Biological diversity: A fascinating world

*José Sarukhán**

How many species are there on earth?

Among biologists devoted to studying the ecology of systems or populations, as well as specialists in conservation biology, one often hears the comment that in contrast with what we might call the "physical world," our knowledge of the other, "biological world" is truly incipient and consequently very incomplete. Let us see if this is the case.

The earth's equatorial and polar diameters are known with great precision, as is the average distance between the earth, the sun and the moon. We also have an approximate calculation of the number of stars in our galaxy. Since the previous century no corner of the earth has remained unexplored; for many decades we have had precise information about the physical and chemical characteristics of our atmosphere and, more recently, we have obtained information about the many elements that distinguish the oceans and continents, through the permanent observations made by artificial satellites orbiting the earth. At the *micro level* —the other extreme of the "physical world"— numbers and sizes of known atoms and subatomic particles have been precisely measured. A good student of physics, who knows Avogadro's number, can make a reasonable estimate of the number of atoms contained in this issue of *Universidad de México* magazine.[1]

The former are only a few of the many examples of the degree of precision and understanding reached by humanity with regard to our "physical world." Not only is there a great quantity of knowledge about the physical environment, but the predictions made by man about how and when the majority of physical phenomena occur are also quite correct.

This is not the case for the biological components that make up man's environment, despite the fact that —unlike the aforementioned examples— they are found in a much more restricted spatial area at a scale much closer to that of human beings.

If we ask the most basic of questions about this biological world —"How many species of organisms are there on earth?"— we are unable to provide an answer, even in terms of the closest order of magnitude. Estimates vary between 10 million and 100 million species, and are nothing more than that —estimates.

Some biologists, among them the renowned entomologist Edward O. Wilson, have estimated the number of *known* species —that is, those which have been "christened" with a Latin binomial (the species' scientific birth certificate) and can be found in a museum somewhere in the world. Wilson (1988) calculates that slightly more than 1.4 million species of plants, animals and microorganisms have been named. Most evolutionary biologists believe that this figure represents less than 10 per cent of the species really inhabiting this planet.

An agency of the United Nations (PNUMA) recently promoted a Global Evaluation of Biodiversity, which estimates the number of known species as 1.75 million and the possible total of species as between 7 and 20 million.

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At the beginning of the 1980s, Terry Erwin (1982), an entomologist from the Smithsonian Institute, developed a method of capturing insects living in the treetops of the Panamanian jungle (30-50 meters high). This method consists of fumigating the trees in a controlled way with insecticide and, some hours later, collecting the insects which have fallen to the ground. On the basis of the number of species of coleoptera (Erwin is a specialist on these insects) found in his collection of specimens, he calculates that there should exist close to 30 million species of arthropods in the world's tropical regions. Other research, carried out in Southeast Asian jungles and the forests of England and South Africa using methods similar to Erwin's, led to estimates that there may be close to 10 million species of arthropods in the world.

More than half of known species are arthropods (close to 875 thousand); that is, all animals —such as insects, arachnids and crustaceans— which have chitinous, articulated bodies. Almost 90 percent of these are insects (Fig. 1). At the same time, it is estimated that some 250,000 species of higher plants exist, of which angiosperms (flowering plants) represent nearly 90 percent (220,000).

These estimates were made on the basis of field samples and result from the degree of knowledge we have obtained regarding various groups of organisms. They are obviously subject to a series of unproven

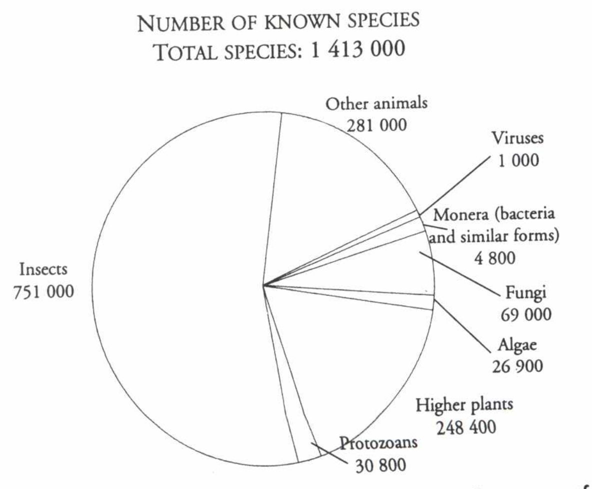


Fig.1 Distribution of known species among the main groups of organisms, according to E.O.Wilson (1988).

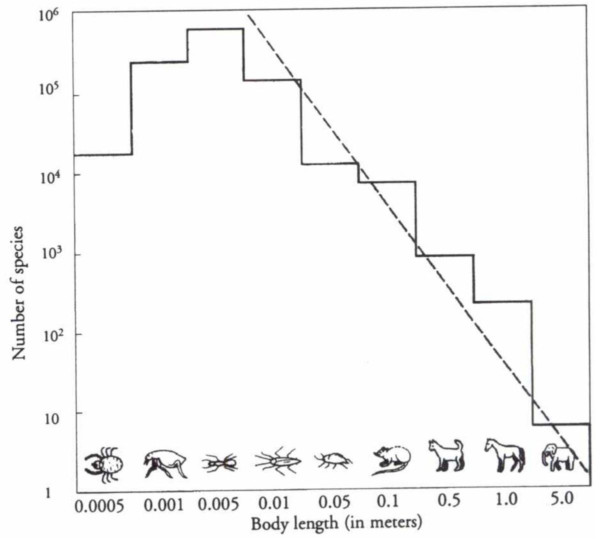


Fig.2 Relation between the organism's body size and the number of land animal species corresponding to each size. May (1990).

suppositions, due precisely to the lack of taxonomic knowledge, in particular with regard to insects. Any variation in the percentage which a group is believed to represent, in relation to a fairly well-known total, produces very significant modifications in the final estimate. However, Robert May (1990) carried out a theoretical calculation based on the relation between the body size of land-based animals and the number of *known* species corresponding to those sizes. May graphed the number of species as a function of their size on a "log-log" scale and found an almost linear regression, with a slope close to minus two, which predicts a total number of species of *land animals* close to or greater than 10 million (Fig. 2). If we take into account that many of the lesser-known species of land animals are precisely those of the most inconspicuous sizes, and that May was referring only to species of land animals, we see that his data back up the empirical estimates suggesting total numbers of species in the tens of millions.

Thanks to the most recent studies about the ocean floor, J. Frederick Grassle (1991) concludes that in that environment —formerly thought of as a "desert" with low temperatures and almost total darkness, subject to enormous pressure— there should be tens of millions of animal species, most of them minuscule invertebrates.

Our ignorance about bacteria and other microorganisms is truly colossal. Apart from the problems due to their tiny size and their presence in nearly every part of the planet, it is a very complex task to scientifically catalogue and cultivate them in controlled media, in order to study them adequately. Given their prodigious disposition for reproduction and very short life span, they are able to generate new species with relative frequency. J. Goksoyr and V. Torsvik (1990), a pair of Norwegian biologists, tried to define how many species of bacteria were living in the soil of a Norwegian forest by using DNA hybridization techniques on bacterial material they had gathered. The result was that in one gram of earth from this forest there were between 4 and 5 thousand species of bacteria. While this number was similar to that reported in a study of riparious sediment, also in Norway, there was very little duplication of species from one site to the other. If this occurs in two sites which are relatively close together and whose climates are fairly similar, what can we expect to find in different soils and climates as different from each other as a tropical forest, a savannah or a mangrove swamp? Not to speak of the myriad of specialized bacteria which live in strict symbiosis with each of the millions of plant and animal organisms existing on earth (Buchner, 1965).

But we should not have the impression that inconspicuous species, bacteria and other microorganisms are the only ones left to be discovered. Twelve years ago a new species, *Nanaloricus mysticus*, was discovered, which turned out to be so different from any other animal known to date, that a new phylum of organisms (Loricifera) was formed, equivalent to the phylum of vertebrates or that of arthropods. This new category of animals is made up of many new species, which were subsequently discovered in habitats similar to that of the first species. Since 1942 no new family of higher plants had been discovered. Less than ten years ago, Esteban Martínez of UNAM's Institute of Biology discovered a new plant species in the Chiapas jungle: *Lacandonia schismatica*, which constituted a new plant family. The last family of plants to be identified was found in 1991 (*Ticodendraceae*); its range extends from the Chimalapas in Oaxaca to Panama.

We would all agree that the cetaceans are animals of a conspicuous size. The famous "little cow" (*Phocoena sinus*) from the Gulf of California, now protected because of the danger of extinction, was discovered in 1958. Four years ago, in 1991, a new species of whale was discovered in the waters off Peru (Ralls and Brownell, 1991).

Up to this point I have only mentioned issues having to do with species diversity. But this is not the only biological variant. To all of the foregoing we must add that which exists *within* each species, resulting from the genetic recombination characteristic of organisms which reproduce sexually. This genetic variable is the "raw material" acted upon by evolutionary processes, the result of which is the creation of new species.

The only conclusion we may draw from the information cited above is that the real number of animal, plant, bacteria and microorganism species on earth is extremely large; that we are unfamiliar with more than 90 percent of these species and are far from being able to estimate their number or even to provide an acceptable approximation.

Biological diversity in Mexico

A growing interest in ecological matters, both local and global, has been awakened over the past two decades among all societies. Thus, it is no longer much of a novelty to note that Mexico is among the four or five countries with the greatest number of species in its territory.

In fact, with only 1.5 percent of the continental mass's total area, Mexico has 10 percent of the known species of plants and land animals. Our country has the highest number of reptile species (717); and is second, after Indonesia, in the concentration of land mammal species (455) and fourth in amphibians (282) and higher plants (around 26,000) (Fig. 3). In

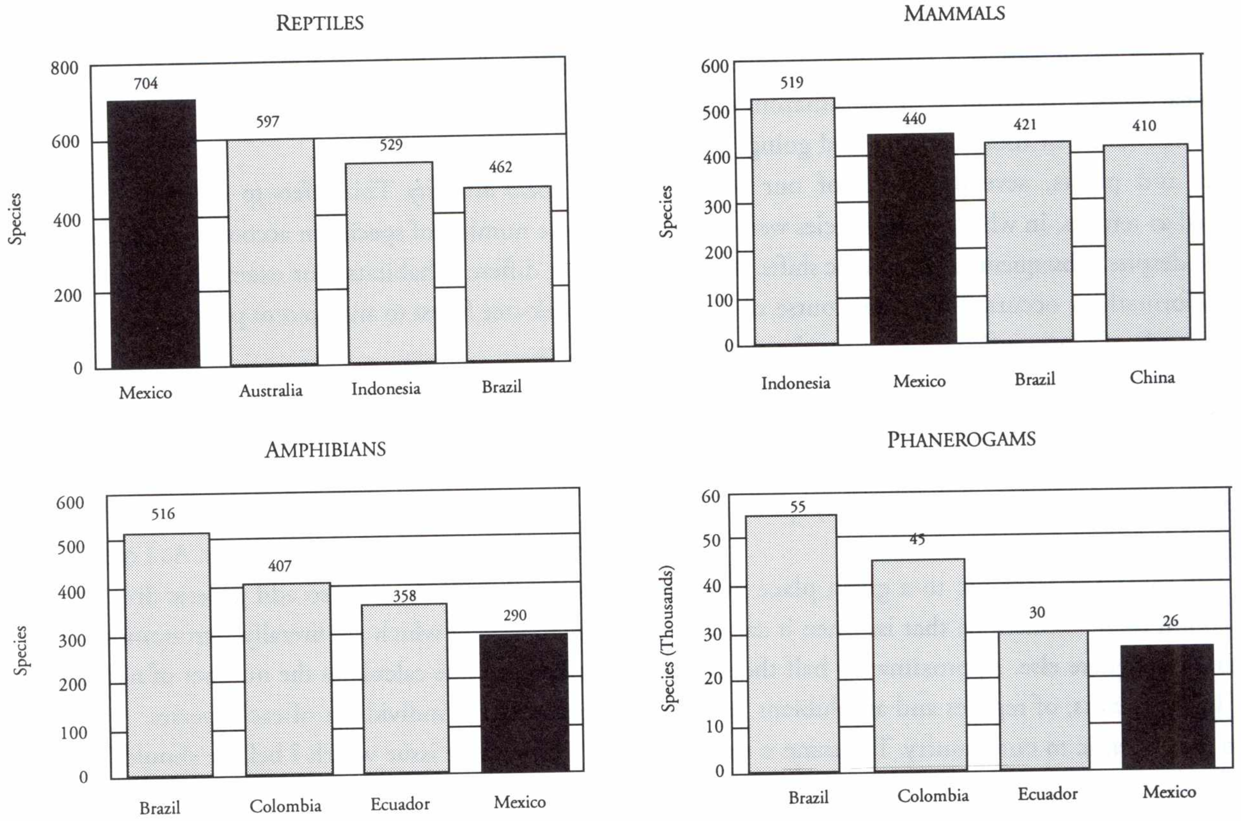


Fig.3 Number of species in Mexico and in other countries of high biological diversity. According to Mittermeier (1992); Arita & León (1993) and Flores (1993).

terms of insects, marine organisms, fungi and microorganisms, our lack of knowledge is such that there is no way to know what proportions of them may be found in our territory.

Practically all of the world's biomes may be found in Mexico. What is the cause of this great biological wealth? In reality there are many causes; I will sum up the most significant. One of the most important is our country's geographical (latitudinal) location. Mexico is situated between the boreal and tropical regions, thereby constituting a sort of hybrid of these two great areas, as a result of which it shares many species with them. Our proximity to the Caribbean has also allowed for the development, in Mexico, of many species typical of that zone.

Another extremely important cause is the country's geological history, which means that it possesses regions of very diverse ages and a great variety of geological substrates. In addition there is an extremely varied topography dominated by the rugged mountain ranges criss-crossing the country, with the exception of the broad coastal plain of the Gulf of Mexico and the Yucatán peninsula.

The latitude at which Mexico is located, its extensive coasts and topography make possible an extraordinary variety of macro- and microclimates. These range from Mediterranean to humid tropical climates; from the hottest deserts to frigid tundra, with all types of temperate climates in between. Each ravine in our mountains may have its own particular microclimate.

As a bridge between the boreal and tropical zones, Mexico has also served as the end point or stopping place for many migrations, as a result of great climatic changes that occurred over the course of different geological epochs. In the most recent of these changes, during the glacial periods of the Pleistocene, many species from the northern region migrated southwards and settled in our territory. When glaciation came to an end and temperatures rose, many tropical species (originating in the Amazon) migrated northwards. In these comings and goings of animals and plants, several regions of our territory served as refuges, in which many species were able to settle despite subsequent large climatic shifts. All these transformations occurred over the course of tens of thousands of years, sufficient time for the evolution, within these refuges, of species different from the original ones. This was a decisive factor in the existence, in our country, of an enormous number of species of flora and fauna, among them the many species found only in Mexico.

A species is endemic to a given place when it is found there exclusively; that is, when it cannot be found anywhere else. Approximately half the species of higher plants, of reptiles and amphibians in Mexico are endemic to our country. The same is true of a third of the mammals.

Foreign as well as domestic researchers and institutions have made important efforts with the objective of learning more about Mexico's flora and fauna, but very much remains to be done in terms of gathering information on this country's biota, given that —apart from land vertebrates— most animal and vegetable groups are still known only to a limited extent.

Since 1929, UNAM has played a central role in the pursuit of knowledge regarding the flora and fauna of Mexico. As the nation's trustee for scientific collections of animals and plants, in the past as well as the present it has had the country's largest body of personnel devoted to taxonomic and systems research. The Institute of Biology in particular, but also the Institute of Sea Sciences and Limnology, the Faculty of Sciences and the Ecology Center, carry out the work of exploration, collection and systematization of animals and plants, as well as research on their biology and ecology.

Levels at which biological diversity is measured

Biologists measure biological diversity at various "levels":

Alpha diversity. This corresponds simply to the number of species from the same group (spiders, for instance) found in a given place, let us say within ten hectares of oak-tree forest.

Beta diversity. This refers to the rate of increase in the number of species in accordance with samples from different habitats. For example, in going from an oak-tree forest to an adjacent prairie, to a pine forest, etc.

Gamma diversity. This is the total number of species present in a large region, for example Mexico as a whole.

These are what we might call the "orthodox" divisions in the study of biodiversity. As I mentioned previously, one should also add genetic diversity, the dimensions of which are literally astronomical, especially when one calculates the number of nucleotides present in the individuals of each species.

One more issue which I believe should be taken into consideration, even though it has to do with a situation which is not uniquely and directly a result of organic evolution, is the *cultural diversity* of man. This strikes me as quite relevant since, at least in principle, it is intimately linked to the biological diversity, in the strict sense, to which I have referred in this article. In fact, the fundamental substrate for the wealth of human cultures is their relation to the environment in which they develop, in particular the elements of flora and fauna, and physical milieu, which affect them. Along these lines, it is not surprising that many of the richest and most varied ancient cultures and civilizations originated in regions with a high degree of biological diversity. Examples include the civilizations of China, India and Southeast Asia, as well as those of Mesoamerica —in particular the Olmecs and Mayas. All of them include a very particular philosophy regarding the natural environment, based on a deep knowledge of and respect for nature. One must, of course, point out that the civilizations that arose in the Mediterranean area do not conform to this schema.

A direct result of such interactions between society and biological resources is the "invention" of

The Mesoamerican region is characterized by colossal biological wealth.

cultivated plants and the parallel development of a technological culture: agri*culture*. The Mesoamerican region, characterized by colossal biological wealth, provides an enormous variety of cultivated plants which currently feed millions of human beings. Examples include the many varieties of corn, beans, squash, chiles, avocados, tomatoes, cacao, tobacco and vanilla.

The quantity of knowledge acquired regarding fauna and, in particular, flora in this region is paralleled only in India, China and parts of Southeast Asia. Mexico's Indian peoples know and use an enormous variety of plants for different purposes, especially those related to food and medicine. It is estimated that around 25 percent of Mexico's higher plant species are used in some way (Table 1). Mexican herbal medicine is one of the richest in the world — a world in which, according to the World Health Organization, 85 percent of the population still makes use of medicinal plants. Nevertheless, the enormous wealth of knowledge possessed by our country's indigenous ethnic groups is, like many of the nation's plants, in danger of disappearing due to the intense processes of "aculturization" all these groups are experiencing, among other reasons as a result of the shift to urban areas.

TABLE I
NUMBER OF SPECIES UTILIZED AND NAMES AMONG SOME INDIANS GROUPS IN MEXICO

Ethnic group	Species present	Species named and utilized
Tarahumaras (Chihuahua)	1,000	398
Seri (Sonora)	2,703	516
Nahuas and others (Veracruz)	8,500	1,597
Purhépecha (Michoacán)	500	230
Mayas (Yucatán)	1,936	909
Tzeltales (Chiapas)	10,000	1,040

Source: Caballero and Mapes, 1985.

How can we conserve our biological diversity?

Several mass extinctions have occurred in the paleontological history of our planet. We do not know the causes of these extinctions, with the possible exception of the one which took place about 65 million years ago and caused the disappearance of the dinosaurs and the beginning of the flourishing of mammals and birds. The cataclysm which produced that distinction seems to have consisted of a large celestial object crashing into a point in the north of what today is the Yucatán peninsula. Equivalent to an enormous nuclear explosion, the crash produced a crater approximately 200 kilometers in diameter, as well as an enormous quantity of dust which darkened the earth's atmosphere for a long period of time, drastically changing the world's climate and, consequently, the environmental conditions that had permitted the existence of these enormous reptiles.

The appearance on earth of hominids —our immediate ancestors— less than four million years ago coincides with the moment in which the greatest biological wealth was registered in the history of our planet. Man enters as the last actor in a great work of theater brimming with characters and history. Coincidentally, man also appears approximately at the mid-point of the period during which life will exist on this planet. That is, three or four billion years from now, our sun —the earth's only source of energy— will have become a red dwarf star and will later be extinguished; during this process life as we know it will have been extinguished.

Careful "harvesting" of a range of jungle products is one conservation strategy.

Despite their great richness, the species existing today represent no more than one percent of the total number of species that have existed over the course of this long, four-billion-year history. This is a revealing fact, since while it is true that in different conditions diverse groups of species have known natural rates of evolution and extinction, and that extinction is species' inevitable fate, which only a few succeed in evading for a longer period of time, it is also true that none of the extinction rates is as high as that which human beings are currently producing as a result of demographic growth, industrial activity and social development. If this process of extensive modification of natural ecosystems continues, man will be the cause of the most severe mass extinction in the more than four billion years of the earth's history.

Some may question the importance of losing perhaps half of the species that exist today; some may even think that the broad range of technologies which man generates will be the answer to the problems that could be posed for human life by an extinction of such a magnitude.

There are several reasons that should be sufficient cause for humanity taking firmer steps towards the conservation of our planet's extremely rich biological patrimony. Some of these reasons —those which can most easily be "sold" to man's utilitarian side— are economic in nature. For example, one can mention the great number of organisms —most of them plants, although there are some cases from the animal kingdom— which have been used by the pharmaceutical industry or are potential raw materials for making new medicines. This potential is particularly important now that the great multinational pharmaceutical companies have, once again, become interested in exploring the enormous wealth of flora that exists in tropical areas. Another example is the use of plants by the food industry, whose attention is primarily focused on the areas with the greatest wealth of flora. This is leaving aside the enormous reservoir of genetic variability present in the wild forms of many plants which are cultivated by man.

Some 250 000 species of higher plants exist, of which angiosperms (flowering plants) represent nearly 90%.

Other reasons which should also awaken society's interest have to do with the numerous "services" provided by natural ecosystems, although these are not so easily measured in economic terms. These "services" range from absorbing carbon monoxide from the atmosphere and converting into oxygen, thereby maintaining life —including our own— in the conditions prevailing on our planet, to the conservation of the water sources and hydraulic systems crucial to the existence of agricultural, urban and industrial areas. Who can calculate the economic value of individuals that make up populations which are associated and organized into an ecosystem responsible for the aforementioned "services"? Who can calculate the costs of a severe imbalance within an ecosystem caused by the extinction of key species, resulting in a reduction in the ability to absorb the run-off caused by rain and the drastic decrease in water supplies to a growing city which lacks possibilities for "importing" water?

Lastly, there are other reasons having nothing to do with economic criteria —at least not directly— but which are also important, in my opinion. These have to do with the psychological aspects of man and his spiritual development.

Primitive societies lived in intimate contact with an enormous number of life forms. While their members' minds could only partially confront the challenge this signified, they intensely sought to understand the parts of this world that were most relevant and of the most concern to them, fully conscious that correct behavior vis à vis this challenge led to life and well-being, while mistakes meant illness, hunger and death. This was a process, which might be described as implacable but natural, of the relationship between human beings and their environment. The mark of this process, carried out over tens or hundreds of thousands of years, could not be erased over the course of those few generations (basically two centuries) in which we have lived our modern, urban existence.

Is it too late to carry out concrete, effective actions aimed at protecting areas of special importance due to their biological wealth and/or the endemic species they contain? The answer is a categorical *no*. While it is true that the situation is critical in some respects and in some places, it is also true that in recent years a greater clarity and consciousness has arisen regarding these phenomena, which has led to some important steps towards at least reducing the rate of destruction or extinction of a large number of species. Hundreds of voices and organizations exert pressure on governments to take action in this field. Nevertheless, much clearly remains to be done and it is up to our generation and those that follow to keep up the struggle to save life as we know it on our planet.

Different ways of preserving species are applied in different countries. We may divide them into two groups which correspond to two major strategies, which are not mutually exclusive.

The first consists of maintaining individuals of species outside of their zone of origin (*ex situ*), sometimes in conditions of cryo-conservation (this is mainly the case with collections of seeds, embryos, tissues or organs); or of a few mature individuals in zoos, aquariums or botanical gardens. While there is quite a bit of experience with this form of conservation and it has proven effective in protecting some species in extreme danger of extinction, it clearly has very important limitations in terms of the ability to conserve a large number of individuals, species and —in particular— populations, communities and ecosystems which make up and give value to biological diversity.

A second strategy consists of preserving regions or portions thereof with one or several ecosystems which are important due to the large number of species they contain, the endemic nature of these species, or their ecological importance and the "services" they provide to the human community. This *in situ* conservation is obviously the most suitable and effective, and should be the easiest to carry out.

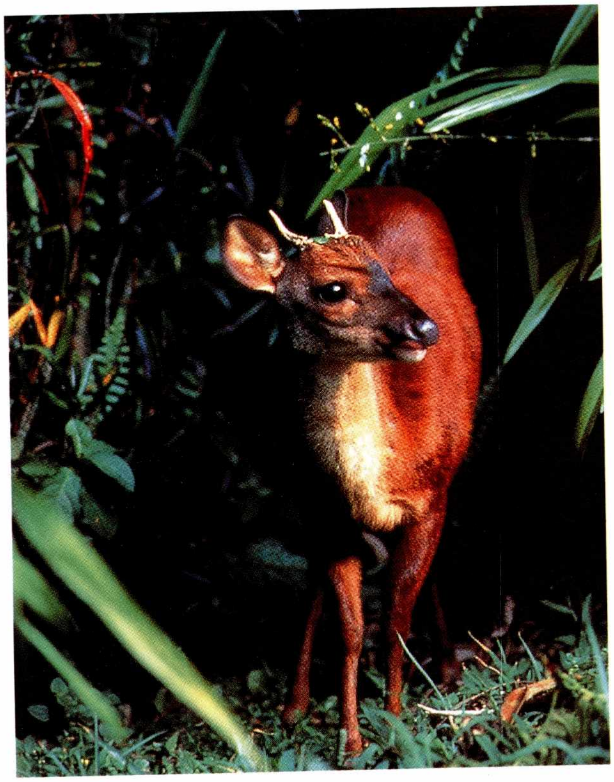
It will be much more difficult to replace the jungles or forests once they are disturbed.

Yet it frequently turns out to be more difficult to achieve, due to the many interests affecting the given regions. Less than 4.5 percent of the planet's land surface is protected by some kind of legal schema (as national parks, biosphere reserves, biological stations, etc.), and this small portion is divided into a multiplicity of small territories in constant danger of being modified.

Of course, maximum efforts would have to be devoted to this kind of protected area in order to seriously influence the conservation —and even the recovery— of biological diversity. While the purchase of large areas in order to protect them may be appealing as the most effective and direct course of action, it does not turn out to be the most suitable one even in the case of the developed countries which have the resources for doing this. In these countries, moreover, social pressure on such areas is relatively low and there are legal preservation mechanisms whose functioning is satisfactory. In the less economically developed countries, which possess most of the world's biological wealth, there is a high level of demographic pressure on the land as well as greater economic development needs. This strategy is therefore scarcely viable, if not impossible, in such countries.

Many ecologists working in the world's tropical areas believe —and I agree with them completely— that the best way to protect these zones is to find ways they can be exploited which provide economic support to the owners, conservation of the ecosystem —or at least the preservation of the community's arboreal structure— and protection of the soil's fertility. This is far from easy, but it will be much more difficult to replace the jungles or forests once they are disturbed, let alone to recover species which have disappeared.

Isolated examples of such efforts exist in various parts of the world, from the careful "harvesting" of a range of jungle products (butterflies, birds, rubber, plants for decoration, etc.) to jungle-cultivation efforts based on the ecosystem's natural process of regeneration. In my opinion, the main challenge facing such schemas —which are genuinely interesting even if they only point towards some of the ways in which an ecosystem can be conserved while economic benefit may be derived from it— is maintaining an ongoing, predictable market for the products that result from this conservationist effort. The big obstacle such production schemes face —and it may be an insurmount-



Different ways of preserving species are applied in different countries.

able one— is the fight against competition from an economy of free circulation of commodities, against the great industrial corporations which dominate markets and which have no interest whatsoever in this type of product or these forms of production, as well as against the fact that governments provide absolutely no fiscal or economic incentives for maintaining these production systems.

Until and unless a radical change of course makes it possible to overcome these obstacles, I believe that conservationist schemas for using ecosystems will be severely limited and will be unable to reproduce themselves in many other parts of the world. This is a well-defined area of action and responsibility for governments of countries, like our own, which possess this immensely important resource: biological diversity.

Humanity and biodiversity: An indissoluble relationship

Despite the enormous advance of science, modern societies have not fully understood that man is the product of a process of organic evolution which began approximately four billion years ago and that he therefore shares the elements of his characteristic genetic code with all beings presently living and those that have lived throughout all of those years. The nucleotides of our genes are imprinted, in some part, with a piece of the billions of histories lived by the species that came before us. In Edward O. Wilson's words, humanity has co-evolved with the rest of life on this planet; our genes do not bear the characteristics of other worlds.

The behavior, if not the conceptions, of most people demonstrate an attitude which would seem simply to erase that accumulation of years in which man lived with his environment, as if one had the right to take unlimited advantage of the planet in the same way as tourists do at a vacation spot.

It remains unknown whether the process of organic evolution that occurred on this planet (or a similar one) has taken place in other of the universe's astronomical objects. What is certain, in any case, is that the future of man on earth, and consequently in the universe, depends on him and him alone. No other species on earth, so far as we know, has emerged from the process of organic evolution with the power and ability that human beings have not only to under-

Cultivated plants currently feed millions of human beings.

Biological diversity has developed for billions of years.

stand the process which produced them but to modify it profoundly —whether through the incipient ability to create new species or the infinitely greater, demonstrated ability to exterminate them by profoundly changing the environment in which they develop. By abruptly modifying this process, which occurred over the course of billions of years, man takes into his own hands not only the future of the large number of species which have accompanied him in his evolution, but also, as I have already noted, his own future.

By putting into practice the ability to modify his environment in the way he has done, man threatens the very stage upon which he is but one more actor. Can there be a play without a stage, without a context, without other basic actors to support the role played by human beings in this performance?

Life on earth will not be extinguished until our sun is extinguished. No matter what atrocious calamity is unleashed by the actions of man —which could make the human species disappear or reduce it to conditions of social, cultural or physical impairment which today seem totally unacceptable and like something out of a science fiction movie— life, the process of biological variation subject to the forces of natural selection, to mutations, will continue and will take unpredictable paths, creating new forms and allowing for marvelous new adaptations to the environment of the future. So long as solar energy exists and it can be collected and transformed by organisms on earth, life on this planet —with *Homo sapiens* or without him— will not cease.

The spirit which distinguishes us from the rest of the earth's organisms originated on the same evolutionary stage on which biological diversity has developed for billions of years. To deny the imperious necessity of preserving this evolutionary stage is equivalent to denying the origin of that spirit.

The forces of natural selection will continue and will take unpredictable paths.

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The fundamental substrate for the wealth of human cultures is their relation to the environment.