CHARTING THE BIOSPHERE: BUILDING GLOBAL CAPACITY FOR SYSTEMATICS SCIENCE

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MANAGING THE BIOSPHERE: THE ESSENTIAL ROLE OF BIODIVERSITY SCIENCE

About 175 nations have ratified the Convention on Biological Diversity and thereby signaled their intention to strive, in principle, for a sustainable world. This raises a simple question: Do we possess sufficient scientific information about the biosphere to manage it sustainably, even assuming that the political will for doing so exists? The answer to this question clearly is no.

That being the case, the pessimists among us might claim that we now live in the best of all possible worlds with respect to what we know versus what we need to know. The pessimists would therefore argue that our ignorance can only get worse as the global trends of environmental transformation accelerate, because as the world's ecosystems get more and more degraded and destroyed, it will require an increasing amount of knowledge to put things back together again and to make up for the lost goods and services provided by these biotic landscapes.

At the other extreme, the optimists among us might claim that, given a political imperative to use our biological resources sustainably, we already have a sufficiently large body of knowledge, and if only it were made available to the world's nations, resource management could become much more efficient and cost-effective and move us far in the direction of sustainability.

Contributing to the pessimists' view is the fact that the world community, sometimes including scientists who study biodiversity, often fails to recognize how much knowledge it will require to manage the biosphere to the point where it can provide meaningful and healthy lives for the world's people into the future. Obviously, scientific information is not sufficient by itself to right the world's environmental wrongs, but it is essential (Cracraft 1996). Several vignettes will emphasize this point.

First, the United States spends more money each year on environmental science than any other country, yet the evidence suggests that we are not managing our lands sustainably (PCAST 1998). Although much of the reason for this lies in a political-economic imperative to exploit our resources for short-term gains, an insufficiency of scientific knowledge has hindered proper management in many cases (NRC 1993a,b). Land managers are continually saying that they lack sufficient knowledge about the resources under their stewardship. One has only to examine how forest lands are being managed in North America to see the extent to which that insufficiency contributes to inappropriate land management (papers in Kohm and Franklin 1997; Pickett and others 1997).

Second, we are not the world. Many of us live in industrial economies that are privileged beyond belief. Much of the world, in contrast, is relatively poor and lacks even the rudiments of decent scientific infrastructure (Cracraft 1995). It is said that countries housing 80% of the world's biodiversity have only about 6% of the world's scientists. We can quibble about the numbers, but the observation is correct enough to make the point: Most of the world's nations will not have a reasonable chance of achieving a sustainable future unless knowledge about their natural resources is improved dramatically and quickly. Consider one simple example. In a recent perspective on biological research efforts in Serengeti National Park, Sinclair (1995) listed numerous gaps in basic biological knowledge of that system that impede efforts at effective resource management. Not knowing the causes of death in the wild dog (*Lycaon pictus*), for instance, hinders any informed design for its recovery program. Given that the Serengeti is probably the most thoroughly studied protected area in Africa, the obvious question is, What about the protected areas in other countries of that magnificent continent? Where will the biological knowledge to manage those ecosystems come from? If Serengeti is taken as an exemplar of the amount of knowledge that will be required to achieve effective conservation management, it is difficult to believe that inputs of researchers and financial support from developed countries will ever be sufficient to address similar needs in other parts of Africa. The only solution is to see the capacity in each country increase.

Third, because it is exceedingly difficult to comprehend the extraordinary dependence of most of the world's people on natural ecosystems, we tend to underestimate the magnitude of the problem confronting us. Around the world, people use tens of thousands of species to meet their daily needs. If these uses are to be managed in a sustainable manner, much more biological information will be required than the scientific community can deliver today. And, to emphasize the depth of the problem, that information will generally have to be gathered at, and applied to, the local level, much like the information needed for the wild dog in the Serengeti. We cannot expect to accumulate knowledge in some abstract database and not have it mean something to the people whose livelihoods and future depend on it.

Scientific knowledge of biodiversity must accumulate year after year if the biosphere is to be managed effectively. The health of the world's people, their food supply, and the ecological services provided by intact ecosystems are all threatened when knowledge of biodiversity does not advance.

One way of seeing the need is to do a simple thought experiment. Ask what might be the consequences for society if systematics knowledge had been frozen 40 years ago, with no new advances allowed. Here are some examples:

- Society would be without the benefit of all the agricultural systematics research that has mitigated the devastating effects of pests and invasive species over the last 40 years.
- Society would be without an understanding or identification of many vectors of disease that were discovered during this period.
- There would be no knowledge about many of the newly emergent diseases that have ravaged human societies, AIDS being the most pernicious.
- Medical science and biotechnology would be years behind current levels because the thermophilic bacteria that have made possible the polymerase chain reaction and all its benefits for diagnostic medicine would not have been discovered.
- None of the wild crop relatives that were discovered in the last 40 years would be available for improving our foods.

This demonstration of the importance of systematics to society could be expanded easily (*Annals of the Missouri Botanical Garden* 1996; *Biodiversity and Conservation* 1995; *BioScience* 1995; Cotterill 1995; Janzen 1993; Miller and Rossman 1997; Patrick 1997; Systematics Agenda 2000 1994a,b; Thompson 1997). The other biodiversity sciences are equally important for society, and "freezing" their knowledge at what it was 40 years ago would have similar adverse consequences. In ecology, for example, we would lack much of the basic science that has underpinned the new disciplines of landscape ecology, restoration ecology, and conservation biology. Without that knowledge, managing our biosphere would be essentially impossible.

Investment in biodiversity science—even what is often thought to be mundane, unexciting, or old-fashioned—is one of the best investments society can make for its long-term well-being. The poor old systematist toiling over the discovery, description, and identification of groups of insect pests or disease vectors potentially will contribute as much to society, in saving millions of lives and billions of dollars, as will most so-called modern research. We need to cherish and nourish all biodiversity scientists because our future depends on them (Cracraft 1996).

SYSTEMATICS-SCIENCE CAPACITY: WHAT IS IT?

Systematics is the most fundamental of the biodiversity sciences inasmuch as it is concerned with discovering, describing, and monographing Earth's species diversity. Like most sciences, systematics can be defined by its research questions and objectives. Within systematics, taxonomy is the science of discovering, describing, and classifying species and groups of species; phylogenetics is the discipline that attempts to understand the evolutionary (historical) relationships among species and groups; and classification is the means by which that understanding is translated into hierarchical (Linnaean) groupings and information systems that form the basis for effective communication about life's diversity (Systematics Agenda 2000 1994a,b).

Given that broad view of the systematics enterprise, systematics-science capacity can be taken to include all the components of infrastructure and human resources that support the systematics research effort and make its results available to those who need them. The most important infrastructure relevant to systematics is specimen-based collections housed in systematics research institutions of various kinds (Cotterill 1995, 1997). The world's collections contain over 2 billion specimens, and these constitute society's only permanent record of Earth's biodiversity. Collections take many forms, and for systematics to flourish, systematists must have access to them: natural-history museums, herbariums, frozen-tissue collections, seed banks, type-culture collections, and, for some types of studies, living material in zoos and botanical gardens. Systematics infrastructure includes the computational means to store information about collections, particularly the information associated with specimens; to analyze character-based information for phylogenetic analysis; and to facilitate communication with systematists at other institutions. Infrastructure also includes libraries through which a researcher can obtain access to prior systematics work and facilities for training of professional and paraprofessional scientists and support staff; these constitute the human resources needed for systematics research.

Systematics collections serve a much broader role than providing a basis for scientific research, and it is the broader role that is often important for many countries (Cotterill 1997). Through their exhibits and other programs, collection-based institutions, such as museums and botanical gardens, are essential in educating the public about the benefits of, and threats to, biodiversity. These institutions also are sites for formal science education of people as varied as young schoolchildren, professionals, and paraprofessionals. Little of this could take place without the scientific collections that form the foundation of educational programs.

AN AGENDA FOR SYSTEMATICS

Earth's biodiversity is poorly known. Although 1.7 million species have been recognized and described (Hammond 1995; Heywood 1995; May this volume), many specialists think that tens of millions of species are unknown to science. Our understanding of the relationships of these taxa is still in its infancy, but it is this understanding that serves as an organizing framework for information systems useful to both basic and applied biology. The world's natural-history collections house a treasury of biodiversity information associated with their specimens; for the most part, very little of this information is available digitally to the world user community (Blackmore 1996; Systematics Agenda 2000 1994a,b).

SYSTEMATICS-SCIENCE CAPACITY IN THE DEVELOPING WORLD

Countries differ greatly in their capacity to undertake research in systematics. Recent compilations in the UN Environment Program's *Global Biodiversity Assessment* (Heywood 1995) describe the global patterns of numbers and sizes of plant collections and numbers of institutions that house collections of various sorts (museums, zoos, aquariums, and botanical gardens); these patterns can be expected to reflect the general level of systematics capacity in each country and among regions. Figure 1 summarizes the numbers for six regions. Europe and North America, not unexpectedly, have the highest capacity, followed by Asia. South America, Australasia, and Africa have the least capacity. It is enormously difficult to obtain accurate numbers because such collections are defined, counted, or estimated in different ways; but the figure shows the pattern mentioned earlier: the species-rich areas of the world have the least capacity. The situation could be even worse than the figure suggests; within many of these regions, one country, such as South Africa within Africa or Australia within Australasia, dominates the statistics. Many countries lack the rudiments of capacity, and a surprising number have no botanical or zoological collections.

The numbers of natural-history collections, zoos, and other infrastructure also constitute a measure of the availability of scientists and training facilities essential

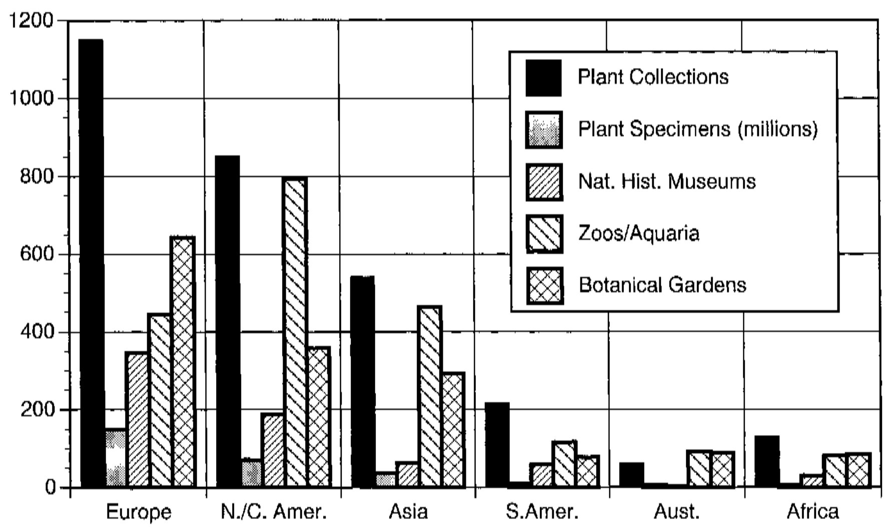

FIGURE 1 Systematics capacity can be measured by numbers of natural-history collections, here categorized into six regions: Europe, including former Soviet Union; North America and Central America; Asia, including China, southern and southeast Asia, and Japan; South America; Australasia and Oceania; and Africa. For all regions except Europe, single country dominates numbers. This means that systematics capacity in other countries in those regions is worse than implied by regional numbers alone. As measured by these collections, regions with least capacity include most island nations, Africa, Central America, eastern Europe, and countries making up former Soviet Union.

for developing human resources. The numbers indicate that many regions of the world lack adequate capabilities for professional and paraprofessional training.

As mentioned earlier, systematics capacity in the developing world is inadequate to confront the loss of biodiversity and to serve as a basis for its effective management as a resource for sustainable development. At the same time, systematists recognize that systematics capacity in the wealthy countries is incapable of filling the need. In fact, systematics capacity in the developed nations is barely adequate—many authorities would say totally inadequate—to meet those countries' own demands for systematics information (Blackmore 1996; Oliver 1988; Parnell 1993; Systematics Agenda 2000 1994a,b). We have no choice but to develop systematics capacity in all nations, particularly in the species-rich regions where the need is greatest.

AN OVERVIEW OF SYSTEMATICS AGENDA 2000 INTERNATIONAL: BUILDING A GLOBAL SCIENCE INITIATIVE

Many international organizations have called for a more thorough understanding of life's diversity through increased systematics research. It is generally estimated that we know perhaps 5% of Earth's species. Given that current knowledge and use of the known species generate trillions of dollars of economic activity—indeed, that use is the engine of the world economy—and sustains the lives of all of us, it is reasonable to expect that substantial increase in knowledge of the world's biota will add immeasurably to societal well-being in the form of new uses and benefits. The international biodiversity science program, DIVERSITAS, has recognized the need for increased research in systematics. Thus, systematic biology was recently added as a core research element of the program. Filling that role is Systematics Agenda 2000 International (SA2000I). Systematics Agenda 2000 began as a consortium of systematics societies in the United States but has expanded internationally as a program of the International Union of Biological Sciences and as a component of DIVERSITAS (Blackmore and Cutler 1996).

The activities of SA2000I are organized around three broad missions encompassing the major research fields of systematic biology: inventorying and describing of biodiversity, understanding the history of life, and using that understanding to create predictive classifications and information systems for the world user community. Since its inception, SA2000I has advanced the view that systematics knowledge of life's diversity is essential to ensure societal well being. To fulfill this societal role, systematics must solve the problem of expansion of relevant infrastructure and human resources, especially in countries that now have little or no capacity.

Inventory

Inventories are at the heart of the global discovery effort, but many countries are ill equipped to take stock of their biological heritage according to their own needs and priorities. In an effort to correct that, SA2000I held a workshop on inventories at the American Museum of Natural History, New York, in September

1998. The workshop was designed to assess country requirements for inventories, establish how priorities can be set to meet inventory needs, determine the best research strategies to satisfy country goals, and undertake an assessment of current capacity. The workshop also addressed issues and strategies for building capacity (AMNH 1999).

Phylogeny

Knowledge of phylogenetic relationships is often seen as an academic exercise of little practical importance. In fact, phylogenetic hierarchies are the foundation for creating the predictive classifications and information systems that are of immeasurable value to society. The use of biodiversity is made possible by understanding where a taxon belongs in the hierarchy and how its characteristics compare with those of close relatives. Indeed, at some level, all uses of biodiversity depend on knowledge of phylogenetic relationships and how they are translated into information systems.

Although systematists have made major strides in the last decade in understanding the interrelationships of life, corroborated hypotheses of relationships are still lacking for most groups, including some of the best studied, such as birds and mammals. That lack of understanding constitutes a critical impediment to developing efficient information systems. Phylogenetic research is global in its perspective; given the rate at which phylogenetic relationships are being resolved and the uncoordinated nature of present research, it will take many decades to achieve a satisfactory overview of the history of life. Such a delay will hinder our efforts to build bioinformatics systems that are maximally predictive—a goal that is integral to the clearinghouse mechanism of the Convention on Biological Diversity.

To address this need, SA2000I will be organizing an international research effort to produce a corroborated phylogeny of the higher taxa by the year 2010. This will be accomplished by coordinating research activities within and among working groups of investigators focusing on specific major taxa, with priority given to those of high societal importance. SA2000I's international research effort will also be concerned with incorporating new technologies, such as those associated with the Human Genome Project, and with building capacity for phylogenetic research in countries that lack it.

Systematics Bioinformatics

SA2000I has major efforts under way to improve the accessibility of systematics information. The research program on phylogenetics will contain a component on how phylogenetic information can be made widely available. A very successful effort within SA2000I and DIVERSITAS is Species 2000, an international initiative to assemble a scientifically reliable database of all the world's currently described species in a framework that links species names to other databases that house information about them. This program is of immense importance for managing what we know about biodiversity.

The systematics community recognizes that a major impediment to managing and sustainably using biodiversity is that the vast majority of the information associated with the specimens housed in the world's natural-history institutions is unavailable to users of systematics information. Many museums and herbariums are making an effort to put their collections on databases, but for the largest institutions this is a formidable and expensive task. The costs of verifying the information and maintaining it electronically are also high. Yet, the benefits of this information to the world's nations are too substantial to ignore. The industrial nations, which house 80–90% of all the biological specimens, have an obligation to repatriate the information so that it can be used for resource management and other activities. How to overcome the many challenges, particularly in terms of costs and effective information management, has not been addressed sufficiently at the international level.

BUILDING SYSTEMATICS CAPACITY: SOME EXAMPLES

What strategies should be adopted to confront current impediments to building systematics science internationally and to redress the imbalance in capacity between the developed and the developing countries? Two general things must happen. First, the wealthy countries must increase their commitment to promoting systematics. This includes not only increasing their own scientific research and capacity, but also ensuring that those programs benefit developing countries as well (for example, through training); and they must increase aid targeted to building and improving systematics capacity in developing countries. Second, the developing countries must do more to help themselves. Even if needed financial resources ultimately come from outside, developing nations must recognize the importance of systematics for their future prosperity and seek ways to increase its capacity.

Many positive things are happening, of course. The world's nations, through the Convention on Biological Diversity and its Global Taxonomy Initiative (Australian Biological Resources Study 1998; Environment Australia 1991), have acknowledged the critical role of systematics and have called for countries to increase their capacity. Funding for systematics has increased in many developed countries, and that has provided benefits to nations in developing regions as well. And many developing nations have themselves initiated programs to increase systematics capacity. A number of these efforts are worth highlighting because they provide models for other countries in their efforts to create or improve systematics capacity. The projects discussed below are by no means the only successful initiatives, and a particular example might not be the most effective or appropriate for another country, but they encompass an array of different approaches.

Costa Rica: INBio. The Instituto Nacional de Biodiversidad (INBio) of Costa Rica was established in 1989 and has gained worldwide renown for its program of national biodiversity inventory, bioprospecting, and training (Reid and others 1993). Inventory efforts not only are designed to increase knowledge of the Costa Rican biota and to incorporate it into electronic databases, but also are a major component of the country's bioprospecting efforts. Costa Rica is taking a lead role in transferring its successes to other tropical countries through training workshops. [For a more detailed description, see Gámez this volume.]

Mexico: CONABIO. In 1992, Mexico established the Comision Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) to coordinate and promote research activities in many Mexican institutions. A major objective of CONABIO is to inventory the biota of Mexico; to accomplish this, CONABIO has begun to form databases and network its own national collections and has sent scientists to museums and herbariums around the world to create databases of Mexican specimens in these collections. The result is one of the most comprehensive geo-referenced sets of biodiversity information linked to voucher specimens found anywhere in the world. [See Soberón this volume for a description.] In addition, CONABIO has major programs designed to train professional and paraprofessional taxonomists.

Indonesia: LIPI. To meet its obligations under the Convention on Biological Diversity, Indonesia has undertaken an ambitious Global Environmental Facility project designed to increase systematics capacity and provide a framework for documenting and managing its biodiversity. Through the Research and Development Center of Biology in the Indonesian Institute of Sciences (LIPI), a non-departmental government institution, infrastructure and human resources are being strengthened. New collections and research facilities are being built, and an intensive program of training of professional systematists at overseas institutions has begun. In addition, information associated with specimens is being put into databases, and computer facilities are being expanded to provide managerial support for the collections.

Bangladesh: National Herbarium. Another example of building systematics capacity is the construction of the new Bangladesh National Herbarium. The government of Bangladesh included a new herbarium in its aid proposal to the United Kingdom's Overseas Development Administration (ODA) in 1989. The project was accepted, and ODA (now the Department for International Development) asked systematist Vernon Heywood to act as consultant to plan the building, equip it, and set up a staff training program. The UK contribution to the project is over £1.2 million (US $2 million), and the government of Bangladesh covered the cost of site preparation. The project includes, in addition to the new herbarium building, laboratories, a library, and modern equipment and electronic communication systems. For its part, the government of Bangladesh is providing running costs, a scientific staff of 14, and technical and support personnel. The herbarium opened in 1998, and already there are plans to expand its original scope. This effort is noteworthy in that it was possible with little initial investment to create a locus for infrastructure-building and capacity-building that will extend well into the future.

Southern Africa: SABONET. A final example is the Southern Africa Botanical Network (SABONET), a consortium of the herbariums in 10 southern African nations. Supported by funds from the Global Environmental Facility (GEF) and the US Agency for International Development, SABONET is building capacity through improved and expanded infrastructure, training, inventorying, databases, and information networks. A major goal of the project is to strengthen the core group of professional and paraprofessional botanists in each of the 10 countries so that programs of inventorying and monitoring can be undertaken, collection management strengthened, and training expanded.

RECOMMENDATIONS FOR BUILDING SYSTEMATICS CAPACITY

These are encouraging times for systematics (Scoble 1997). The preceding examples show that many countries are improving their systematics capacity dramatically. But much remains to be accomplished. Most countries in the species-rich regions of the world have little capability for systematics research and training, and wealthy countries, although providing support through various national or international aid agencies, are not providing sufficient support to have a major effect in most of the poorer countries.

The various activities described above provide a framework for formulating some recommendations that have relevance for countries that wish to improve their systematics capacity, even if sometimes it must be at a relatively low level (see also AMNH 1999; Wheeler and Cracraft 1997).

Regional Cooperation

The significance of SABONET is that it shows how a regional cooperative program can synergistically improve the capacity and scientific knowledge base of many countries for less money than would be required if it were undertaken country by country. Such cooperative ventures also raise the capacity of countries that have the least capacity to the point where they might be able to pursue systematics programs independently. SABONET began in the scientific community itself and shows what can result when scientists in different countries work together. Such regional cooperation makes sense, especially because many of the countries lack sufficient capacity to undertake research or training programs on their own. No country can house all the necessary expertise, but regional cooperation and sharing of information are possible. This can be particularly effective if the countries involved share a regional, ecologically coherent biota. That would be true, for example, of the countries in East Africa, the countries of Central Africa that share the Congo Basin, countries in West Africa, the Andean countries of South America, and countries that share the Amazon Basin.

Building Capacity within Countries

The previous discussion described how different countries have found distinct ways of improving systematics capacity. Some, such as Indonesia, have undertaken major programs to improve their national systematics collections. Others, such as Mexico, have attempted to enhance cooperation and coordination among existing collections. CONABIO, moreover, has invested a relatively small sum of money to form databases of collections in other countries and has thereby substantially expanded its systematics knowledge base and its ability to manage Mexico's biological resources.

Individual countries can take the initiative to seek donor funds to improve systematics capacity. Most of the countries discussed have sought GEF funding or are in partnership with donor countries. In many poor countries, a relatively small amount of money can have a large long-term effect. The creation of the Bangladesh National Herbarium is a case in point, and such cooperative programs can lead to long-term commitments on the part of the recipient nations to maintain human resources and training.

Many aid proposals from developing countries could include a systematics research component that would establish or upgrade their capacity to preserve in natural-history institutions a permanent record of their biological diversity. Such collections would also provide key support for long-term monitoring and management programs. A particularly cost-effective approach to incorporating systematics information into biodiversity activities would be to emulate the example of CONABIO and seek funds to form databases of collections that have large holdings of specimens, which could then be used in electronic databases for management purposes.

The Role of the Wealthy Countries

Wealthy countries must do more. Small programs in wealthy countries can have large effects. The United Kingdom's contribution to building the Bangladesh National Herbarium is an important example. In the United States, the National Science Foundation initiated a short-term competition, Partnerships for Enhancing Expertise in Taxonomy (PEET), designed to improve systematics knowledge of little-known and neglected taxa and to train new students in them. A small number of funding cycles have already had a substantial impact, and continued support is certain to produce a pool of expertise that will have a long-term and worldwide influence because many of the students being trained are from developing countries.

Wealthy countries need to make a substantial contribution to building worldwide systematics capacity. Perhaps no other initiative would be as effective as providing funds for compiling databases of the largest natural-history collections and making that information available to other countries.

The Role of Systematists

Very few of the activities described above could have taken place without the leadership of the systematics community itself. Scientists must convince policymakers of the importance of systematics research and systematics infrastructure and work with them to design effective programs. Such programmatic activities as DIVERSITAS and SA2000I will be particularly helpful in providing a framework for promoting systematics within countries and establishing regional consortia.

ACKNOWLEDGMENTS

I thank Peter Raven for his inspiration and leadership in pulling the Forum on Biodiversity together and for inviting me to participate. I am grateful to Vernon

Heywood for sharing information about the Bangladesh National Herbarium. Tania Williams and the staff of the National Research Council provided considerable help, for which I am appreciative.

REFERENCES

AMNH [American Museum of Natural History]. 1999. The global taxonomy initiative: using systematic inventories to meet country and regional needs. New York NY: Center for Biodiversity and Conservation, American Museum of Natural History.

Australian Biological Resources Study. 1998. The global taxonomy initiative: shortening the distance between discovery and delivery. Australian Biological Resources Study. Canberra Australia: Environment Australia. 18p.

Annals of the Missouri Botanical Garden. 1996. The Systematics Agenda 2000 Symposium. Ann Missouri Bot Gard 83:1–66.

Biodiversity and Conservation. 1995. Special issue: Systematics Agenda 2000. Biodiv Cons 4:451–519.

BioScience. 1995. Special issue: systematics. BioScience 45: 670–714.

Blackmore S. 1996. Knowing the Earth's biodiversity: challenges for the infrastructure of systematics biology. Science 274:63–4.

Blackmore S, Cutler D. 1996. Systematics Agenda 2000: the challenge for Europe. Linn Soc Occas Publ No 1. Cardigan UK: Samara Pub Ltd.

Cotterill FPD. 1995. Systematics, biological knowledge and environmental conservation. Biodiv Cons 4:183–205.

Cotterill FPD. 1997. The second Alexandrian tragedy, and the fundamental relationship between biological collections and scientific knowledge. In: Nudds JR, Pettitt CW (eds). The values and valuation of natural science collections. London UK: Geological Soc. p 227–41.

Cracraft J. 1995. The urgency of building global capacity for biodiversity science. Biodiv Cons 4:463–75.

Cracraft J. 1996. Systematics, biodiversity science, and the conservation of the Earth's biota. Verh Dtsch Zool Ges 89(2):41–7.

Environment Australia. 1998. The Darwin declaration. Australian Biological Resources Study. Canberra Australia: Environment Australia. 14 p.

Hammond PM. 1995. Described and estimated species numbers: an objective assessment of current knowledge. In: Allsopp CD, Colwell RR, Hawksworth DL (eds). Microbial diversity and ecosystem function. Wallingford UK: CAB Intl p 29–71.

Heywood VH (ed). 1995. Global biodiversity assessment. Cambridge UK: Cambridge Univ Pr.

Janzen DH. 1993. Taxonomy: universal and essential infrastructure for development and management of tropical wildland diversity. In: Sandlund OT, Schei P (eds). Trondheim Norway. Proc Norway/UNEP Expert Conf Biodiversity. p 100–13.

Kohm KA, Franklin JF. 1997. Creating a forestry for the 21st century. Washington DC: Island Pr.

Miller DR, Rossman AY. 1997. Biodiversity and systematics: their application to agriculture. In: Reaka-Kudla ML, Wilson DE, Wilson EO (eds). Biodiversity II. Washington DC: Joseph Henry Pr. p 217–29.

NRC [National Research Council]. 1993a. Research to protect, restore, and manage the environment. Washington DC: National Acad Pr.

NRC [National Research Council]. 1993b. A biological survey for the nation. Washington DC: National Acad Pr.

Oliver JH Jr. 1988. Crisis in biosystematics of arthropods. Science 239:967.

Parnell J. 1993. Plant taxonomic research, with special reference to the tropics: problems and potential solutions. Cons Biol 7:809–14.

Patrick R. 1997. Systematics: a keystone to understanding biodiversity. In: Reaka-Kudla ML, Wilson DE, Wilson EO (eds). Biodiversity II. Washington DC: Joseph Henry Pr. p 213–6.

Pickett STA, Ostfeld RS, Shachak M, Likens GE. 1997. The ecological basis of conservation. New York NY: Chapman & Hall.

PCAST [President's Committee of Advisors on Science and Technology]. 1998. Teaming with life: investing in science to understand and use America's living capital. Washington DC: Office of Technology Assessment. 86 p.

Reid WV, Laird AL, Mayer AM, Gamez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C. 1993. Biodiversity prospecting: using genetic resources for sustainable development. Washington DC: World Resources Inst.

Scoble MJ. 1997. The transformation of systematics? Trends Ecol Evol 12:465–6.

Sinclair ARE. 1995. Serengeti past and present. In: Sinclair ARE, Arcese P (eds). Serengeti II. Chicago IL: Univ Chicago Pr. p 3–30.

Systematics Agenda 2000. 1994a. Systematics Agenda 2000: charting the biosphere. New York NY: Systematics Agenda 2000, a consortium of the American Society of Plant Taxonomists, the Society of Systematics Biologists, and the Willi Hennig Society in cooperation with the Association of Systematics Collections. p 1–20.

Systematics Agenda 2000. 1994b. Systematics Agenda 2000: charting the biosphere. Technical report. New York NY: Systematics Agenda 2000, a consortium of the American Society of plant Taxonomists, the Society of Systematics Biologists, and the Willi Hennig Society, in cooperation with the Association of Systematics Collections. p 1–34.

Thompson FC. 1997. Names: the keys to biodiversity. In: Reaka-Kudla ML, Wilson DE, Wilson EO (eds). Biodiversity II. Washington DC: Joseph Henry Pr. p 199–211.

Wheeler QD, Cracraft J. 1997. Taxonomic preparedness: are we ready to meet the biodiversity challenge? In: Reaka-Kudla ML, Wilson DE, Wilson EO (eds). Biodiversity II. Washington DC: Joseph Henry Pr. p 435–46.