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Biodiversity: The World of Life

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BIBLIOGRAPHIC ESSAY

The World of Life: Biodiversity Studies

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Introduction

What is biodiversity?

For some 15 years the public has witnessed a sustained worldwide movement that concerns itself with understanding the natural diversity of life, and how such diversity can be conserved. The word "biodiversity" itself (short for "biological diversity") is a recently coined term that has been in common use only during that period; nevertheless, the crisis that surrounds the subject has quickly made it one of the most frequently discussed topics in the natural and applied sciences. So what is this "biodiversity," and why do its defenders argue that its investigation should become a major human priority?

The definition part of this question is the subject of a recent piece (in *Biodiversity II*, ed. by M. Reaka-Kudla et al.) from one of the movement's primary figures, Harvard zoologist Edward O. Wilson:

> So what is it? Biologists are inclined to agree that it is, in one sense, everything. Biodiversity is defined as all hereditarily based variation at all levels of organization, from genes within a single local population or species, to the species composing all or part of a local community, and finally to the communities themselves that compose the living parts of the multifarious ecosystems of the world. The key to effective analysis of biodiversity is the precise definition of each level of organization when it is being addressed.

This definition may strike some observers as being just the slightest bit vague, at least to the extent that it fails to explain how the concept is related to the various natural studies that make it up, and that in fact have existed as independently conceived lines of research for more than a century in several cases. In *Biodiversity: A Reference Handbook*, author Anne Becher has recognized three basic components to biological diversity: genetic, taxonomic (species), and ecological, but while this division serves a categorical purpose, it may first be more helpful to distinguish between "biodiversity itself," and what may be termed "biodiversity studies." The latter we can recognize as the array of research approaches that have come together to study the phenomena of natural diversity and its conservation. As Wilson notes on the first page of the same essay quoted above, ". . . what finally has given it such widespread attention is the realization that it is disappearing." More than this, however, only by the mid-1980s was it realized that significant loss of biodiversity might have serious worldwide ethical, economic, and even survival ramifications. At that point, the state of the planet's biodiversity became more than just a matter of natural science alone, it became an identifiable worldwide crisis.

As a result, we can now speak in rather separate terms of biodiversity itself, and the agenda of the movement that has taken up the study of the biodiversity crisis. This separation of concepts is particularly important in the present context, because the literature on the former, concerned as it is with the basic description of millions of species of animals and plants—not to mention suborganismal levels of organization and communities, ecosystems, and the biosphere as a whole—would exist (and did exist) independent of the recent biodiversity movement. Practically every state in the nation is represented by at least one monographic study of its resident mammals, as are many individual species of mammals (and even particular mammals from particular states!). The real gist of the biodiversity movement, however, is the effort to relate the details of such diversity to its various levels of manifestation, and especially to our capacity for managing it globally in a sustainable fashion.

The natural science part of biodiversity studies thus is concerned with systematic study of the causes of observed diversity patterns. Such causes may have predominantly geographical, morphological, historical, ecological, or anthropogenic components, or any combination of these. Related discoveries are sometimes extraordinary and have the most profound implications; for example, on the basis of a long series of paleontological investigations it now seems reasonable to conclude that every so many years a mountain-sized chunk of rock has hit the earth, each time obliterating a substantial percentage of the species living on it. How society is to deal with this and many other less traumatic realities of related type is ultimately a social problem, and herein lies the rationale for a social science of biodiversity. Loosely speaking, the main concerns involved are applied, conservation-oriented ones, but the arguments extend far beyond conservation for conservation's sake.

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Why should we care?

A very good question, at least for those who have not already committed themselves to an involvement with the movement. Several main reasons can be given:

(1) *Aesthetic grounds.* Since at least the middle of the 19th century there have been those who have argued that to diminish the grandeur of our natural surroundings is to invite a cheapening of the human experience. As diversity in its various other senses has always appeared to be connected with the maintenance of a healthy human society, this argument is hard to dismiss—whether one looks at the question *purely* in terms of æsthetics, or in a more applied sense focussing on various aspects of human education, recreation, and industry.

(2) *Moral and ethical grounds.* The argument as to aesthetics can be taken one step further to embrace moral and ethical rationales. Some plead directly for the rights of animals, plants, or communities, or secondarily, in defending the notion that human beings have evolved into the planet's caretakers, and that it is a responsibility both to ourselves and the rest of the biosphere to contribute intelligently to its management and maintenance.

(3) *Economic grounds.* The most cogent practical arguments for conserving biodiversity concern the state of the human pocketbook and our aspirations for a sustainable economy. The costs of ignoring biodiversity depletion are numerous, and are still being identified and elucidated. Inevitably, however, we can be sure that biodiversity loss equals lost capital, since every aspect of our existence as physical beings is affected by it at one level or another.

(4) *Survival grounds.* As pointed out above, the search to uncover the full range of forces that have conspired to produce the biodiversity we now witness may yield unpredictable findings, up to and including the revelation that we may still be prone to cosmic collisions capable of destroying the entire biosphere. Less dramatic (but perhaps equally fatal) scenarios involving, e.g., destruction of the ozone layer or global overwarming are also imaginable; such concerns may seem remote to many observers, but inasmuch as the best scientific advice suggests that monumental dangers could be involved, we would be well advised as a society to continue looking into such possibilities and how they might be treated should they actually take place.

Bibliographic Control

In considering the concept of bibliographic control on biodiversity-related studies, it should first be reiterated that there is a vast amount of subject material. The literature of "biodiversity itself" has classically been arranged in library and other collections to mirror general systematic understandings of the organisms and community/ecosystem types involved, e.g., according to protozoans, birds, or wetlands. But biodiversity *studies* have no such logical association in our collections. To be sure, a "biological diversity" subject heading has been established by the Library of Congress, and many of those items that concern the subject *in general* may be found under QH 75, but this heading actually contains but a minuscule percentage of the entire related literature. To find the rest requires poring over the materials under subject headings as diverse as agroecology, bioethics, botany, ecology, forestry, environmental law, environmental economics, ethnobotany, endangered species, ecotourism, genetics, microbiology, and zoology.

The scattered nature of the topics involved in biodiversity studies in turn makes it difficult to produce reference materials covering the subject. As of this writing, there is no dictionary of biodiversity, no (comprehensive) atlas of biodiversity, no directory related specifically to biodiversity studies, no yearbook or almanac of biodiversity research, and no indexing or abstracting service specially devoted to the biodiversity-related serial literature. The first comprehensive bibliography on the subject to appear was this writer's *Biodiversity Studies: A Bibliographic Review*, published in early 2000. Becher's introductory handbook, written primarily for a college freshman readership level, was published in 1998 (and is now available as an online resource), but there is still no all-purpose professional-level handbook on the subject. A promising event is the late 2000 publication of the multivolume *Encyclopedia of Biodiversity*, edited by noted ecologist Simon A. Levin. In addition, a fine quality coffee table-like reference work, *Precious Heritage: The Status of Biodiversity in the United States* (edited by Bruce Stein et al.), was recently published and promises to provide an excellent all-purpose review that can be appreciated by almost any level of educated readership.

This essay does not concentrate on Web-based resources, but the subject is in fact being increasingly well served in that direction. Most biodiversity-related sites still concentrate on the animals and plants themselves, but a number take a broader approach. See, for example, *Biodiversity* (World Resources Institute); *Biodiversity and Biological Collections Web Server* (Julian Humphries); *Biodiversity: Digital Library* (Academic Info); *Biodiversity: Measuring the Variety of Nature* (Biogeography & Conservation Lab, Natural History Museum, London); *Biodiversity Related Web Sites* (The Natural Heritage Network); *Information Dissemination for Nature Conservation* (European Centre for Nature Conservation); *The Virtual Library of Ecology & Biodiversity* (Rice University and CCBN).

Historical Threads

In 1910 the then-87-year-old Alfred Russel Wallace (1823-1913), colleague of Charles Darwin and codiscoverer of the principle of natural selection, published his last great treatise on natural science, *The World of Life*. In this work he attempted to draw together some 60 years of observation and study of nature into a single statement about the unity and diversity of living things. Despite Wallace's peculiarly teleological spin on things,

the result was in some respects the first most obvious antecedent of the modern biodiversity movement. Indeed, over his long career Wallace had at one point or another given attention to nearly all of the main dimensions of the present understanding of the subject, and in 1863, nearly 50 years earlier (in his article "On the Physical Geography of the Malay Archipelago"), he had penned the words that are now the most quoted passage in the subject's history:

> . . . my object has been to show the important bearing of researches into the natural history of every part of the world upon the study of its past history. An accurate knowledge of any group of birds or of insects, and of their geographical distribution, may assist us to map out the islands and continents of a former epoch; the amount of difference that exists between the animals of adjacent districts being closely dependent upon preceding geological changes. By the collection of such minute facts alone can we hope to fill up a great gap in the past history of the earth as revealed by geology, and obtain some indications of the existence of those ancient lands which now lie buried beneath the ocean, and have left us nothing but these living records of their former existence. It is for such inquiries the modern naturalist collects his materials; it is for this that he still wants to add to the apparently boundless treasures of our national museums, and will never rest satisfied as long as the native country, the geographical distribution, and the amount of variation of any living thing remains imperfectly known. He looks upon every species of animal and plant now living as the individual letters which go to make up one of the volumes of our earth's history; and, as a few lost letters may make a sentence unintelligible, so the extinction of the numerous forms of life which the progress of cultivation invariably entails will necessarily obscure this invaluable record of the past. It is, therefore, an important object, which governments and scientific institutions should immediately take steps to secure, that in all tropical countries colonised by Europeans the most perfect collections possible in every branch of natural history should be made and deposited in national museums, where they may be available for study and interpretation. If this is not done, future ages will certainly look back upon us as a people so immersed in the pursuit of wealth as to be blind to higher considerations. They will charge us with having culpably allowed the destruction of some of those records of Creation which we had it in our power to preserve; and while professing to regard every living thing as the direct handiwork and best evidence of a Creator, yet, with a strange inconsistency, seeing many of them perish irrecoverably from the face of the earth, uncared for and unknown.

Wallace is perhaps both history's preeminent naturalist-collector and greatest-ever authority on tropical nature. He spent four years as a professional collector in the Amazon (1848-52) and eight more in Indonesia (1854-62), then known as the Malay Archipelago. During the latter expedition he accomplished what he is now best known for, his independent discovery of the principle of natural selection. Wallace's communication of his discovery to Darwin is one of the history of science's most repeated stories, but it is only one chapter in his life story. Wallace's main contributions to what we would now call biodiversity studies include (1) the first paper ("On the Law Which Has Regulated the Introduction of New Species") uniting an evolutionary perspective with the study of the distribution patterns of living things (this produced a starting point for the subsequent development of the field of historical biogeography); (2) the discovery and description of the faunal discontinuity between the western and eastern Indonesian islands that became known as "Wallace's Line" ("On the Zoological Geography of the Malay Archipelago"); (3) the famous scientific travel book *The Malay Archipelago*, which includes descriptions of his pursuit and study of the orangutan and birds of paradise; (4) the book *The Geographical Distribution of Animals*, a cornerstone in the evolution of the field of zoogeography; (5) the book *Tropical Nature and Other Essays*, which dwelled on various subjects of interest to students of tropical environments; and (6) the book *Island Life*, which treated in detail the various forces at work in these instructively special natural settings.

Significant loss of biodiversity might have serious worldwide ethical, economic, and even survival ramifications.

Wallace was of course by no means the only middle-19th-century naturalist who pondered the wonders of biological diversity. His longtime friend Henry Walter Bates, of "Batesian mimicry" fame, spent some 12 years in the Amazon basin and produced another great classic on tropical nature, *The Naturalist on the River Amazons* (1863). Meanwhile, Darwin had been painstakingly working out his own version of the theory of natural selection for some twenty years, in large part as the result of his celebrated voyage around the world on *H. M. S. Beagle* in the years 1831-36. The first important outcome of this trip was Darwin's 1838 book *Journal of Researches* ..., a work that proved to be an inspiration to many later naturalists, including Wallace and Bates. Earlier yet, in 1799-1804, the celebrated German geographer Alexander von Humboldt had engaged in extensive scientific travels in tropical South and Central America that had laid a foundation for later efforts in the fields of biogeography, climatology, and ecology. Further information on the work of 19th-century naturalists has been provided by Joel S. Schwartz in his excellent essay "The Roots of Evolutionary Ideas: How Travel to Exotic Lands Changed Natural History."

If we believe that biodiversity studies focus not only on the "whats" of natural diversity but also on the "hows" and "whys,"

however, the single most important early development leading to their inception was the publication of Darwin's *On the Origin of Species* in late 1859. Darwinian natural selection gave workers the critical tool for understanding change in life over long periods of time, and thus a vehicle for determining why diversity characteristics might differ from place to place. On the Continent, Darwin's cause was taken up most notably by the German zoologist Ernst Haeckel. Moreover, and perhaps not surprisingly, in Haeckel's work lay some of the beginnings of the field of ecology (including his invention of the term "ekologie" itself), which rapidly exploited new understandings of the meaning of adaptations to functionally link organisms to one another.

Progress in that other important aspect of biodiversity studies—its conservation—proceeded more slowly. The first milestone was the 1864 book *Man and Nature* by the American author George Perkins Marsh, who cogently argued for natural resource conservation in an era when few were listening. Wallace, too, made such arguments from time to time; so did the great American naturalist John Muir in books like *The Yosemite*, but it was not until well into the 20th century that interest was raised to a level eliciting significant public involvement. A sustained environmental movement was finally sparked by the 1962 publication of Rachel Carson's famous study *Silent Spring*, which alerted the public to the dangers of pesticide application. Shortly thereafter, interest in subjects such as tropical deforestation and endangered species and habitats began to grow, and to increasingly attract the public's attention.

Meanwhile, scientific studies in a dozen or more fields were developing in such a fashion as to increase sympathy for the notion that the diversity of life represented something distinct enough to be studied and conserved on its own terms. A brief notice of the most visible of these fields is given below, under the heading "Biodiversity: The Main Academic Fields of Study."

Thus, by the mid-1980s the global scientific community was starting to move toward a new synthesis based on the conclusion that the diversity of life was something quite fundamental—not only for its own sake and as grist for the basic research mill, but as a commodity that if lost, or even degraded, would likely impact the quality of human civilization in profound ways. A conference exploring these themes, "National Forum on BioDiversity," was organized for fall 1986 under the auspices of the National Academy of Sciences and the Smithsonian Institution. By the time the conference proceedings were published in 1988 as *Biodiversity* under the editorship of Edward O. Wilson, a new worldwide movement was well under way. This movement featured, as explained earlier, efforts to study the diversity of life itself and also the emergence of arguments focusing on reasons for societal-level concern.

The remainder of this essay describes the progress and literature of the main individual studies that make up the biodiversity movement.

Overviews

Despite the reasonably straightforward picture we can paint of what biodiversity *is*, providing a summary of the progress (including the important literature) of the studies involved is actually rather difficult, partly because of the relative newness of the subject as a concerted "movement," partly from its great scope when considered in more than cursory terms, and because most of the important literature of the subject is of a technical nature. As a result, and because researchers are still in the early stages of exploring the dimensions of the study, there are actually relatively few key works that everyone would agree are central to the subject's emergence. The reality is that the literature is dominated by literally hundreds of edited collections of essays and conference proceedings, and a very large number of studies and essays published in hundreds of professional journals.

Here this difficulty is addressed by focusing a bit more on people than is typical for a review of this type. The message intended is that one can probably enter into the literature on a given subject just as well by following the work of a particular individual as by seeking out a single representative book or paper.

That said, there are in fact a fair number of works that do present good general introductions to, and/or overviews of, the subject of biodiversity. See *Biodiversity II: Understanding and Protecting Our Biological Resources*, ed. by Marjorie L. Reaka-Kudla et al.; *The Earth as Transformed by Human Action*, ed. by Billie Lee Turner et al.; Niles Eldredge's *Life in the Balance*; John D. Gage and Paul A. Tyler's *Deep-Sea Biology*; *Global Biodiversity: Status of the Earth's Living Resources*, ed. by Brian Groombridge; *Global Marine Biological Diversity*, ed. by Elliot A. Norse; Michael A. Huston's *Biological Diversity*; George Evelyn Hutchinson's classic paper "Homage to Santa Rosalia, or Why Are There So Many Kinds of Animals?"; *The Living Planet in Crisis*, ed. by Joel Cracraft and Francesca Grifo; Jonathan Marks's *Human Biodiversity: Genes, Race, and History*; *Nature's Services: Societal Dependence on Natural Ecosystems*, ed. by Gretchen C. Daily; Reed F. Noss and A.Y. Cooperrider's *Saving Nature's Legacy*; *Protection of Global Biodiversity*, ed. by Lakshman D. Guruswamy and Jeffrey A. McNeely; Lloyd Timberlake's *Africa in Crisis*; Richard J. Tobin's *The Expendable Future: U. S. Politics and the Protection of Biological Diversity*; and Edward O. Wilson's *The Diversity of Life*.

Biodiversity: The Main Academic Fields of Study

The main academic disciplines that concern themselves with biodiversity studies have historical beginnings that predate, some by well more than one hundred years, the actual movement. Moreover, with the exception of one of these fields (conservation biology) it is

entirely possible to be involved in related work that has little to do with the study of biodiversity *per se*.

Agricultural Ecology/Agroecology. Agroecology emerged as a recognizable study from the somewhat broader field of agricultural ecology in the late 1970s. It emphasizes the ecosystem-level study of agriculture as a sustainable process, in so doing drawing attention to biogeochemical cycling processes, the roles of the great diversity of soil and surface organisms in contributing to those processes, and the kinds of agency produced by humankind. *Important works: Agroecology*, ed. by C. Ronald Carroll et al.; *Agroecology*, ed. by Stephen R. Gliessman; Miguel Altieri's *Agroecology*; John Vandermeer and Ivette Perfecto's *Breakfast of Biodiversity: The Truth about Rain Forest Destruction.*

Biogeography. Biogeographers have concerned themselves with the study of the distribution of plants and animals for more than two hundred years, extending back at least to the time of Alexander von Humboldt. Biogeographical data provided the single most important impetus for the development of the theory of natural selection, and continue to inform in the new context of biodiversity studies. The subject is very interdisciplinary and unusual to the extent that it tends to attract interest from a broad range of scientists who normally work on other, more specialized, subjects. One of the best current surveys of the state of the field is James H. Brown and Mark V. Lomolino's *Biogeography* (1998). *Important works:* James H. Brown's *Macroecology;* A. Hallam's *An Outline of Phanerozoic Biogeography*; Gareth J. Nelson and Norman Platnick's *Systematics and Biogeography: Cladistics and Vicariance*; Michael L. Rosenzweig's *Species Diversity in Space and Time*; Ian F. Spellerberg and John W.D. Sawyer's *An Introduction to Applied Biogeography.*

Conservation Biology. The field of conservation biology is a rather new discipline, reflecting the move away from an earlier emphasis on single species-oriented kinds of biological management. Indeed, its own development in the late 1970s was an important precursor to the biodiversity movement in general. *Important works:* Mark A. Burgman et al., *Risk Assessment in Conservation Biology*; Graeme Caughley and Anne Gunn's *Conservation Biology in Theory and Practice*; *Conservation Biology: The Science of Scarcity and Diversity*, ed. by Michael E. Soulé; O.H. Frankel and Michael E. Soulé's *Conservation and Evolution*; Richard B. Primack's *Essentials of Conservation Biology*; *Principles of Conservation Biology*, ed. by Gary K. Meffe and C. Ronald Carroll; *Quantitative Methods for Conservation Biology*, ed. by Scott Ferson and Mark Burgman; *Viable Populations for Conservation*, ed. by Michael E. Soulé.

Interest in subjects such as tropical deforestation and endangered species and habitats began to grow.

Ecology. Ecology as a recognized discipline has existed for well over one hundred years. Most investigations of biodiversity are at one level or another firmly grounded in ecological studies, and indeed many of the most important contributions to the development of the biodiversity movement have been made by professional ecologists. *Important works: Behavioral Ecology and Conservation Biology*, ed. by T.M. Caro; C.S. Holling's classic "Resilience and Stability of Ecological Systems"; Robert H. MacArthur and Edward O. Wilson's classic *The Theory of Island Biogeography*; Stuart L. Pimm's *The Balance of Nature?*; *Species Diversity in Ecological Communities*, ed. by Robert E. Ricklefs and Dolph Schluter; David Tilman's "Biodiversity: Population versus Ecosystem Stability"; Richard H. Yahner's *Eastern Deciduous Forest: Ecology and Wildlife Conservation.*

Environmental Economics. The relation of environmental economics to biodiversity studies tends to be overlooked, but the importance of using economics as an argument for the conservation of biodiversity cannot be overestimated. *Important works: Ecological Economics*, ed. by Robert Costanza; Alan Gilpin's *Environmental Economics*; David W. Pearce and R. Kerry Turner's *Economics of Natural Resources and the Environment*; David W. Pearce and Jeremy J. Warford's *World without End: Economics, Environment, and Sustainable Development.*

Evolutionary, Historical, and Systematic Biology. These three fields have increasingly become so intertwined that one can scarcely separate them anymore. It is ultimately the objective of workers within these studies to provide a systematic understanding of the history of life, including coming to grips with the factors underlying the particular kinds of changes the planet's life has undergone. Such investigations may focus on factors either internal and external—or both—to the organisms and other biosystems involved. *Important works:* James H. Brown's *Macroecology*; Russell F. Doolittle et al., "Determining Divergence Times of the Major Kingdoms of Living Organisms with a Protein Clock"; *Evolution of Biological Diversity*, ed. by Anne E. Magurran and Robert M. May; K.G. Field et al., "Molecular Phylogeny of the Animal Kingdom"; O.H. Frankel and Michael E. Soulé's *Conservation and Evolution*; Stephen J. Gould and Niles Eldredge's classic "Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered"; Motoo Kimura's *The Neutral Theory of Molecular Evolution*; Lynn Margulis and Karlene V. Schwartz's *Five Kingdoms: An Illustrated Guide to the Phyla of Life on Earth*; Michael L. Rosenzweig's *Species Diversity in Space and Time*; Steven M. Stanley's *Macroevolution, Pattern and Process*; Mary Jane West-Eberhard's "Phenotypic Plasticity and the Origins of Diversity"; E.O. Wiley's *Phylogenetics: The Theory and Practice of Phylogenetic Systematics.*

Landscape Ecology. Landscape ecology is a rather new field incorporating large-scale aspects of geographical, ecological, and conservation studies. One of its important inspirations is the mid-20th-cen-

tury work of the great conservationist Aldo Leopold, whose celebrated 1949 book concerning "the land ethic," *A Sand County Almanac*, is basic reading for any budding environmentalist. Two good surveys of the field are Richard T.T. Forman and Michel Godron's *Landscape Ecology* and Monica G. Turner's "Landscape Ecology: The Effect of Pattern on Process." *Important work:* Robert A. Askins's *Restoring North America's Birds: Lessons from Landscape Ecology.*

Population Biology. Population biology studies are primarily a 20th-century phenomenon involving the genetic, ecological, and evolutionary analysis of species at the population level. In the 1980s the population-level study of spatially fragmented species populations led to the development of what is known as metapopulation theory, which has great importance to the analysis of such subjects as extinction, speciation, and reserve design. *Important works: Biodiversity Dynamics: Turnover of Populations, Taxa, and Communities*, ed. by Michael L. McKinney and James A. Drake; Ilkka Hanski and Michael E. Gilpin's "Metapopulation Dynamics: Brief History and Conceptual Domain"; Alan Hastings and Susan Harrison's "Metapopulation Dynamics and Genetics"; *Metapopulation Biology: Ecology, Genetics, and Evolution*, ed. by Ilkka Hanski and Michael E. Gilpin.

Biodiversity: Special Subjects

It merits constant reminding that biodiversity studies concern themselves with *all* factors contributing to the diversity of life and its conservation. Some of these factors are of a purely ecological and/or evolutionary ("natural") sort, but many others involve human agency, whether this may mean how people have transported species from here to there, deliberately or inadvertently eradicated them for various reasons, or now find themselves in the position of having to come up with social, economic, and political solutions to deal with the results of their errant ways. A quick survey of some of the main related special subjects and works follows:

Action and recovery plans and programs; ecological restoration. Identifying what needs attention and prioritizing plans are only the first steps in the process of conserving biodiversity; the hardest work comes in figuring out how to effect recovery and restoration. Much of the literature in this realm revolves around site-specific considerations, but it is also an active arena for theoretical discussion. *Important works: Environmental Restoration*, ed. by John J. Berger; *Restoration Ecology*, ed. by William R. Jordan et al.; *Restoration of Endangered Species*, ed. by Martin L. Bowles and C.J. Whelan; *Restoring Diversity*, ed. by Donald Falk et al.

Agrobiodiversity. Biodiversity investigators concern themselves not only with natural forms of diversity, but with that inherent in domesticated and semidomesticated forms as well. Among the ramifications of loss of agrobiodiversity are problems linked to environmental degradation, food supply reduction, and loss of resistance to pest species. *Important work: Biodiversity in Agroecosystems*, ed. by Wanda W. Collins and Calvin O. Qualset.

Amphibian population declines. One of the most intriguing special problems in biodiversity studies is the well-publicized, alarming degree to which amphibian population levels have decreased in many places in recent years. Investigators worry that the reductions may be indicative of some yet-unidentified environmental cause that could also adversely affect other organisms. *Important works:* Andrew R. Blaustein et al., "Amphibian Declines"; Joseph H.K. Pechmann et al., "Declining Amphibian Populations."

Animal rights and welfare. Although concern for animal rights and welfare predates the biodiversity movement, the new context has provided additional food for thought. The two classic works on this subject are Tom Regan's *The Case for Animal Rights* and Peter Singer's *Animal Liberation: A New Ethics for Our Treatment of Animals.*

Biodiversity loss. Biodiversity loss is a much more complicated problem than can be imagined by thinking solely in terms of species extinctions. Indeed, the problem extends to spatially larger and smaller levels through such matters as habitat and quality of life loss, and genetic depletion. *Important works: The Big Kill: Declining Biodiversity in America's Lakes and Rivers*, ed. by David S. Wilcove and Michael J. Bean; *Biodiversity Loss: Economic and Ecological Issues*, ed. by Charles A. Perrings et al.; John D. Tuxill and Jane A. Peterson's *Losing Strands in the Web of Life.*

Biodiversity measurement, assessment, and monitoring. An army of researchers has been concerning itself with the fundamental matter of how to go about measuring, assessing, and monitoring biodiversity in its various manifestations. Two related lines of study, for example, involve identifying what are known as "keystone" and "indicator" species to simplify sampling strategies for monitoring ecosystem health. An important technique known as "rapid assessment" makes use of such species to provide quick overviews where detailed canvassing is unfeasible. *Important works: The Big Kill: Declining Biodiversity in America's Lakes and Rivers*, ed. by David D. Wilcove and Michael J. Bean; Clive G. Jones et al., "Organisms as Ecosystem Engineers"; Anne E. Magurran's *Ecological Diversity and Its Measurement*; Reed F. Noss's "Indicators for Monitoring Biodiversity: A Hierarchical Approach"; *Quantitative Methods for Conservation Biology*, ed. by Scott Ferson and Mark Burgman.

Biodiversity valuation. One of the most important arguments for biodiversity preservation is that it is in one respect or another valuable. Related discussions often (but not always) involve economic modeling techniques, one of the most relevant of which is "contingent valuation." *Important works:* Robert Costanza et al., "The Value of the World's Eosystem Services and Natural Capital"; Ronald G. Cum-

mings et al., *Valuing Environmental Goods: An Assessment of the Contingent Valuation Method*; W. Michael Hanemann's "Valuing the Environment through Contingent Valuation"; Robert C. Mitchell and R.T. Carson's *Using Surveys to Value Public Goods: The Contingent Valuation Method*; David W. Pearce's *Economic Values and the Natural World.*

Biodiversity and pharmaceuticals prospecting. The ever-escalating search for new drugs from natural sources provides one of the best practical arguments for the preservation of biodiversity. But people are becoming increasingly aware that there are many, many other uses of the by-products of living things (not to mention the organisms themselves in many instances), and interest in this direction is creating its own set of problems, including what has been termed "biopiracy" (the overly exploitative removal of resources from the world's less powerful states by representatives of its more powerful ones). *Important Works: Biodiversity Prospecting*, ed. by Walter V. Reid et al.; Vandana Shiva's *Biopiracy: The Plunder of Nature and Knowledge.*

Biological invasions and introductions. Change is, as for most things, one of the most important characteristics of biodiversity. One of the most significant contributors to biodiversity change at any given location is its level of affliction by invading or introduced species. Some of the latter have become major pests and famous stories in their own right: the Argentine ant, the Giant African snail, the zebra mussel, the gypsy moth, the starling, the Indian mongoose, and so on. Required initial reading on this subject includes the classic *The Ecology of Invasions by Animals and Plants*, by Charles S. Elton. *Important works: Biological Invasions: A Global Perspective*, ed. by J.A. Drake et al.; Chris Bright's *Life out of Bounds: Bioinvasion in a Borderless World*; James T. Carlton and J.B. Geller's "Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms"; George W. Cox's *Alien Species in North America and Hawaii*; *Ecology of Biological Invasions*, ed. by R.H. Groves and J.J. Burdon; Mark Williamson's *Biological Invasions.*

Biomass use (especially, burning). Biomass reduction through forest and other kinds of clearance has a number of possible serious implications, including environmental (both atmospheric and terrestrial/aquatic) degradation and climate alteration. See *Biomass Burning and Global Change* and *Global Biomass Burning*, both ed. by Joel S. Levine.

Biotechnology: genetic engineering/transgenic organisms. Most people do not connect biotechnology to the biodiversity crisis, but there are many related concerns. The release of transgenic organisms into the environment (especially as related to agricultural plans), for example, could potentially have major effects on ecological stabilities. *Important works: Biotechnology and Plant Genetic Resources: Conservation and Use*, ed. by J.A. Callow et al.; Charles S. Gasser and R.T. Fraley's "Genetically Engineering Plants for Crop Improvement"; *Introduction of Genetically Modified Organisms into the Environment*, ed. by Harold A. Mooney and Giorgio Bernardi; Calestous Juma's *The Gene Hunters*; Vandana Shiva's *Monocultures of the Mind*; James M. Tiedje et al., "The Planned Introduction of Genetically Engineered Organisms."

Birds. Because birds are both numerically common creatures and relatively easy to observe and monitor, many ornithologists have become involved in biodiversity-oriented studies. One of their many subjects of concern has been the recent decline in numbers of migrating songbirds in the New World. *Important works:* Richard M. DeGraaf and John H. Rappole's *Neotropical Migratory Birds*; *Ecology and Conservation of Grassland Birds of the Western Hemisphere*, ed. by Peter D. Vickery and James R. Herkert; *Ecology and Conservation of Neotropical Migrant Landbirds*, ed. by John M. Hagan and David W. Johnston; Paul R. Ehrlich et al., *Birds in Jeopardy*; *Endemic Bird Areas of the World*, ed. by Alison J. Stattersfield et al.; John Terborgh's *Where Have All the Birds Gone?*

Body size, morphology, and shape trends. One of the most fundamental aspects of diversity in the living world is the range of body shapes and sizes that various creatures have adopted to carve out their individual niches. Investigators have been examining a range of geographical, ecological, and evolutionary controls on the process since the 19th century. *Important works:* Mike Foote's "The Evolution of Morphological Diversity"; *Scaling in Biology*, ed. by James H. Brown and Geoffrey B. West.

Canopy studies. It only quite recently became apparent that we have probably vastly underestimated the number of species, especially insects, inhabiting the canopy zone of forests. *Important work:* Mark W. Moffett's *The High Frontier: Exploring the Tropical Rainforest Canopy.*

Captive breeding/ex situ conservation. When other means of conservation fail, the last resort is often to remove individuals from their natural surroundings and attempt to encourage their breeding under controlled conditions. For a good readable survey of the subject, see Colin Tudge's *Last Animals at the Zoo: How Mass Extinction Can Be Stopped.*

Climatic environmental change. Although global warming and other such subjects (including the greenhouse effect and the ozone layer problem) can be studied at a level more or less detached from matters of biodiversity, it should be apparent that any related effects are very likely to have profound impacts on the world of life. Studies in this arena often spotlight the degree to which human activities have worked at cross-purposes: corporate and political structures are not often easily swayed by mere scientific arguments. *Important works: Climate Change: The IPCC Scientific Assessment*, ed. by J.T. Houghton et al.; *Global Warming: The Greenpeace Report*, ed. by Jeremy Leggett; *Global Warming and Biological Diversity*, ed. by Robert L. Peters and Thomas E. Lovejoy; *The Greenhouse Effect, Climatic Change, and Ecosystems*, ed. by Bert Bolin; Bill McKibben's *The End of Nature*; Michael Oppenheimer and R.H. Boyle's *Dead Heat: The Race against the Greenhouse Effect*; Peter M. Vitousek's "Beyond Global Warming: Ecology and Global Change."

Collections and banks: museum, genetic, and other. Not only is it important to maintain the research collections of the world's natural history museums for purposes of basic research; also needed are seed and germplasm banks to ensure a continuing supply of the raw genetic material necessary to the maintenance of agrobiodiversity. *Important works:* Peter Davis's *Museums and the Natural Environment*; *Gene Banks and the World's Food*, by Donald L. Plucknett et al.; Gary Paul Nabhan's *Enduring Seeds: Native American Agriculture and Wild Plant Conservation*; *Sampling the Green World: Innovative Concepts of Collection, Preservation, and Storage of Plant Diversity*, ed. by Tod F. Stuessy and S.H. Sohmer

Corridor studies. A good number of researchers have been investigating the special problems associated with the maintenance and/or construction of habitat corridors that will ensure a minimum level of genetic exchange between remnant and/or fragmenting populations. *Important works: The Role of Corridors*, ed. by Denis A. Saunders and Richard J. Hobbs; Daniel K. Rosenberg et al., "Biological Corridors: Form, Function, and Efficacy"; Daniel S. Simberloff and J. Cox's "Consequences and Costs of Conservation Corridors."

Deforestation. The drawbacks associated with the reduction of the world's great forests have been recognized since the time of Marsh and Wallace in the mid-19th century. *Important works:* Judith Gradwohl and Russell Greenberg's *Saving the Tropical Forests*; Philip Hurst's *Rainforest Politics: Ecological Destruction in South-East Asia*; Norman Myers's *The Primary Source*; Thomas K. Rudel and Bruce Horowitz's *Tropical Deforestation: Small Farmers and Land Clearing in the Ecuadorian Amazon*; David Skole and Compton Tucker's "Tropical Deforestation and Habitat Fragmentation in the Amazon: Satellite Data from 1978 to 1988."

Diversity characteristics and measures: abundance, diversity gradients, species-area relations, etc. Under this subject heading we may place any number of studies that dwell on the micro- and macrocharacteristics of diversity *per se.* For example, it is well established that within most families or orders of living things, there are more species that live in low latitude areas than in high latitude ones. *Important works:* Joseph H. Connell's classic "Diversity in Tropical Rain Forests and Coral Reefs"; David J. Currie's "Energy and Large-Scale Patterns of Animal- and Plant-Species Richness"; Michael A. Huston's classic "A General Hypothesis of Species Diversity"; Robert K. Peet's "The Measurement of Species Diversity."

Endangered and threatened species. Biodiversity loss is most dramatically evidenced through the process of extinction, and those forms nearing extinction are said to be endangered or threatened. Many 20th-century workers have concerned themselves with the single-species management of endangered species, and the biodiversity movement has added to such study through investigations cast at the ecological and landscape levels. *Important works:* Diane Ackerman's *The Rarest of the Rare: Vanishing Animals, Timeless Worlds*; *The Atlas of Endangered Species*, ed. by John A. Burton; Paul Ehrlich and Anne Ehrlich's *Extinction: The Causes and Consequences of the Disappearance of Species*; *The Last Extinction*, ed. by Les Kaufman and Kenneth Mallory; Charles C. Mann and Mark L. Plummer's *Noah's Choice: The Future of Endangered Species*; Norman Myers's *The Sinking Ark.*

Endemic species and "hotspots" analyses. Endemic species are those that have a limited geographical range, and "hotspots" are those areas populated by many at-risk endemic forms. One strategy for conserving biodiversity involves the maximization of protection afforded to such localities. *Important works:* Andrew P. Dobson et al., "Geographic Distribution of Endangered Species in the United States"; *Endemic Bird Areas of the World*, ed. by Alison J. Stattersfield et al.; Russell A. Mittermeier et al., *Hotspots: Earth's Biologically Rich-*

est and Most Endangered Terrestrial Ecoregions; J.R. Prendergast et al., "Rare Species, the Coincidence of Diversity Hotspots and Conservation Strategies."

Environmental ethics. The ethical relationship of humankind to its environment is a subject that has gained increasing attention in recent years: to what degree should we consider ourselves liable for all the physical exploitation we sponsor? *Important works:* Robin Attfield's *The Ethics of Environmental Concern*; J. Baird Callicott's *In Defense of the Land Ethic*; Roderick F. Nash's *The Rights of Nature: A History of Environmental Ethics*; Holmes Rolston's *Environmental Ethics*; Christopher D. Stone's *Earth and Other Ethics: The Case for Moral Pluralism*; Paul W. Taylor's *Respect for Nature: A Theory of Environmental Ethics.*

Environmental perception and philosophy. Some may consider these subjects a bit far afield from the matter of biodiversity conservation, but it is nevertheless a fact that the public will not fully support such efforts until it is understood how and why they feel as they do about related questions. *Important works: The Biophilia Hypothesis*, ed. by Stephen R. Kellert and Edward O. Wilson; J. Baird Callicott's *In Defense of the Land Ethic*; Bill Devall and George Sessions's *Deep Ecology*; Ursula Goodenough's *The Sacred Depths of Nature*; Roderick F. Nash's *Wilderness and the American Mind*; Bryan G. Norton's *Toward Unity among Environmentalists*; Edward Osborne Wilson's *Biophilia.*

Environmentalism. The political, social, and economic advocates of the environment have a strong collective voice in today's society. The biodiversity crisis has provided yet more fodder for their cannon. *Important works: Conserving the Environment*, ed. by Laura K. Egendorf; Andrew Dobson et al., *Green Political Thought*; Paul R. Ehrlich and Anne Ehrlich's *Betrayal of Science and Reason* and *The Population Explosion*; Garrett J. Hardin's classic "The Tragedy of the Commons"; Bryan G. Norton's *Toward Unity among Environmentalists*; Jonathan Weiner's *The Next One Hundred Years.*

Ethnobotany. Ethnobotany as an interdisciplinary field extends well beyond the scope of biodiversity studies *per se.* Still, many of the relationships between plants and human culture—especially indigenous cultures—figure strongly in our quest for greater knowledge of nature. For example, indigenous knowledge of the healing properties of native plants aids in the search for new commercial medicines. *Important works:* Paul Alan Cox's *Nafanua: Saving the Samoan Rain Forest*; *Ethnoecology: Situated Knowledge/Located Lives*, ed. by Virginia D. Nazarea; *Medicinal Resources of the Tropical Forest*, ed. by Michael J. Balick et al.; Mark J. Plotkin's *Tales of a Shaman's Apprentice*; Richard E. Schultes and Robert F. Raffauf's *The Healing Forest: Medicinal and Toxic Plants of the Northwest Amazonia.*

Extinction and extinction rates. Extinction is the primary vehicle of biodiversity loss, and its most apparent manifestation. But its causes are complex and various, and have kept a sizable population of investigators busy hypothesizing causes for well over a hundred years. *Important works:* Paul R. Ehrlich and Anne Ehrlich's *Extinction*; Niles Eldredge's *The Miner's Canary*; *Extinction Rates*, ed. by John H. Lawton and Robert M. May; David M. Raup's *Extinction: Bad Genes or Bad Luck?*; Beverly Peterson Stearns and Stephen C. Stearns's *Watching, from the Edge of Extinction.*

Fishes and fisheries. Freshwater and marine environments have received relatively less attention with respect to the biodiversity crisis than have terrestrial environments, but this by no means suggests that they are less afflicted with related problems. *Important works:* P.J. Doherty and D.M. Williams's "The Replentishment of Coral Reef Fish Populations"; *The Ecology of Fishes on Coral Reefs*, ed. by Peter F. Sale; Gene S. Helfman et al., *The Diversity of Fishes*; Christian Lévêque's *Biodiversity Dynamics and Conservation: The Freshwater Fish of Tropical Africa.*

Food sources and supply. There is increasing concern that current agriculture practices may not ensure that future demands for food are met. One of the most important aspects of this concern is whether we can maintain a satisfactory diversity of food types, given problems such as shrinking gene pools in the source species from which our domestic varieties have been developed. *Important works:* Kenny Ausubel's *Seeds of Change*; Cary Fowler and Pat Mooney's *Shattering: Food, Politics, and the Loss of Genetic Diversity*; *Gene Banks and the World's Food*, by Donald L. Plucknett et al.

Forest conservation and management. It is not only the tropical forests that are in trouble in many parts of the world. Logging operations and commercial development threaten many higher latitude locations as well, endangering natural repositories of biodiversity such as old-growth forests. *Important works: Eastern Old-Growth Forests: Prospects for Rediscovery and Recovery*, ed. by Mary Byrd Davis; Judith Gradwohl and Russell Greenberg's *Saving the Tropical Forests*; *Maintaining Biodiversity in Forest Ecosystems*, ed. by Malcolm L. Hunter; Elliott A. Norse's *Ancient Forests of the Pacific Northwest.*

Gaia hypothesis. The Gaia hypothesis—the notion that the biosphere has evolved in the long-term and large-scale sense as though it were a single giant organism—is a highly controversial point of view that most scientists do not accept at present. Yet the idea continues to draw attention and attract advocates. *Important works:* Brandon Carter's "The Anthropic Principle and Its Implications for Biological Evolution"; John R. Gribbin's *Hothouse Earth*; James E. Lovelock's *Gaia: A New Look at Life on Earth*; James E. Lovelock's *The Ages of Gaia*; Dorion Sagan's *Biospheres: Metamorphosis of Planet Earth*; *Scientists on Gaia*, ed. by Stephen H. Schneider and Penelope J. Boston.

Gap analysis. Gap analysis is an important technique wherein ecosystem and species distribution maps are compared to the extent of existing nature preserves. This tends to draw attention to "gaps"; that is, to places where the network of preserves is incomplete with respect to its protection

of high species diversity environments. *Important works: Gap Analysis: A Geographic Approach*, by J. Michael Scott et al.; *Gap Analysis: A Landscape Approach*, ed. by J. Michael Scott et al.

Genetic/germplasm diversity and resources. Genetic diversity and its conservation is a subject not often connected by the public to biodiversity studies, but expect to hear more and more about related subjects as time goes on. *Important works:* Mark D. Adams and A.R. Kerlavage's "Initial Assessment of Human Gene Diversity"; O.H. Frankel et al., *The Conservation of Plant Diversity*; Richard Frankham's "Conservation Genetics"; *Genetics and the Extinction of Species*, ed. by Laura F. Landweber and Andrew P. Dobson; J.L. Hamrick et al., "Factors Influencing Levels of Genetic Diversity in Woody Plant Species"; Russell Lande's "Genetics and Demography in Biological Conservation."

Habitat/landscape/ecosystem fragmentation and patch dynamics. Fragmentation of natural habitats has a variety of important ramifications for natural diversity. For example, heavily fragmented populations can be prone to inbreeding, which may hasten local extinction. *Important works: The Ecology of Natural Disturbance and Patch Dynamics*, ed. by S.T.A. Pickett and P.S. White; Lenore Fahrig and G. Merriam's "Conservation of Fragmented Populations"; Larry D. Harris's *The Fragmented Forest*; Denis A. Saunders et al., "Biological Consequences of Ecosystem Fragmentation: A Review."

Indigenous peoples, traditional knowledge, and intellectual property rights. Not only can one make the argument that traditional lifestyles are themselves an aspect of biodiversity that should be conserved, but the increasing exploitation of the homelands of native peoples for natural products is fraught with a variety of ethical and moral issues. *Important works: Conservation of Neotropical Forests: Working from Traditional Resource Use*, ed. by Kent H. Redford and Christine Padoch; *Indigenous Peoples and the Future of Amazonia*, ed. by Leslie E. Sponsel; *The Law of the Mother: Protecting Indigenous Peoples*, ed. by Elizabeth Kemf.

Insects. The enormous numbers of both individuals and species of insects make them of vital concern to biodiversity studies. *Important works: The Conservation of Insects and Their Habitats*, ed. by N. Mark Collins and Jeremy Thomas; Bert Hölldobler and Edward O. Wilson's *The Ants*; *Perspectives on Insect Conservation*, ed. by Kevin J. Gaston et al.; Michael J. Samways's *Insect Conservation Biology.*

Island biology/biogeography. Islands have been regarded as "living laboratories" of evolution for some 150 years, and the study of their biota has produced many important advances in theory over that period. But their special geographic and ecological features make them irresistible targets for development, and in ways often antagonistic to the welfare of their resident faunas and floras. *Important works: Hawaiian Biogeography: Evolution on a Hot Spot Archipelago*, ed. by Warren L. Wagner and V.A. Funk; *Islands: Biological Diversity and Ecosystem Function*, ed. by Peter M. Vitousek et al.; Robert H. MacArthur and Edward O. Wilson's classic *The Theory of Island Biogeography*; David Quammen's *The Song of the Dodo*; Robert J. Whittaker's *Island Biogeography: Ecology, Evolution, and Conservation*; Mark Williamson's *Island Populations.*

Mammals. *Important works:* Gerardo Ceballos and James H. Brown's "Global Patterns of Mammalian Diversity, Endemism, and Endangerment"; *Conservation and Management of Marine Mammals*, ed. by John R. Twiss and Randall R. Reeves; Robert C. Lacy's "Importance of Genetic Variation to the Viability of Mammalian Populations"; *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*, ed. by Don E. Wilson et al.

Mass extinctions. It has become increasingly apparent that Earth's biota has undergone a series of massive simultaneous extinction episodes throughout our geological past. Researchers are still trying to sort out the causes and whether these may portend trouble ahead for humankind. *Important works:* Walter Alvarez's *T. Rex and the Crater of Doom*; Douglas H. Erwin's *The Great Paleozoic Crisis*; A. Hallam and P.B. Wignall's *Mass Extinctions and Their Aftermath*; *Quaternary Extinctions: A Prehistoric Revolution*, ed. by Paul S. Martin and Richard G. Klein; Peter Douglas Ward's *The End of Evolution* and *On Methuselah's Trail: Living Fossils and the Great Extinctions.*

Microorganisms. It is sometimes forgotten that the diversity of the microscopic world is every bit as great as that at our own scale of being. One can expect many future surprises within this domain of study. *Important works:* Susan M. Barns et al., "Remarkable Archaeal Diversity Detected in a Yellowstone National Park Hot Spring Environment"; Øivind Bergh et al., "High Abundance of Viruses Found in Aquatic Environments"; Laurie Garrett's *The Coming Plague*; *Microbial Diversity and Ecosystem Function*, ed. by D. Allsopp et al.; N.R. Pace's "A Molecular View of Microbial Diversity and the Biosphere."

Parasites and parasitism. Parasitism is another phenomenon whose importance to biodiversity has been rather overlooked until recent years. Its implications both for evolutionary trends and ecological structures are now being much more closely examined. *Important works:* Gerald W. Esch and Jacqueline Fernandez's *A Functional Biology of Parasitism*; Bland J. Finlay's "The Global Diversity of Protozoa and Other Small Species"; Robert Poulin's "Species Richness of Parasite Assemblages."

Protected areas and reserve design. The most conventional and widely supported means of conserving biodiversity involves setting aside parcels of land (and water) in an effort to protect them from human overexploitation. Related studies feature both economic discussions and social ones; an example of the latter kind of consideration is the way buffer zones between protected and unprotected parcels of land complicate the lives of people living nearby. *Important works: Continental Conservation:*

Scientific Foundations of Regional Reserve Networks, ed. by Michael E. Soulé and John Terborgh; *A Global Representative System of Marine Protected Areas*, ed. by Graeme Kelleher et al.; *Parks in Peril*, ed. by Katrina Brandon et al.; Craig L. Shafer's *Nature Reserves: Island Theory and Conservation Practice*; Richard I. Vane-Wright et al., "What to Protect?—Systematics and the Agony of Choice."

Rare species. As the result of factors both internal and external to a given population, it is possible for a species to be rare but not threatened or endangered, or threatened or endangered but not rare. The population dynamics of naturally rare species thus have their own special kind of implications for biodiversity conservation. *Important works: The Biology of Rarity*, ed. by William E. Kunin and Kevin J. Gaston; Kevin J. Gaston's *Rarity*; J.R. Prendergast et al., "Rare Species, the Coincidence of Diversity Hotspots and Conservation Strategies."

Reptiles and amphibians. *Important works:* Trevor J.C. Beebee's *Ecology and Conservation of Amphibians*; *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, ed. by Ronald W. Heyer et al.; National Research Council, *Decline of the Sea Turtles*; *Patterns of Distribution of Amphibians: A Global Perspective*, ed. by William E. Duellman.

Scale, spatial. The selection quoted earlier from the writings of E. O. Wilson draws attention to the idea that biodiversity must be considered in its manifestations "at all levels of organization"—that is to say, at the level of individual organisms, local (communities and populations) settings, regional patterns and assemblages, and global interdependencies. Variation in the spatial scale at which biodiversity is manifest is in fact one of its most essential features and a research subject that in the future is likely to attract increasing interest. *Important works:* M. Julian Caley and Dolph Schluter's "The Relationship between Local and Regional Diversity"; Simon A. Levin's "The Problem of Pattern and Scale in Ecology"; Michael W. Palmer and P.S. White's "Scale Dependence and the Species-Area Relationship"; John A. Wiens's "Spatial Scaling in Ecology."

Sustainable use and development. Over the past 20 years or so a philosophy of natural resource management based on the concept of its sustainable use has gathered much international support. The study of biodiversity loss has only served to intensify this interest. *Important works:* Lester Russell Brown's *Building a Sustainable Society*; *Global Biodiversity: Status of the Earth's Living Resources*, ed. by Brian Groombridge; Jane Lubchenco et al., "The Sustainable Biosphere Initiative: An Ecological Research Agenda"; David W. Pearce's *Economic Values and the Natural World*; David W. Pearce and Jeremy J. Warford's *World without End: Economics, Environment, and Sustainable Development.*

Tropical forests. The post-World War devastation of the world's tropical forests is one of the most serious crises confronting biodiversity conservation. Human population pressures are mainly at the root of the problem—the quintessential example of the snake swallowing its own tail: the world's great tropical forests are made up of millions of species, and some of them might provide the clues necessary to solving many of our most pressing social problems, medical and otherwise. *Important works: The Conservation Atlas of Tropical Forests: Africa*, ed. by Jeffrey A. Sayer et al.; *The Conservation Atlas of Tropical Forests: Asia and the Pacific*, ed. by N. Mark Collins et al.; Judith Gradwohl and Russell Greenberg's *Saving the Tropical Forests*; Norman Myers's *The Primary Source: Tropical Forests and Our Future*; Douglas Southgate's *Tropical Forest Conservation*; John Terborgh's *Diversity and the Tropical Rain Forest*; T.C. Whitmore's *Tropical Rain Forests of the Far East.*

Conclusion

Biodiversity as a study began in the 20th century, but it will surely be the 21st century that will witness its ultimate worth to the perpetuation of human existence. Along the way we can expect to see the development of a much more substantial research infrastructure, and with it new educational programs and political agenda. We can also expect that more attention will be given to gaining bibliographic control over the subject: it will become increasingly apparent how different scales of living organization are interrelated, and how, in turn, the literature generated in one field can be related to that produced in others.

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http://www.wri.org/wri/biodiv/biodiv.html

Biodiversity and Biological Collections Web Server (Julian Humphries)
http://www.Keil.ukans.edu/

Biodiversity: Digital Library (Academic Info)
http://www.academicinfo.net/biodivlibrary.html

Biodiversity: Measuring the Variety of Nature (Biogeography & Conservation Lab, Natural History Museum, London)
http://www.nhm.ac.uk/science/projects/worldmap/

Biodiversity Related Web Sites (The Natural eritage Network)
http://www.heritage.tnc.org/oth_svrs.html

Information Dissemination for Nature Conservation (European Centre for Nature Conservation)
http://www.ecnc.nl/doc/servers/informat.html

The Virtual Library of Ecology & Biodiversity (Rice University and CCBN)
http://www.conbio.net/vl/browse/