



CHAPTER

I

THE CURRENT STATE OF BIOLOGICAL DIVERSITY

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Biological diversity must be treated more seriously as a global resource, to be indexed, used, and above all, preserved. Three circumstances conspire to give this matter an unprecedented urgency. First, exploding human populations are degrading the environment at an accelerating rate, especially in tropical countries. Second, science is discovering new uses for biological diversity in ways that can relieve both human suffering and environmental destruction. Third, much of the diversity is being irreversibly lost through extinction caused by the destruction of natural habitats, again especially in the tropics. Overall, we are locked into a race. We must hurry to acquire the knowledge on which a wise policy of conservation and development can be based for centuries to come.

To summarize the problem in this chapter, I review some current information on the magnitude of global diversity and the rate at which we are losing it. I concentrate on the tropical moist forests, because of all the major habitats, they are richest in species and because they are in greatest danger.

THE AMOUNT OF BIOLOGICAL DIVERSITY

Many recently published sources, especially the multiauthor volume *Synopsis and Classification of Living Organisms*, indicate that about 1.4 million living species of all kinds of organisms have been described (Parker, 1982; see also the numerical breakdown according to major taxonomic category of the world insect fauna prepared by Arnett, 1985). Approximately 750,000 are insects, 41,000 are vertebrates, and 250,000 are plants (that is, vascular plants and bryophytes). The remainder consists of a complex array of invertebrates, fungi, algae, and microorganisms (see Table 1-1). Most systematists agree that this picture is still very incomplete except

TABLE 1-1 Numbers of Described Species of Living Organisms^a

Kingdom and Major Subdivision	Common Name	No. of Described Species	Totals	
<i>Virus</i>	Viruses	1,000 (order of magnitude only)	1,000	
<i>Monera</i>	Bacteria	3,000	4,760	
	Bacteria	60		
	Blue-green algae	1,700		
<i>Fungi</i>	Zygomycete fungi	665	4,760	
	Cup fungi	28,650		
	Basidiomycete fungi	16,000	46,983	
	Water molds	580		
	Chytrids	575		
	Cellular slime molds	13		
	Plasmodial slime molds	500		
<i>Algae</i>	Green algae	7,000		
	Brown algae	1,500		
	Red algae	4,000		
	Chrysophyte algae	12,500		
	Dinoflagellates	1,100		
	Euglenoids	800		
<i>Plantae</i>	Mosses, liverworts, hornworts	16,600	26,900	
	Psilopsids	9		
	Lycophytes	1,275		
	Horsetails	15		
	Ferns	10,000		
	Gymnosperms	529		
	Dicots	170,000		
	Monocots	50,000		
<i>Protozoa</i>	Protozoans:	30,800		
	Sarcomastigophorans, ciliates, and smaller groups			
<i>Animalia</i>	Sponges	5,000		30,800
	Jellyfish, corals, comb jellies	9,000		
<i>Porifera</i>	Flatworms	12,200		30,800
	Nematodes (roundworms)	12,000		
<i>Cnidaria, Ctenophora</i>	Annelids (earthworms and relatives)	12,000		

TABLE 1-1 Continued

Kingdom and Major Subdivision	Common Name	No. of Described Species	Totals
<i>Mollusca</i>	Mollusks	50,000	989,761
<i>Echinodermata</i>	Echinoderms (starfish and relatives)	6,100	
<i>Arthropoda</i>	Arthropods	751,000	989,761
<i>Insecta</i>	Insects	123,161	
<i>Other arthropods</i>			
<i>Minor invertebrate phyla</i>		9,300	
<i>Chordata</i>			
	Tunicates	1,250	
	Acorn worms	23	
<i>Vertebrata</i>	Vertebrates	63	
	Lampreys and other jawless fishes		
	Sharks and other cartilaginous fishes	843	
<i>Osteichthyes</i>	Bony fishes	18,150	
<i>Amphibia</i>	Amphibians	4,184	
<i>Reptilia</i>	Reptiles	6,300	
<i>Aves</i>	Birds	9,040	
<i>Mammalia</i>	Mammals	4,000	
TOTAL, all organisms		<u>43,853</u>	1,392,485

^aCompiled from multiple sources.

in a few well-studied groups such as the vertebrates and flowering plants. If insects, the most species-rich of all major groups, are included, I believe that the absolute number is likely to exceed 5 million. Recent intensive collections made by Terry L. Erwin and his associates in the canopy of the Peruvian Amazon rain forest have moved the plausible upper limit much higher. Previously unknown insects proved to be so numerous in these samples that when estimates of local diversity were extrapolated to include all rain forests in the world, a figure of 30 million species was obtained (Erwin, 1983). In an even earlier stage is research on the epiphytic plants, lichens, fungi, roundworms, mites, protozoans, bacteria, and other mostly small organisms that abound in the treetops. Other major habitats that remain poorly explored include the coral reefs, the floor of the deep sea, and the soil of tropical forests and savannas. Thus, remarkably, we do not know the true number of species on Earth, even to the nearest order of magnitude (Wilson, 1985a). My own guess, based on the described fauna and flora and many discussions with entomologists and other specialists, is that the absolute number falls somewhere between 5 and 30 million.

A brief word is needed on the meaning of species as a category of classification. In modern biology, species are regarded conceptually as a population or series of populations within which free gene flow occurs under natural conditions. This means that all the normal, physiologically competent individuals at a given time are capable of breeding with all the other individuals of the opposite sex belonging

to the same species or at least that they are capable of being linked genetically to them through chains of other breeding individuals. By definition they do not breed freely with members of other species.

This biological concept of species is the best ever devised, but it remains less than ideal. It works very well for most animals and some kinds of plants, but for some plant and a few animal populations in which intermediate amounts of hybridization occur, or ordinary sexual reproduction has been replaced by self-fertilization or parthenogenesis, it must be replaced with arbitrary divisions.

New species are usually created in one or the other of two ways. A large minority of plant species came into existence in essentially one step, through the process of polyploidy. This is a simple multiplication in the number of gene-bearing chromosomes—sometimes within a preexisting species and sometimes in hybrids between two species. Polyploids are typically not able to form fertile hybrids with the parent species. A second major process is geographic speciation and takes much longer. It starts when a single population (or series of populations) is divided by some barrier extrinsic to the organisms, such as a river, a mountain range, or an arm of the sea. The isolated populations then diverge from each other in evolution because of the inevitable differences of the environments in which they find themselves. Since all populations evolve when given enough time, divergence between all extrinsically isolated populations must eventually occur. By this process alone the populations can acquire enough differences to reduce interbreeding between them should the extrinsic barrier between them be removed and the populations again come into contact. If sufficient differences have accumulated, the populations can coexist as newly formed species. If those differences have not yet occurred, the populations will resume the exchange of genes when the contact is renewed.

Species diversity has been maintained at an approximately even level or at most a slowly increasing rate, although punctuated by brief periods of accelerated extinction every few tens of millions of years. The more similar the species under consideration, the more consistent the balance. Thus within clusters of islands, the numbers of species of birds (or reptiles, or ants, or other equivalent groups) found on each island in turn increases approximately as the fourth root of the area of the island. In other words, the number of species can be predicted as a constant X (island area)^{0.25}, where the exponent can deviate according to circumstances, but in most cases it falls between 0.15 and 0.35. According to this theory of island biogeography, in a typical case (where the exponent is at or near 0.25) the rule of thumb is that a 10-fold increase in area results in a doubling of a number of species (MacArthur and Wilson, 1967).

In a recent study of the ants of Hispaniola, I found fossils of 37 genera (clusters of species related to each other but distinct from other such clusters) in amber from the Miocene age—about 20 million years old. Exactly 37 genera exist on the island today. However, 15 of the original 37 have become extinct, while 15 others not present in the Miocene deposits have invaded to replace them, thus sustaining the original diversity (Wilson, 1985b).

On a grander scale, families—clusters of genera—have also maintained a balance within the faunas of entire continents. For example, a reciprocal and apparently symmetrical exchange of land mammals between North and South America began

3 million years ago, after the rise of the Panamanian land bridge. The number of families in South America first rose from 32 to 39 and then subsided to the 35 that exist there today. A comparable adjustment occurred in North America. At the generic level, North American elements dominated those from South America: 24 genera invaded to the south whereas only 12 invaded to the north. Hence, although equilibrium was roughly preserved, it resulted in a major shift in the composition of the previously isolated South American fauna (Marshall et al., 1982).

Each species is the repository of an immense amount of genetic information. The number of genes range from about 1,000 in bacteria and 10,000 in some fungi to 400,000 or more in many flowering plants and a few animals (Hinegardner, 1976). A typical mammal such as the house mouse (*Mus musculus*) has about 100,000 genes. This full complement is found in each of its myriad cells, organized from four strings of DNA, each of which comprises about a billion nucleotide pairs (George D. Snell, Jackson Laboratory, Maine, personal communication, 1987). (Human beings have genetic information closer in quantity to the mouse than to the more abundantly endowed salamanders and flowering plants; the difference, of course, lies in what is encoded.) If stretched out fully, the DNA would be roughly 1-meter long. But this molecule is invisible to the naked eye because it is only 20 angstroms in diameter. If we magnified it until its width equalled that of wrapping string, the fully extended molecule would be 960 kilometers long. As we traveled along its length, we would encounter some 20 nucleotide pairs or "letters" of genetic code per inch, or about 50 per centimeter. The full information contained therein, if translated into ordinary-size letters of printed text, would just about fill all 15 editions of the *Encyclopaedia Britannica* published since 1768 (Wilson, 1985a).

The number of species and the amount of genetic information in a representative organism constitute only part of the biological diversity on Earth. Each species is made up of many organisms. For example, the 10,000 or so ant species have been estimated to comprise 10¹⁵ living individuals at each moment of time (Wilson, 1971). Except for cases of parthenogenesis and identical twinning, virtually no two members of the same species are genetically identical, due to the high levels of genetic polymorphism across many of the gene loci (Selander, 1976). At still another level, wide-ranging species consist of multiple breeding populations that display complex patterns of geographic variation in genetic polymorphism. Thus, even if an endangered species is saved from extinction, it will probably have lost much of its internal diversity. When the populations are allowed to expand again, they will be more nearly genetically uniform than the ancestral populations. The bison herds of today are biologically not quite the same—not so interesting—as the bison herds of the early nineteenth century.

THE NATURAL LONGEVITY OF SPECIES

Within particular higher groups of organisms, such as ammonites or fishes, species have a remarkably consistent longevity. As a result, the probability that a given species will become extinct in a given interval of time after it splits off from other species can be approximated as a constant, so that the frequency of species surviving

through time falls off as an exponential decay function; in other words, the percentage (but not the absolute number) of species going extinct in each period of time stays the same (Van Valen, 1973).¹ These regularities, such as they are, have been interrupted during the past 250 million years by major episodes of extinction that have been recently estimated to occur regularly at intervals of 26 million years (Raup and Sepkoski, 1984).

Because of the relative richness of fossils in shallow marine deposits, the longevity of fish and invertebrate species living there can often be determined with a modest degree of confidence. During Paleozoic and Mesozoic times, the average persistence of most fell between 1 and 10 million years: that is, 6 million for echinoderms, 1.9 million for graptolites, 1.2 to 2 million for ammonites, and so on (Raup, 1981, 1984).

These estimates are extremely interesting and useful but, as paleontologists have generally been careful to point out, they also suffer from some important limitations. First, terrestrial organisms are far less well known, few estimates have been attempted, and thus different survivorship patterns might have occurred (although Cenozoic flowering plants, at least, appear to fall within the 1- to 10-million-year range). More importantly, a great many organisms on islands and other restricted habitats, such as lakes, streams, and mountain crests, are so rare or local that they could appear and vanish within a short time without leaving any fossils. An equally great difficulty is the existence of sibling species—populations that are reproductively isolated but so similar to closely related species as to be difficult or impossible to distinguish through conventional anatomical traits. Such entities could rarely be diagnosed in fossil form. Together, all these considerations suggest that estimates of the longevity of natural species should be extended only with great caution to groups for which there is a poor fossil record.

RAIN FORESTS AS CENTERS OF DIVERSITY

In recent years, evolutionary biologists and conservationists have focused increasing attention on tropical rain forests, for two principal reasons. First, although these habitats cover only 7% of the Earth's land surface, they contain more than half the species in the entire world biota. Second, the forests are being destroyed so rapidly that they will mostly disappear within the next century, taking with them hundreds of thousands of species into extinction. Other species-rich biomes are in danger, most notably the tropical coral reefs, geologically ancient lakes, and coastal wetlands. Each deserves special attention on its own, but for the moment the rain forests serve as the ideal paradigm of the larger global crisis.

Tropical rain forests, or more precisely closed tropical forests, are defined as habitats with a relatively tight canopy of mostly broad-leaved evergreen trees

sustained by 100 centimeters or more of annual rainfall. Typically two or more other layers of trees and shrubs occur beneath the upper canopy. Because relatively little sunlight reaches the forest floor, the undergrowth is sparse and human beings can walk through it with relative ease.

The species diversity of rain forests borders on the legendary. Every tropical biologist has a favorite example to offer. From a single leguminous tree in the Tambopata Reserve of Peru, I recently recovered 43 species of ants belonging to 26 genera, about equal to the entire ant fauna of the British Isles (Wilson, 1987). Peter Ashton found 700 species of trees in 10 selected 1-hectare plots in Borneo, the same as in all of North America (Ashton, Arnold Arboretum, personal communication, 1987). It is not unusual for a square kilometer of forest in Central or South America to contain several hundred species of birds and many thousands of species of butterflies, beetles, and other insects.

Despite their extraordinary richness, tropical rain forests are among the most fragile of all habitats. They grow on so-called wet deserts—an unpromising soil base washed by heavy rains. Two-thirds of the area of the forest surface consists of tropical red and yellow earths, which are typically acidic and poor in nutrients. High concentrations of iron and aluminum form insoluble compounds with phosphorus, thereby decreasing the availability of phosphorus to plants. Calcium and potassium are leached from the soil soon after their compounds are dissolved from the rain. As little as 0.1% of the nutrients filter deeper than 5 centimeters beneath the soil surface (NRC, 1982). An excellent popular account of rain forest ecology is given by Forsyth and Miyata (1984).

During the 150 million years since its origin, the principally dicotyledonous flora has nevertheless evolved to grow thick and tall. At any given time, most of the nonatmospheric carbon and vital nutrients are locked up in the tissue of the vegetation. As a consequence, the litter and humus on the ground are thin compared to the thick mats of northern temperate forests. Here and there, patches of bare earth show through. At every turn one can see evidence of rapid decomposition by dense populations of termites and fungi. When the forest is cut and burned, the ash and decomposing vegetation release a flush of nutrients adequate to support new herbaceous and shrubby growth for 2 or 3 years. Then these materials decline to levels lower than those needed to support a healthy growth of agricultural crops without artificial supplements.

The regeneration of rain forests is also limited by the fragility of the seeds of the constituent woody species. The seeds of most species begin to germinate within a few days or weeks, severely limiting their ability to disperse across the stripped land into sites favorable for growth. As a result, most sprout and die in the hot, sterile soil of the clearings (Gomez-Pompa et al., 1972). The monitoring of logged sites indicates that regeneration of a mature forest might take centuries. The forest at Angkor (to cite an anecdotal example) dates back to the abandonment of the Khmer capital in 1431, yet is still structurally different from a climax forest today, 556 years later. The process of rain forest regeneration is in fact so generally slow that few extrapolations have been possible; in some zones of greatest combined damage and sterility, restoration might never occur naturally (Caufield, 1985; Gomez-Pompa et al., 1972).

¹Van Valen's original formulation, whose difficulties and implications are revealed by more recent research, has been discussed by Raup (1975) and by Lewin (1985). These studies deal with the clade, or set of populations descending through time after having split off as a distinct species from other such populations. They do not refer to the chronospecies, which is just a set of generations of the same species that is subjectively different from sets of generations.

Approximately 40% of the land that can support tropical closed forest now lacks it, primarily because of human action. By the late 1970s, according to estimates from the Food and Agricultural Organization and United Nations Environmental Programme, 7.6 million hectares or nearly 1% of the total cover is being permanently cleared or converted into the shifting-cultivation cycle. The absolute amount is 76,000 square kilometers (27,000 square miles) a year, greater than the area of West Virginia or the entire country of Costa Rica. In effect, most of this land is being permanently cleared, that is, reduced to a state in which natural reforestation will be very difficult if not impossible to achieve (Mellilo et al., 1985). This estimated loss of forest cover is close to that advanced by the tropical biologist Norman Myers in the mid-1970s, an assessment that was often challenged by scientists and conservationists as exaggerated and alarmist. The vindication of this early view should serve as a reminder always to take such doomsday scenarios seriously, even when they are based on incomplete information.

A straight-line extrapolation from the first of these figures, with identically absolute annual increments of forest-cover removal, leads to 2135 A.D. as the year in which all the remaining rain forest will be either clear-cut or seriously disturbed, mostly the former. By coincidence, this is close to the date (2150) that the World Bank has estimated the human population will plateau at 11 billion people (The World Bank, 1984). In fact, the continuing rise in human population indicates that a straight line estimate is much too conservative. Population pressures in the Third World will certainly continue to accelerate deforestation during the coming decades unless heroic measures are taken in conservation and resource management.

There is another reason to believe that the figures for forest cover removal present too sanguine a picture of the threat to biological diversity. In many local areas with high levels of endemism, deforestation has proceeded very much faster than the overall average. Madagascar, possessor of one of the most distinctive floras and faunas in the world, has already lost 93% of its forest cover. The Atlantic coastal forest of Brazil, which so enchanted the young Darwin upon his arrival in 1832 ("wonder, astonishment & sublime devotion, fill & elevate the mind"), is 99% gone. In still poorer condition—in fact, essentially lost—are the forests of many of the smaller islands of Polynesia and the Caribbean.

HOW MUCH DIVERSITY IS BEING LOST?

No precise estimate can be made of the numbers of species being extinguished in the rain forests or in other major habitats, for the simple reason that we do not know the numbers of species originally present. However, there can be no doubt that extinction is proceeding far faster than it did prior to 1800. The basis for this statement is not the direct observation of extinction. To witness the death of the last member of a parrot or orchid species is a near impossibility. With the exception of the showiest birds, mammals, or flowering plants, biologists are reluctant to say with finality when a species has finally come to an end. There is always the chance (and hope) that a few more individuals will turn up in some remote forest remnant or other. But the vast majority of species are not monitored at all. Like the dead

of Gray's "Elegy Written in a Country Churchyard," they pass from the Earth without notice.

Instead, extinction rates are usually estimated indirectly from principles of biogeography. As I mentioned above, the number of species of a particular group of organisms in island systems increases approximately as the fourth root of the land area. This has been found to hold true not just on real islands but also on habitat islands, such as lakes in a "sea" of land, alpine meadows or mountaintops surrounded by evergreen forests, and even in clumps of trees in the midst of a grassland (MacArthur and Wilson, 1967).

Using the area-species relationship, Simberloff (1984) has projected ultimate losses due to the destruction of rain forests in the New World tropical mainland. If present levels of forest removal continue, the stage will be set within a century for the inevitable loss of 12% of the 704 bird species in the Amazon basin and 15% of the 92,000 plant species in South and Central America.

As severe as these regional losses may be, they are far from the worst, because the Amazon and Orinoco basins contain the largest continuous rain forest tracts in the world. Less extensive habitats are far more threatened. An extreme example is the western forest of Ecuador. This habitat was largely undisturbed until after 1960, when a newly constructed road network led to the swift incursion of settlers and clear-cutting of most of the area. Now only patches remain, such as the 0.8-square-kilometer tract at the Rio Palenque Biological Station. This tiny reserve contains 1,033 plant species, perhaps one-quarter of which are known only to occur in coastal Ecuador. Many are known at the present time only from a single living individual (Gentry, 1982).

In general, the tropical world is clearly headed toward an extreme reduction and fragmentation of tropical forests, which will be accompanied by a massive extinction of species. At the present time, less than 5% of the forests are protected within parks and reserves, and even these are vulnerable to political and economic pressures. For example, 4% of the forests are protected in Africa, 2% in Latin America, and 6% in Asia (Brown, 1985). Thus in a simple system as envisioned by the basic models of island biogeography, the number of species of all kinds of organisms can be expected to be reduced by at least one-half—in other words, by hundreds of thousands or even (if the insects are as diverse as the canopy studies suggest) by millions of species. In fact, the island-biogeographic projections appear to be conservative for two reasons. First, tropical species are far more localized than those in the temperate zones. Consequently, a reduction of 90% of a tropical forest does not just reduce all the species living therein to 10% of their original population sizes, rendering them more vulnerable to future extinction. That happens in a few cases, but in many others, entire species are eliminated because they happened to be restricted to the portion of the forest that was cut over. Second, even when a portion of the species survives, it will probably have suffered significant reduction in genetic variation among its members due to the loss of genes that existed only in the outer portions.

The current reduction of diversity seems destined to approach that of the great natural catastrophes at the end of the Paleozoic and Mesozoic eras—in other words,

the most extreme in the past 65 million years. In at least one important respect, the modern episode exceeds anything in the geological past. In the earlier mass extinctions, which some scientists believe were caused by large meteorite strikes, most of the plants survived even though animal diversity was severely reduced. Now, for the first time, plant diversity is declining sharply (Knoll, 1984).

HOW FAST IS DIVERSITY DECLINING?

The area-species curves of island systems, that is, the quantitative relationship between the area of islands and the number of species that can persist on the islands, provide minimal estimates of the reduction of species diversity that will eventually occur in the rain forests. But how long is "eventually"? This is a difficult question that biogeographers have attacked with considerable ingenuity. When a forest is reduced from, say, 100 square kilometers to 10 square kilometers by clearing, some immediate extinction is likely. However, the new equilibrium will not be reached all at once. Some species will hang on for a while in dangerously reduced populations. Elementary mathematical models of the process predict that the number of species in the 10-square-kilometer plot will decline at a steadily decelerating rate, i.e., they will decay exponentially to the lower level.

Studies by Jared Diamond and John Terborgh have led to the estimation of the decay constants for the bird faunas on naturally occurring islands (Diamond, 1972, 1984; Terborgh, 1974). These investigators took advantage of the fact that rising sea levels 10,000 years ago cut off small land masses that had previously been connected to South America, New Guinea, and the main islands of Indonesia. For example, Tobago, Margarita, Coiba, and Trinidad were originally part of the South American mainland and shared the rich bird fauna of that continent. Thus they are called land-bridge islands. In a similar manner, Yapen, Aru, and Misol were connected to New Guinea. In the study of the South American land-bridge islands, Terborgh found that the smaller the island, the higher the estimated decay constant and hence extinction rate. Terborgh then turned to Barro Colorado Island, which was isolated for the first time by the rise of Gatun Lake during the construction of the Panama Canal. Applying the natural land-bridge extinction curve to an island of this size (17 square kilometers) and fitting the derived decay constant to the actual period of isolation (50 years), Terborgh predicted an extinction of 17 bird species. The actual number known to have vanished as a probable result of insularization is 13, or 12% of the 108 breeding species originally present. The extinction rates of bird species on Barro Colorado Island were based on careful studies by E. O. Willis and J. R. Karr and have been recently reviewed by Diamond (1984).

Several other studies of recently created islands of both tropical and temperate-zone woodland have produced similar results, which can be crudely summarized as follows: when the islands range from 1 to 25 square kilometers—the size of many smaller parks and reserves—the rate of extinction of bird species during the first 100 years is 10 to 50%. Also as predicted, the extinction rate is highest in the smaller patches, and it rises steeply when the area drops below 1 square kilometer. To take one example provided by Willis (1979), three patches of subtropical forest

isolated (by agricultural clearing) in Brazil for about a hundred years varied from 0.2 to 14 square kilometers, and, in reverse order, their resident bird species suffered 14 to 62% extinction rates.

What do these first measurements tell us about the rate at which diversity is being reduced? No precise estimate can be made for three reasons. First, the number of species of organisms is not known, even to the nearest order of magnitude. Second, because even in a simple island-biogeographic system, diversity reduction depends on the size of the island fragments and their distance from each other—factors that vary enormously from one country to the next. Third, the ranges of the known species have not been worked out in most cases, so that we cannot say which ones will be eliminated when the tropical forests are partially cleared.

However, scenarios of reduction can be constructed to give at least first approximations if certain courses of action are followed. Let us suppose, for example, that half the species in tropical forests are very localized in distribution, so that the rate at which species are being eliminated immediately is approximately this fraction multiplied by the rate-percentage of the forests being destroyed. Let us conservatively estimate that 5 million species of organisms are confined to the tropical rain forests, a figure well justified by the recent upward adjustment of insect diversity alone. The annual rate of reduction would then be $0.5 \times 5 \times 10^6 \times 0.007$ species, or 17,500 species per year. Given 10 million species in the fauna and flora of all the habitats of the world, the loss is roughly one out of every thousand species per year. How does this compare with extinction rates prior to human intervention? The estimates of extinction rates in Paleozoic and Mesozoic marine faunas cited earlier (Raup, 1981, 1984; Raup and Sepkoski, 1984; Van Valen, 1973) ranged according to taxonomic group (e.g., echinoderms versus cephalopods) from one out of every million to one out of every 10 million per year. Let us assume that on the order of 10 million species existed then, in view of the evidence that diversity has not fluctuated through most of the Phanerozoic time by a factor of more than three (Raup and Sepkoski, 1984). It follows that both the per-species rate and absolute loss in number of species due to the current destruction of rain forests (setting aside for the moment extinction due to the disturbance of other habitats) would be about 1,000 to 10,000 times that before human intervention.

I have constructed other simple models incorporating the quick loss of local species and the slower loss of widespread species due to the insularization effect, and these all lead to comparable or higher extinction rates. It seems difficult if not impossible to combine what is known empirically of the extinction process with the ongoing deforestation process without arriving at extremely high rates of species loss in the near future. Curiously, however, the study of extinction remains one of the most neglected in ecology. There is a pressing need for a more sophisticated body of theories and carefully planned field studies based on it than now exist.

WHAT CAN BE DONE?

The biological diversity most threatened is also the least explored, and there is no prospect at the moment that the scientific task will be completed before a large

fraction of the species vanish. Probably no more than 1,500 professional systematists in the world are competent to deal with the millions of species found in the humid tropic forests. Their number may be dropping, due to decreased professional opportunities, reduced funding for research, and the assignment of a higher priority to other disciplines. Data concerning the number of taxonomists, as well as detailed arguments for the need to improve research in tropical countries, are given by NRC (1980). The decline has been accompanied by a more than 50% decrease in the number of publications in tropical ecology from 1979 to 1983 (Cole, 1984).

The problem of tropical conservation is thus exacerbated by the lack of knowledge and the paucity of ongoing research. In order to make precise assessments and recommendations, it is necessary to know which species are present (recall that the great majority have not even received a scientific name) as well as their geographical ranges, biological properties, and possible vulnerability to environmental change.

It would be a great advantage, in my opinion, to seek such knowledge for the entire biota of the world. Each species is unique and intrinsically valuable. We cannot expect to answer the important questions of ecology and other branches of evolutionary biology, much less preserve diversity with any efficiency, by studying only a subset of the extant species.

I will go further: the magnitude and control of biological diversity is not just a central problem of evolutionary biology; it is one of the key problems of science as a whole. At present, there is no way of knowing whether there are 5, 10, or 30 million species on Earth. There is no theory that can predict what this number might turn out to be. With reference to conservation and practical applications, it also matters why a certain subset of species exists in each region of the Earth, and what is happening to each one year by year. Unless an effort is made to understand all of diversity, we will fall far short of understanding life in these important respects, and due to the accelerating extinction of species, much of our opportunity will slip away forever.

Lest this exploration be viewed as an expensive Manhattan Project unattainable in today's political climate, let me cite estimates I recently made of the maximum investment required for a full taxonomic accounting of all species: 25,000 professional lifetimes (4,000 systematists are at work full or part time in North America today); their final catalog would fill 60 meters of library shelving for each million species (Wilson, 1985a). Computer-aided techniques could be expected to cut the effort and cost substantially. In fact, systematics has one of the lowest cost-to-benefit ratios of all scientific disciplines.

It is equally true that knowledge of biological diversity will mean little to the vast bulk of humanity unless the motivation exists to use it. Fortunately, both scientists and environmental policy makers have established a solid linkage between economic development and conservation. The problems of human beings in the tropics are primarily biological in origin: overpopulation, habitat destruction, soil deterioration, malnutrition, disease, and even, for hundreds of millions, the uncertainty of food and shelter from one day to the next. These problems can be solved in part by making biological diversity a source of economic wealth. Wild species are in fact both one of the Earth's most important resources and the least

utilized. We have come to depend completely on less than 1% of living species for our existence, the remainder waiting untested and fallow. In the course of history, according to estimates made by Myers (1984), people have utilized about 7,000 kinds of plants for food; predominant among these are wheat, rye, maize, and about a dozen other highly domesticated species. Yet there are at least 75,000 edible plants in existence, and many of these are superior to the crop plants in widest use. Others are potential sources of new pharmaceuticals, fibers, and petroleum substitutes. In addition, among the insects are large numbers of species that are potentially superior as crop pollinators, control agents for weeds, and parasites and predators of insect pests. Bacteria, yeasts, and other microorganisms are likely to continue yielding new medicines, food, and procedures of soil restoration. Biologists have begun to fill volumes with concrete proposals for the further exploration and better use of diversity, with increasing emphasis on the still unexplored portions of the tropical biota. Some of the most recent and useful works on this subject include those by Myers (1984), NRC (1975), Office of Technology Assessment (1984), Oldfield (1984), and the U.S. Department of State (1982). In addition, an excellent series of specialized publications on practical uses of wild species have been produced during the past 10 years by authors and panels commissioned by the Board on Science and Technology for International Development (BOSTID) of the National Research Council.

In response to the crisis of tropical deforestation and its special threat to biological diversity, proposals are regularly being advanced at the levels of policy and research. For example, Nicholas Guppy (1984), noting the resemblance of the lumbering of rain forests to petroleum extraction as the mining of a nonrenewable resource for short-term profit, has recommended the creation of a cartel, the Organization of Timber-Exporting Countries (OTEC). By controlling production and prices of lumber, the organization could slow production while encouraging member states to "protect the forest environment in general and gene stocks and special habitats in particular, create plantations to supply industrial and fuel wood, benefit indigenous tribal forest peoples, settle encroachers, and much else." In another approach, Thomas Lovejoy (1984) has recommended that debtor nations with forest resources and other valuable habitats be given discounts or credits for undertaking conservation programs. Even a small amount of forgiveness would elevate the sustained value of the natural habitats while providing hard currency for alternatives to their exploitation.

Another opportunity for innovation lies in altering somewhat the mode of direct economic assistance to developing countries. A large part of the damage to tropical forests, especially in the New World, has resulted from the poor planning of road systems and dams. For example, the recent settlement of the state of Rondonia and construction of the Tucuruí Dam, both in Brazil, are now widely perceived by ecologists and economists alike as ill-conceived (Caulfield, 1985). Much of the responsibility of minimizing environmental damage falls upon the international agencies that have the power to approve or disapprove particular projects.

The U.S. Congress addressed this problem with amendments to the Foreign Assistance Act in 1980, 1983, and 1986, which call for the development of a strategy for conserving biological diversity. They also mandate that programs funded

through the U.S. Agency for International Development (USAID) include an assessment of environmental impact. In implementing this new policy, USAID has recognized that "the destruction of humid tropical forests is one of the most important environmental issues for the remainder of this century and, perhaps, well into the next," in part because they are "essential to the survival of vast numbers of species of plants and animals" (U.S. Department of State, 1985). In another sphere, The World Bank and other multinational lending agencies have come under increasing pressure to take a more active role in assessing the environmental impact of the large-scale projects they underwrite (Anonymous, 1984).

In addition to recommendations for international policy initiatives, there has recently been a spate of publications on the linkage of conservation and economic use of tropical forests. Notable among them are *Research Priorities in Tropical Biology* (NRC, 1980), based on a study of the National Research Council; *Technologies to Sustain Tropical Forest Resources* (OTA, 1984), prepared by the Office of Technology Assessment for the U.S. Congress; and the *U.S. Strategy on the Conservation of Biological Diversity* (USAID, 1985), a report to Congress by an interagency task force. Most comprehensive of all—and in my opinion the most encouraging in its implications—is the three-part series *Tropical Forests: A Call for Action*, released by the World Resources Institute, The World Bank, and the United Nations Development Programme (1985). The report makes an assessment of the problem worldwide and reviews case histories in which conservation or restoration have contributed to economic development. It examines the needs of every tropical country with important forest reserves. The estimated cost to make an impact on tropical deforestation over the next 5 years would be U.S. \$8 billion—a large sum but surely the most cost-effective investment available to the world at the present time.

In the end, I suspect it will all come down to a decision of ethics—how we value the natural worlds in which we evolved and now, increasingly, how we regard our status as individuals. We are fundamentally mammals and free spirits who reached this high a level of rationality by the perpetual creation of new options. Natural philosophy and science have brought into clear relief what might be the essential paradox of human existence. The drive toward perpetual expansion—or personal freedom—is basic to the human spirit. But to sustain it we need the most delicate, knowing stewardship of the living world that can be devised. Expansion and stewardship may appear at first to be conflicting goals, but the opposite is true. The depth of the conservation ethic will be measured by the extent to which each of the two approaches to nature is used to reshape and reinforce the other. The paradox can be resolved by changing its premises into forms more suited to ultimate survival, including protection of the human spirit. I recently wrote in synecdochic form about one place in South America to give these feelings more exact expression:

To the south stretches Surinam eternal, Surinam serene, a living treasure awaiting assay. I hope that it will be kept intact, that at least enough of its million-year history will be saved for the reading. By today's ethic its value may seem limited, well beneath the pressing concerns of daily life. But I suggest that as biological knowledge grows the ethic will shift fundamentally so that everywhere, for reasons that have to do with the very fiber of the brain, the fauna and flora of a country will be thought part of the national

heritage as important as its art, its language, and that astonishing blend of achievement and farce that has always defined our species (Wilson, 1984).

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P A R T

I

CHALLENGES TO THE PRESERVATION OF BIODIVERSITY

"As Ponci sang, he felt a shadow move over his face. Drops of the first cooling rain splashed his skin. He opened his eyes to glance down onto the ground before him. Lizard was gone. Instead, looming out of the west, a huge dark cloud built skyward. Little spurts of dust rose in puffs as the rain began to fall. Ponci looked back toward the village and saw rain pouring in slanting silver sheets onto the thirsty fields in the distance. Their song had been answered. In his weariness, his feet continued to lift as he trotted toward home in the gentle wash of sweet rain."

The breathing in my ear stopped, and slowly the room came back into focus with my nose smelling the moist earth. There's a man with a large watering can sprinkling the dirt floor to settle the dust. He has just finished, and the people in a shuffling of feet settle back again to wait, when a quickened keening brings all of us together at once. The door opens, and from somewhere in the darkness comes the unmistakable sound of metal bells. The deer, eagle, and butterfly dancers are coming. The drums are beating. The singing men's voices can be heard. The people's patience will again be rewarded, and life will be remembered, in the dance, in the song, in the story.



A CHRISTIAN VIEW OF BIODIVERSITY

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Most people are distressed by the widespread destruction of species of living things. There is a deep sense that this is a serious loss to the planet. The major problem does not arise from direct approval of the destruction of species and of the simplification of the environment. It arises from the lack of awareness of the consequences of our actions and from the primacy of other concerns. In the pursuit of economic gain, most people do not want to be bothered by questions about biodiversity.

This volume, and the activities of many of its authors, are designed to heighten awareness of what we are doing to our biosphere. The correct assumption is that heightened awareness and intensified attention are the primary needs. People will act more appropriately if they are reminded again and again of the effects of their actions.

The authors of this section have a different role. We were asked to reflect on *why* biodiversity is important. It is not necessary to answer this question for people to recognize its importance. Nevertheless, good answers to our question are urgent, because the intuitive sense of importance is gradually weakened if its justification is not articulated. Also, there are ways of viewing the world that make concern about endangered species appear to be an esoteric or sentimental matter. Indeed, this type of world view is dominant in much of our society. We can all remember many of the disparaging comments that were made about concerns that a species of snail darter interfered with the building of a dam. Staying power in defense of biodiversity probably depends on a world view that grounds it more deeply than sentiment, however natural and healthy that sentiment may be.

The most obvious way to argue for biodiversity is to show how it benefits human beings. In the foregoing sections, much evidence was given for the risk to the

human future that would be presented by a drastic simplification of various ecosystems. Hence there is a strong argument that for the sake of the future of our own species, we need to be concerned with biodiversity.

On the other hand, this argument is limited. Human beings have survived the disappearance of thousands of species with relatively little practical loss. If the only reason for preserving a particular species of insect or fish is its value to us, there will be many occasions when other needs will seem far more pressing. Furthermore, our sense of the importance of biodiversity is in fact not adequately reflected in the practical anthropocentric arguments. We *feel* that other species should have their place, even if they do not benefit us. Can we explain or justify this feeling? One argument, a valid one I believe, is that all living things have intrinsic value. Not only are they of instrumental value to one another and to us, they also have value in and of themselves. They are of value for themselves. Hence, our destruction of other living things, while inevitable, should never be taken lightly. The reasons for destruction may be good ones—our need for food, for example. But we should not underestimate the cost to others. We should tread lightly on the Earth rather than bulldoze away all inconvenient objects.

Whereas this argument is a good one in itself, it does not go very far to explain the specific value of biodiversity. It does explain why we should avoid unnecessary destruction of living things, but it does not explain why a variety of such things is better than a monoculture. If by destroying the biodiversity of a prairie we can bring about the monoculture of a wheat field, and if the total number of insects and animals that are supported is not fewer, then there would seem to be no loss. The value of members of the lost species is made up by the value of more members of the species that is preserved.

Another argument, also valid in my opinion, is based on relations. The human species is not apart from others but is instead intricately and intimately related to the remainder of the web of life. When we experience the whole biosphere in this way, we experience destruction of any of its species as a diminution of ourselves. The sense of relatedness has two dimensions. One dimension is genetic. We are kin to other living things. We have a common ancestry that has impressed itself in common genetic elements. The same sensibility that gives us a special sense of responsibility toward other human beings who are related to us can operate to give us a sense of responsibility for the other species to which we are also related.

The second dimension is ontological. We are increasingly realizing that individual entities, including individual human beings, do not exist apart from relations with other beings. We are constituted by our relations. Of course, many of our most important relations are with other human beings. But by no means all. We are related to the whole world of inanimate and animate things. We are part of them, and they are part of us. To feel this relationship with other things is not sentimentality but reality.

Although this is all true, it still does not go far enough to explain our sense of the importance of biodiversity. It does strongly support the sense of the intrinsic value of other living things. It cuts against the widespread Western dualism that places human beings above and outside nature. It works against the dominant

Western ethics that has taught us that only human welfare really matters. It reintegrates us into the web of life and thereby heightens our sense of its importance for us. But it does not tell us specifically why biodiversity has its own inherent value.

The category that comes to mind when we reflect on the value of diversity is aesthetics. At least in traditional art we have thought that the complexity of forms that could be brought into unity and harmony correlated with the greatness of a piece of art. Today, some qualifications would be required, but the general principle still holds. The same applies to experience generally. There is a richness of experience that correlates with the manifold contents that jointly make their contributions.

Much of our negative reaction to the destruction of species seems to stem from this sense that there are possibilities of experience forever lost. We are aware that some of our environments have already been simplified in ways that have impoverished our experience, and we are disturbed at the prospect that such impoverishment continues. Some of the experiences that were possible for us will not be available to our children. We rightly feel this as a loss that we should try to prevent, even at considerable cost in more practical realms of life.

This, too, is a strong and valid argument that goes far to reflect the feelings that are engendered by our awareness of the simplification of the biosphere. Yet it still fails to deal with our total concern. There are myriad species that have lived and died unknown by humans. It is true that their disappearance sets limits on what future generations can experience. But often in ordinary human experience, the ones that are lost do not differ sufficiently from others that remain to affect any but the most perceptive human beings. Judged simply by their potential contribution to the richness of human experience, many species seem to be of limited importance.

There is a deeper sense on our part that even when we are not ourselves able to benefit even aesthetically from the presence of other species, they are still making a contribution to the whole that is irreplaceable. Indeed, in one sense, this is self-evident. Surely the whole is diminished in some way by the loss of any of its parts!

The problem is that it is not so easy to locate this loss. We often try to locate it in human experience of the whole, but we have already seen that this is too limited a locus. It seems to be the whole-as-such that is impoverished. Yet this makes sense only if we can speak of the whole as having its own unity, its own perspective, its own experience.

We theists believe that just such unity, perspective, and experience does characterize the whole. From our point of view, the sense of the importance of biodiversity reflects an often unconscious recognition that the whole is indeed much more than the sum of its parts. Human beings sense that every creature, and especially every species, makes its contribution to the richness of the inclusive or divine experience.

It is this inclusive experience that provides the norm by which all of us are truly evaluated and judged. God knows us better than we know ourselves, and it is this knowledge of us that is the truth about us. For God, I am of no more worth than

my neighbor, and hence when I treat my neighbor as a mere means to my own advantage I act wrongly. For God, no one nation is inherently of more worth than others. Hence, we act wrongly when we seek our own national advantage at the expense of other peoples. For God, every species has value. We do wrong when we treat other species as if they existed only for our sake and as if they could be destroyed with impunity when it is convenient for us to do so.

It would be going too far to say that the value of biodiversity is explicitly taught in the Bible. What we mean by this term presupposes much scientific knowledge that is not reflected in the Jewish and Christian scriptures. Nevertheless, the rudiments of the idea are present, and the extension of Biblical teaching into our own time strongly supports the concerns of biodiversity.

Consider the first chapter of Genesis. This account of creation has had profound effects on Western culture. There are features of this story that have been used to justify a mode of human relation to other creatures that has been profoundly destructive. But let us look at the story again.

One point that is striking in this account is that when God created the various plants and animals, God saw that they were good. There is no suggestion here that they were good because they would be useful to human beings. They were good in themselves and thus contributed to the divine satisfaction. Specifically, the story says that God blessed them and told them to be fruitful and to multiply, each according to its kind.

Now it is true that human beings are presented in a special light. We *are* one species among others, but we are also more than that. We are that species that is made in the image of God, and this is closely related to the assertion that God has given us dominion over other living things.

The resulting sense of rightful dominion has been important to the readers of the Bible, and this sense can be reaffirmed today. However, there is no question but that the story has been interpreted to mean that human beings are free to use and destroy other living things at will; and this interpretation needs to be strongly rejected.

Human beings are placed in a position in relation to other creatures much like that of God in relation to the whole of creation. God has dominion over all. We have dominion over the other creatures. God exercises dominion for the sake of those over whom the dominion is exercised. Similarly, the political ruler of Israel is to rule for the sake of those who are governed. A king who uses his power to amass riches for himself at the expense of the suffering of the ruled is a despot, not one who exercises rightful dominion. There is no justification here to suppose that human dominion over other creatures is a sanction of selfish exploitation. The meaning of the dominion given to us is much better expressed in servanthood and stewardship than in exploitation.

This book's content expresses a profoundly biblical view of the relation of human beings to the other species who with us constitute the biodiversity of the world. It recognizes that we human beings do exercise a determinative power over other creatures. Whether hundreds of thousands of species survive depends on the decisions of humans. It would be pointless to deny that we exercise dominion. But

unlike so many who have asserted their dominion, we are acknowledging that with power comes responsibility—specifically, responsibility to God. To wipe out unnecessarily whole species of those creatures over whom we exercise stewardship is to betray that stewardship and to impoverish the experience of God. It is a crime against our Creator.

The Earth was also seen from space by the more discerning eye of instruments, and it was this view that confirmed James Hutton's vision of a living planet. When seen in infrared light, the Earth is a strange and wonderful anomaly among the planets of the solar system. Our atmosphere, the air we breathe, was revealed to be outrageously out of equilibrium in a chemical sense. It is like the mixture of gases that enters the intake manifold of an internal combustion engine, i.e., hydrocarbons and oxygen mixed, whereas our dead partners Mars and Venus have atmospheres like gases exhausted by combustion.

The unorthodox composition of the atmosphere radiates so strong a signal in the infrared range that it could be recognized by a spacecraft far outside the solar system. The information it carries is *prima facie* evidence for the presence of life. But more than this, if the Earth's unstable atmosphere was seen to persist and was not just a chance event, then it meant that the planet was alive—at least to the extent that it shared with other living organisms that wonderful property, homeostasis, the capacity to control its chemical composition and keep cool when the environment outside is changing.

When on the basis of this evidence, I reanimated the view that we were standing on a superorganism rather than just a ball of rock (Lovelock, 1972; 1979), it was not well received. Most scientists either ignored it or criticized it on the grounds that it was not needed to explain the facts of the Earth. As the geologist H. D. Holland (1984, p. 539) put it, "We live on an Earth that is the best of all possible worlds only for those who are well adapted to its current state." The biologist Ford Doolittle (1981) said that keeping the Earth at a constant state favorable for life would require foresight and planning and that no such state could evolve by natural selection. In brief, scientists said, the idea was teleological and untestable. Two scientists, however, thought otherwise; one was the eminent biologist Lynn Margulis and the other the geochemist Lars Sillen. Lynn Margulis was my first collaborator (Margulis and Lovelock, 1974). Lars Sillen died before there was an opportunity. It was the novelist William Golding (personal communication, 1970), who suggested using the powerful name Gaia for the hypothesis that supposed the Earth to be alive.

In the past 10 years these criticisms have been answered—partly from new evidence and partly from the insight provided by a simple mathematical model called Daisy world. In this model, the competitive growth of light- and dark-colored plants on an imaginary planet are shown to keep the planetary climate constant and comfortable in the face of a large change in heat output of the planet's star. This model is powerfully homeostatic and can resist large perturbations not only of solar output but also of plant population. It behaves like a living organism, but no foresight or planning is needed for its operation.

Scientific theories are judged not so much by whether they are right or wrong as by the value of their predictions. Gaia theory has already proved so fruitful in this way that by now it would hardly matter if it were wrong. One example, taken from many such predictions, was the suggestion (Lovelock et al., 1972) that the compound dimethyl sulfide would be synthesized by marine organisms on a large scale to serve as the natural carrier of sulfur from the ocean to the land. It was known at the time that some elements essential for life, like sulfur, were abundant



CHAPTER

THE EARTH AS A LIVING ORGANISM

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The idea that the Earth is alive may be as old as humankind. The ancient Greeks gave her the powerful name Gaia and looked on her as a goddess. Before the nineteenth century even scientists were comfortable with the notion of a living Earth. According to the historian D. B. McIntyre (1963), James Hutton, often known as the father of geology, said in a lecture before the Royal Society of Edinburgh in the 1790s that he thought of the Earth as a superorganism and that its proper study would be by physiology. Hutton went on to make the analogy between the circulation of the blood, discovered by Harvey, and the circulation of the nutrient elements of the Earth and of the way that sunlight distills water from the oceans so that it may later fall as rain and so refresh the earth.

This wholesome view of our planet did not persist into the next century. Science was developing rapidly and soon fragmented into a collection of nearly independent professions. It became the province of the expert, and there was little good to be said about interdisciplinary thinking. Such introspection was inescapable. There was so much information to be gathered and sorted. To understand the world was a task as difficult as that of assembling a planet-size jigsaw puzzle. It was all too easy to lose sight of the picture in the searching and sorting of the pieces.

When we saw a few years ago those first pictures of the Earth from space, we had a glimpse of what it was that we were trying to model. That vision of stunning beauty; that dappled white and blue sphere stirred us all, no matter that by now it is just a visual cliché. The sense of reality comes from matching our personal mental image of the world with that we perceive by our senses. That is why the astronaut's view of the Earth was so disturbing. It showed us just how far from reality we had strayed.

in the oceans but depleted on the land surfaces. According to Gaia theory, a natural carrier was needed and dimethyl sulfide was predicted. We now know that this compound is indeed the natural carrier of sulfur, but at the time the prediction was made, it would have been contrary to conventional wisdom to seek so unusual a compound in the air and the sea. It is unlikely that its presence would have been sought but for the stimulus of Gaia theory.

Gaia theory sees the biota and the rocks, the air, and the oceans as existing as a tightly coupled entity. Its evolution is a single process and not several separate processes studied in different buildings of universities.

It has a profound significance for biology. It affects even Darwin's great vision, for it may no longer be sufficient to say that organisms that leave the most progeny will succeed. It will be necessary to add the proviso that they can do so only so long as they do not adversely affect the environment.

Gaia theory also enlarges theoretical ecology. By taking the species and the environment together, something no theoretical ecologist has done, the classic mathematical instability of population biology models is cured.

For the first time, we have from these new, these geophysiological models a theoretical justification for diversity, for the Rousseau richness of a humid tropical forest, for Darwin's tangled bank. These new ecological models demonstrate that as diversity increases so does stability and resilience. We can now rationalize the disgust we feel about excesses of agribusiness. We have at last a reason for our anger over the heedless deletion of species and an answer to those who say it is mere sentimentality.

No longer do we have to justify the existence of the humid tropical forests on the feeble grounds that they might carry plants with drugs that could cure human disease. Gaia theory forces us to see that they offer much more than this. Through their capacity to evaporate vast volumes of water vapor, they serve to keep the planet cool by wearing a sunshade of white reflecting clouds. Their replacement by cropland could precipitate a disaster that is global in scale.

A geophysiological system always begins with the action of an individual organism. If this action happens to be locally beneficial to the environment, then it can spread until eventually a global altruism results. Gaia always operates like this to achieve her altruism. There is no foresight or planning involved. The reverse is also true, and any species that affects the environment unfavorably is doomed, but life goes on.

Does this apply to humans now? Are we doomed to precipitate a change from the present comfortable state of the Earth to one almost certainly unfavorable for us but comfortable to the new biosphere of our successors? Because we are sentient there are alternatives, both good and bad. In some ways the worse fate in store for us is that of becoming conscripted as the physicians and nurses of a geriatric planet with the unending and unseemly task of forever seeking technologies to keep it fit for our kind of life—something that until recently we were freely given as a part of Gaia.

Gaia philosophy is not humanist. But being a grandfather with eight grandchildren I need to be optimistic. I see the world as a living organism of which we are a part; not the owner, nor the tenant, not even a passenger. To exploit such

a world on the scale we do is as foolish as it would be to consider our brains supreme and the cells of other organs expendable. Would we mine our livers for nutrients for some short-term benefit?

Because we are city dwellers, we are obsessed with human problems. Even environmentalists seem more concerned about the loss of a year or so of life expectation through cancer than they are about the degradation of the natural world by deforestation or greenhouse gases—something that could cause the death of our grandchildren. We are so alienated from the world of nature that few of us can name the wild flowers and insects of our locality or notice the rapidity of their extinction.

Gaia works from an act of an individual organism that develops into global altruism. It involves action at a personal level. You well may ask, So what can I do? When seeking to act personally in favor of Gaia through moderation, I find it helpful to think of the three deadly Cs: combustion, cattle, and chain saws. There must be many others.

One thing you could do, and it is no more than an example, is to eat less beef. If you do this, and if the clinicians are right, then it could be for the personal benefit of your health; at the same time, it might reduce the pressures on the forests of the humid tropics.

To be selfish is human and natural. But if we chose to be selfish in the right way, then life can be rich yet still consistent with a world fit for our grandchildren as well as those of our partners in Gaia. //

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