The Biological Diversity Crisis
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The Biological Diversity Crisis

Despite unprecedented extinction rates, the extent of biological diversity remains unmeasured

Edward O. Wilson

Certain measurements are crucial to our ordinary understanding of the universe. What, for example, is the mean diameter of Earth? 12,742 km. How many stars are there in the Milky Way? 10^{11}. How many genes in a small virus particle? 10 (in ϕX174 phage). What is the mass of an electron? 9.1×10^{-28} grams. How many species of organisms are there on Earth? We don't know, not even to the nearest order of magnitude.

Of course, the number of *described* species is so impressive that it might appear complete. The corollary would be that systematics is an old-fashioned science concerned mostly with routine tasks. In fact, about 1.7 million species have been formally named since Linnaeus inaugurated the binomial system in 1753. Some 440,000 are plants, including algae and fungi; 47,000 are vertebrates; and according to one meticulous estimate published in 1985 by R. H. Arnett, 751,012 are insects. The remainder are assorted invertebrates and microorganisms.

But these figures alone grossly underestimate the diversity of life on

The pool of diversity is a challenge to basic science and a vast reservoir of genetic information

Earth, and its true magnitude is still a mystery. In 1964 the British ecologist C. B. Williams, employing a combination of intensive local sampling and mathematical extrapolation, projected the number of insect species at three million (Williams 1964). During the next 20 years, systematists described several new complex faunas in relatively unexplored habitats such as the floor of the deep sea. They also began to use electrophoresis and ecological studies routinely, enabling them to detect many more sibling species. A few writers began to put the world's total as high as ten million species.

In 1982 the ante was again raised threefold by Terry L. Erwin (1983) of the National Museum of Natural History. He and other entomologists had developed a technique that for the first time allowed intensive sampling of the canopy of tropical rainforests. This layer of leaves and branches conducts most of the photosynthesis and is clearly rich in species. But it has been largely inaccessible because of its height (a hundred feet or more), the slick surface of the trunks, and the swarms of stinging ants and wasps that break forth at all levels. To overcome these difficulties, a projectile with a line attached is first shot over one of the upper branches. A canister containing an insecticide and swift-acting knockdown agent is then hauled up into the canopy, and the contents are released as a fog by radio command. As the insects and other arthropods fall out of the trees (the chemicals do not harm vertebrates), they are collected in sheets laid on the ground. The numbers of species proved to be far greater than previously suspected because of unusually restricted geographical ranges and high levels of specialization on different parts of the trees. Erwin extrapolated a possible total of 30 million insect species, mostly confined to the rainforest canopy.

If astronomers were to discover a new planet beyond Pluto, the news would make front pages around the world. Not so for the discovery that the living world is richer than earlier suspected, a fact of much greater import to humanity. Organic diversity has remained obscure among scientific problems for reasons having to do with both geography and the natural human affection for big organisms. The great majority of kinds of organisms everywhere in the world are not only tropical, but also inconspicuous invertebrates such as insects, crustaceans, mites, and nematodes. The mammals, birds, and flowering plants of the North Temperate Zone, on which natural history research and popular writing have largely focused, comprise relatively few species. In one aggregate of 25 acres of rainforest in Borneo, for example, about 700 spe-

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cies of trees were identified;[1] there are no more than 700 native tree species in all of North America. Familiarity with organisms close to home gives the false impression that the Linnaean period has indeed ended. But a brief look almost anywhere else (for example the Australian fauna illustrated in Figure 1) shows that the opposite is true.

Why does this lack of balance in knowledge matter? It might still be argued that to know one kind of beetle is to know them all, or at least enough to get by. But a species is not like a molecule in a cloud of molecules. It is a unique population of organisms, the terminus of a lineage that split off thousands or even millions of years ago. It has been hammered and shaped into its present form by mutations and natural selection, during which certain genetic combinations survived and reproduced differentially out of an almost inconceivably large number possible.

In a purely technical sense, each species of higher organism is richer in information than a Caravaggio painting, Bach fugue, or any other great work of art. Consider the typical case of the house mouse, *Mus musculus*. Each of its cells contains four strings of DNA, each of which comprises about a billion nucleotide pairs organized into a hundred thousand structural genes. If stretched out fully, the DNA would be roughly one 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 equaled that of a wrapping string to make it plainly visible, the fully extended molecule would be 600 miles long. As we traveled along its length, we would encounter some 20 nucleotide pairs to the inch. The full information contained therein, if translated into ordinary-sized printed letters, would just about fill all 15 editions of the *Encyclopaedia Britannica* published since 1768.

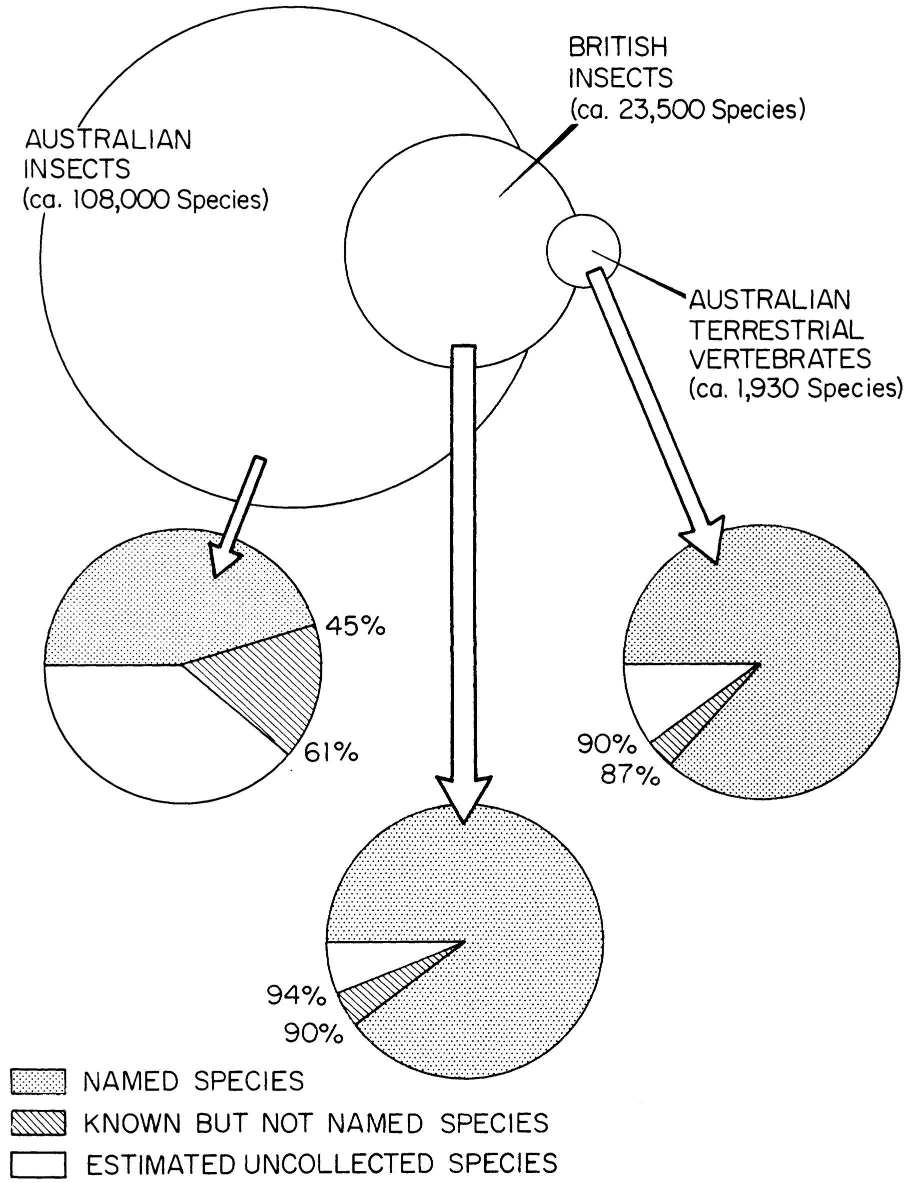
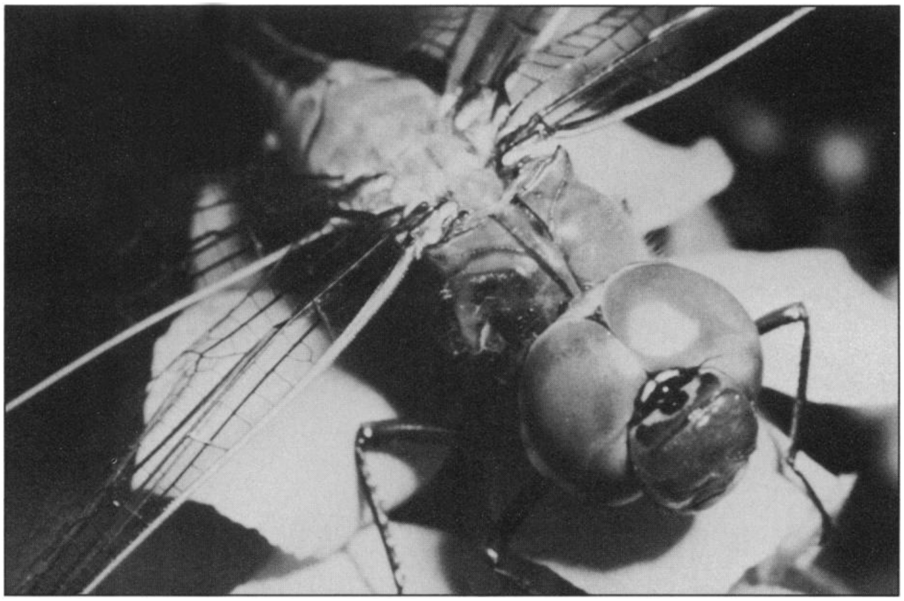


Figure 1. The status of research on diversity is illustrated in this comparison of the estimated sizes of Australian insect, British insect, and Australian terrestrial vertebrate faunas (top) and the levels of taxonomic knowledge about them. Modified from Taylor (1983).

Perhaps because organic diversity is so much greater and richer in history than previously imagined, it has proved difficult to express as a coherent subject of scientific inquiry. What *is* the central problem of systematics? Its practitioners, who by necessity limit themselves to small slices of the diversity, understand but seldom articulate a mission of the kind that enspirits particle physics or molecular genetics. For reasons that transcend the mere health of the discipline, the time has come to focus on such an effort. Indeed, if one considers other disciplines that depend directly upon systematics, including ecology, biogeography, and behavioral biology, an entire hierarchy of important problems present themselves.

But one problem stands out, for progress toward its solution is needed to put the other disciplines on a permanently solid basis. For taxonomy, the key question is the number of living species. How many exist in each major group from bacteria to mammals? Where is each found, and how does it differ from related species? I believe that we should aim at nothing less than a full count, a complete catalog of life on Earth. To attempt an absolute measure of diversity is a mission worthy of the best effort from science.

[1]Peter S. Ashton, 1985, personal communication. Arnold Arboretum, Harvard University.



Green dragonfly (family Libellulidae). Photo: Ronald Bork.

The magnitude and cause of biological diversity is not just the central problem of systematics; it is one of the key problems of science as a whole. It can be said that for a problem to be so ranked, its solution must promise to yield unexpected results, some of which are revolutionary in the sense that they resolve conflicts in current theory while opening productive new areas of research. In addition, the answers should influence a variety of related disciplines. They should affect our view of humanity's place in the order of things and open opportunities for the development of new technology of social importance. These several criteria are, of course, very difficult to attain, but I believe the diversity problem meets them all.

To this end, the problem can be restated as follows: If there are indeed 30 million species, why didn't 40 million evolve, or 2000, or a billion? Many ramifications spring from this ultimate Linnaean question. We would like to know whether something peculiar about the conformation of the planet or the mechanics of evolution itself led to the precise number that does exist. At the next level down, why is there an overwhelming preponderance of insect species on the land, but virtually none of these organisms in the sea? Hot spots of disproportionately high diversity of plants and animals occur within larger rainforests, and we need to know their contents and limits. Would it be possible to increase the diversity of natural systems artificially to levels above those in nature without destabilizing them? Only taxonomic analysis can initiate and guide research on these and related topics.

The relation of systematics research to other biological disciplines becomes clearer if one considers the way diversity is created. A local community of plants and animals, of the kind occupying a pond or offshore island, is dynamic in its composition. New colonists arrive as old residents die off. If enough time passes, the more persistent populations evolve into local endemic species. On islands as large as Cuba or Oahu, the endemics often split into two or more species able to live side by side. The total play of these forces (immigration, extinction, and evolution leading to species multiplication) determines the global amount of diversity. To understand each of the forces in turn is automatically to address the principal concerns of ecology, biogeography, and population genetics. Our current understanding of the forces is still only rudimentary. The science addressing them can be generously put at about the level of physics as it was in the late nineteenth century.

There is in addition a compelling practical argument for attempting a complete survey of diversity. Only a tiny fraction of species with potential economic importance has been used (Myers 1983, Oldfield 1984). A far larger number, tens of thousands of plants and millions of animals, have never even been studied well enough to assess their potential. Throughout history, for example, a total of 7000 kinds of plants have been grown or collected as food. Of these, 20 species supply 90% of the world's food and just 3—wheat, maize, and rice—constitute about half. In most parts of the world, this thin reservoir of diversity is sown in monocultures particularly sensitive to insect attacks and disease. Yet waiting in the wings are tens of thousands of edible species, many demonstrably superior to those already in use.

The case of natural sweeteners serves as a parable of untapped resource potential among wild species. A plant has been found in West Africa, the katemfe *(Thaumatococcus daniellii),* that produces proteins 1600 times sweeter than sucrose. A second West African plant, the serendipity berry *(Dioscoreophyllum cumminsii),* produces a substance 3000 times sweeter. The parable is the following: Where in the plant kingdom does the progression end? To cite a more clearly humanitarian example, one in ten plant species contains anticancer substances of variable potency, but relatively few have been bioassayed. Economists use the expression "opportunity costs" for losses incurred through certain choices made over others, including ignorance and inaction. For systematics, or more precisely the neglect of systematics and the biological research dependent upon it, the costs are very high.

Biological diversity, apart from our knowledge of it, is meanwhile in a state of crisis. Quite simply, it is declining. Environmental destruction, a worldwide phenomenon, is reducing the numbers of species and the amount of genetic variation within individual species. The loss is most intense in the tropical rainforests. In prehistoric times, these most species-rich of all terrestrial habitats covered an estimated 5 million square miles. Today they occupy 3.5 million square miles and are being cut down at an annual rate of 0.7%, that is, 25,000 square miles or an area the size of West Virginia. The effect this deforestation has on diversity can be approximated by the following rule of thumb in biogeography. When the area of a habitat is reduced to one-tenth, the number of species that can persist in it indefinitely will eventually decline to one-half. That much habitat reduction has already been passed in many parts of the tropics. The forests of Madagascar now occupy less than ten percent of their original cover, and the once teeming Brazilian Atlantic forests are down to under one percent. Even great wilderness areas are giving way. If present levels of deforestation continue, the stage will be set within a century for the inevitable loss of about 12% of the 700 bird species in the Amazon Basin and 15% of the plant species in South and Central America (Simberloff 1984).

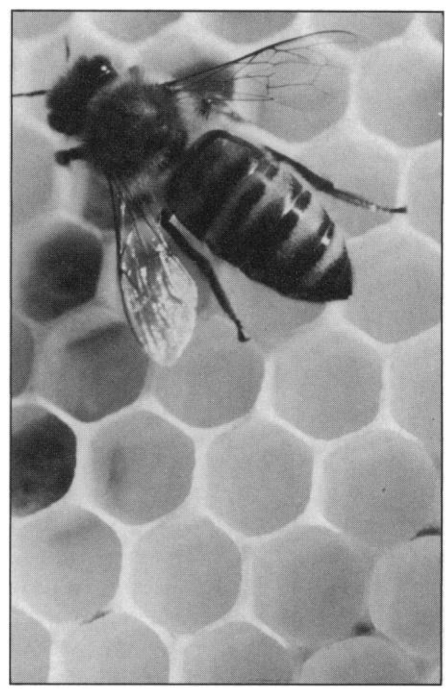
No comfort should be drawn from the spurious belief that because extinction is a natural process, humans are merely another Darwinian agent. The rate of extinction is now about 400 times that recorded through recent geological time and is accelerating rapidly. Under the best of conditions, the reduction 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 for 65 million years. And in at least one respect, this human-made hecatomb is worse than any time in the geological past. In the earlier mass extinctions, possibly caused by large meteorite strikes, most of the plant diversity survived; now, for the first time, it is being mostly destroyed (Knoll 1984).

A complete survey of life on Earth may appear to be a daunting task. But compared with what has been dared and achieved in high-energy physics, molecular genetics, and other branches of "big science," it is in the second or third rank. To handle ten million species even with the least efficient old-fashioned methods is an attainable goal. If one specialist proceeded at the cautious pace of an average of ten species per year, including collecting, curatorial work, taxonomic analysis, and publication, about one million person-years of work would be required. Given 40 years of productive life per scientist, the effort would consume 25,000 lifetimes. That is not an excessive investment on a global scale. The number of systematists worldwide would still represent less than ten percent of the current population of scientists working in the United States alone and fall short of the standing armed forces of Mongolia and the population of retirees in Jacksonville. Neither does information storage present an overwhelming problem, even when left wholly to conventional libraries. If each species were given a single double-columned page for the diagnostic taxonomic description, a figure, and brief biological characterization, and if the pages were bound into ordinary 1000-page, six-centimeter-wide hardcover volumes, the 10,000 or so final volumes of this ultimate catalog would fill 600 meters of library shelving. That much is far below the capacity of some existing libraries of evolutionary biology. The library of Harvard's Museum of Comparative Zoology, for example, occupies 4850 meters of shelving.

But I have given the worst scenario imaginable to establish the plausibility of the project. Systematic work can be speeded many times over by new procedures now coming into general use. The Statistical Analysis System (SAS), a set of computer programs currently running in over 4000 institutions worldwide, permits the recording of taxonomic identifications and localities of individual specimens and the automatic integration of data into catalogs and biogeographic maps (La Duke et al. 1984). Other computer-aided techniques rapidly compare species across large numbers of traits, applying unbiased measures of overall similarity, the procedure known as phenetics. Still others assist in sorting out the most likely patterns of phylogeny by which species split apart to create diversity, or cladistics. Scanning electron microscopy has speeded the illustration of insects and other small organisms and rendered descriptions more accurate. The DELTA system, developed and used at Australia's Commonwealth Scientific and Industrial Research Organization, codes data for the automatic identification of specimens (Dallwitz 1980, Taylor 1983). Elsewhere, research is being conducted that might lead to computerized image scanning for automatic description and data recording.

In North America, about 4000 systematists work on 3900 systematics collections (Edwards 1984 and personal communication). But a large fraction of these specialists, perhaps a majority, are engaged only part time in taxonomic research. More to the point, few can identify organisms from the tropics, where both the great majority of species exist and extinction is proceeding most rapidly. Probably no more than 1500 trained professional systematists in the world are competent to deal with tropical organisms. Their number may be declining from decreased professional opportunities, reduced funding for research, and assignment of higher priority to other disciplines (National Research Council 1980). To take one especially striking example, ants and termites make up about one-third of the animal biomass in tropical forests. They cycle a large part of the energy in all terrestrial habitats and include the foremost agricultural pests, which cause billions of dollars of damage yearly. Yet there are exactly eight entomologists worldwide with the general competence to identify tropical ants and termites, and only five of these are able to work at their specialty full time.

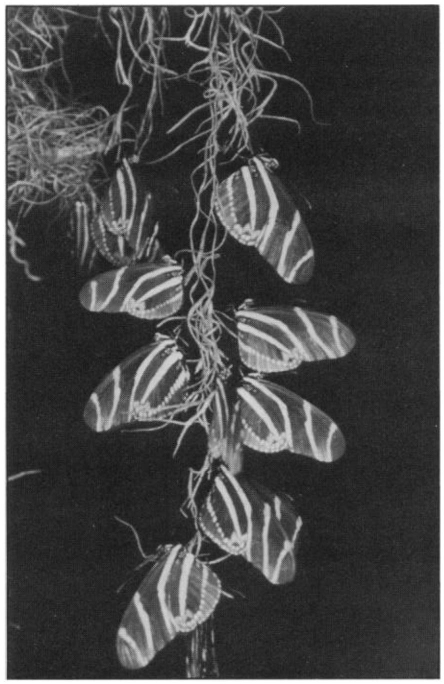
It is not surprising to find that the neglect of species diversity retards other forms of biological research. Every ecologist can tell of studies delayed or blocked by the lack



Honeybee *(Apis mellifera)*. Photo: R. Bork.

of taxonomic expertise. In one recent, typical case, William G. Eberhard consulted most of the small number of available (and overworked) authorities to identify South and Central American spiders used in a study of web-building behavior. He was able to obtain determinations of only 87 of the 213 species included, and then only after considerable delay. He notes that "there are some families (e.g., Pholcidae, Linyphiidae, Anyphaenidae) in which identifications even to genus of Neotropical species are often not possible, and apparently will not be until major taxonomic revisions are done. On a personal level, this has meant that I have refrained from working on some spiders (e.g., Pholcidae, one of the dominant groups of web spiders in a variety of forest habitats, at least in terms of numbers of individuals) because I can't get them satisfactorily identified."[2]

If systematics is an indispensable handmaiden of other branches of research, it is also a fountainhead of discoveries and new ideas, providing the remedy for what the biologist and philosopher William Morton Wheeler once called the dry rot of academic biology. Systematics has never been given enough credit for this second, vital role. Every time I walk into a fresh habitat, whether tropical forest, grassland, or desert, I become quickly aware of the potential created by a knowledge of classification. If biologists can identify only a limited number of species, they are likely to gravitate toward them and end up on well-trodden ground; the rest of the species remain a confusing jumble. But if they are well trained in the classification of the organisms encountered, the opportunities multiply. The known facts of natural history become an open book, patterns of adaptation fall into place, and previously unknown phenomena offer themselves conspicuously. By proceeding in this opportunistic fashion, a biologist might strike a new form of animal communication, a previously unsuspected mode of root symbiosis, or a relation between certain species that permits a definitive test of competition theory. The irony is that successful research then gets labeled as ecology, physiology, or almost anything else but its *fons et origo,* the study of diversity.



Nocturnal roosting aggregation of zebra butterflies *(Heliconius charitonius)* in Florida. Photo: James L. Castner.

Systematics is linked in such a manner not only to the remainder of biology but to the fortunes of the international conservation movement, which is now focusing its attention on the threatened environments of the tropics. Plans for systems of ecological reserves have been laid by the International Union for Conservation of Nature and Natural Resources (IUCN), UNESCO, and a growing number of national governments from Australia and Sri Lanka to Brazil and Costa Rica. The aim is to hold on to as many species as possible within the limits imposed by population pressures and the cost of land purchase. The long-term effects of this enterprise can only be crudely predicted until systematics surveys are completed, country by country. In the United States a proposal for a National Biological Survey (NABIS) has been presented to Congress [see p. 686]. The program would establish a survey to describe all the plants and animals, fund basic taxonomic studies to this end, and produce identification manuals, catalogs, and other practical aids (Kosztarab 1984). If multiplied across many countries, such efforts could bring the full assessment of biological diversity within reach.

Systematics surveys are cost-efficient and provide large proportionate yields with small absolute increments in support. In fiscal 1985, the National Museum of Natural History, the largest organization of its kind in the United States, spent $12.8 million to support 85 scientists engaged partly or wholly in taxonomic studies. In the same year, the Program in Systematic Biology of the National Science Foundation granted $12 million for basic taxonomic research, while other programs in the NSF and Department of Interior provided $13.8 million for support of museum services, studies of endangered species, and other activities related to systematics. The worldwide support for basic tropical biology, including systematics and ecology, is only about $50 million. Just 1000 annual grants of $50,000 devoted to tropical organisms would double the level of support and revitalize the field. To illustrate the difference in scale, the same amount added to the approximately $3.5 billion spent on health-related biology in the United States would constitute an increment of 1.4%, causing a barely detectable change.

In case such an investment, which approximately equals the lifetime cost of one F15 Eagle fighter-bomber, might seem removed from the immediate interests of the United States, let me close with an observation on the importance of biological research to foreign policy. The problems of Third World countries, most of which are in the tropics, are primarily biological. They include excessive population growth, depletion of soil nutrients, deforestation, and the decline of genetic diversity in crop and forest reserves. It is no coincidence that Haiti and El Salvador, which force themselves on our attention at such frequent intervals, are the most densely populated and environmentally degraded countries in the Western Hemisphere, rivaled only by Grenada (another trouble spot) and three other small Caribbean island-nations. Virtually all reports on the subject released by the National Research Council and Office of Technology Assessment during the past ten years agree that the intricate economic and

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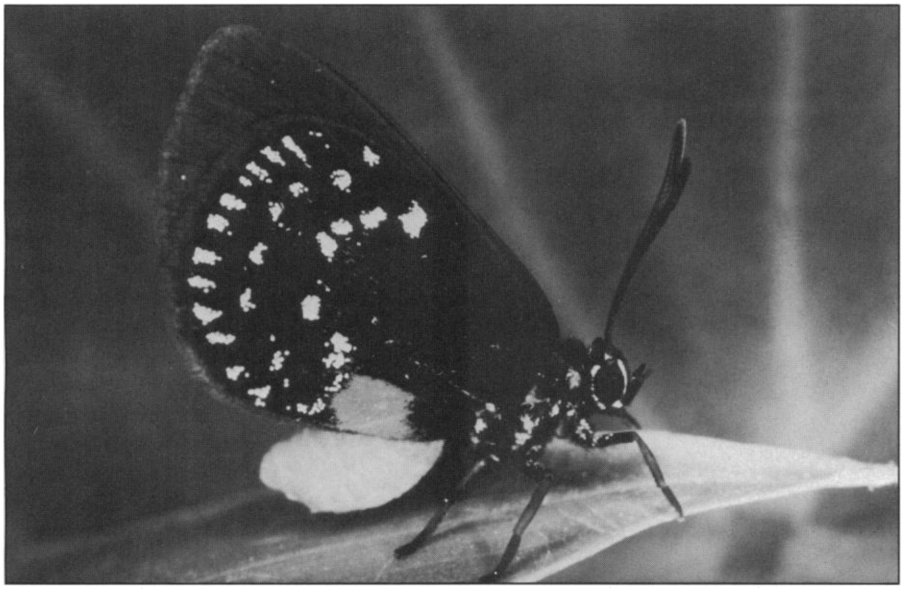
[2]Letter from W. G. Eberhard, 1985. Universidad de Costa Rica, Ciudad Universitaria.



Florida atala *(Eumaeus atala)*. Photo: J. L. Castner.

social problems of tropical countries cannot be solved without a more detailed knowledge of the environment. Increasingly, that must include a detailed account of native faunas and floras.

Congress has addressed this problem in limited degree through the 1980 amendment to the Foreign Assistance Act, which mandates that programs funded through the Agency for International Development include an assessment of environmental impact. In implementing this policy, AID recognizes 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" (Department of State memorandum 1985).

Moving further, AID set up an Interagency Task Force in 1985 to consider biological diversity as a comprehensive issue. In its report to Congress, *US Strategy on the Conservation of Biological Diversity* (AID 1985), the task force evaluated the current activities of the dozen federal agencies that have been concerned with diversity, including the Smithsonian Institution, the Environmental Protection Agency, and AID itself. The most important recommendations made by the group, in my opinion, are those that call for the primary inventory and assessment of native faunas and floras. In fact, not much else can be accomplished without this detailed information.

AID also supports research programs in which nationals of the recipient countries are principal investigators, and US citizens serve as collaborators. This arrangement is a proven way to build science and technology in the Third World and is particularly well suited to tropical biology. Studies of diversity are best conducted at sites of maximum diversity. They are labor-intensive and require less expensive instrumentation than most kinds of research. Perhaps most important, their relevance to national identity and welfare are immediately obvious.

To put the matter as concisely as possible, biological diversity is unique in the evenness of its importance to both developed and developing countries and in the cost-effectiveness of its study. The United States would do well to seek a formal international agreement among countries, possibly in the form of an International Decade for the Study of Life on Earth, to improve financial support and access to study sites. To spread technical capability where it is most needed, arrangements can be made to retain specimens within the countries of their origin while training nationals to assume leadership in systematics and the related scientific disciplines.

In *Physics and Philosophy,* Werner Heisenberg suggested that science is the best way to establish links with other cultures because it is concerned not with ideology but with nature and humanity's relation to nature. If that promise can ever be met, it will surely be in an international effort to understand and save biological diversity. This being the only living world we are ever likely to know, let us join to make the most of it.

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Leaf-mimicking mantid *(Choerododid rhombicollis)*, Panama. Photo: J. L. Castner.

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References cited

Agency for International Development (AID). 1985. *US Strategy on the Conservation of Biological Diversity: An Interagency Task Force Report to Congress.* Washington, DC.

Arnett, R. H., Jr. 1985. *American Insects.* Van Nostrand Reinhold, New York.

Dallwitz, M. J. 1980. A general system for coding taxonomic descriptions. *Taxon* 29: 41–46.

Edwards, S. R. 1984. The systematics community: priorities for the next decade. *ASC Newsletter* (Association of Systematics Collections) 12(5): 37–40.

Erwin, T. L. 1983. Beetles and other insects of tropical forest canopies at Manaus, Brazil, sampled by insecticidal fogging. Pages 59–75 in S. L. Sutton, T. C. Whitmore, and A. C. Chadwick, eds. *Tropical Rain Forest: Ecology and Management.* Blackwell Scientific Publications, Edinburgh, UK.

Knoll, A. H. 1984. Patterns of extinction in the fossil record of vascular plants. Pages 21–68 in M. H. Nitecki, ed. *Extinctions.* University of Chicago Press, Chicago.

Kosztarab, M. 1984. A biological survey of the United States. *Science* 223: 443.

La Duke, J. C., D. Lank, and T. Sirek. 1984. Utilization of statistical analysis systems (SAS) as a revisionary tool and cataloguing program. *ASC Newsletter* 12(2): 13–14.

Myers, N. 1983. *A Wealth of Wild Species.* Westview Press, Boulder, CO.

National Research Council (NRC). 1980. *Research Priorities in Tropical Biology.* National Academy of Sciences, Washington, DC.

Oldfield, M. L. 1984. *The Value of Conserving Genetic Resources.* US Department of the Interior, Washington, DC.

Simberloff, D. S. 1984. Mass extinction and the destruction of moist tropical forests. *Zh. Obshch. Biol.* 45: 767–778.

Taylor, R. W. 1983. Descriptive taxonomy: past, present, and future. In E. Highley and R. W. Taylor, eds. *Australian Systematic Entomology: A Bicentenary Perspective.* Commonwealth Scientific and Industrial Research Organization, Melbourne.

US Department of State. 1985. Humid tropical forests: AID policy and program guidance. Memorandum. Washington, DC.

Williams, C. B. 1964. *Patterns in the Balance of Nature.* Academic Press, New York.

Juvenile Australian katydid (family Tettigoniidae), Seaforth, New South Wales, Australia. Photo: Art Daniel.