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Editorial

On the Future of Conservation Biology

Conservation biology has been aptly described as a discipline with a deadline, but for those who work in this intensive-care ward of ecology it is more precisely a never-ending avalanche of deadlines. The conservation biologist knows that each imperiled species is a masterpiece of evolution, potentially immortal except for rare chance or human choice, and its loss a disaster. You and I will be entirely forgotten in a thousand years, but, live or die, the black-footed ferret, barndoor skate, Lefevre's riffle shell, Florida torreya, and the thousands of other species now on the brink of extinction will not be forgotten, not while there is a civilization. Our conservation successes, the only truly enduring part of us, will live in their survival.

Conservation biologists are crisis managers who ply the full array of biological organization from gene to ecosystem. Their scientific work is both basic and practical. It is also one of the most eclectic of intellectual endeavors. Consider the following example from recent media headlines: survival of the red-cockaded woodpecker, a bird (an *American* bird no less) turns upon our knowledge of its distribution and natural history, survival of the mature pine woodland in which it lives, the economic and political forces that erode its nest sites, the legislation that protects it, and, not least, the moral precepts that support the very idea of ecosystem and species conservation.

No real basis exists—as some writers have imagined—for conflict between ecosystem studies and single-species studies in conservation biology. Each is vital and intellectually dependent upon the other. Within the broader framework of ecosystem studies, community ecology in particular is about to emerge as one of the most significant intellectual frontiers of the twenty-first century. Although it still has only a mouse's share of science funding, it stands intellectually in the front rank with astrophysics, genomics, and neuroscience. Community ecologists face the daunting challenge of explaining how biotas are assembled and sustained. Most of their effort today is in description and analysis, with closest attention paid to one species or to several species as modules. As time passes, more resources will be put into the mathematical modeling and experimental manipulation of entire assemblages, from the bottom up, species to communities. Biotas, like cells and brains, are prime targets for the emerging field of general complexity theory. They have already been singled out as paradigms of complex adaptive systems and are certain to attract the attention not just of ecologists but also of physicists, molecular biologists, and others who are running short of virgin fields of inquiry.

Like the rest of science, community ecology advances by repeated cycles of reduction and synthesis, in which bottom-up analysis of the working parts explains the complex whole and, in reciprocity, an evolving theory of the complex whole guides further exploration of the working parts. The relevance of this perpetual process to conservation biology is as follows. The more or less independently evolved key working parts are the species. In the future, solid advances in community ecology will depend increasingly on a detailed knowledge of species and their natural history, which feeds and drives theory.

It follows that community ecology and conservation biology are in desperate need of a renaissance of systematics and natural history. By systematics I mean much more than just the phylogenetic analysis of already known species. Phylogenetic reconstruction, currently the dominating focus of systematics, obviously is worth doing, but more scientifically important and far more urgent for human welfare is the description and mapping of the world biota. They are scientifically important because descriptive systematics is the foundation for community ecology. And they are urgent because the development of a mature, accessible knowledge of global biodiversity is necessary for conservation theory and practice.

Few biologists other than systematists appreciate how little is known of Earth's biodiversity. Estimates of the total number of species still vacillate wildly: 3,600,000 at the low end and 111,700,000 at the high end (*Global Biodiversity Assessment*, 1995). The estimated number of species described and given scientific names ranges between 1.5 and 8 million. Here also the true number is only a matter of speculation. Even figures for the relatively well-studied vertebrates are spongy. Estimates for the extant fish species of the world, including both described and undescribed, range from 15,000 to 40,000. That figure becomes a veritable black hole in the case of the bacteria and archaea, whose species could with equal ease number either in the thousands or in the tens of millions.

Natural history is still further behind. Even among the named species—never mind those still undiscovered—only a minute fraction, less than 1%, have been studied beyond the essentials of habitat preference and diagnostic anatomy. In general, ecologists and conservation biologists appear not to fully appreciate how thin the ice is on which they skate.

The full exploration of the living part of this planet will be an adventure of megascience, summoning the energy and imagination of our best minds. Its relevance to human welfare was spelled out in the Convention on Biological Diversity of the 1992 Earth Summit, and much of its methodology and possible organizational flowchart by Systematics Agenda 2000. Funding is still limited given the task at hand but is rising under the auspices of organizations such as the Global Environmental Facility and special programs of the U.S. National Science Foundation.

If conservation biology is to mature into an effective science, pure systematics must be accompanied by a massive growth of natural history. For each species, for the higher taxa to which it belongs, and for the populations it comprises, there is value in every scrap of information. Serendipity and pattern recognition are the fruit of encyclopedic knowledge gathered for its own sake. For example, all that can be learned about an endangered conifer on New Caledonia, about the rest of the conifers of New Caledonia, and about every other member of the entire world conifer flora, deserves dedicated pursuit. Periodic summaries of the information are rightfully placed into *Nature, Science, Proceedings of the National Academy of Sciences*, and other mainstream journals. Just being there, they help recruit the media to the good cause. For in order to care deeply about something important it is first necessary to know about it. So let us resume old-fashioned expeditions at a quickened pace, solicit money for permanent field stations, and expand the support of young scientists—call them "naturalists" with pride—who by inclination and the impress of early experience commit themselves to deep knowledge of particular groups of organisms.

Naturalists at heart, conservation biologists in ultimate purpose, they are in every sense of the word modern scientists. Their purview comprises systematics, ecology, and conservation biology, increasingly empowered by methodology for the accumulation and analysis of electronic databases. Their technology expands according to Moore's Law: a doubling of microchip capacity every 18 months. In 1999 a new initiative, Species 2000, set out, at last, to catalog all named species of organisms and thus provide an instantly accessible census of known global biodiversity. In 1999 the Megascience Forum of the Organization for Economic Cooperation and Development (OECD) authorized the creation of the Global Biodiversity Information Facility (GBIF), whose charge is to coordinate and bring on-line all the rapidly accumulating electronic databases for various groups of organisms. The effort will be aided by the growth of regional institutions such as the East Asian Network for Taxonomy and Biodiversity Conservation, headquartered in Seoul, and the Biodiversity Foundation for Africa, based in Bulawayo.

By 2020 or earlier the combined methodology might work as follows. Imagine an arachnologist making a first study of the spider fauna of an isolated Ecuadorian rain forest. He (or she, recognizing with admiration the powerful and growing influence of women scientists in this discipline) sits in camp sorting newly collected specimens with the aid of a portable, internally illuminated microscope. After quickly sorting the material to family or genus, he enters the electronic keys that list character states for, say, 20 characters and pulls out the most probable names for each specimen in turn. Now the arachnologist consults monographs of the families or genera available on the World Wide Web, studying the illustrations, pondering the distribution maps and natural history recorded to date. If monographs are not yet available, he calls up digitized photographs from the GBIF files of the most likely type specimens taken wherever they are—London, Vienna, Sao Paulo, anywhere photographic or electron micrographs have been made—and compares them with the fresh specimens by panning, rotating, magnifying, and pulling back again for complete views. Does this specimen belong to a new species? He records its existence (noting the exact location from his global positioning system receiver), habitat, web form, and other relevant information into the GBIF, and he states where the voucher specimens will be placed—perhaps later to become type specimens. Informatics has thus allowed the type specimens of Ecuadorian spiders in a sense to be repatriated to Ecuador, and new data on its spider fauna to be made immediately and globally available.

The arachnologist has accomplished in a few hours what previously consumed weeks or months of library and museum research. He understands that biodiversity studies advance along two orthogonal axes. First are monographs, which treat all of the species across their entire ranges, and second are local biodiversity studies, which describe in detail the species occurring in a single locality, habitat, or region. When expanded to include more and more groups, local biodiversity studies may eventually cover all local plants, animals, and microorganisms, creating an all-taxa biotic inventory (ATBI), a truly solid base for community ecology in its full complexity.

These cross-cutting databases open new avenues of useful analysis for the conservation biologist. When information on elevation, slope, vegetation cover, soil type, rainfall, and other biotic and abiotic properties of the study site are digitized, overlaid with one another, and matched with similar overlays from the surrounding region, the range of new and rare species can be predicted. At least a good guess can be made about where each in turn is most likely to occur. To single-species searches and mapping can be added the already well-developed technique of gap analysis, in which the overlays include cropland, human habitation, transportation routes, ground and runoff water reserves, and current reserves. With such information available in easily accessible form, regional conservation becomes not only scientifically sound but a great deal easier to achieve in the political arena.

Systematics and natural history also form the requisite empirical base for population viability analyses (PVAs), which are key instruments for predicting the future of species at risk and devising means for pulling them back to safety. Furthermore, PVAs will in time allow the prognosis of exotic species most likely to become invasive, that is, destined to grow from harmless beachhead populations to levels that are economically and environmentally destructive. At the present time we notoriously lack the capacity to identify potential pests such as the zebra mussel, red imported fire ant, green crab, brown tree snake, and miconia before they are irreversibly established. The general public will be unanimously on the side of conservationists in this effort. The zebra mussel alone, while exterminating native mussel populations, also shuts down electrical utilities by clogging water intake pipes. The resulting losses will accumulate, according to the U.S. Fish and Wildlife Service, to 5 billion dollars by the year 2002. This example by itself should have enough weight on the balance sheet to justify major financial support for ecology and conservation biology.

To build encyclopedic hypertexts of systematics and natural history is simultaneously to promote ecotourism, which the governments of many developing countries now see as a principal source of foreign-exchange income. In Costa Rica, for example, tourism with a strong natural-history slant, yielding upwards of a billion dollars a year, has now passed banana and coffee production as the chief source of external income.

Systematics and natural history databases also are obviously necessary for bioprospecting, the search for new pharmaceuticals, agricultural crops, fibers, and other natural products that can be harvested from wild species. The same is true for genes to be used in interspecific transfers, one of the driving forces of the new and future giant industry of genetic engineering.

When large arrays of species are studied for their intrinsic interest, the result is a heuristic surge in basic and applied research in other domains of biology. New phenomena are discovered and research agendas suggested never dreamed of by those with the opposite research strategy, which is to choose a problem within the ambit of existing knowledge and then to search for a species—any species—useful for its solution. Thus, conservation biologists of the coming century will, so long as they draw strength from the groundwork of biodiversity exploration, serve science handsomely and lead humanity toward one of its noblest goals.

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