The Challenges of Sciences. A Tribute to Carlos Chagas
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BIODIVERSITY AND THE HUMAN PROSPECT

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The world's biological diversity, or biodiversity, is a priceless gift to humanity, one on which we base our existence on Earth. Biodiversity feeds us, provides most of our medicines, protects our watersheds, and enriches our lives with beauty. For these reasons, I would like to state clearly from the beginning that I consider the loss of biodiversity caused by human beings to be a moral outrage, a completely unacceptable treatment of the planet that supports us, and in contradiction of all religious teachings. In addition, it is a disastrous strategy from the standpoint of human survival and human options in the future.

Human beings have grown and developed in a rich context of biological diversity, and the properties of our bodies and our minds reflect relationships that are millions of years old. In form and inspiration, our art, our music, and many of our deepest aesthetic and cultural inspirations reflect aspects of biological diversity. We feel nurtured when we are in a place where plants or animals are also present, and by the same token, often feel isolated when were are in a place where it is not. Plants make us feel comfortable, and most of the rooms, offices, and dwellings in which we live and work have plants, aquarium fishes, cats, dogs, or other animals around. We have a natural affinity for them, an affinity that is not surprising given our history, which only for a very short time has us living in villages, towns, and cities.

Given these relationships, and the increasingly rapid extinction of large numbers of organisms, one can wonder with our colleagues Paul Ehrlich and E.O. Wilson, whether man has a right to destroy such a large proportion of what, as far as we know, are our only living companions in the universe. It is for this fundamentally important reason that we must pay careful attention to the fate of biological diversity and our responsibility in

bringing about its loss. In addition, there are numerous practical reasons to be concerned with this loss, and I shall discuss these briefly.

From an individual point of view, biological diversity, and specifically plants, provides all of our food, either directly or indirectly (after being consumed by animals or other organisms), so we are for this reason alone utterly dependent on it. In addition, for the majority of people in the world, plants provide the sole or overwhelmingly predominant source of medicine. It is interesting to note, in connection with the use of plants as medicines by human beings, that higher primates, such as baboons and chimpanzees, also have been observed to use plants essentially as medicines, as dietary supplements in cases of nutritional deficiency or in cases of infestation by parasitic worms; and it is clear that among the more highly evolved vertebrates the use of medicines really is broader than the human race itself. No wonder, then, that we should have begun to find, and that most people in the world should still find, their major source of medicines in natural materials such as plants. The complex and highly diverse biological molecules that evolved in plants and in other organisms as a way of maintaining their status in the world's ecosystems by repelling potential herbivores or preventing diseases, have become important for us as medicines. Even in this age of combinatorial chemistry one cannot, in the final analysis, find enough basic molecules to work with, and by examining those that have evolved naturally one can still find useful starting points for further chemical discoveries. Indeed, the methods of microanalysis and microseparation now being developed promise many new opportunities for the use of natural products from plants and other organisms over the next decade or so.

Many other uses of biological materials can also be enumerated: for example, wood and other building materials; cloth, from such sources as cotton or linen (from flax plants); or biomass, for energy, either fossil (petroleum, natural gas, or coal) or living. Organisms also provide materials that form the basis of many diverse industrial processes, whether actively, as fermentation by yeast, or chemical processes stimulated by microfungi, or simply as starting points in the industrial production of many chemicals. What is not talked about quite as often as examples of this kind, however, is the application of modern biology to the diversity of organisms. Watson and Crick's postulate of the double-helical model of DNA came only in 1953, less than 50 years ago; the first transfer of a gene from one kind of organism to another unrelated one came in 1973 (Boyer and Cohen, about 28 years ago); the first experiments with genetically modified organisms, less than 20 years ago. Increasingly widespread use of the kinds of geneti-

cally modified plants, discussed by Maxine Singer (this symposium), really began in the early 1990s, and continues to increase rapidly. As we begin the 21st century and the new millennium, many of us share the opinion that this should be the "century of biology"; and what we mean by this slogan is that our understanding of biological processes, and particularly of sustainable biological systems, has been developed to the point at which we should be able to create sustainable systems, both at the level of the sustainable productivity of individual species productive and at the level of ecosystems. These new applications should enable us to achieve further progress without at the same time destroying even more of the Earth's natural capacity to support us, a topic that I shall discuss subsequently.

Over the past few years, we have begun to elucidate the complete base sequences of the genomes of individual kinds of organisms, starting with viruses and bacteria, and continuing on to yeasts, *Drosophila*, nematodes, flowering plants (*Arabidopsis* and rice), and human beings. These remarkable achievements open up whole new vistas for human progress, since they enable us to understand more fully than has earlier been possible the relationships between different kinds of organisms and their genes in an evolutionary context. In the face of such developments, the loss of a major proportion of biological diversity just as we are beginning more fully to understand is poses real obstacles for future progress, both basic and applied. Questions can now be asked, for example, about why human beings may have only about 30,000 genes, but something on the order of 100,000 kinds of proteins. In addition, we immediately begin to ask how it can be that all placental mammals, taking basic sequences and gene function into consideration, have basically the same array of genes, but can still be as strikingly diverse as they are. It has long been known that the genes of human beings and chimpanzees are virtually identical, even in base sequence: what does this mean for interpreting the differences between them? At least a third of the genes of flowering plants are essentially like those of human beings and other placental mammals: what does this signify for the interpretation of GMOs and the nature of opportunities for their further development and use?

In fact, it is the evolutionary relationship between genes and families of genes during the 3.8 billion or more years that life has existed on Earth that will ultimately provide the most exciting and most informative analysis of life on Earth at a genetic level, and the best tools for applying that knowledge to human benefit. Such knowledge can be based only on a thorough appreciation of diversity; it is therefore exceedingly ignorant to allow a

major proportion of diversity to disappear before we have even begun to understand it. It is estimated that we have given names to only about 1.6 million species of plants, animals, fungi, and microorganisms, of the 10 million or more that exist – so most of the organisms that we are driving to extinction in such large numbers as we enter the 21st century have never been studied by anyone: their very existence is unknown. The great American conservationist Aldo Leopold said, in his collection of essays "A Sand County Almanac" (1949) that the first rule of intelligent tinkering is to save all the cogs and wheels. Collectively, however, we are discarding. That is precisely the opposite of what we are collectively doing, however: we are throwing away the cogs and wheels as we try to make better and better machines from the ones that are left!

In addition to the importance of individual organisms for human beings, we also need to consider their importance as components in biological communities and ecosystems. For example, organisms in nature mitigate the effects of soil erosion and protect watersheds. In New York City in the 1990s, for example, water quality was restored to approximately its original state by restoring the ecology of the watersheds in the Catskill Mountains from which the City's water supply was derived, as for example by limiting the use of pesticides and building up the cover of shrubs and other vegetation, for about a third of the price ($1.5 billion) that it would have cost to construct water purification plants to accomplish the same purpose. This kind of ecosystem restoration makes possible the continuation of ecosystem services, services that natural ecosystems provide free: other such services include providing homes for insects that pollinate crops and for birds that eat destructive insects, controlling local climates and precipitation – about half of the rainfall in the Amazon is associated with the forest cover – and in generally keeping ecosystems in balance, whether they be terrestrial, freshwater, marine inshore, or deep-sea ecosystems. The value of those ecosystem services is incalculable – we simply could not survive without them.

Four hundred human generations (approximately 10,000 years) ago, at a time when human beings were first discovering how to cultivate crops to produce food for themselves, the population of the entire whole world – all of the continents together – was a few million people – equivalent to the population of Rome at the present time. When human beings were hunter-gatherers, and before they began to live together in villages, towns, and cities, and to develop what we consider civilization, behaviors (whether genetic or learned) that were adaptive, useful, and constructive were favored. Since

those behaviors predominated over some two million years of human history, while people have lived together in communities for only about 10,000 years, it seems certain that we still we have the original ones to a large extent, and that we probably have just begun the process of learning how to live together in such a way as to allow everyone to contribute what they can. In the world of the present, where nearly half of a total of more than 6 billion people live in cities of more than a million inhabitants, we must forge new rules for living in harmony with nature and with ourselves.

Over the past 10,000 years, human populations have grown slowly to probably several hundred million at the time of Christ, to probably half a billion in late medieval to early Renaissance times, to perhaps 800 million at the start of the Industrial Revolution in the middle of the 18th Century, and just about reached 1 billion at a time in the 1790s when the Reverend Thomas Malthus was predicting that human population growth would inevitably outstrip our ability to produce food, and that we therefore were in for mass starvation. What the Reverend Malthus did not take into his calculations was the invention of the steam engine and many other productive mechanical systems, which first depended on the massive use of fuels such as wood and subsequently on the millions of years of accumulation of fossil fuels of biological origin – petroleum, natural gas, and coal. The discovery of these fuels and their widespread utilization made it possible for human beings to find other ways to wring more productivity out of the Earth. But as the human population over that 200-year period has grown from a billion to over 6 billion people, radical changes have occurred in life on Earth, many of them during the last 50 years. In this period of runaway growth, it is striking to remember that the last billion people were added in the last 12 years, and a billion people in the 13 years before that. As recently as 1975, the global population was four billion; 50 percent were added to the global population in the last quarter century, and although both absolute growth and percentage growth have slowed down, the first decades of the next century are likely to see the addition of another 2 billion people – the first billion of them in not much more than the 12 years in which the last billion people were added, because the base is now so high that even though percentage growth and absolute numbers have gone down, the overall number is still increasing rapidly.

Population is by no means the only problem in the world, although we often tend to overemphasize it. The problem is one of population multiplied by affluence, the level of consumption, multiplied by the technology that is used – a factor that can be positive or negative. If one calculates that peo-

ple in affluent countries such as Europe and North America consume at about 30 times the rate of rural people in Brazil or Indonesia, about 30 times as much energy or any other substance to support their lives, then one can readily calculate that, multiplying the 200 million people added in Europe and the United States since the end of World War II by 30, one would have a total consumption equal to that of 6 billion rural Indonesians. That, of course, leads right into another very serious moral problem that many have pointed out: whether those of us who live in affluent countries have the right to consume so much of what the world has to offer, or whether we ought not (and I think the answer is clear) be thinking much more carefully about our common management of this planet. In any event, over the past 50 years, while the global population has grown from 2.5 billion to over 6 billion people, we have exhausted about a fifth of the world's topsoil, a similar amount of its agricultural lands, cut down about a third of its forests without replacing them, increased carbon dioxide – the primary human-produced greenhouse gas in the atmosphere – by about a sixth, and depleted the stratospheric ozone layer by about 7 or 8 percent, thus increasing the incidence of malignant skin cancer by about 20 percent in temperate latitudes. These changes are extraordinarily serious, and they clearly are going on to a degree that cannot be sustained.

This relationship was pointed out very clearly by participants at the 1992 Earth Summit in Rio de Janeiro, but very little has been done as a result. Nevertheless, as George Schaller, the great American conservationist, of the Wildlife Conservation Society in New York, put it, we cannot afford another century like the past one. We simply cannot afford it; because we, the human race, are living on our accumulated natural capital and not on the interest or natural productivity – just the same as a family would be living on a bank account that way, and it is a proposition that cannot continue. The world will find sustainability, because continued human activities lead to a condition that is sustainable worldwide; what we are talking about, therefore, is not whether we are going to survive or die. We are clearly going to survive. What we are discussing is the kind of a world in which we want our children and grandchildren and their grandchildren to live. This world will differ remarkably from place to place, depending on the efforts of individual people in different places. Some will be healthy and prosperous, and rich in biological diversity and natural beauty and productivity, and others will be impoverished, homogenized, desertified, and not places that we can consider fit for human beings. The choice is ours.

Regardless of whether we have enough moral character to worry about the fate of people all over the world, where a quarter of our fellow human beings are living on less than $1 a day and half of them are literally starving, we are nonetheless engaged in a collective management of our planet, a partnership that can work out for everyone's benefit only if we do begin in some way to form a kind of partnership. This partnership will, in my opinion and the opinion of many others who have thought about it, require substantial change in moral viewpoint. It will not come about simply by recitation of dreary facts about how different parts of the world are going downhill or how many people are starving. The change that it will take to make us address the world dilemma overall is basically a change that must occur within us. Along the way, however, paying attention to biological diversity is something that we can do to our very great advantage. In the spirit of Carlos Chagas, whose life we remember with great appreciation, let us dedicate ourselves to developing our common appreciation of the whole human race, and of the biological diversity that supports it in its great variability and magnificence throughout the world.