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# The future of biological diversity in a crowded world

*(Ernst Mayr Lecture on 29th October 2002)*

## *Introduction*

It is a great pleasure to give this lecture, named in honour of Ernst Mayr. Ernst has had a truly remarkable and influential career, beginning as one of the major figures – along with the interpreter of the fossil record G G Simpson, and the population geneticists Haldane, Fisher and Wright – in the "Neo-Darwinian Revolution" of the first half of the 20th century, and continuing through to the two major books he published this year (a definitive work on New Guinea birds with Jared Diamond, and an autobiographical account of major themes in biological philosophy and history).

To prepare a paper worthy of Ernst Mayr is thus a daunting task. I am encouraged, however, by the fact that Ernst is primarily an evolutionary biologist, whereas my own contributions have been mainly in ecology – the environmental theatre on which the evolutionary play is acted out. My presentation, in outline, begins by asking: how well do we know the world of plants, animals and microorganisms 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.

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. I end by discussing estimates of the costs of effective action, and more generally why we should care.


## *How many species are there?*

The systematic naming and recording of animal species began relatively recently, with the tenth edition of Linneaus' "Systema Naturae", which in 1758 recognised some 9,000 species. Plant species names date from his earlier work, "Species Plantarum", in 1753. 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 1). It should be emphasised that this maldistribution reflects the vagaries of intellectual fashion, and most certainly does not reflect the relative importance of, say, vertebrates versus invertebrates in maintaining the structure and function of ecosystems. Reorganising our priorities rapidly, to learn more about the little things that arguably run a lot of the natural world, will not be easy. Fascination with the furries and featheries goes deep: in the UK, the Royal Society for the Protection of Birds (RSPB)

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

Table 1
The taxonomy of taxonomists: a rough estimate of the distribution of the taxonomic workface among broad taxonomic groups, in Australia, USA, and UK (after Gaston & May 1992)

has almost 1 million members; the analogous society for plants (the Botanical Society of the British Isles) has around 10,000; and there is no corresponding society to express affection for nematodes.

In what follows, I will restrict attention to eukaryotic species – essentially animals, plants and fungi (broadly defined). A molecular biologist could justifiably argue that these eukaryotic species represent only a recently diversified tip of an evolutionary tree whose main flowering is among bacteria and archaea. But what is meant by species among bacteria and the like is vastly different from what is meant among plants and animals (see, for example, Bisby and Coddington, 1995; Vane-Wright, 1992). For instance different strains of what is currently classified as a single bacterial species, *Legionella pneumophila*, have nucleotide-sequence homologies (as revealed by DNA hybridisation) of less than 50 %; this is as large as the characteristic genetic distance between mammals and fishes. Relatively easy exchange of genetic material among different "species" of such microorganisms means, I think, that basic notions about what constitutes a species are necessarily different between animals and bacteria. This holds even more strongly for viral species, many of which are best regarded as "quasispecies swarms" (Nowak 1992).

### Numbers of named species

A recent major assessment, for the IUCN (Hammond 1995), of the total number of distinct species that have been named and recorded emphasises the uncertainties caused by synonyms. This 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 %.

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 roughly ten years ago (augmented by 0.01 million each year for roughly 10 years); see Table 2.

| Group | Hammond (1995) | May (1999) |
|---|---|---|
| Protozoa | 40 | 40 |
| Algae | 40 | 40 |
| Plants | 270 | 270 |
| Fungi | 70 | 70 |
| <u>Animals</u> | <u>1,320</u> | <u>1,080</u> |
|    *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 |

Table 2
Number of named, distinct species of eukaryotes (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* |
|      *(crusts)* | *(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 | | | |

Table 3
Estimated total numbers of living species (in thousands)

All such estimates are dominated by insect totals. And the way such estimates are made provides eloquent testimony to the deep connection between taxonomy and systematics on the one hand, and fundamental questions in ecology and evolution on the other. By way of illustration, I sketch just three examples of such intertwining.

Suppose we really understood how the working of the evolutionary play, in varied ecological theatres, has shaped food webs. We would then, for example, understand some of the observed patterns, such as the ubiquitous rule that the number of links in food chains connecting eater to eaten (plant to herbivore; herbivore to carnivore; carnivore to top predator; etc.) rarely exceeds four, regardless of the productivity of the environment or whether the constituent animals are warm or cold-blooded (with very different efficiencies of energy transfer from one level to the next). If we had such understanding, we could derive from it a rough, overall average ratio of numbers of animal species (secondary consumers) to plant species (primary producers). And, given that we know the total number of plant species, fairly reliably, to be of the general order of 300 thousand, we could thus assess the rough total number of animal species. Sadly – some would say incredibly – we do not have this ecological understanding. We have a few scattered studies in large and small food webs (although even here, such empirical knowledge is vastly less than it should be), which broadly suggest 10 animal species per plant species on average. So, on this empirical basis, but lacking any fundamental understanding, we might guess at something of the order of 3 million animal species in total.

The line of attack which I favour has been elaborated by Gaston and Hudson (1994). They first ask what fractions of the species in particular taxa are found in each of nine biogeographic realms (these nine representing a slight extension of the conventional Wallace scheme); the reference taxa range from general categories (such as higher plants, amphibians, birds, and mammals) to very particular ones (such as dragonflies, tiger beetles and swallowtails). Gaston and Hudson then take a range of estimated total numbers of insect species in the Nearctic realm (ie, North America) and in Australia, and scale them up to global totals on these biogeographic bases. For example, given that Nearctic higher plants represent 6.5 % of the global total, an estimated total 200,000 Nearctic insect species would imply around 3 million species. For their fairly wide range of estimators, Gaston and Hudson arrive at global insect totals in the range of 1 – 10 million. And, looking at this range in a bit more detail, my best guess would be 4 million. This estimate also accords with Terry Erwin's (Personal Communication) recent estimate that preliminary keying-out of some of his tropical-canopy beetle collection suggests around 80 % of the species are new (which, multiplying the insects total in Table 2 by 5, also gives around 4 million).

Yet another approach is to look at empirical patterns in numbers of species in different categories of physical size, which, for animals of characteristic length above about 0.5 cm, suggest a roughly 100-fold increase in species numbers for each 10-fold decrease in characteristic length. Extending this down to sub-millimetre size

categories, where our current taxonomic knowledge is so deficient, would imply a global total of something like 3–10 million species. The problem, yet again, is that we are utterly ignorant of the ecological and evolutionary forces that underpin these interesting but empirical species-size patterns. Such ignorance simultaneously under-mines the above estimate, and highlights the interconnection between ecological/evolutionary questions and basic taxonomic facts/ignorance. For a more full discussion, see May (1990, 1999).

## Taxonomy Tomorrow

Underlying many of the lamentable uncertainties discussed above is the lack of co-ordinated and centralised catalogues widely available in digital form, along with the "hand crafted" traditions of many taxonomists and systematists. If there are indeed another five million eukaryotic species yet to be discovered and recorded, then at the current rate of around 10,000 per year we are looking at another 500 years to complete the task. New technologies will undoubtedly speed this up. I envision, within the next 20 years or so, that a tiny scraping from an interesting new specimen brought back from an expedition will be put into a sophisticated sequencing-plus-computing machine, which will print out the species identity (known or new), along with its evolutionary place on a molecular-based phylogenetic tree. Many contemporary taxonomists and systematists will be appalled at this prospect! But our need to understand the diversity we have, and the consequences of its diminishment, re-quire faster and more synoptic approaches than those time-honoured from a more leisurely past.

In all this, the rate-limiting step will, of course, remain the craft of collecting speci-mens in the field.

Recent initiatives, some prompted by a UK House of Lords inquiry into the state of our knowledge about biological diversity, foreshadow changes. Godfray (2002) writes "The rigidity built into current rules and codes of taxonomy – which include prohibition of purely electronic description – is now a brake on progress, imprisoning the subject in outdated methodologies, and rendering it difficult or impossible to at-tract the major funds needed to reverse its slow decline". Other recent articles (Gewin 2002, Bisby et al. 2002) echo Godfray's theme, amplifying it with ideas – use of "parataxonomists" and concepts of "morphospecies" – that could speed up the tasks of collection and rough identification.

All this, as we shall see below, is a race against the clock. Many aspects of research on biological diversity are time limited, in ways found essentially nowhere else in science.

## Extinction Rates

### The Past

The history of life on Earth, written in the fossil record over the past 600 million years (my) 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 1). 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 106 to 107 years); there is, however, much variation both within and among groups, and some groups have lifespans significantly longer or shorter than this (see Table 4).
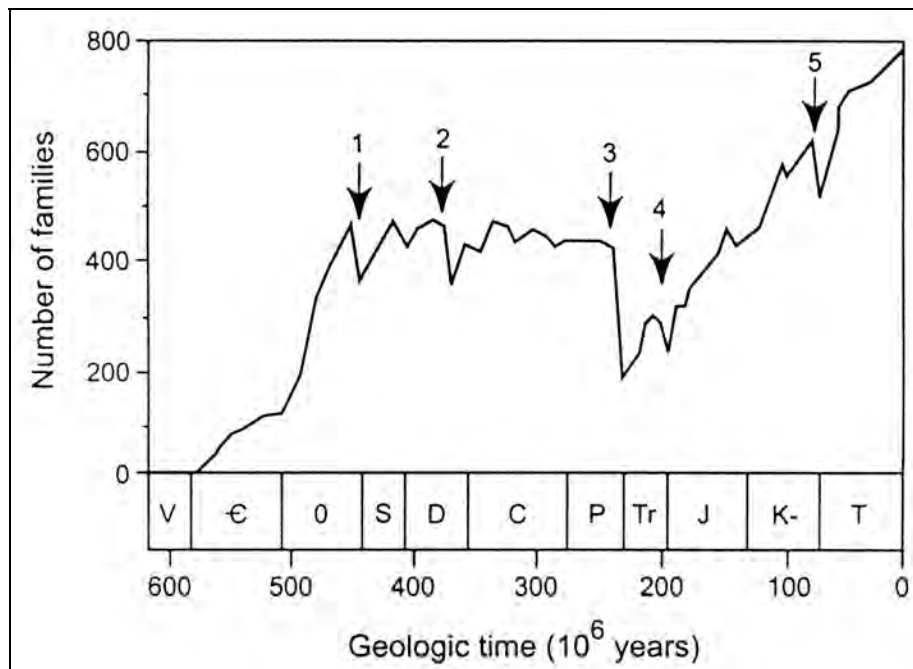


Figure 1
The history of the diversity of marine animal families, as shown by the fossil record over time. The curve connects 77 discrete data points, each giving the total number of well-skeletonized families from a particular stratigraphic stage. The arrows indicate the Big Five episodes of mass extinction. The length of the various geological epochs are indicated on the time axis (V, Vendian; C, Cambrian; O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous; P, Permian; Tr, Triassic; J, Jurassic; K, Cretaceous; T, Tertiary).

| 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 & Stanley (1978) | 1–2 |
| Diatoms | Van Valen (1973) | 8 |
| Dinoflagellates | Van Valen (1973) | 13 |
| Planktinic foraminifers | Van Valen (1973) | 7 |
| Cenozoic bivalves | Raup & Stanley (1978) | 10 |
| Echinoderms | Durham (1970) | 6 |
| Silurian graptolites | Rickards (1977) | 2 |
| | | 6–7 |
| Part II: information compiled by R. Cocks | | |
| Silurian graptolites | Koren & Rickards (1996) | 0.2 |
| Cambrian trilobites | Davidek et al. (in press) | 0.4 |
| Brachiopods | Cocks (pers. comm.) | 0.5 |
|    Rodents | Cocks (pers. comm.) | 0.3–1.0 |
|    Perrissodactyls | Cocks (pers. comm.) | 0.5 |
|    Insectivores | Hooker (pers. comm.) | 3 |
| Corals (tertiary-recent) | Budd et al. (1996) | 0.2–7 (average 4) |
| Forams | Buzas & Culver (1984) | 14–16 |
| Coccoliths | Young (pers. comm.) | c. 10 |

Table 4
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)

Comparing this few million year average lifespan with the 600 my 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 my ago and whose average life-span may be characteristically longer than 10 my, it could be that today's species represent more like 5 %, or conceivably even 10 %, of those ever to have graced our planet.

## Current Extinction Rates

Our ignorance about total numbers of insect and other invertebrate species is nothing compared with our ignorance about current extinction rates among them. Over the past century, rigorously documented extinctions in well-studied groups – primarily birds and mammals – have run around one species each year. Even for these groups, such certified extinctions are surely underestimates. Diamond (1989), for instance, found that of 164 recorded bird species in the Solomon Islands, 12 had apparently not been seen since 1953 (nor could he find them), yet only one had a IUCN extinction certificate. This stimulated interesting further work – no fun like scoring off a friend – which found 7 of the putatively extinct 12. But 5 almost certainly are gone, representing a 5-fold IUCN underestimate in this instance. More striking is Mohsin and Ambok's (1983) 4-year search for the 266 species of exclusively freshwater fishes recorded in the 19th century in lowland peninsular Malaysia, which found only 122; many of these are surely extinct, yet none show in the IUCN catalogue. And the IUCN extinctions for insects tell only of intellectual fashion, and nothing of real extinctions: of 73 recorded extinct, 43 are Hawaiian *drosophila*; only 8 are mainland insects (7 from USA, 1 from Germany); not one is a tropical insect.

The essential problem is our lack of systematic knowledge. Reviewing Terborgh's "Requiem for Nature" (1999), McKibben (2000) has written "You can follow the changes in the value of the Japanese yen second by second from your desktop; reporters by the dozen struggle valiantly to explain the particulars of Microsoft's anti-trust defense. But who can tell whether the tropical forest is disappearing more or less speedily than it was in the late 1980s when every singer worth her faded jeans was cutting a CD in its defense? This question is surely worth attention, since the equatorial jungles contain more examples of creation's fabulous imagination than any other ecosystem, and since its trees are a key part of the earth's system for cleansing excess carbon dioxide from the atmosphere. Perhaps you have a dim sense that some agreements have been signed to protect the rainforests, some programs put in place. But are they working? What strategies make the most sense to preserve what's left? Far more money and attention is devoted to, say, searching for and describing the possible remains of microbial life in the dust of Mars.".

Given that we do not know today's total numbers of species to within a factor 10 or so, and that we know even less about numbers of extinctions, anyone who purports to tell you how many species went extinct last year is a fool. But that does not mean we cannot say some relatively precise things.

*Comparing Past with Present Extinction Rates*

We have just noted that among the relatively well-studied bird and mammal species there has been roughly one extinction per year over the past century, and that this estimate is very conservative. There are a total of around 14,000 such species. So the typical bird or mammal species has, in effect, in recent years been playing a game of Russian Roulette with a single bullet in a gun of 14,000 chambers. This translates into an average expected species lifetime, before extinction, of around $10^4$ years at current rates, if birds and mammals are typical (which, of course, they might not be). Ten thousand years may sound a long time, but it 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 suggests species' life expectancies of around a few hundred to one thousand years. One of these approaches is based on ecological 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 suggests 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). Recent work (Seabloom et al. 2002) points out that correlation between human activities and spatially aggregated patterns of habitat conversion can easily cause extinction rates to exceed those predicted from simplistic species-area relations. 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, 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, 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 & May 1997). There is also recent work, which is broadly related, exploring phylogenetic patterns in extinction risk; this may represent the beginnings of a "calculus of extinction risk" (Lockwood et al. 2002). 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).

## Costs and concerns

The causes of extinction are many and varied. Immediate causes can be overexploitation, habitat destruction, introduced alien species, and commonly combinations of two or all three of these. The ultimate cause, of course, is still-expanding human populations, currently sequestering to our own use somewhere between one quarter to one half of all terrestrial primary productivity – an event no other species has approached in the history of life on earth. Against this background, currently about 6.3 % of the earth's land area is set aside as wildlife refuges or other protected areas of one kind or another, at an estimated annual cost of around £6 billion per year (Balmford et al. 2002).

James, Gaston and Balmford (1999) estimate that it would cost around £30 billion per year to expand this to 10 % of the terrestrial surface, properly protected and with compensation to indigenous peoples. Some of this area is envisioned as wilderness, but much as sustainably used by people with sympathetic regard to their environment. More ambitious and yet more speculative, the authors suggest that the "greening" of agriculture – a Doubly Green or Evergreen Revolution – would cost around £300 billion per year, creating a world less in tension between "refuges" and "agribusiness". By now, the sums seem vast. Viewed in perspective, however, this ambitious figure is only 1 % of global GDP. And this conventionally calculated GDP takes no account of the ecosystem services which built the biosphere and continue to keep it a place where life can flourish (pollinating plants; cleaning waters; absorbing

or balancing greenhouse gases; breeding fish in estuaries; and endlessly on). Recent and necessarily rough estimates put the value of such services as comparable with conventional GDP, at around £30 trillion per year (Costanza et al. 1997). A rather different, but again necessarily imprecise, estimate is that the overall benefit:cost ratio of an effective global programme for the conservation of remaining wild nature is at least 100:1 (Balmford et al. 2002).

It seems to me that investing 1 % of global GDP to ensure the continuing delivery of such ecosystem services (themselves of magnitude comparable to such GDP) is wise. But the problem – a deep and intractable problem – is that we have no evolutionary experience of asking people to act, at inconvenience to many, on behalf of a seemingly distant future and for the general good.

And anyway, some will say, do we really need today's biodiversity to ensure tomorrow's ecosystem services? More generally, why should we care about preserving biological diversity? I would list the reasons for caring under three broad headings, which might be called narrowly utilitarian, broadly utilitarian, and ethical.

### 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 are 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 UK 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."

The problem, however, is that no one of these three arguments is necessarily compelling. First, it seems likely to me that tomorrow's Biotechnological Revolution will design its new medicines, new materials, and other new products from the molecules up, based on our increasing understanding of the molecular machinery of life. Second, I fear that we may be clever enough to create a world that is grievously biologically impoverished, but nevertheless sustainable – the hateful world of the cult movie *Bladerunner*. And although I find the third, ethical argument totally compelling, I wonder what force it would have if I were dirt poor, struggling to feed my children. These are uncomfortable admissions.

## *Conclusion*

The previous century has seen more advance 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.

For most who share the beliefs set out in the previous sentence, the motives come from the heart, from beliefs and values. But the actions, to be effective, need to come from the head, to be coldly analytic. There are tensions here. Too much conservation action is directed to the targets the heart engages – furries and featheries. Table 1 showed taxonomic effort improperly skewed to vertebrates, but the academic conservation literature is worse. A recent survey of 2,700 articles in the two major conservation research journals over the past 15 years found 69 % of the papers dealing with vertebrates (moreover birds and mammals – less than 30 % of all vertebrate species – account for 80 % of these papers), 20 % dealing with plants, and only 11 % with invertebrates (half these papers being devoted to butterflies, which are honorary birds) (Clark & May 2002, Stein et al. 2002). And conservation action is worse again, being almost exclusively focussed on "charismatic megafauna", big mammals and attractive birds.

We need the motives from the heart, but the analytic actions from the head. Writing of the icy analysis the great Indian author V. S. Naipaul brings to bear on the world's problems, Anita Desai has said he inhabits a space "beyond regret or hope". We need something even more difficult: deep regret and powerful hope for heartfelt motivation, but ecological and environmental understanding, beyond regret or hope, to guide effective action. No easy trick.

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