Knowing the Earth's Biodiversity: Challenges for the Infrastructure of Systematic Biology

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Human survival has always been dependent on our ability to recognize, understand, and utilize biological diversity. However much we learn to manipulate our environment, we cannot escape our dependency on biodiversity for food, medicines, and materials (*1*) or for the ecological services provided by healthy, diverse ecosystems (*2*). Many cultures have devised oral or written classifications of the living world, but the modern science of systematic biology emerged from the practice of collecting and preserving representative specimens in biological collections. The research collections held in systematic biology institutes remain the ultimate source of knowledge about the identity, relationships, and properties of the species with which we share the Earth. Publications and information systems derived from these collections serve to focus and synthesize this knowledge in a readily usable form.

A decade after the National Forum on Biodiversity (*3*) brought issues of biodiversity to the fore, the inescapable need to know more about the diversity of life on Earth remains largely unmet. Numerous reports have highlighted the central role of systematic biology in this endeavor (*4–6*). A recent review of global biodiversity (*7*) makes it clear that knowledge derived from biological collections will affect the quality of life enjoyed in the future by influencing decision-making processes and aiding new discoveries. The tragedy is that while scientific developments heighten the predictive power and relevance of systematic biology, declining funds are limiting the ability of institutes around the world to respond to the widely recognized challenges of documenting biodiversity.

The Work and the Workforce

To date, about 1.7 million out of an estimated 13.6 million species have been identified and described (*6*). Even for mammals, flowering plants, and other groups where the majority of the species are thought to have been discovered, much important work remains in order to establish evolutionary relationships. To harness the predictive power of systematic biology, it is necessary to progress beyond the initial documentation and place each species in context among its nearest relatives. Only then can we make predictions about the occurrence of shared properties, such as drought tolerance or toxicity, in species of particular importance to us. Extending the traditional comparison of form and structure to include DNA sequences is becoming routine and helps systematists to discover natural groups that share a common ancestry.

The global workforce, considered to number about 7000 systematists, is clearly inadequate given the scale of these tasks (*6*). Worse still, opportunities for recruitment appear to be declining (*4, 5*). In Britain, the UK Systematics Forum (*8*) has recently collected information on the qualifications, workplace, age, and expertise of some 600 scientists for a study that will be used in the development of a national strategy for systematic biology research. One clear trend, repeated across Europe, and perhaps elsewhere, is the concentration of systematic effort into specialized institutes such as museums and botanic gardens and a decline in systematists among the academic staff of universities. This pattern has intensified concern about the training of future systematists, and problems are already encountered in recruiting scientists to work on many groups of organisms. Fortunately, impressive results can be achieved when even a small number of universities champion the teaching of systematics. Three new masters degree courses have been developed since the UK National Environment Research Council's (NERC's) Taxonomy Initiative (*9*) began in 1993.

The Geography of Biodiversity and Systematists

It might be argued that, given the imbalance between the distribution of scientists and of biodiversity (*4, 6*), a decline among systematists in the developed countries is best compensated for by the current growth of systematic capacity in tropical countries, where biodiversity is greater. Well-known examples of such expansion are the Instituto Nacional de Biodiversidad (INBio) in Costa Rica, the Herbarium and Museum Zoologicum Bogoriense in Indonesia, and the Comisíon Nacional pare Conocimiento y de la Biodiversidad (CONABIO) in Mexico. The successful contribution of parataxonomists (*10*) to biodiversity inventories has also provided an effective boost to the workforce at the front line. Although some observers have predicted that increased capacity in the developing countries will reduce the importance of the long-established biological collections in developed countries, the opposite is true. The growing demand for knowledge of biodiversity around the world heightens the significance of the established collections. It remains a fact that the best place to begin to create a national inventory of biodiversity is in the world's major biological collections rather than an immediate excursion into the field. In these collections it is possible to capitalize on centuries of investment in exploration, curation, and research. Access to well-identified and carefully curated specimens, especially type specimens (*11*), is essential for the accurate identification of all but the best known species. To provide such access to those who need it presents one of the greatest obstacles to progress in discovering and classifying biodiversity. Computerized information systems can readily replace handwritten catalogs or card indices and can store images and data as an alternative to the direct consultation of specimens and libraries. The arteries of the information superhighway can provide intercontinental accessibility. The technology exists but the resources do not!

As the millennium draws to a close, the principal barrier to the provision of globally available information systems for the species so far known and preserved in systematic biology collections is the cost of transferring information to computerized media. Financing the creation of such information systems is beyond the resources of the institutions that possess the knowledge base of specimens and expertise, and there are no obvious alternative funding mechanisms. Agencies that fund research consider the task insufficiently innovative, whereas development funds, such as those of the Global Environment Facility, are targeted directly to developing countries. The irony is that all countries stand to benefit from global biodiversity information systems comprising distributed, but interconnected, databases.

The lack of such information systems hampers progress on many fronts, including the development and implementation of National Biodiversity Action Plans and the quest for new biological resources. In the absence of precise information about biodiversity, there may seem to be little alternative to generalizations and assumptions based on "functional species." Valuable though such concepts are for some purposes,

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they are a poor proxy for knowledge about species and do not, for example, facilitate the utilization of new genetic resources from biodiversity (*1*, *10*).

What Needs to Happen?

Many reports have highlighted the urgent need for a dramatic increase in the scale of effort directed toward knowing the Earth's biodiversity (*4*, *7*). New funds need to be channeled into efforts that meet the most pressing needs. Some of the priorities are clear, but there has been little structured research into the future requirements for systematic information. To meet this need and to enable the development of a national strategy for systematic biology research, the UK Systematics Forum now plans to conduct a market survey among the many user communities. The users are extraordinarily diverse. Systematics impacts upon many areas of basic science, especially ecology, but it also contributes to wealth-creating industries and the quality of life. New organisms and new genes are sought by agriculture, horticulture, and the pharmaceutical industry. Conservation is an increasingly precise science with a growing requirement for systematic input. Knowledge of the identity and relationships of disease organisms and their vectors is required to counter present and future health threats.

Whatever the detailed findings of this survey, systematic biology must coordinate its activities at an international level, not merely nationally, to achieve its full potential. The term "taxasphere" has been coined by Dan Janzen (*10*) to refer to the global community of systematists, who hold the key to providing knowledge about biodiversity. For the taxasphere to become a reality rather than remain simply a notion will require coordination and strategic planning. It will require research effort to be targeted toward the groups, habitats, and regions for which information is most urgently needed. Curiosity alone will not identify the priorities. Concerted efforts will be needed to train systematists for groups in which expertise is scarce or lacking. The establishment of an international program for systematics might best begin with an International Year of Biodiversity, convened to focus global efforts. The existing International Biosphere–Geosphere Program cannot do this because it is concerned with modeling global processes at the highest level, not with discovering global richness at the species level.

Changes will not come without new resources. One of the most pressing priorities is for financial instruments to facilitate access to information held in the world's major collections. Financing the infrastructure of science is often problematic. Governments and international development agencies should realize that investing now in computerizing systematic biology collections will pay dividends now and in the future. Until species information, based firmly on reference specimens, is readily available on the Internet, those engaged in practical projects directed toward the sustainable management or conservation of our environment and living resources must make do with inadequate approximations.

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8. The UK Systematics Forum is funded by the Office of Science and Technology as part of the government response to the 1992 House of Lords report (*5*). It has a committee drawn from institutes with substantial biological collections and is available on the Internet at http://www.nhm.ac.uk/uksf/
9. The NERC Taxonomy Initiative started in 1993, following a report by J. Krebs [*Evolution and Biodiversity: the New Taxonomy* (NERC, 1992)] in response to the 1992 House of Lords report (*5*).
10. D. H. Janzen, *Am. Entomol.* **37**, 159 (1994); in *Proceedings of the Norway/UNEP Expert Conference on Biodiversity, Trondheim, Norway*, O. T. Sandland and P. J. Schei, Eds. (NINA, Trondheim, 1993), pp. 100–113; *Association of Systematic Collections Bulletin*, in press.
11. Type specimens are the reference specimens to which the application of a particular species name is anchored.

12. This Policy Forum is based on a presentation at the symposium on "The Science of Biodiversity" organized during the AAAS 1996 Annual Meeting and Science Exposition by A. Roosevelt and P. R. Crane.