Threats to Biodiversity

Habitat destruction, mostly in the tropics, is driving thousands of species each year to extinction. The consequences will be dire—unless the trend is reversed

by Edward O. Wilson

The human species came into being at the time of greatest biological diversity in the history of the earth. Today as human populations expand and alter the natural environment, they are reducing biological diversity to its lowest level since the end of the Mesozoic era, 65 million years ago. The ultimate consequences of this biological collision are beyond calculation and certain to be harmful. That, in essence, is the biodiversity crisis.

In one sense the loss of diversity is the most important process of environmental change. I say this because it is the only process that is wholly irreversible. Its consequences are also the least predictable, because the value of the earth's biota (the fauna and flora collectively) remains largely unstudied and unappreciated. Every country can be said to have three forms of wealth: material, cultural and biological. The first two we understand very well, because they are the substance of our everyday lives. Biological wealth is taken much less seriously. This is a serious strategic error, one that will be increasingly regretted as time passes. The biota is on the one hand part of a country's heritage, the product of millions of years of evolution centered on that place and hence as much a reason for national concern as the particularities of language and culture. On the other hand, it is a potential source for immense untapped material wealth in the form of food, medicine and other commercially important substances.

EDWARD O. WILSON was one of the first to call attention to the global decline in biological diversity and to sound the alarm on the consequences of its loss. His interest in living organisms, especially ants, stems back to his childhood, which was devoted to the exploration and collection of living things, and to his undergraduate studies in evolutionary biology at the University of Alabama. He received his Ph.D. in biology from Harvard University, where he is now Frank B. Baird, Jr., Professor of Science and Curator in Entomology. Wilson has made major contributions to a number of fields, including the behavior and evolution of social insects, chemical communication and the evolution of social behavior. He has been awarded the National Medal of Science, the Pulitzer Prize in general nonfiction for his book *On Human Nature* and the Tyler Prize for environmental achievement.

It is a remarkable fact, given the interdependence of human beings and the other species that inhabit the planet, that the task of studying biodiversity is still in an early stage. Although systematics is one of the two oldest formal disciplines of biology (the other is anatomy), we do not even know to the nearest order of magnitude the number of species of organisms on the earth. With the help of other specialists, I have estimated the number of species that have been formally described (given a Latinized scientific name) to be about 1.4 million. Even conservative guesses place the actual number of species at four million or greater, more than twice the number described to date.

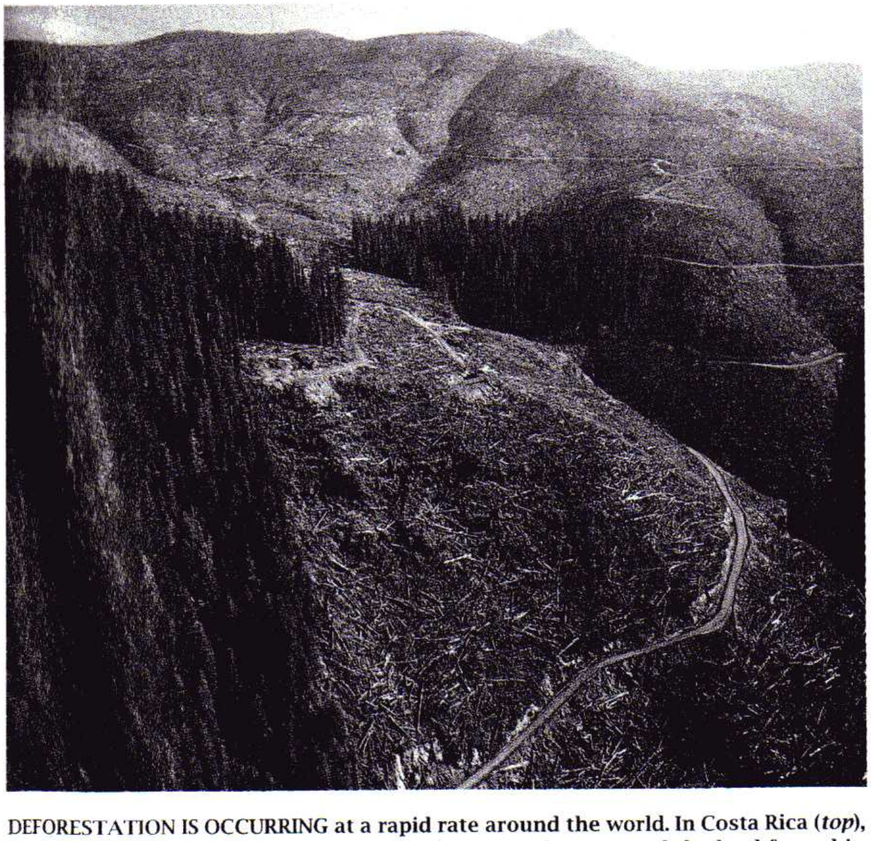
Terry L. Erwin of the Smithsonian's National Museum of Natural History believes the number of species to be even greater. With the help of co-workers, he applied an insecticidal fog to the forest canopy at localities in Brazil and Peru in order to obtain an estimate of the total number of insect and other arthropod species in this rich but still relatively unexplored habitat. By extrapolating his findings to moist tropical forests around the world and by including a rough estimate of the number of ground-dwelling species in his calculations, Erwin arrived at a global total of 30 million species. Even if this number proves to be a considerable overestimate, the amount of biodiversity in the world is certain to be projected sharply upward in other, compensatory ways.

Groups such as the mites and fungi, for example, are extremely rich and also very underexplored, and habitats such as the floors of the deep sea are thought to harbor hundreds of thousands of species, most of which remain undescribed. Even the number of bacterial species on the earth is expected to be many times greater than the 3,000 that have been characterized to date. To take one example, an entirely new flora of bacteria has recently been discovered living at depths of 350 meters or more beneath the ground near Hilton Head, South Carolina. Even new species of birds continue to turn up at an average rate of two per year.

Systematists are in wide agreement that whatever the absolute numbers, more than half of the species on the earth live in moist tropical forests, popularly referred to as rain forests. Occupying only 6 percent of the land surface, these ecosystems are found in warm areas where the rainfall is 200 centimeters or more per year, which allows broad-leaved evergreen trees to flourish. The trees typically sort into three or more horizontal layers, the canopy of the tallest being 30 meters (about 100 feet) or more from the ground. Together the tree crowns of the several layers admit little sunlight to the forest floor, inhibiting the development of undergrowth and leaving large spaces through which it is relatively easy to walk.

The belief that a majority of the

TROPICAL RAIN FORESTS, such as this one in northern Costa Rica, are among the most species-rich habitats on the earth. The enormous biological diversity found in these forests can be explained by the fact that the most species-rich groups on the planet, the invertebrates and flowering plants, are concentrated there. The vegetation, much of it broad-leaved evergreens, is extremely lush; the tallest trees tower as much as 30 meters (100 feet) above the rain-forest floor.



DEFORESTATION IS OCCURRING at a rapid rate around the world. In Costa Rica (*top*), as well as in parts of South America, rain forest is often cut and the land fenced in and converted to pasture. Unlike temperate forests, where nutrients accumulate in the soil, tropical forests typically have poor-quality soil. Consequently, within two or three years after being cleared, soil that once supported dense vegetation becomes too nutrient-poor to provide much grass for grazing cattle. In the U.S. (*bottom*), the impact of large-scale logging operations can be clearly seen in this photograph of a mountain range in the state of Washington. The scattered logs in the foreground are trees that have been cut and stripped of their branches and are waiting to be collected.

planet's species live in tropical rain-forest habitats is not based on an exact and comprehensive census but on the fact that the two overwhelmingly species-rich groups, the arthropods (especially insects) and the flowering plants, are concentrated there. Other extremely species-rich environments exist, including the coral reefs and abyssal plains of the oceans and the heathlands of South Africa and southwestern Australia, but these appear to be outranked substantially by the rain forests.

Every tropical biologist has stories of the prodigious variety in this one habitat type. From a single leguminous tree in Peru, I once retrieved 43 ant species belonging to 26 genera, approximately equal to the ant diversity of all of the British Isles. In 10 selected one-hectare plots in Kalimantan in Indonesia, Peter S. Ashton of Harvard University found more than 700 tree species, about equal to the number of tree species native to all North America. The current world record at this writing (certain to be broken) was established in 1988 by Alwyn H. Gentry of the Missouri Botanical Garden, who identified approximately 300 tree species in each of two one-hectare plots near Iquitos, Peru.

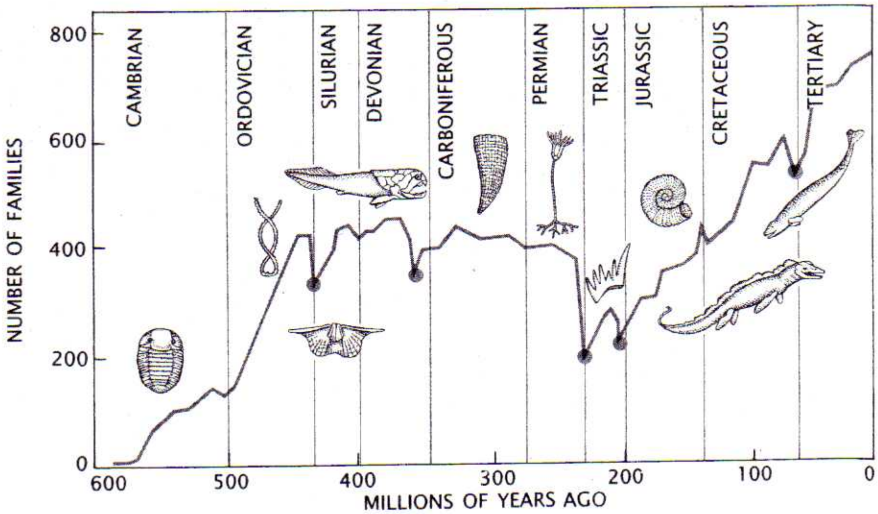
Why has life multiplied so prodigiously in a few limited places such as tropical forests and coral reefs? It was once widely believed that when large numbers of species coexist, their life cycles and food webs lock together in a way that makes the ecosystem more robust. This diversity-stability hypothesis has given way during the past 20 years to a reversed cause-and-effect scenario that might be called the stability-diversity hypothesis: fragile superstructures of species build up when the environment remains stable enough to support their evolution during long periods of time. Biologists now know that biotas, like houses of cards, can be brought tumbling down by relatively small perturbations in the physical environment. They are not robust at all.

The history of global diversity is reflected in the standing diversity of marine animals, the group best represented in the fossil record. The trajectory can be summarized as follows: after the initial "experimental" flowering of multicellular animals, there was a swift rise in species number in early Paleozoic times (some 600 million years ago), then plateaulike stagnation for the remaining 200 million years of the Paleozoic era and finally a slow but steady climb through the Mesozoic and Cenozoic eras to diversity's present all-time high [*see illustration at right*].

The overall impression gained from examining these and comparable sets of data for other groups of organisms is that biological diversity was hard won and a long time in coming. Furthermore, the procession of life was set back by five massive extinction episodes during the Ordovician, Devonian, Permian, Triassic and Cretaceous periods. The last of these is by far the most famous, because it ended the age of dinosaurs, conferred hegemony on the mammals and ultimately, for better or worse, made possible the origin of our own species. But the Cretaceous crisis was minor compared with the great Permian crash some 240 million years ago, which extinguished between 77 and 96 percent of all marine animal species. As David M. Raup of the University of Chicago has observed, "If these estimates are even reasonably accurate, global biology (for higher organisms, at least) had an extremely close call." It took five million years, well into Mesozoic times, for species diversity to begin a significant recovery.

What lessons can be drawn from these extinction episodes of the past? It is clear that recovery, given sufficient time, is sometimes possible. It is also true that in some cases new species can be created rapidly. A large minority of flowering-plant species have originated in a single generation by polyploidy—a multiplication of chromosome sets, either within a single individual or following the hybridization of two previously distinct species. Even geographic speciation, in which populations diverge genetically after being separated by a barrier such as a strait or desert, can in extreme cases lead to the evolution of new species in as few as from 10 to 100 generations. Hence, it might be argued that when a mass extinction occurs the deficit can be made up in a relatively short time. But under such circumstances pure *numbers* of species mean little. What matters more, in terms of the spread of genetic codes and the multiple ways of life they prescribe, is diversity at the higher taxonomic levels: the number of genera, families and so on.

A species is most interesting when its traits are sufficiently unique to warrant its placement in a distinct genus or even a higher-level taxon, such as a family. A concrete example helps to illustrate my point. In western China a new species of muntjac deer was recently discovered, which appears to differ from the typical muntjac of Asia only in chromosome number and in a few relatively minor anatomical traits. Human beings intuitively value this slightly differentiated species, of course, but not nearly so much as they value the giant panda, which is so distinctive as to be placed in its own genus (*Ailuropoda*) and family (Ailuropodidae).



BIOLOGICAL DIVERSITY has increased slowly over time, set back occasionally by mass extinctions. There have been five mass-extinction events so far: at the close of the Ordovician, Devonian, Permian, Triassic and Cretaceous periods, when the number of families of marine organisms declined by 12, 14, 52, 12 and 11 percent, respectively. The extinction event at the end of the Permian was by far the most severe; since then diversity has slowly increased to its present all-time high. It is now declining at an unprecedented rate, however, as a result of human activity.

Within the past 10,000 years biological diversity has entered a wholly new era in the turbulent history of life on the earth. Human activity has had a devastating effect on species diversity, and the rate of human-induced extinctions is accelerating. The heaviest pressure has hitherto been exerted on islands, lakes and other isolated and strongly circumscribed environments. Fully one half of the bird species of Polynesia have been eliminated through hunting and the destruction of native forests. In the 1800's most of the unique flora of trees and shrubs on St. Helena, a tiny island in the South Atlantic, was lost forever when the island was completely deforested. Hundreds of fish species that are endemic to Lake Victoria, formerly of great commercial value as food and aquarium fish, are now threatened with extinction as the result of the careless introduction of one species of fish, the Nile perch. The list of such biogeographic disasters is extensive.

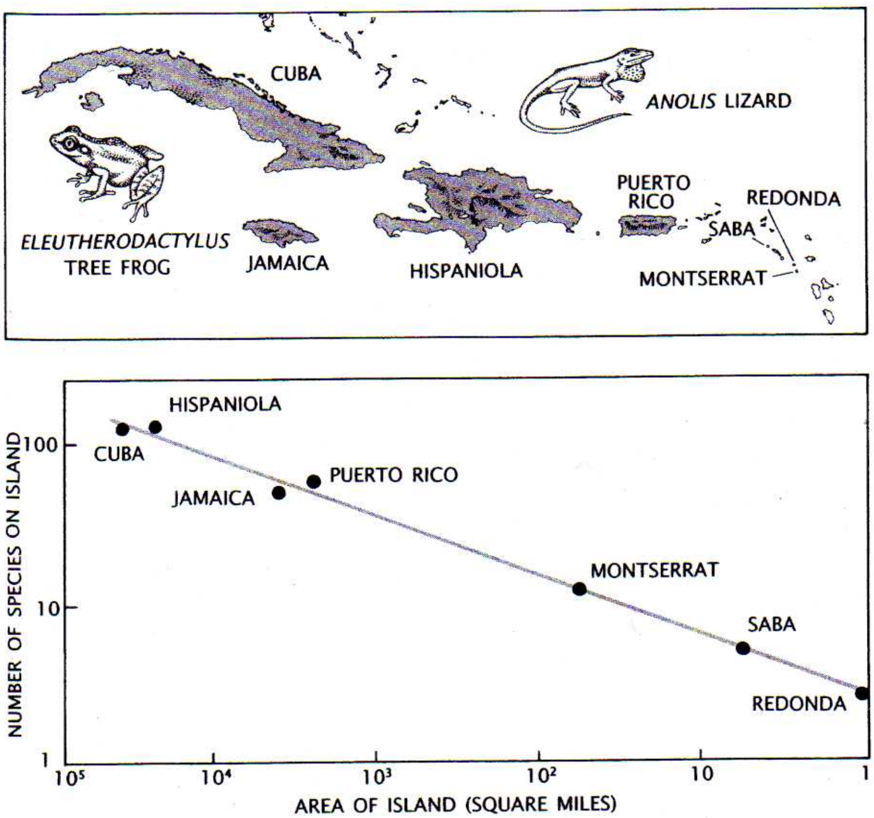
Serious as the episodes of pinpoint destruction are, they are minor compared with the species hecatomb caused by the clearing and burning of tropical rain forests. Already the forest has been reduced to approximately 55 percent of its original cover (as inferred from soil and climate profiles of the land surface), and it is being further reduced at a rate in excess of 100,000 square kilometers a year. This amount is 1 percent of the total cover, or more than the area of Switzerland and the Netherlands combined.

What is the effect of such habitat reduction on species diversity? In archipelago systems such as the West Indies and Polynesia, the number of species found on an individual island corresponds roughly to the island's area: the number of species usually increases with the size of the island, by somewhere between the fifth and the third root of the area. Many fall close to the central value of the fourth root. The same relation holds for "habitat islands," such as patches of forest surrounded by a sea of grassland. As a rough rule of thumb, a tenfold increase in area results in a doubling of the number of species. Put the other way, if the island area is diminished tenfold, the number of species will be cut in half.

The theory of island biogeography, which has been substantiated at least in broad outline by experimental alterations of island biotas and other field studies, holds that species number usually fluctuates around an equilibrium. The number remains more or less constant over time because the rate of immigration of new species to the island balances the extinction rate of species already there, and so diversity remains fairly constant. The relation between the theory of island biogeography and global diversity is an important one: if the area of a particular habitat, such as a patch of rain forest, is reduced by a given amount, the number of species living in it will subside to a new, lower equilibrium. The rich forest along the Atlantic coast of Brazil, for example, has been cleared to less than 1 percent of its original cover; even in the unlikely event that no more trees are cut, the forest biota can be expected to decline by perhaps 75 percent, or to one quarter of its original number of species.

I have conservatively estimated that on a worldwide basis the ultimate loss attributable to rain-forest clearing alone (at the present 1 percent rate) is from .2 to .3 percent of all species in the forests per year. Taking a very conservative figure of two million species confined to the forests, the global loss that results from deforestation could be as much as from 4,000 to 6,000 species a year. That in turn is on the order of 10,000 times greater than the naturally occurring background extinction rate that existed prior to the appearance of human beings.

Although the impact of habitat destruction is most severely felt in tropical rain forests, where species diversity is so high, it is also felt in other regions of the planet, particularly where extensive forest clearing is taking place. In the U.S. alone, some 60,000 acres of ancient forests are being cut per year, mostly for lumber that is then exported to Japan and other countries in the Pacific rim. Most severely affected are the national forests of the Pacific Northwest, from which some 5.5 billion board-feet of timber were harvested in 1987, and Alaska's Tongass National Forest, where as much as 50 percent of the most productive forestland has been logged since 1950. Although reforestation in these areas is possible, the process of regrowth may last 100 years or more.



NUMBER OF SPECIES on an island corresponds to its size. As a general rule, when the area of an island increases tenfold, the number of species on it doubles. This is easily demonstrated for an island archipelago, such as the West Indies (*top*), where there are numerous islands of different sizes. The numbers of species of reptiles and amphibians on five islands, including *Anolis* lizards and *Eleutherodactylus* tree frogs, were counted and the combined total plotted against the area of each island. As the curve shows (*bottom*), a large island, such as Cuba, has more than twice as many species as, say, the smaller island of Saba. These findings have important implications for conservation biology because the data can be used to predict species loss from habitat destruction and to determine the optimal size of wildlife preserves.

How long does it take, once a habitat is reduced or destroyed, for the species that live in it to actually become extinct? The rate of extinction depends on the size of the habitat patch left undisturbed and the group of organisms concerned. In one ingenious study, Jared M. Diamond of the University of California at Los Angeles and John W. Terborgh of Duke University counted the number of bird species on several continental-shelf islands, which until about 10,000 years ago had been part of the mainland but then became isolated when the sea level rose. By comparing the number of species per island with the number of species on the adjacent mainland, Diamond and Terborgh were able to estimate the number of species each island had lost and to correlate the rate of species loss with island size.

Their model has been reasonably well confirmed by empirical studies of local bird faunas, and the results are sobering: in patches of between one and 20 square kilometers, a common size for reserves and parks in the tropics and elsewhere, 20 percent or more of the species disappear within 50 years. Some of the birds vanish quickly. Others linger for a while as the "living dead." In regions where the natural habitat is highly fragmented, the rate of species loss is even greater.

These extinction rates are probably underestimates, because they are based on the assumption that the species are distributed more or less evenly throughout the forests being cut. But biological surveys indicate that large numbers of species are confined to very limited ranges; if the small fraction of the forest habitat occupied by a species is destroyed, the species is eliminated immediately. When a single ridge top in Peru was cleared recently, more than 90 plant species known only from that locality were lost forever.

Ecologists have begun to identify "hot spots" around the world—habitats that are rich in species and also in imminent danger of destruction. Norman Myers, an environmental consultant with wide experience in the tropics, has compiled a list of threatened rain-forest habitats from 10 places: the Chocó of western Colombia, the uplands of western Amazonia, the

SATELLITE IMAGE of the northern tip of Prince of Wales Island in Tongass National Forest, Alaska, shows the extent to which the region has been clear cut. Areas that have recently been cleared and are barren of tree cover are indicated in pink; those that have been cut but have started to recover are light green; areas where the forest has not yet been disturbed are dark green. The image covers about 400 square miles.

Atlantic coast of Brazil, Madagascar, the eastern Himalayas, the Philippines, Malaysia, northwestern Borneo, Queensland and New Caledonia. Other biologists have similarly classified certain temperate forest patches, heathlands, coral reefs, drainage systems and ancient lakes. One of the more surprising examples is Lake Baikal in Siberia, where large numbers of endemic crustaceans and other invertebrates are endangered by rising levels of pollution.

The world biota is trapped as though in a vise. On one side it is being swiftly reduced by deforestation. On the other it is threatened by climatic warming brought on by the greenhouse effect. Whereas habitat loss is most destructive to tropical biotas, climatic warming is expected to have a greater impact on the biotas of the cold temperate regions and polar regions. A poleward shift of climate at the rate of 100 kilometers or more per century, which is considered at least a possibility, would leave wildlife preserves and entire species ranges behind, and many kinds of plants and animals could not migrate fast enough to keep up.

The problem would be particularly acute for plants, which are relatively immobile and do not disperse as readily as animals. The Engelmann spruce, for example, has an estimated natural dispersal capacity of from one to 20 kilometers per century, so that massive new plantings would be required to sustain the size of the range it currently occupies. Margaret Davis and Catherine Zabinski of the University of Minnesota predict that in response to global warming four North American trees—yellow birch, sugar maple, beech and hemlock—will be displaced northward by from 500 to 1,000 kilometers. Hundreds of thousands of species are likely to be similarly displaced; how many will adapt to the changing climate, not having migrated, and how many will become extinct is, of course, unknown.

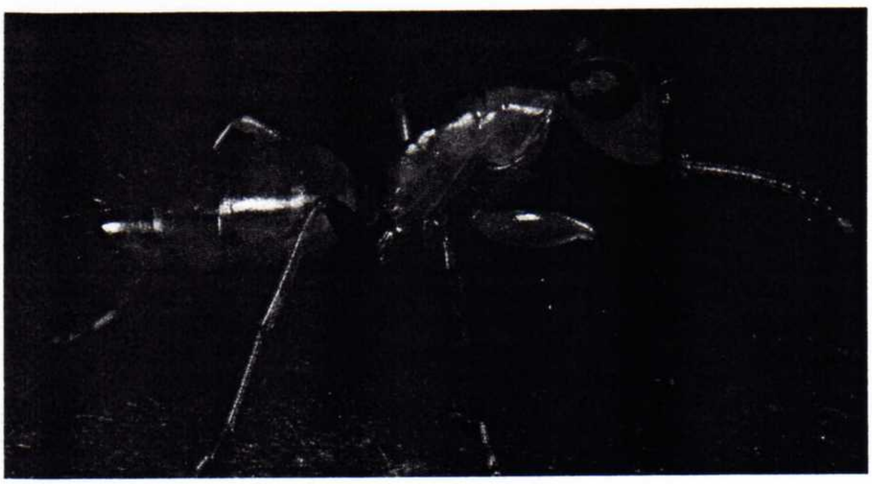
Virtually all ecologists, and I include myself among them, would argue that every species extinction diminishes humanity. Every microorganism, animal and plant contains on the order of from one million to 10 billion bits of information in its genetic code, hammered into existence by an astronomical number of mutations and episodes of natural selection over the course of thousands or millions of years of evolution. Biologists may eventually come to read the entire genetic codes of some individual strains of a few of the vanishing species, but I doubt that they can hope to measure, let alone replace, the natural species and the great array of genetic strains composing them. The power of evolution by natural selection may be too great even to conceive, let alone duplicate. Without diversity there can be no selection (either natural or artificial) for organisms adapted to a particular habitat that then undergoes change. Species diversity—the world's available gene pool—is one of our planet's most important and irreplaceable resources. No artificially selected genetic strain has, to my knowledge, ever outcompeted wild variants of the same species in the natural environment.

It would be naive to think that humanity need only wait while natural speciation refills the diversity void created by mass extinctions. Following the great Cretaceous extinction (the latest such episode), from five to 10 million years passed before diversity was restored to its original levels. As species are exterminated, largely as a result of habitat destruction, the capacity for natural genetic regeneration is greatly reduced. In Norman Myers's phrase, we are causing the death of birth.

Wild species in tropical forests and other natural habitats are among the most important resources available to humankind, and so far they are the least utilized. At present, less than one tenth of 1 percent of naturally occurring species are exploited by human beings, while the rest remain untested and fallow. In the course of history people have utilized about 7,000 plant species for food, but today they rely heavily on about 20 species, such as wheat, rye, millet and rice—plants for the most part that Neolithic man encountered haphazardly at the dawn of agriculture. Yet at least 75,000 plant species have edible parts, and at least some of them are demonstrably superior to crop species in prevalent use. For example, the winged bean, *Psophocarpus tetragonolobus*, which grows in New Guinea, has been called a one-species supermarket: the entire plant—roots, seeds, leaves, stems and flowers—is edible, and a coffeelike beverage can be made from its juice. It grows rapidly, reaching a height of 15 feet in a few weeks, and has a nutritional value equal to that of soybeans.

Wild plant and animal species also represent vast reservoirs of such potentially valuable products as fibers and petroleum substitutes. One example is the babassú palm, *Orbignya phalerata*, from the Amazon basin; a stand of 500 trees produces about 125 barrels of oil a year. Another striking example is the rosy periwinkle, *Catharanthus roseus*, an inconspicuous little plant that originated in Madagascar. It yields two alkaloids, vinblastine and vincristine, that are extremely

PLANTS FROM TROPICAL RAIN FORESTS are the source of food, medicine and other commercially valuable products. The rosy periwinkle, *Catharanthus roseus* (*left*), contains substances that are effective against some cancers, and the babassú palm, *Orbignya phalerata* (*right*), produces bunches of fruit (each one weighing about 200 pounds), from which oil (for cooking and other purposes) can be extracted.



INSECT DIVERSITY is extraordinarily high in tropical rain forests, where millions of species, including this ant from the island of Sulawesi in Indonesia, have yet to be inventoried. The ant, which is unusual for its large eyes and robotlike movements, belongs to the genus *Opisthopsis* but has not yet been given a species name.

effective against Hodgkin's disease and acute lymphocytic leukemia. The income from these two substances alone exceeds $100 million a year. Five other species of *Catharanthus* occur on Madagascar, none of which have been carefully studied. At this moment one of the five is close to extinction due to habitat destruction.

Biological diversity is eroding at a swift pace, and massive losses can be expected if present rates continue. Can steps be taken to slow the extinction process and eventually bring it to a halt? The answer is a guarded "yes." Both developed and developing (mostly tropical) countries need to expand their taxonomic inventories and reference libraries in order to map the world's species and identify hot spots for priority in conservation. At the same time, conservation must be closely coupled with economic development, especially in countries where poverty and high population densities threaten the last of the retreating wildlands. Biologists and economic planners now understand that merely setting aside reserves, without regard for the needs of the local population, is but a short-term solution to the biodiversity crisis.

Recent studies indicate that even with a limited knowledge of wild species and only a modest effort, more income can often be extracted from sustained harvesting of natural forest products than from clear-cutting for timber and agriculture. The irony of cutting down tropical forests in order to grow crops or graze cattle is that after two or three years the nutrient-poor topsoil can no longer support the agricultural activity for which it was cleared in the first place.

Thomas Eisner of Cornell University has suggested that in addition to the compilation of biological inventories, programs should be established to promote chemical prospecting around the world as part of the search for new products. The U.S. National Cancer Institute has begun to do just that: their natural products branch is currently screening some 10,000 substances a year for activity against cancer cells and the AIDS virus.

It has become equally clear that biological research must be tied to zoning and regional land-use planning designed not only to conserve and promote the use of wild species but also to make more efficient use of land previously converted to agriculture and monoculture timber. More efficient land use includes choosing commercial species well suited to local climatic and soil conditions, planting mixtures of species with yields higher than those of monocultures and rotating crops on a regular basis. These methods relieve pressure on natural lands without reducing their overall productivity. No less important are social studies and educational programs that focus directly on the needs of the people who live on the land.

I have enough faith in human nature to believe that when people are both economically secure and aware of the value of biological wealth they will take the necessary measures to protect their environment. Out of that commitment will grow new knowledge and an enrichment of the human spirit beyond our present imagination.

FURTHER READING

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