. Such "canonical" lognormal patterns can be interpreted as arising from the multiplicative interplay of many ecological and evolutionary factors. These patterns have implications, amongst other things, for understanding the different kinds of "rarity" (Rabinowitz et al, 1986; Gaston, 1994); see Table 1. In particular, they imply that to be rare is by no means necessarily to be in danger of extinction. This latter point appears frequently to be misunderstood: for example, the current IUCN Red List of Threatened Plants (Walter and Gillett, 1997) unaccountably, and unlike the corresponding animal lists, treats all "rare" plants as threatened.

Table 1. The distribution of 160 plant species from the *Biological Flora of the British Isles*, classified into eight categories according to geographic distribution (wide or narrow), habitat specificity (broad or restricted), and local abundance (somewhere large or everywhere small). We would recognise the circled category (wide distribution, broad range of habitats, locally abundant somewhere) as "common;" the other seven categories represent "seven kinds of rarity" (after Rabinowitz *et al*, 1986).

Local population size	Geographic distribution			
	Wide habitat specificity		Narrow habitat specificity	
	Broad	Restricted	Broad	Restricted
Somewhere large	(58)	71	6	14
Everywhere small	2	6	0	3

Species-Area Relations. Other things being equal, there is a relation between a region's area and the number of species found in it. A tenfold reduction in area (as when a reserve is established, and its surroundings modified) roughly halves the number of species. More generally, there is a power law relationship, $S = cA^z$; here S denotes the number of species, A the area, c is a constant which varies from group to group, and the exponent z is usually in the range 0.2-0.3. Figure 1 gives an illustrative example. Interestingly, this relation follows from the "canonical" lognormal distribution of species relative abundance mentioned above, combined with the additional assumption that total numbers of individuals scale roughly linearly with area (for a recent review, see May and Stumpf, 2000). Given the shakiness of these theoretical assumptions, it is perhaps surprising that the species-area relationship is so widely found in nature. It has important implications. In particular, we shall see below how it can be used to make tentative projections about future extinction rates.

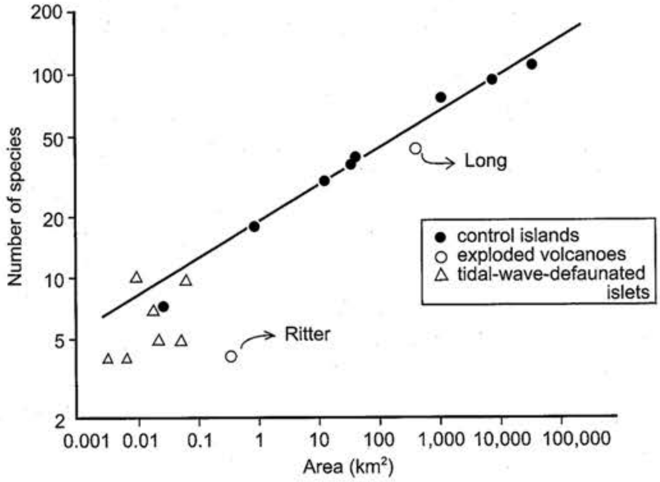

Figure 1. An example of the relation between species number and island area in an archipelago: number of resident, nonmarine, lowland bird species S on islands in the Bismarck Archipelago, plotted as a function of island area on a double logarithmic scale. The solid circles represent relatively undisturbed islands, and the straight line $S = 18.9\,A^{0.18}$ was fitted by least-mean-squares through the points for the seven largest islands. The open circles refer to the exploded volcanoes, Long and Ritter, where species number is still below equilibrium, especially on Ritter, because of incomplete regeneration of vegetation. The open triangles refer to coral islets inundated by the Ritter tidal wave in 1888. (From Diamond, 1974).

Numbers of Species in Relation to their Physical Sizes. The numbers of species of animals in different categories of physical size vary systematically. For terrestrial animals, a decrease by a factor 10 in characteristic linear dimensions (or, equivalently, a factor 1,000 in mass) roughly results in 100 times more species (May, 1978); see Figure 2. This rough rule holds down to size categories around a few millimetres; species numbers fall away below this. What are the ecological or evolutionary origins of this rough rule, which holds true over four or more orders-of-magnitude in characteristic lengths of animals on land, and roughly similarly in the sea (Fenchel, 1993)? To what extent—and why—is the breakdown in this rule at small sizes real, and to what extent may it be a consequence of less knowledge about smaller things?

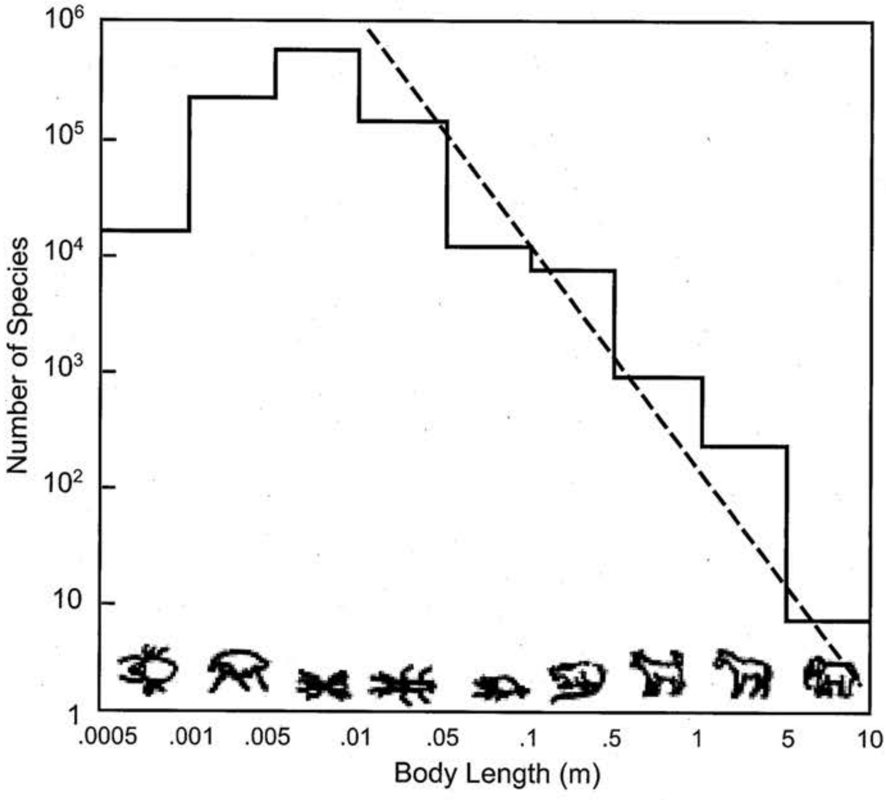

Figure 2. A crude estimate of the distribution of all terrestrial animals categorized according to characteristic length L. The dashed line indicates the relation $S - L^{-2}$, as in Fig. 3 (S = number of species). (After May, 1978)

Body Sizes and Geographical Ranges. Patterns in the relations between the body sizes and the geographical ranges of species are only just beginning to receive systematic attention. It is possible that geographical ranges are typically more extensive for relatively large organisms and for microorganisms (protozoa and below) than for mid-size organisms (insects). If true, such patterns—which are entwined with the species-size effects mentioned immediately above—are relevant, amongst other things, to possible range modifications associated with climate change.

Patterns in Foodweb Structure. It has been strongly argued that each plant or animal species in a foodweb typically is connected—eating or being eaten—with only 3 to 5 other species. Why so roughly constant a number, and why so small? Also, the lengths of food chains in such webs—the number of links connecting the primary producing plants, through the animals eating them, and those eating them, and so on, to the top predators— typically are only 3 to 4 links long, with surprisingly little variation within and among foodwebs. Again, why so roughly constant a rule, and why are chains so short? Although these important empirical patterns (Pimm et al, 1991) may in part be artifacts of the way humans gather and analyse complicated data, there are important questions here. Various explanations currently contend: efficiency of energy transfer from level to level within a foodchain; relations between the dynamics of the system and its structure; evolutionary instability of excessively complex chains; and others. But every explanation proposed so far has important weaknesses.

Connections Among Seemingly Different Questions. To illustrate how the above questions are intimately entwined with seemingly simpler questions of how many species there are on earth, consider the relation between foodweb patterns and global species numbers. If we really had a fundamental understanding of how foodweb structure was determined by evolutionary and ecological factors in specific environments, we could predict the average ratio between the number of animal species and the number of primary producing plant species that ultimately sustain them, in foodwebs in particular environments, and thence the overall global average such ratio. We can be fairly certain, to within 10% or so, that the global total of plant species is around 300,000. So if we knew the animal/plant species ratio, we could assess the total number of animal species, by this indirect argument based on understanding ecosystem structure. Unfortunately, we have no such understanding. Such rough empirical data as are available suggest that the animal/plant species ratio is around 10 in foodwebs, although with much variation from place to place. This very rough empirical estimate suggests a global total of about 3-million animal species; we shall return to this below.

Dynamics of Plant and Animal Populations

Another, very different, strand of my work is ultimately related to biodiversity, because of the surprising light it sheds on how populations can react to disturbance.

The Balance of Nature? Early work on "the balance of nature" implicitly tended to assume that population numbers would be roughly steady, unchanging from year to year, unless affected by environmental fluctuations. But the factors regulating the densities of plant and animal populations—food supplies, predators, infectious diseases, nest sites or other territorial considerations, and many others—tend to operate in a nonlinear way. That is, the strengths of the feedbacks that govern the possible steady or "equilibrium" population size themselves depend on population size, so that if the population doubles, it does not simply mean that per capita birth rates and death rates double; birth rates may fall, and death rates rise, more than proportionately or "linearly." This is what "nonlinear" means. In effect, two plus two does not necessarily add up to four when the governing mechanisms are nonlinear.

Chaos and Other Surprises. The simplest nonlinear equations representing how biological populations may be regulated by feedback mechanisms can exhibit a bewildering, almost magical, array of behaviour. The simplest such equations, of the kind suggested by various people working on insect and on fish populations as descriptions of their systems, can—although purely deterministic, with no statistical elements—give rise not only to the expected constant "equilibrium" solutions, but alternatively to stable and self-generated cycles of boom and bust, or even more surprisingly, to apparently random fluctuations. For a population, such as many temperate insects, with discrete non-overlapping generations (adults appearing each year, laying eggs to develop into next year's adults, then dying), a simple metaphor is $X_{t+1} = rX_t (1 - X_t)$. Here X_t is the population in year t, scaled so that if X ever gets as large as 1, it extinguishes itself, and r is its intrinsic growth rate at low density (when X is close to 0). As can be verified by iterating this simple equation on a hand-held calculator, if r is between 1 and 3, this equation describes a population that settles to a constant equilibrium value, as earlier ecological intuition required. If r is above 3 but below about 3.57, we see self-sustained cycles. For r bigger than 3.57, but below 4, there is "chaos," apparently random fluctuations, generated by this trivially simple deterministic equation. This behaviour is illustrated in Figure 3.

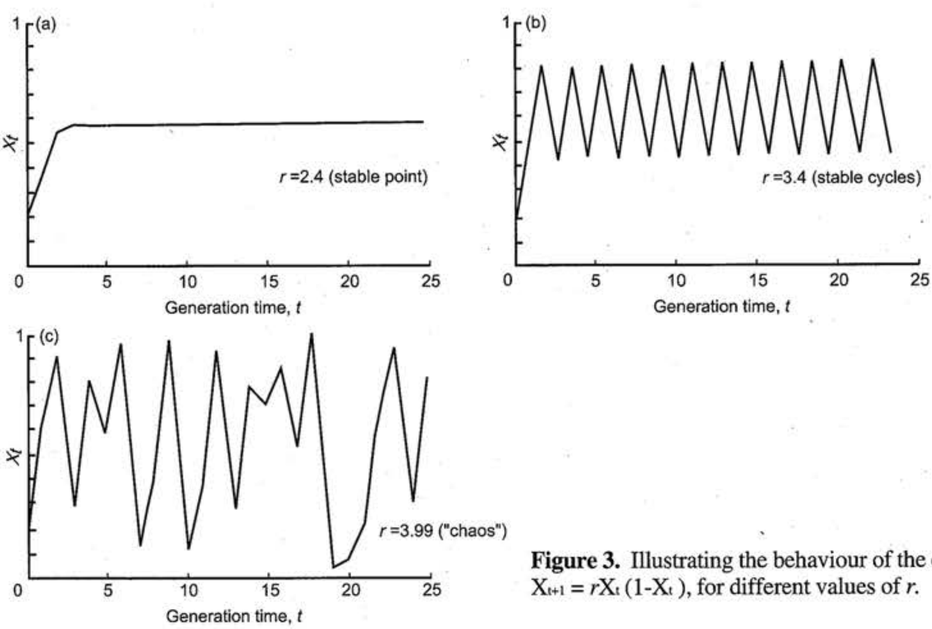

Figure 3. Illustrating the behaviour of the equation $X_{t+1} = rX_t (1-X_t)$, for different values of *r*.

General Implications of Chaos. This observation, motivated by purely ecological questions, was one of the strands that brought chaos centre stage across the sciences (May, 1974, 1976; the other strand was Lorenz's (1963) meteorological metaphor, based on a more complicated set of three differential equations). The recognition that simple and fully deterministic rules or equations can generate dynamical patterns that are effectively indistinguishable from random noise has very deep implications for science. It effectively marks the end of the Newtonian dream that knowing the rules will enable prediction; predicting local weather beyond about 10–15 days is not just a problem of computational power, but of the inherent unpredictability of chaotic dynamical systems.

Ecological Implications of Chaos. The implications of cyclic and, even more, of chaotic, dynamics for ecology are widespread. Often the "balance of nature" is disturbed by environmental fluctuations; this has long been recognised. But often the "balance of nature" is inherently cyclic or irregularly fluctuating, driven by the nonlinear dynamics of its own regulatory mechanisms. We have yet fully to realise the implications of this work for understanding the causes and consequences of biological diversity (May, 1985).

Biodiversity

What is the State of our Knowledge? Against the background of ecological questions sketched above, how well do we know the world of plants, animals and microorganismns with which we share this planet? The answer, by any one of a variety of objective measures, must be: not very well. First, estimates of the number of species that have been named and recorded (a simple factual question, like how many books in the library catalogue) range from 1.4 million to 1.8 million. Second, estimates of the total number of species present on Earth today range over more than an order-of-magnitude, from a low of around 3 million to a high of 30 million or possibly much more. And third, we have even less idea of the rates at which species may currently be going extinct, as result of habitat destruction and other consequences of human population growth.

Some Personal Estimates. In this brief overview, I outline my own best guess of the answers to these three questions. For the number of distinct species named and recorded, I emphasise the uncertainties caused by unresolved synonymies. For the likely total number of living species, I set out my reasons for leaning to the lower end of the range of published estimates. And for present and likely future extinctions, I sketch a relatively precise approach, based on comparative rates of extinction, which avoids some of the imprecisions inherent in dealing with total number of species.

Numbers of Named Species: Background. The systematic naming and recording of species began relatively recently, with Linneaus' standard work, which in 1758 recognised some 9,000 species. Today the total number of living species named and recorded has been estimated at around 1.7 to 1.8 million. Amazingly, no centralised catalogue exists. There are synoptic and computerised catalogues for some better-known groups, most notably birds and mammals. But more than half (roughly 56%) of all named species are insects, and the majority of these are still on card catalogues in individual museums and other collections. By one estimate, around 40% of all named beetle species are known from only one site, and many from only one specimen. In short, the amount of taxonomic effort varies very widely from group to group, with roughly one-third of all taxonomists working on vertebrates, another third working on the 10-times more numerous plant species, and the remaining third working on invertebrate animals, which outnumber vertebrate species by at least a factor of 100 (see Table 2).

Table 2. The taxonomy of taxonomists: a rough estimate of the distribution of the taxonomic workforce among broad taxonomic groups, in Australia, U.S.A. and U.K. (after Gaston and May 1992).

		Animals			
	Plants	Vertebrates	Invertebrates	Microorganisms	Fossils
Approximate division of workforce (%)	30	25	35	2-3	5
Estimated total number of living species (Thousands)	300	45	3,000 +	?	-

Numbers of Named Species: Problems. Hammond's (1995) assessment for the IUCN of the total number of distinct species that have been named and recorded emphasises the uncertainties caused by synonyms. His survey estimates that around 13,000 new species are currently named each year, but current rates of resolving synonymies—the same species inadvertently given different names by different people in different collections—reduce this number to around 10,000 distinct new species added yearly to the known total. In effect, this corresponds to a synonymy rate of around 20% in named species, a figure elsewhere cited as representative on more direct grounds (Solow et al, 1995). Of course, any such assessment of known synonymy rates must be a lower limit, with other synonyms yet to be uncovered or accumulating in new work. Solow et al (1995) have made a start on this important problem, suggesting the true synonymy rate may be more like 40%.

Numbers of Named Species: A Current Estimate. Allowing for all this, my recent assessment (May, 1999) is that the current global total of distinct eukaryotic species (broadly, plants, animals and fungi) that have been named and recorded is around 1.5 million. This is lower than Hammond's (1995) 1.74 million, but is consistent with Wilson's (1988) estimate of 1.4 million ten years ago (augmented by 0.01 million each year for 10 years). See Table 3.

Table 3. Number of named, distinct species of eukaryotes (in thousands)

Group	Hammond (1995)	May (1999)
Protozoa	40	40
Algae	40	40
Plants	270	270
Fungi	70	70
Animals	1,320	1,080
Vertebrates	*45*	*45*
Nematodes	*25*	*15*
Molluscs	*70*	*70*
Arthropods	*1,085*	*855*
(crustaceans)	*(40)*	*(40)*
(arachnids)	*(75)*	*(75)*
(insects)	*(950)*	*(720)*
(other)	*(20)*	*(20)*
others	*95*	*95*
Total	1,740	1,500

Total Number of Species Living Today. The true total of extant species, as distinct from those we have named and recorded, is hugely uncertain. My recent assessment of the evidence and uncertainties led to a guess of around 7 million in total, with a plausible range of 5 to 15 million (May, 1999). This is lower than Hammond's (1995) guess of 12-million eukaryotic species, but higher than other estimates which are as low as 3 million or so species in total. Estimates as low as 3 million, or as high as 100 million or more, can be defended. See Table 4.

Table 4. Estimated total numbers of living species (in thousands)

Group	Hammond (1995)		May (1999)
	High – low	Working Figure	
Protozoa	200 – 60	200	100
Algae	1,000 – 150	400	300
Plants	500 – 300	320	320
Fungi	2,700 – 200	1,500	500
Animals	100,000 – 3,000	9,800	5,570
Verts	*55 – 50*	*50*	*50*
Nematodes	*1,000 – 100*	*400*	*500*
Molluscs	*200 – 100*	*200*	*120*
Arthropods	*100,000 – 2,400*	*8,900*	*4,650*
(crust)	*(200 – 75)*	*(150)*	*(150)*
(arachnids)	*(1,000 – 300)*	*(750)*	*(500)*
(insects)	*(100,000 – 2,000)*	*(8,000)*	*(4,000)*
others	*800 – 200*	*250*	*250*
Total	100,000 – 3,500	12,200	6,800

Range	:	100 - 3 million
Plausible range	:	15 - 5 million
Best guess	:	7 million

Total Number of Species: Further Comments. All such estimates are dominated by insect totals. I favour an estimate of around 4-million insect species in total, partly based on the methods developed by Gaston and Hudson (1994). This is lower than Hammond's 8-million insects species, but higher than other estimates of around 2 million, either of which could be correct. My total also reflects a distrust of the dramatic upward revision of fungal species numbers by Hawksworth (1991) and of marine macrofaunal species by Grassle and Maciolek (1992), amongst other things. For more detailed reviews of these hugely important issues, see May (1990, 1994, 1999).

EXTINCTION RATES

The Past. The history of life on Earth, written in the fossil record over the past 600-million years since the Cambrian explosion in the diversity of multicellular organisms, is one of broadly increasing diversity, albeit with many fluctuations and punctuated by episodes of mass extinction; see Figure 4. As reviewed in more detail elsewhere (Sepkoski, 1992; May, 1999), the average lifespan of a species in the fossil record, from origination to extinction, is typically a few million years (that is, of the order 10^6 to 10^7 years); there is, however, much variation both within and among groups, and some groups have lifespans significantly longer or shorter than this; see Table 5. Comparing this few-million-year average lifespan with the 600-million-year fossil record span, we might estimate that 1%-2% of all species ever to have lived are with us today. But, allowing for the fluctuating but steady—very roughly linear—average growth in species diversity since the Cambrian, a better estimate might be 2%-4%. And if we recognise that most of today's species are terrestrial invertebrates (mainly insects), whose patterns of diversification began around 450-million-year ago and whose average lifespan may be characteristically longer than 10-million-year, it could be that today's species represent more like 5%, or conceivably even 10%, of those ever to have graced our planet.

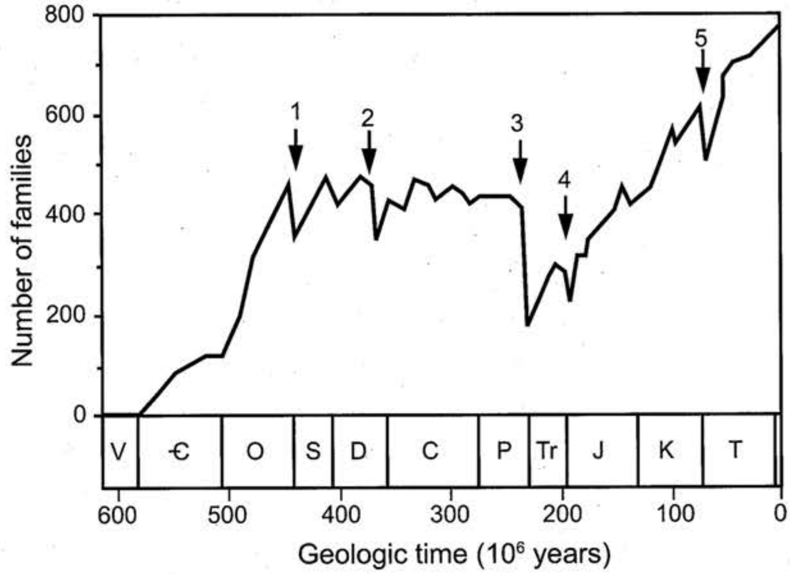

Figure 4. The history of the diversity of marine animal families, as shown by the fossil record over time. The curve connects 77 discrete data points, each giving the total number of well-skeletonized families from a particular stratigraphic stage. The arrows indicate the Big Five episodes of mass extinction. The length of the various geological epochs are indicated on the time axis (V, Vendian; -€, Cambrian; O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous; P, Permian; Tr, Triassic; J, Jurassic; K, Cretaceous; T, Tertiary).

Table 5. Estimated lifespans, from origination to extinction, of various taxa in the fossil record (measured in millions of years). The first part of the Table is after May *et al* (1995), whereas the second part is a new compilation by Robin Cocks (Natural History Museum, London).

TAXON	Date of estimate	Average lifespan (million years)
Part I : References in May *et al* (1995)		
All invertebrates	Raup (1978)	11*
Marine invertebrates	Valentine (1970)	5 – 10
Marine animals	Raup (1991)	4
Marine animals	Sepkoski (1992)	5*
All fossil groups	Simpson (1952)	0.5 – 5
Mammals	Martin (1993)	1
Cenzoic mammals	Raup and Stanley (1978)	1 – 2
Diatoms	Van Valen (1973)	8
Dinoflagellates	Van Valen (1973)	13
Planktinic foraminifers	Van Valen (1973)	7
Cenozoic bivalves	Raup and Stanley (1978)	10
Echinoderms	Durham (1970)	6
Silurian graptolites	Rickards (1977)	2
		6 – 7
Part II : Information compiled by R. Cocks		
Silurian graptolites	Koren and Rickards (1996)	0.2
Cambrian trilobites	Davidek *et al*, in press	0.4
Brachiopods	R. Cocks, pers. comm.	0.5
Rodents	R. Cocks, pers. comm.	0.3 – 1.0
Perrissodactyls	R. Cocks, pers. comm.	0.5
Insectivores	J.J. Hooker, pers. comm.	3
Corals (tertiary-recent)	Budd et al, (1996)	0.2 – 7 (average 4)
Forams	Buzas and Culver (1984)	14 – 16
Coccoliths	J.R. Young, pers. comm.	c. 10

Recent Extinctions. Over the past century, rigorously documented extinctions in well-studied groups—primarily birds and mammals—have run around one species per year. Because tropical species typically receive less attention, true extinction rates of birds and mammals are undoubtedly higher. But even one per year among the roughly 13,000 species of birds and mammals translates to expected species' lifetimes, based on documented recent extinction rates, of around 10^4 years. Although seemingly long, this is shorter by a factor of order 10^{-2} to 10^{-3} than the background average lifespan of 10^6 to 10^7 years seen in the fossil record. That is, recent extinction rates in well-documented groups have run one-hundred to one- thousand times faster than the average background rates.

Guesses About Tomorrow. Looking toward the immediate future, four different approaches to estimating impending rates of extinction suggests species' life expectancies of around a few hundred to one-thousand years. One of these approaches is based on the above-mentioned species-area relations, coupled with assessments of current rates of tropical deforestation or other habitat loss (if tropical forests are being lost at the rate of 1%-2% each year, the species-area relation implies this commits 0.25%-0.5% of their species to extinction, which inverts to a rough estimate of species' lifetimes of roughly 200-400 years). Two other methods are based in different ways on the International Union for the Conservation of Nature's (IUCN's) current catalogue of "endangered" or "vulnerable" species. As reviewed elsewhere (May *et al*, 1995), one of these estimates the average rate at which species in better-studied groups (birds, mammals, palm trees) are climbing the ladder of IUCN categories of endangerment; this suggests expected species' lifetimes in the range 100 to 800 years in these groups. A more precise variant of this approach uses species-by-species assessments of extinction probability distributions as functions of time. Using 10 vertebrate groups (3, 4, 3 orders or families of reptiles, birds and mammals, respectively), Mace (1994) estimates average species' lifetimes in the range 100 to 1,000 years, and mainly in the 300- to 400- year range for mammals and birds. The fourth method uses models for branching processes in phylogenetic trees, along with recent data for bird and mammal orders, to project average times to extinction within bird and mammal orders (McKinney, 1998); under a range of assumptions about branching processes, these models suggest species' lifetimes again of the order of a few- hundred years (characteristically shorter for mammals than birds). Thus, all four of these methods, each of which is unreliable in its own distinctive way, agree in suggesting a further shortening of expected species' lifetimes, to around 10^2 to 10^3 years.

The Sixth Wave of Extinction. Such figures correspond to likely extinction rates of a factor of ten thousand, give or take at most an order of magnitude, above background, over the next century or so. This represents a sixth great wave of extinction, fully comparable with the Big Five mass extinctions of the geological past, but different in that it results from the activities of a single other species rather than from external environmental changes.

A Calculus of Biodiversity? As we face this future, we must ask: does it matter more if we lose 25% of all mammal species than if we lose 25% of the vastly more numerous insect species? Or does it matter equally? Or less? There is need not only for more taxonomic information, but also for a "calculus of biodiversity" based on this information. Such a calculus should, ideally, quantify the taxonomic uniqueness, or amount of independent evolutionary history, inherent in individual species (Vane-Wright et al, 1991; Nee and May, 1997). I would like to see such quantification, along with more explicit recognition of constraining political, economic and social realities, replace emotion in assigning conservation priorities and places on the Ark (although emotional elements should, certainly, also be part of such a quantification). For further review and remarks on this topic, see May *et al* (1995).

Why Value Biological Diversity?

A Narrowly Utilitarian Argument. One argument for the preservation of biological diversity is narrowly utilitarian. It correctly emphasises the benefits already derived from natural products, as foods, medicines and so on. Currently, 25% of the drugs on the shelves in the pharmacy derive from a mere 120 species of plants. But, throughout the world, the traditional medicines of native peoples make use of around 25,000 species of plants (about 10% of the total number of plant species); we have much to learn. More generally, as our understanding of the natural world advances, both at the level of new species and at the level of the molecular machinery from which all organisms are self-assembled, the planet's genetic diversity is increasingly the raw stuff from which our future can be constructed. It seems a pity to be burning the books before we can read them, and before we can create wealth from the recipes on their pages.

A Broadly Utilitarian Argument. Another class of arguments is more diffusely utilitarian. The interactions between biological and physical processes created and maintain the earth's biosphere as a place where life can flourish. With impending changes in climate caused by the increasing scale of human activity, we should be worried about reductions in biological diversity, at least until we understand its role in maintaining the planet's life support systems. The first rule of intelligent tinkering is to keep all the pieces.

An Ethical Argument. For me, however, a third class of argument is the most compelling. It is clearly set out by the U.K. Government in *This Common Inheritance* (HMSO, 1990, ch 1.14): it is "the ethical imperative of stewardship ... we have a moral duty to look after our planet and hand it on in good order to future generations."

Conclusion

The previous century has seen more advances in our understanding of the natural world than has all previous human history. We have applied this scientific understanding to improve lives in both developed and developing countries. We are, however, now beginning to realise some of the unintended adverse consequences of well-intentioned actions: arguably the most significant is the accelerating loss of biological diversity. What happens to our world, and to us and the creatures we share the world with, in the future depends on the actions we take now. As a new century dawns, our greatest challenge remains to ensure that necessary increases in global productivity are achieved in a sustainable and environmentally friendly way.

I believe these are matters of concern for all of us. But effective action must be based on good scientific understanding of the underlying causes, and likely consequences, of loss of biological diversity.

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Profile

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Education and Academic and Professional Activities

1934	Born in August in the United Kingdom.
1958	B.A., Oxford University.
1958-1965	District Officer, Kenya Administration; High School Teacher in Kenya.
1963	Master's Degree, Oxford University.
1966-1969	Freelance writer, photographer and lecturer on African wildlife.
1970-1972	Attended the University of California, Berkeley.
1973	Ph.D., University of California, Berkeley.
1972—	Research projects for the U.S. National Academy of Sciences, the Royal Society in the United Kingdom, the Soviet Academy of Sciences, NASA, the World Bank, United Nations agencies, the OECD, WWF, and many other bodies. Honorary Visiting Fellow, Green College, Oxford University.
1983	Gold Medal, World Wildlife Fund.
1986	Gold Medal, New York Zoological Society.
1987	Special Achievement Award, Sierra Club.
1987	Distinguished Achievement Award, Society for Conservation Biology.
1989	Fellow, World Academy of Art and Sciences.
1992	Volvo Environment Prize.
1994	Member, U.S. National Academy of Sciences.
1995	Sasakawa Prize, United Nations Environment Programme.
1997	Appointed by Queen Elizabeth to the Order of St. Michael and St. George "For Services to the Global Environment."
2000	Ambassador, World Wide Fund for Nature/U.K.

To this day, Dr. Myers has pursued research independent of any single organization, being commissioned to conduct research into environmental problems on behalf of many international organizations while serving as a visiting professor at Harvard, Oxford and many other high-profile universities around the world. One of the characteristics of his research is his penchant for presenting and analyzing new topics ahead of the rest of the world.

Although the extinction of species was thought up to the 1970s to be proceeding at a rate of approximately one per year, Dr. Myers calculated that it was more likely occurring at a rate of one per day. In the late 1970s, he pointed out that the deforestation of tropical rainforests was proceeding at the tremendous rate of 75,000 square kilometers per year. These new suggestions were greeted with skepticism by many at first, but he was proved correct by the facts, including analysis of satellite images.

In the late 1980s, he advocated the "hotspot" approach as the best way to conserve the species that were in the most trouble. This approach concentrates efforts on those areas with large concentrations of species facing extinction. This approach has been adopted by many environmental conservation organizations as a policy for conserving biodiversity.

Dr. Myers, who is well versed in both the natural and social sciences, has also led the world in analyzing such topics as environmental refugees and perverse subsidies. In addition to authoring several hundred scholarly articles, he continues to make a major contribution to progress toward a sustainable future for all through other publications and public appearances.

Our Environmental Future

Dr. Norman Myers

December 2001

The present generation stands at a vital turning point in human history. For the first time since we came out of our caves, entire segments of our planetary ecosystem face terminal threat through mass extinction of species, tropical deforestation, desertification, global warming and a host of other environmental problems. These are economic problems as well since our economies are ultimately dependent on the environmental resource base that supports all human activities. By safeguarding our environments, we are safeguarding our daily well-being too.

Shall we not say, then, that we are a privileged generation to live at a stage in the human enterprise when we have opportunity to save both our Earth and our world? If we succeed with this outsize challenge, we shall surely earn the thanks of numerous generations into the future. Indeed, we are a unique generation. No generation before us has ever faced a similar challenge, because the environmental problems have not remotely matched those of today. No generation that comes after us will ever face such a challenge, because if we do not overcome the problems, our descendants will have nothing left but to cope with the disaster that we pass on to them. It is up to us alone. Fortunately, we still have time to get on top of these problems before they get on top of us. Are we not fortunate beyond dreams to live at this unprecedented time?

Within this exceptionally creative context, a key question arises. What more can we do to surmount our environmental difficulties? In this essay, I propose that we give greater attention to two salient aspects of our challenge; two aspects that do not generally receive the attention they deserve. In fact, I consider they are the two most important factors in our environmental future. I shall plan to give priority attention to them through my research efforts in the coming years. This is research, moreover, that I could not undertake if it were not for the funding supplied by the financial generosity of the Blue Planet Prize.

1. The Future

We all spend a lot of the present thinking about the future. Business leaders focus on the next quarterly sales statement. Bankers fixate on the year-end returns on investment. Politicians are preoccupied with the next election. Citizens ponder all kinds of concerns, from next week to next year, to retirement time.

Whatever our situation and whatever our time horizon, we all "discount" the future. For each and every one of us, one dollar today is worth more than one dollar tomorrow. But consider: a sum of $100 in fifty years discounted at an annual rate of 10% (a frequent rate as dictated by capital markets) is worth less than $1 today. Given the same discount rate of 10%, a cost of $100 billion accruing in 100 years' time (through global warming for example) will have a present value of hardly more than $7 million. With a more modest discount rate of 5%, a cost of $1 billion in 100 years' time will have a present value of only $87 million. Conversely, an investment of $1 today (to counter global warming for instance) will, with a 5% discount rate, be worth almost $18,000 in 200 years' time, and with a 10% discount rate it will be worth $190 million.

The clincher factor is that a discount rate of 10% implies there is no future worth bothering about beyond seven years. Thus, the iron rule of the investment market.

Equally to the point, if the most valuable forest on Earth cannot make its "investment in the future" in less than seven years (most trees in the forest won't produce new adult trees in less than 10 years, more likely 20 years or more), it makes commercial sense for a logger to chop the whole lot down straight away and put the earnings into the stock market with its greater and quicker profit. It is financially rational, too, for a corporation to pursue activities with revenues of $1 million this year even though it recognizes that in fifty years' time these activities will entrain environmental costs—such as writing off a potentially renewable resource—of $100 million.

Thus arises the apparent shortsightedness of investors, if not their outright indifference to the future. It is not that they are truly shortsighted, rather they play by the rules of the marketplace as laid down by society. If society does not like the outcome, it is up to society to change the rules rather than shout foul at the investor (as is the inclination of certain environmentalists).

Within this framework, consider one particular environmental problem, the mass extinction that is overtaking the planet's species. This biotic crisis threatens not only to eliminate large numbers of species (conceivably tens of thousands per year already), but to reduce evolution's capacity to generate replacement species. This "end to birth" phase looks likely to endure for fully five million years and possibly several times longer. Just five-million years—a period twenty times longer than humans have been humans—makes it impossible for us to postulate any realistic discount rate at all.

Moreover, the number of people affected within just five-million years could be as many as 500 trillion, or 10,000 times more people than have ever existed. (Just one trillion is a large number; figure out the length of time made up of one trillion seconds.) The "decision" on mass extinction being taken by the present generation—to allow it to proceed virtually unrestricted—will be far and away the biggest decision ever taken on the unconsulted behalf of future generations. In certain respects it will surely surpass all such past decisions combined. In this situation, are discount rates of any use at all?

This throws a new perspective on what is known as "intergenerational equity" or justice to future generations. The best books on this issue speak of no more than a dozen generations (300 years) ahead, beyond which the future is ostensibly unknowable and of scant practical interest anyway. While there is much uncertainty about what species are "good for," we are effectively saying we are completely certain that 200,000 future generations during those five million years will not be unduly disadvantaged through the mass extinction we are precipitating today. Yet our scientific understanding indicates the opposite is the case.

In any case, can we really envisage so many generations ahead? That is, can we identify with them, can we sense how they will cope with their future world, and imagine what will be their hopes and experiences? I must confess that I myself, for all my professional analysis of the future, cannot personally reach out in my mind beyond just a few generations. I hope one day to see some grandchildren, and I speculate on what sort of children they will eventually produce in turn. But five generations ahead is the best I can manage, try as I might. At the same time, I have to admit that my affluent lifestyle is surely serving to impose injury, however unintentionally, on the future world way beyond five generations, worth 125 years. Global warming, for instance, will degrade the planet for many hundreds of years.

Bottom line: we need a device in addition to discount rates to reflect our evaluations of the future. In fact, to reflect those evaluations that truly count. Relying on the supposed preferences of the marketplace means we would not bother in the least to safeguard the planet's forests, its oceans, its atmosphere or its ozone layer, let alone its climate. But because we do not have an economic alternative to conventional discounting, the case for forests, et cetera, tends to fail by default.

2. Environmental Surprises Ahead

Despite our inability to value the future in any way that makes sense in the long run, we should assume that the future will feature a host of surprises. Yet we suppose that surprises are an unusual, if not a rare, phenomenon. We should start to wrap our minds around the idea of a "surprise–rich" future, however, since surprises are likely to become ever more frequent within our lifetimes. They could also become the most significant single factor in the lives of businesspeople, politicians and, in fact, every single citizen.

Environmentalists view surprises in the technical sense of "discontinuities." A discontinuity arises when something suddenly happens to mark a profound change from the way things have been. For instance, when water cools, it eventually, and without warning, turns from a liquid to a solid, ice—all in a moment. It is the same when it heats and turns into a gas: steam. If you, the reader, are still puzzled, consider that we all have had first-hand experience of an absolute discontinuity, and one of a profoundly personal sort: when we were born. And a related discontinuity awaits us at the end.

We are acquainted with all kinds of other discontinuities. In the economic field, there's been the end of Japan's "bubble economy" in 1989, the abrupt emergence of OPEC, "Black Wednesday" on the U.S. Stock Exchange, and the recent upheavals in Asian financial markets. These crashes constantly take economists by surprise, as if crashes, however often repeated, lie entirely outside the established order of things. As is sometimes said, economists have predicted six of the last three recessions.

In terms of political discontinuities, recall the fall of the Berlin Wall and the end of South Africa's apartheid, plus the peaceful break-up of Czechoslovakia and the democratisation of the Philippines, South Korea, Argentina and Brazil. Also the peaceful collapse of the Suharto regime in Indonesia.

In the environmental arena, we should anticipate a host of discontinuities ahead. The future certainly will not be a simple extension of the past in light of the expanding niche of humankind and its multifarious activities. It behooves come to us to grips with the idea of discontinuities so that they won't take us so much by surprise. Why do they ever take us by surprise? Well, because environmental problems are often problems of which we have scarcely thought.

These surprise phenomena deserve priority attention. Yet science has hardly touched on them. For the most part, they remain black holes of research. Among environmental discontinuities of the recent past—phenomena that should give us a clue about potential future events—are the "bleaching" of coral reefs with extensive morbidity and mortality throughout coral communities; mass mortality of dolphins and seals; phytoplankton blooms; cancer epizootics in marine turtles and fish; population declines among birds, especially North American and European migrants; and fast-growing die-offs of frogs among other amphibians in many parts of the world.

Still other environmental instances include the abrupt emergence of acid rain and the Antarctic ozone hole, likewise the collapse of the Peruvian anchovy fishery in the 1970s and the New England cod fishery in the early 1990s. Broadly viewed as environmental issues, too, are population surprises, notably the sudden soaring of population growth rates in one hundred countries during the 1960s, followed by steep plunges in a few countries in recent times. Who would have supposed that Iran, a fundamentalist Islamic state and as chauvinistic as they come, would need only 14 years to bring down its population growth rate from over 3%, to just 1% per year?

All these events have been unpredictable—or at least they have exceeded our present capacity to predict them. Entirely predictable is our readiness to be caught unawares time after time. We profess to have been surprised by the eruption of AIDS, yet the truly surprising thing is that we were surprised. It was surely inevitable that as huge numbers of people pressed deeper and deeper into tropical forests with their huge reservoirs of new pathogens, one would eventually make the leap from wild animals into humans, whereupon the pathogen would find itself in a bacterium's paradise, with human hosts travelling far and wide across landscapes local and global. As humans invade one "foreign" ecosystem after another, should we not anticipate a whole series of disease disasters?

All this raises a key question that should be at the top of any research agenda for environmentalists, also for economists and political analysts. What surprises should we anticipate for the foreseeable future. Hence, what can we do about them? What if China were to break up into half-a-dozen "Chinas," a not-impossible prospect? Think of the earthquake effects it would generate for global geopolitics. Or consider Saudi Arabia, only semi-stable at best with its lavish, untaxed and oil-subsidized lifestyles becoming unaffordable. What if its autocratic regime were to be undermined by educated princes returning from Harvard and Oxford universities, plus equally educated princesses told they must wear the veil, not drive a car and submit to numerous other restrictions? Were the Saudi regime to collapse or to be despatched by a coup, there would be a swift and sharp rise in oil prices, the spot market leaping to at least $50 per barrel, conceivably $75, not impossibly, $100.

Still more seismic would be some environmental discontinuities, especially climate changes. In the tropical Atlantic, water temperature can grow warmer and warmer without causing severe storms, but once it passes 28 degrees Celsius it starts to generate hurricanes. Even though the increase is merely incremental, it is enough to trigger a discontinuity of exceptional impact. What if, as is all too possible, Caribbean hurricanes no longer bypass Miami, but one of them were to land on top of the city? The damages could easily exceed $100 billion, whereupon the discontinuity would immediately become economic as much as environmental.

Still more to the point, a globally warmed world could melt enough of the Greenland icecap to dislocate the currents of the North Atlantic. Result, the Gulf Stream could shift southwards and leave Britain turned into another Iceland. While this could not happen overnight, the prehistoric record shows it could occur in just a decade or two—lightning speed in terms of the economic traumas implied.

Given the many future global upheavals likely in a world with pressures from unprecedented growth in human numbers and human activities, we can surely expect that environmental changes will emerge faster, larger and more intense. In turn, these will entrain abundant discontinuities of both economic and political kinds, also social and cultural kinds, all arriving at once and making for super discontinuities. There could well be one discontinuity series after another, or rather side by side with each other, overtaking us at accelerating pace, and producing fundamental shifts in global systems of every sort from grand-scale ecosystems to nation states; in fact, the entire human enterprise.

Whether it will precipitate a shift in our understanding is debatable. Thus far, we have a scant idea of what discontinuities lie ahead, nor are we likely to know until they start to happen (if then). The expert in greatest demand will be the specialist in surprises. The secret is to spot those trends that are headed for terminal decline after long build-up of adverse forces bubbling away beneath the surface.

Reader, why not take a moment to try your hand at becoming such an expert—by looking beyond the headlines to seek out the true news. Attempt, in other words, a discontinuity in your own manner of thinking.

Lecture

Exploring The Frontiers of Environmental Science

Dr. Norman Myers

I am deeply grateful to the Asahi Glass Foundation for awarding me this prestigious prize. There are two particular reasons why I feel so appreciative. First, I pursue environmental science in a way different from most of my colleagues around the world. I work on my own as an independent scientist, which is a form of career not usually recognized by a major award. Secondly, you have selected me for work that spans a range of environmental fields: biodiversity, evolution, forests, eco-agriculture, environmental security, population, resource economics and sustainable development. My research is interdisciplinary, spanning both the life sciences and the social sciences. The environmental challenge covers a host of factors with multiple interactions and as such it requires interdisciplinary science. In fact, I specialize in being a generalist, which, like my independent status, is different from what most scientists do—and hence it too is rarely recognized through a top-rank prize. Your award will send a strong message to start-out environmental scientists that they may well be applauded if they pursue an independent or an interdisciplinary career, preferably both.

Let me illustrate with some examples of my environmental research—examples that also illustrate how I have attempted to explore some frontiers of environmental science. In this latter respect too, I sometimes depart from mainstream science. Whereas many scientists concentrate on supplying new answers to established questions, I also prefer to ask if we are raising all the right questions in the first place.

1. Mass Extinction of Species

In 1971, I started to demonstrate that we are into the opening phase of a mass extinction of species. Far from accepting the conventional estimate that species were disappearing at a rate of one per year—a view long established among scientists, conservationists and governments—I calculated that the extinction rate was at least one species per day, possibly many times more. At first my findings were dismissed as exaggerated, but they were eventually proved correct by other scientists' analyses. I have subsequently refined my assessment several times, always with the same conclusion: that we are starting to witness the greatest depletion of life's abundance and variety since the demise of the dinosaurs and associated species 65-million years ago. There is much evidence, albeit less than conclusive, that we could already be losing tens of thousands of species every year, and at a rate at least one-thousand times greater than the "background" rate of the prehistoric past.

2. Tropical Deforestation

In 1978, I undertook a U.S. National Academy of Sciences project to investigate the true rate of tropical deforestation. Using remote sensing data, I demonstrated that the rate was at least 2.5 times greater than had been conventionally supposed, and a rate that was accelerating rapidly. Since tropical forests contain the majority of Earth's species and were being depleted faster than any other ecological zone, I identified the forests as the main locus of the mass extinction underway. While my deforestation findings were viewed in some quarters as alarmist, they were subsequently confirmed by other scientists' surveys. I convened a United Nations conference to get the issue established on political agendas. In 1989, I undertook a follow-up assessment that supported my earlier projections of deforestation.

3. The Hamburger Connection

Also on the deforestation front, I started in the early 1980s to show that the overall problem was not limited to tropical forest countries. It could also originate in developed countries through, for example, their marketplace demand for artificially cheap beef as epitomized through "the hamburger connection" between North America and Central America, and "the cassava connection" between Europe and Southeast Asia. In the first instance, the beef was raised on forestlands converted into pasture, and in the second instance, the cassava, being a rich livestock feed for cattle in Europe, was grown on plantations established by clearing tropical forests. This time I ran into trouble from a hamburger corporation that threatened me with a lawsuit for damages totalling $3 million.

I subsequently documented North/South linkages of similar sort with respect to desertification in the Sahel through European governments' support of export crops, such as groundnuts and cotton, and with respect to desertification in Southern Africa by virtue of beef subsidies from the European Community. The upshot in all these cases was that environmental degradation was caused by marketplace demand from countries way beyond the horizon from where the degradation occurred. It was a case of looking beyond **symptoms** of problems to **sources** of problems—a more productive way to tackle environmental challenges in their full scope.

4. The Triage Concept for Threatened Species

Also in the early 1980s, I broached the concept of "triage" with respect to threatened species. The concept postulates that since we have far too few conservation resources to assist all species under threat, we are obliged to choose (whether deliberately or not) between species: some warrant our support, others cannot. While the choice is rarely made in systematic fashion, it is effectively and increasingly made as an in-built determinant of our save-species efforts. Hence there is a premium on making conservation decisions by design rather than by default. Americans have assigned $15 million to saving a single species, the California condor, whereas the same sum could go far to preserve 200 threatened mollusc species in the Mississippi River system—yet the implicit trade-off has hardly been addressed.

I devised a series of evaluatory criteria by which we can make selective judgements for and against particular species, and do it in informed and methodical fashion. These criteria were based on biological, ecological, genetic, evolutionary, economic, aesthetic and ethical factors. My analyses were eventually adopted as an operational principle by a number of conservation organizations.

Much the same analysis applies of course to entire ecosystems and even biomes. Should we not be making a super priority of tropical forests (even if that is to the detriment of other biomes) on the grounds that the forests feature the great majority of extinctions both present and prospective? These are very hard decisions, demanding the best scientific insights we can mobilize.

5. Tropical Forests and Climate

In the mid-1980s, I synthesized data from the main sectors of the humid tropics to show that contrary to much conventional thinking, tropical forests can indeed influence climate, whether at local, national, regional or even global levels. The forests manifest their influence through disruption of rainfall regimes, increase in the albedo effect, and buildup of greenhouse gases in the atmosphere. More importantly, I evaluated the biomass dynamics of tropical forests with respect to their carbon sinks, concluding that despite established thinking (again), tropical forests play a pivotal role in the global carbon budget insofar as they contain fully one-fifth of all carbon held in the planet's plants and soils. When the forests are burned, they release their carbon, contributing very roughly one-quarter of carbon dioxide build-up in the global atmosphere. I subsequently developed these findings via the Intergovernmental Panel on Climate Change into a mode to mitigate global warming through enhanced forest conservation and reforestation.

6. Economic Value of Species and Genetic Resources

Also in the mid-1980s, I returned to species, assessing the economic values of their genetic resources and with particular respect to sectors such as medicine, agriculture, industry and energy. I calculated that, for instance, the two anti-cancer drugs from the rosy periwinkle generated commercial sales of $200 million per year worldwide, while economic values in terms of the 70,000 working lives saved each year were worth several times more. I further estimated that the commercial value of all plant-derived pharmaceuticals was at least $40 billion per year, yet we enjoyed their benefits after scientists had conducted intensive assessment of only one plant species in one hundred.

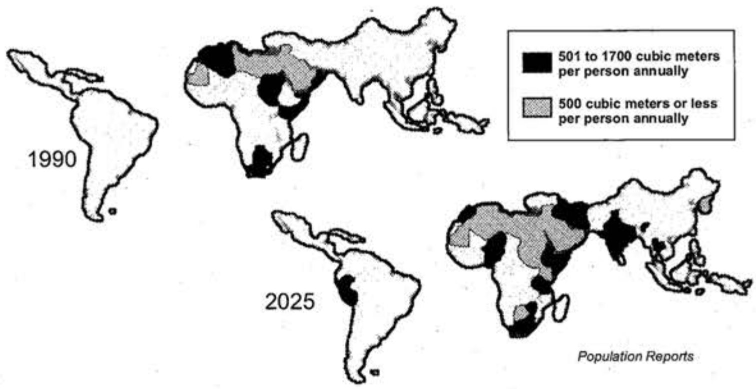
This was the first occasion of demonstrating the capacity of species to exert their financial strength in the marketplace. The findings proved offensive to certain colleagues, some of whom protested that my research was "evil" on the grounds that any species, being unique, is beyond value by definition. Fortunately, the analytic methodology was accepted by the World Health Organization.

7. Environmental Security

Also in the mid-1980s, I broached an entirely new field: the environmental dimension to security issues. I was struck by the Gorbachev warning that the threat from the skies was not so much nuclear missiles but ozone-layer depletion and global warming. I had heard from Middle East leaders that a basic source of the Israel/Arab conflict was not oil but another liquid, water. There were many other potential water conflicts, for instance between Egypt and Ethiopia over the River Nile. By 2025, there could be three-billion people suffering water shortages, the bulk of them sharing international river basins.

Increasing Water Shortages

Developing Countries wit h Water Shortages, 1990 and 2025



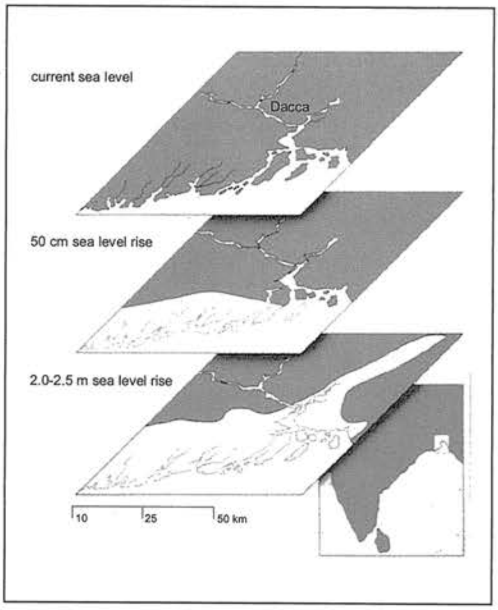
Green, C.P. The Environment and Population Growth: Decade for Action, *Population Reports*, M-10. Johns Hopkins Center for Communication Programs, Population Information Program, May 1992.
Data sources: Falkenmark 1991, United Nations 1989, World Resources Institute 1990.

There are still further illustrations of environmental security, notably desertification, deforestation and fuelwood shortages, all with scope for civil strife, outright violence and military confrontation. I persuaded the World Commission on Environment and Development, a member of which was the Japanese Foreign Minister Mr. Saburo Okita, that its report should include a chapter on these new threats to security. I produced follow-up analyses on population and conflict, examining population pressures as a cause of violence in Rwanda, for example. The overall rationale has been adopted as the underpinnings of security appraisals by nations such as the United States, the United Kingdom, Norway, India and Australia. In 1997, I briefed a conference at the Pentagon in Washington, D.C., attended not only by military experts but by leaders from the White House, the U.S. State Department and the National Security Council. As a result of this conference, there is now a Pentagon department dealing with environmental security.

8. Environmental Refugees

As a subset of Environmental Security, I have investigated the emergent problem of environmental refugees. These are people who feel driven from their homelands for environmental reasons such as soil erosion, water shortages, desertification and fuelwood deficits, plus associated factors, such as population pressures. In the mid-1990s, I calculated that these refugees numbered 25 million, a total greater than all other forms of refugees put together. Their number may well double by 2010, and even reach 200 million in a global warmed world. This is an entirely new phenomenon, with major policy implications for the global community.

PEOPLE AT RISK IN A GLOBALLY-WARMED WORLD	
Country/Region	**Millions at risk**
China	77
Bangladesh	28
India	23
Egypt	15
Island States	1
Drought areas	60
Total	204

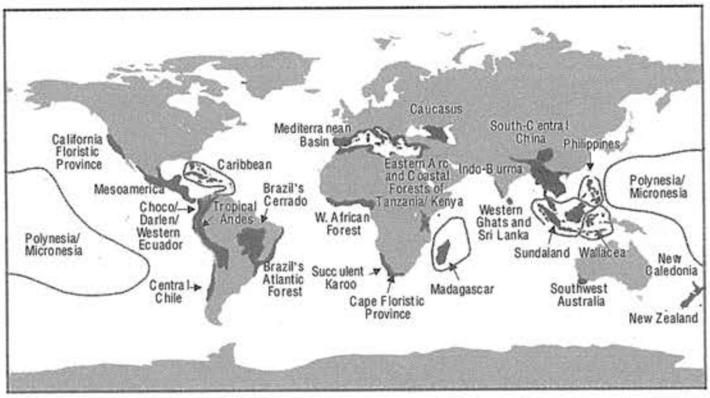


9. Biodiversity Hotspots

In the late 1980s, I returned to species questions. I developed the concept of "biodiversity hotspots," these being areas that feature exceptional concentrations of endemic species in habitats subject to exceptional threat of destruction. Through follow-up analyses in conjunction with Conservation International in Washington, D.C., I have found that over two-fifth of Earth's plant species and over one-third of vertebrate species (except fish) are confined to 25 localities that make up just 1.4 percent of Earth's land surface, these being localities where the species face severe threat of extinction. The 25 hotspots are so environmentally degraded that they have lost at least 70 percent, often 90 percent, of their original vegetation, and look likely, in the absence of expanded conservation efforts, to lose much of the rest within a few decades.

The hotspots analysis has pointed the way to "silver bullet" responses on the part of conservation planners. This contrasts with the scattergun approach of traditional practice that has often sought to be many things to many threatened species, and through insufficient funds has ended up by failing to be much to most such species. The hotspots strategy has been adopted by the World Bank, the Global Environment Facility, the MacArthur Foundation, Conservation International, and several other front-rank organizations in the conservation arena.

Biodiversity Hotspots



Because of the cost-effective nature of the hotspots strategy, the amount invested in hotspots has topped \$600 million in 10 years, the largest sum ever assigned to a single conservation strategy. All 25 hotspots could be safeguarded for only \$500 million per year, a tiny fraction of what governments, international agencies and citizen groups currently spend on conservation. The sum of \$500 million is only twice as much as the Pathfinder mission to Mars, justified largely on biodiversity grounds, vis-à-vis the search for extraterrestrial life. To put it in further perspective, the sum is equivalent to one-twentieth of what Europeans spend on ice cream each year. Were we to preserve the 25 hotspots, we would likely reduce the mass extinction by at least one-third. No other strategy available could accomplish so much for so little.

10. Future Evolution

I have also examined the future course of evolution. In the early 1980s, I began to raise questions about what the current biotic crisis would do to basic evolutionary processes, such as speciation, origination and adaptive radiation. I concluded that the crisis would not only eliminate large numbers of species, but, still more significantly, it would deplete the capacity of evolution to generate replacement species within a recovery phase of 5-10 million years (the usual period following the five mass extinctions of the prehistoric past). The crisis would have this depletive effect by degrading, if not destroying, tropical forests and wetlands that in the prehistoric past have served as the main "powerhouses" of evolution, supplying the bulk of replacement species following mass extinctions. That is to say, the present crisis would severely curtail evolution's capacity to make good the losses of the current mass extinction: "Death is one thing, an end to birth is something else."

In short, we look set to impoverish the planet for a period at least twenty times longer than humans have been humans. The number of future people affected could, in principle, be as many as 10,000 times more than have existed to date. The implicit "decision" we are taking today—through our lack of sufficient action and through its impact on the unconsulted behalf of future generations—is surely the biggest decision in the whole of human history, yet it is almost entirely disregarded by the public and its political leaders. It was tackled for the first time by the scientific community through an international conference that I organized in 1999 through the U.S. National Academy of Sciences.

11. Perverse Subsidies

In the late 1990s, I took a further look at some sources of environmental problems, as opposed to the symptoms of problems that often attract more attention. I analysed those subsidies that exert adverse impact on, not only our environments, but our economies as well. Leading categories include agriculture, fossil fuels, road transportation, water, forests and fisheries. These "perverse" subsides amount to around $2 trillion a year worldwide, hence they have marked capacity to distort our economies in addition to inflicting grandscale injuries on our environments. On both counts, they foster unsustainable development. Ironically the total of $2 trillion is 3.5 times higher than the Rio Earth Summit's budget for sustainable development—a sum that governments dismissed as quite unavailable.

"PERVERSE" SUBSIDIES (billion $s per year)

Perverse subsidies are those which are harmful to both the environment and the economy.

Over-productive agriculture	510
Fossil fuels/nuclear energy	300
Road transportation	780
Mis-use and over-use of water	230
Over-harvesting of fisheries	25
Over-logging of forests	92
Total	1,950

By definition, these are funds going to support unsustainable development. Contrast the Rio Earth Summit budget for sustainable development, $600 billion per year.

Were the perverse subsidies to be phased out, there would be a double dividend. Firstly, the savings would enable governments to revise their fiscal priorities by, for example, cancelling their budget deficits at a stroke and markedly increasing their health and education outlays. Secondly, there would be an end to government support (unwitting as it is) for environmental degradation. In fact, reduction of perverse subsidies would do more for both our environments and our economies than any other single measure.

There are sizeable political obstacles to cancelling the subsidies. In Washington, D.C., the Congress is subject to special interests' lobbying to the extent of $100 million a month. Fortunately, a number of countries have demonstrated that the political obstacles can be overcome. New Zealand, a nation more dependent on agriculture than any other developed nation, has got rid of virtually all its agri-subsidies. Several other nations have slashed their subsidies in the other four sectors. Meantime, a typical American taxpayer funds the subsidies with $2,000 per year, then pays out another $1,000 through environmental repair costs.

12. Sustainable Agriculture

I have examined the challenge of increasing food output by half within the coming two decades, plus the associated challenge of doing it through sustainable agriculture. Of course this is not a new issue, very much the contrary. But many experts assert that conventional agriculture is ever-more successful as witness declining grain prices. Unfortunately, they do not build into their calculus the parallel decline of the environmental resources underpinning long-term agriculture, notably through soil erosion, water deficits, and pollution of several sorts, let alone climate change.

I assessed the depletive impact of the over-loaded resource base through policy appraisals for the World Food Summit in 1996. I showed that if these environmental problems were to be factored in, grain prices would surely be soaring and thus sending urgent messages for adoption of sustainable agriculture via an Evergreen Revolution.

13. Food and Hunger in Sub-Saharan Africa

Following my 24 years of living in Sub-Saharan Africa, I have recently assessed the food prospects for the region. Since 1960, and as per-capita food production has declined, many people have become steadily hungrier. I have calculated that two out of three people are now malnourished, twice as many as officially estimated. Yet governments and development agencies seem largely indifferent to the adverse trend; their implicit response, by virtue of their lack of sufficient action, is to suppose it can be allowed to keep on declining indefinitely. Of course this is the opposite of what they intend, but their record implies as much.

SUB-SAHARAN AFRICA

Total people malnourished today .... **two-thirds of the regional population**	**400 million**
Total on verge of starvation .... **receiving less than 75% of daily minimum calories**	**100 million**
If malnutrition continues to spread among a growing population, then total on verge of starvation in 2010	**130 million**
If only 5% of 130 million die, as in the case of recent local famine disasters, then total likely to die	**6.5 million**

I have demonstrated that the downward spiral cannot long continue before people cease to grow more hungry. They will start to die, and in unprecedently large numbers. (This is not to ignore that in certain countries the overwhelming source of mortality will lie with AIDS—a disease that is potentiated by malnutrition, and vice versa.) Fortunately, there are vigorous and urgent initiatives available to raise food output and to slow population growth, both possible as witness the efforts of a few enlightened countries, whereupon the region could become self-sufficient in food within two decades.

14. New Consumers

Seventeen developing and three transition nations now feature over one-billion people with enough household income to enjoy meat every day and to buy cars in fast-growing numbers. Already they possess purchasing power matching that of the United States. Their numbers may well increase by half by 2010, and their purchasing power by still more. Their strongly meat-based diet entails environmental problems in that the meat is often raised on grain, which overloads croplands and diverts much water in countries with water shortages. The new consumers possess 125-million cars or 22 percent of the global fleet, and by 2010 the total could jump to 300-million cars or 38 percent. Cars not only cause much local pollution, but are the fastest growing source of carbon dioxide emissions, which contribute roughly half of global warming processes.

NEW CONSUMERS

Total new consumers today:
1.07 billion
(300 million in China, 140 million in India)

and with collective purchasing power of PPP$6.1 trillion, almost equivalent to the United States

NEW CONSUMERS' CARS (millions)

	Total 1999	Projected 2010
20 New Consumer countries	125	230
United States	162	185
World	525	800

Cars are the fastest-growing source of CO_2 emissions—already 15% of all energy-related emissions worldwide.

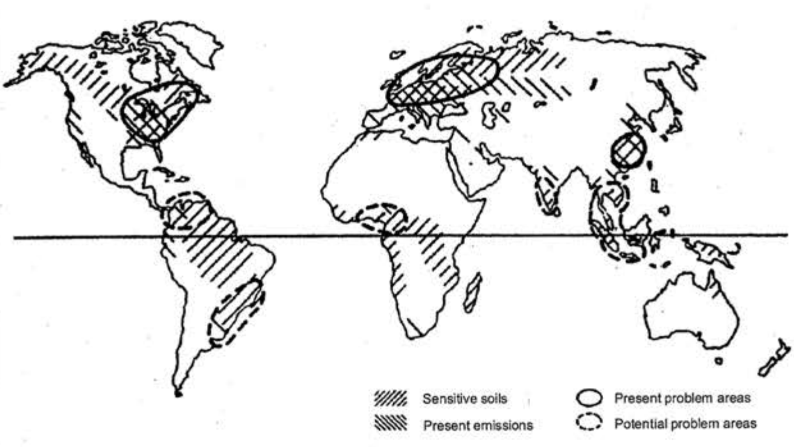
Of course, these people should be enabled to enjoy their new found affluence, provided they do not impose undue environmental and hence economic harm at both local and international levels. Hopefully, the new consumers can learn from the mistakes, also the positive experiences, of the long affluent nations in order that their environmental impacts remain acceptable. Hopefully too, the rich-world consumers can be persuaded to adopt less environmentally harmful lifestyles, which could then serve as models for the new consumers. There is much scope for "Factor Four" and even "Factor Ten" reductions in energy use, greater recycling of materials, enhanced pollution controls and other forms of waste management, in fact, resource conservation all round.

15. Environmental Surprises

I suspect that my main scientific contribution may eventually prove to be my research into environmental problems that hitherto remain unknown, or at least unrecognized. At the 1972 Stockholm Conference on the Human Environment, there was no mention of what have subsequently come to be acknowledged as front-rank problems: mass extinction of species, tropical deforestation, desertification, ozone-layer depletion, and climate change. With 20/20 hindsight (that exact science), we can now see that with greater inclination to raise new questions, scientists could have identified some of these problems ahead of time, and thus moved to forestall them. I believe that the biggest environmental problems ahead could well be ones we have not even thought of as yet—but that we could pinpoint with a more expansive approach to research agendas.

Many "environmental surprises" are likely to arise in the form of what are technically known as discontinuities, or non-linear switches in patterns and processes, often brought about by synergized interactions between two or more environmental problems. The stock example of a discontinuity lies with water, which can suddenly turn from a liquid into either a solid or a gas. Environmental discontinuities have included deforestation-derived declines in tropical rainfall, ozone-layer depletion and global warming. In the biodiversity field, there have been abrupt mass mortalities of dolphins and seals, phytoplankton blooms, cancer epizootics in fish, bleaching of coral reefs, and the precipitous decline of Peru's anchoveta fishery and amphibians worldwide. We have also witnessed many synergized interactions, such as acid rain and wild fires in conjunction with over-heavy logging of tropical forests.

Both discontinuities and synergisms are recognized by scientists to be among the most important phenomena in nature, and they are likely to become more frequent in a world of increasing environmental pressures among other problems (economic, social, political). Yet they receive only a fraction of the research attention they deserve, despite ground-breaking research such as my colleague Professor May has cited with respect to chaos theory and related issues. I plan to use part of the Blue Planet funds to press ahead with research on the issue from the standpoint of intersectoral linkages with their many policy implications. Fortunately, there can be positive discontinuities in the policy arena, generating reinforced leverage and multiplier effects, as witness the Ozone Layer Treaty, the plunge in birth rates in several countries, and the start on slashing perverse subsidies.



Schematic map showing regions that currently have acidification problems, and regions where, based on soil sensitivity, expected future emissions and population density, acidification might become severe in the future

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These 15 issues are what I regard as my main research products. They began in the early 1970s when I was still a student at the University of California and I raised the warning about the mass extinction of species underway. That was also the time of the Stockholm Conference on the Human Environment, and as noted above, I was struck that the participants made no mention of mass extinction as a major environmental problem. Nobody had thought to ask if it was a problem at all, even though if it had been recognized we could have done more to reduce its ultimate scope.

Nor did the scientists at Stockholm mention any of several other issues (listed above) that subsequently came to be recognized as front-rank environmental problems. All of them could, with a modicum of readiness to look beyond conventional thinking, have been brought to the urgent attention of political leaders. It was this that persuaded me that the best scientific career I could follow would be, not so much to generate new answers to recognized questions, but to ask if we are raising all the right questions in the first place. It is an unusual form of career—and in retrospect the most stimulating I could have chosen. What a rewarding life it has been: wandering around on the horizons of environmental science, seeking one new question after another—and doing it at a time when environmental science is needed in its full scope if it is to support our Earth and our world.

Conclusion

In summary, there have been three dimensions to my professional career. I have worked as independent scientist. I have practised interdisciplinary science. I have preferred to identify new questions. None of these fits the usual mould of science. This returns me to the main reason why I am specially pleased to be selected for your Blue Planet Prize. You have recognized a scientist who has long stood apart from mainstream science. I hope this helps you to understand how much I welcome your gesture. Moreover, through your award you have set me free financially to tackle those environmental questions that I consider most important. I can now set out on what I hope will be the most productive phase of my entire career.

I also like to think you have selected me not just as an environmental scientist but as an environmental activist. Right from my start in 1970, I have made it a rule to take my research findings and policy recommendations to governments, international agencies and political leaders in dozens of countries. I have pressed the environmental cause with prime ministers and presidents on four continents, with the head of the World Bank and United Nations agencies, and with corporate chiefs in many lands, including Japan. In addition, I have publicized the environment on television and radio and through newspapers and magazines. I have addressed 5,000 people in London and I have sat down in front of bulldozers in Australia. I hope that, through your selection of me for your Prize, you are encouraging more scientists to jump into the public arena and alert the world to our environmental problems—and our opportunities. These voices are sorely needed.

A Concluding Comment. We live at an altogether unprecedented time in human history. Entire segments of our planetary ecosystem face terminal threat through deforestation, desertification, global warming and a host of other environmental problems. This prompts an overriding thought. Are we not a privileged generation to live at a time when we have opportunity to save both our Earth and our world? No generation in the past has enjoyed such an opportunity, since the problems were not there. No generation in the future will enjoy the same opportunity, because if we do not get on top of the problems before they get on top of us, our descendants will have nothing left to do but to pick up the pieces we pass on to them. We are fortunate indeed to live at a time of such a once-and-for-all challenge. It is a super-size challenge, and if we measure up to it, we shall surely feel five metres tall. Above all, we shall earn the thanks of numerous generations to come.

Major Publications

Dr. Norman Myers

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