J. Nat. Conserv. 10, 145–153 (2002)

http://www.urbanfischer.de/journals/jnc

Journal for
Nature Conservation

The role of taxonomy in conserving biodiversity

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Key words: Biodiversity, taxonomy, conservation priorities, biotechnology.

Introduction

No conservationist doubts that taxonomy is an essential tool for understanding biodiversity, as it provides the organising principle for thinking about this vast topic. Thus the reawakening of interest in this scientific discipline is very welcome. Two recent major scientific-technical advances will make taxonomy an even more useful tool for conservation in the coming years.

The first advance has been in genetics, or rather genomics. The unravelling of the genetic code of numerous species, not least of them *Homo sapiens*, has made the previously-arcane science of genetics much more accessible. We soon will be able to determine the DNA of any species relatively quickly and inexpensively. Within a decade or so it may be simpler to extract enough sequence data from an individual organism to assign it to a "sequence cluster" (equivalent to species) than to key it out using traditional methods. DNA assessment through polymerase chain reaction (PCR) has doubled the number of known major divisions within life's two prokaryotic domains, Bacteria and Archaea (Boucher and Doolittle 2002). Just as bacterial taxonomy is now nearly all sequence-based, new ways of classifying insects, nematodes and perhaps even many plants and fish might be developed that are quite different from current taxonomy (Godfray, 2002). DNA-based taxonomy may provide new and unexpected insights into mammals and birds as well, for example the recent finding that the duck-billed platypus (an egg-laying mammal) is far more closely related to marsupials than was formerly thought (Penny and Hasegawa 1997).

The second advance is in microchip-based information management, as Moore's Law (which states that the storage capacity of microchips will double and the price will be reduced by half every 18 months) continues to hold. This means that a field biologist soon will be able to store all necessary taxonomic information on an instrument as small as a Palm Pilot or Pocket PC, enabling him or her to instantly identify every species encountered, assess its taxonomic relationships, and retrieve relevant ecological, morphological, economic and conservation information. And as digital cameras become the norm, it will be easy to make taxonomy increasingly more visual, and hence even more accessible.

Museum-based taxonomists, too, are benefiting from this revolution, with an increasing number of museums and botanical gardens automating their specimen collections, and providing facilities for remote access, improving coordination of collections at universities that support teaching and research, improving linkages between collections in different institutions, and helping to generate new distribution maps at a speed that was previously impossible (Cohn 1995).

Numerous current efforts to put taxonomy on the Web demonstrate the feasibility of this technology, including the International Plant Name Index (www.ipni.org); the Tree of Life Project (www.tolweb.org/tree), which provides phylogenies; the Integrated Taxonomic Information System (www.itis.usda.gov); the Global Biodiversity Information Facility (www.gbif.org); http://species analyst.net, a search engine to access multiple data bases of specimen information from collections located throughout North America; and the All Species Foundation (www.all-species.org) which intends to make an inventory of all species on earth within the next 25 years. It is perhaps worth noting parenthetically that this task may seem less daunting now than it did just a few months ago, because it appears that the number of species is actually manageable, perhaps closer to 10 million than the 100 million that some have speculated (Novotny et al. 2002).

The revolutionary advances in genetics and information management are enabling the vast amount of

1617-1381/02/10/03-145 $ 15.00/0

data generated from biological specimens to be organised, managed, and converted into useful biological knowledge. We can reasonably expect these technologies to continue to expand in speed, sophistication, storage capacity, and application, while declining in price. Thus the re-invigorated information science of taxonomy can help to open up many new areas of research and application, providing a significant boost to field biology. We all need to strongly push the practical application of these two technologies to the major biodiversity challenges facing modern society.

Why is taxonomy critical to conservation action?

Historically, conservation has focused on charismatic species or major vegetation types. With the advent of biodiversity as a conceptual tool, more comprehensive approaches are now coming into vogue. Under the Convention on Biological Diversity, Parties have agreed to take an ecosystem approach to conservation, requiring a more sophisticated system for classifying ecosystems, building better understanding of the habitat requirements of a diverse array of species, enhancing understanding of successional stages within ecosystems, and seeking to conserve entire assemblages. This will require harnessing taxonomic expertise across a wide variety of organisms. For example, Hunter and Webb (2002) outline some simple methods for professional and amateur lichenologists to gather and present lichen data in a way that will make their expertise useful to conservation activities. These approaches for systematically gathering and analysing useful data include time- and area-constrained searches, recording abundances, listing common as well as threatened species, using "control" areas, and characterising the environmental context of each survey site. While the particular methods they describe are for surveys of lichens, the approach is also directly relevant to other types of surveys and the general principles are relevant to all species surveys designed to inform conservation efforts. The basic point is to provide a structure to the field work of both professional and amateur field biologists, in helping to ensure that the taxonomic and ecological data generated by these field taxonomists can make the strongest possible contribution to conservation efforts.

First things first: describing life on earth

Alpha taxonomy, the discovery, description and classification of species, is essential to the answering of such crucial ecological questions as the spatial organisation of genomes, species and communities. Such work needs to continue and accelerate. It is over-optimistic to hope that we can one day describe all life on earth?

In advocating an inventory of the complete taxonomic richness of one particular site, Janzen and Hallwachs (1993) contend that this will enable the complexity of wildland biodiversity to become "a life-enriching stimulus and an engine of economic development. Without this understanding, wild biodiversity is only a dull green obstacle to humanity's domesticates and a deteriorating sponge for human waste. Taxonomy and inventory are basic technology to achieve this understanding".

While it may not be feasible to conduct such a detailed inventory at a larger scale, one indication of the utility of a global list of species that is combined with distribution data is the BirdLife International work in identifying important bird areas for various parts of the world (Stattersfield et al. 1998). Their methodology has demonstrated its relevance at various scales and has helped to inform decisions on priorities at national and international levels. If such information were available for other groups, imagine how much more powerful our advice would be regarding issues such as the establishment of new protected areas and the management of the existing ones.

Combinations of techniques can be used by taxonomists to generate novel findings. For example, Murphy et al. (2001) used a "general-time reversible plus gamma plus invariance model of sequence evolution and likelihood-based inferential techniques, including parametric bootstrap tests and Bayesian methods with Markov Chain Monte Carlo sampling" to assess phylogenetic relationships and examine alternative positions for the roots of the family tree of placental mammals. They demonstrated, for example, that the cetaceans are most closely related to the hippos; that the carnivores are most closely related to the pangolins; and that the flying lemurs are most closely related to the tree shrews, which are only distantly related to the shrews and even farther away from the elephant shrews. While none of this is of any particularly obvious immediate economic benefit, it is providing important understanding about the relationships among the various groups of mammals and our relationships with them.

But do decision makers really care about how many species are living on our planet? Perhaps not; but if we are unable to estimate the number of species even to an order of magnitude, then our credibility on issues such as extinction rates is seriously undermined. Conversely, if we are able to describe with confidence the status and trends of an adequate representation of species, then our credibility will be greatly enhanced, along with our influence.

Building public support by celebrating the diversity of life

Conserving biodiversity needs stronger public support, and one essential for such support is good information. Taxonomy enables us to constantly celebrate the diversity of life, thereby earning stronger public support for biodiversity. Dramatic discoveries draw public attention. Just this year a whole new phylum of microbes was discovered, living in a submarine hot vent. The new phylum, named “Nanoarchaeota”, lives in hypothermophilic vents where temperatures often exceed 80° Celsius (Huber et al. 2002), leading to speculation that similarly-adapted life forms may be found on other planets that may be characterised by extreme conditions (as judged by Earth-bound ecologists).

Primitive and miniscule prokaryotes, which have no intercellular organelles or nucleus, are not the only new discoveries. In 2001, highly diverse assemblages of tiny eukaryotes (which possess organelles and a nucleus for their DNA, and therefore are ultimately allied with humans) were discovered in the Pacific and along the Antarctic Polar front (Lopez-Garcia et al. 2001; Moon-Van der Staay et al. 2001). In 2002, Namibia yielded the first new order of insects to be discovered since before the First World War. Called the Mantophasmatodea (Klass et al. 2002), they were originally described from specimens collected in Namibia and Tanzania in the early years of last century, sitting unidentified in museums in Berlin and Lund, Sweden. But earlier this year, an expedition to the Brandberg mountain of Namibia found specimens living in tall grass. Two species have now been described and several more may await description. They apparently prey on other insects, but it is not yet known whether they are remnants of a once-widespread group that is perilously close to extinction, or whether they might still be widespread in Africa – a real challenge to African field taxonomists.

Major revelations are also appearing among the higher vertebrates. For example, 24 new species and subspecies of monkeys have been described since 1990, and the forests of war-torn Laos and Vietnam have thrown up a whole suite of new large herbivores, including a distinctive forest antelope and a bovid ultimately related to wild cattle (Timm and Brandt 2001). And among plants, botanists have discovered three new families of flowering plants in Central America and southern Mexico over the past decade (Raven and Wilson 1992). And who knows what wonders still await us?

Taxonomy also helps to package information for the public. For example, the millions of visitors to public displays of museum collections, zoos, and botanical gardens have generated much broader public support for biodiversity, and such public information needs to be expanded.

Supporting decisions needed for conserving biodiversity

Taxonomic information is essential for addressing many critical conservation issues, especially across international borders. These include problems as diverse as the spread of invasive alien species, conservation of migratory birds, the emergence of new diseases, the decline of amphibians, and the impact of animal trade.

Diamond (1987) contends that “all decisions about conservation, wildlife regulations and creation of new national parks are based on faunal and floral catalogues defined by the information that specimens provide about species and races, their geographical variation and distribution”. That said, we still have a very long way to go. Even the best-studied systems of national parks remain remarkably poorly known in terms of their species composition. For example, in a study of 250 national park units in the USA, Ruggiero et al. (1992) found that just 18% of the parks have 80% or better inventories of mammals, 27% have such coverage of birds, 13% for reptiles and amphibians, and 18% for fishes. They propose a complete inventory of the vascular flora and vertebrate fauna of the national park system as a basis for determining its contribution to conserving the country’s biodiversity.

Vane-Wright (1993) proposes a biodiversity conservation strategy based on systemic analyses of geographic ranges and taxonomic relationships of a wide variety of taxa, leading to the identification of effective global, national and local networks of protected areas and other ecosystem management approaches. The technical requirements for such systematic biodiversity evaluation include:

- Taxic measurement that incorporates richness with estimates of difference and distribution;
- Efficiency in site selection, based on complementarity (yet still including sufficient redundancy to be robust in the face of changing conditions);
- Flexibility to achieve the goal in relation to real options (based on irreplaceability); and
- Viability of ecosystem diversity, based on analyses and application of appropriate population management techniques to ensure sustainability.

The intention is to conserve the greatest possible amount of biodiversity and even, in a worst-case scenario, to undertake the restoration ecology that may be required to sustain the biosphere in a condition fit for human life. Thus taxonomy contributes as a foundation of the very future of our species, as well as the rest of the planet's biodiversity that we hope will accompany us into the future.

Taxonomy can also contribute to the development of powerful analytical systems that will:

- Enable defensible targets for conservation action to be established;
- Agree appropriate priorities for reaching such targets;
- Provide the basis for assessing sub-optimal solutions; and
- Provide the flexibility that is necessary to adapt to ever-changing biological, social, and political realities (Vane-Wright 1993).

A critical issue for all of those who care about biodiversity is being able to predict the future consequences of current actions, both of conservation and of over-exploitation. Taxonomy helps contribute to such predictability, providing the systematic basis for extrapolating from existing knowledge (Vane-Wright 1996). Even under the current situation of very partial knowledge about biodiversity of prokaryotes, and at species level for eukaryotes, taxonomy provides the framework within which new discoveries can be placed.

Some challenges facing the taxonomy-conservation interface

What is a species?

Defining what one means by a species is by no means an exact science. Some biologists argue at great length against the concept of species. For example, Hey (2001) contends that named species often do not accurately match real evolutionary groups, which may be true enough; but the "species", whether defined as a biological species, a morphological species, an evolutionary species, or a genotypic cluster, still plays a fundamental role in advancing scientific understanding of biodiversity, inspiring questions about the way that evolution works and the boundaries and internal structure of evolutionary groups. Perhaps it is most appropriate to consider species concepts as models, and avoid wasting too much time on discussing the "reality" of such models; the reality is that species concepts still play an important role in furthering our understanding of biodiversity, and curiosity-driven science continues to motivate taxonomists to improve our understanding of the concept of species.

While recognising the utility of this approach, we also need to recognise that some flexibility in application is required. Hybridisation is so common in plants, at least, that the biological species concept may not be nearly as useful for botanists as it might be for, say, ornithologists. For conservationists the problem of hybridisation bedevils our efforts to conserve highly endangered species. Some have even insisted that "bad taxonomy" can kill when distinct species are not afforded specific status (Gittleman and Pimm 1991), a graphic illustration of the "species problem". And surely taxonomists can help to convince decision makers that, for example, the Borneo and Sumatra subspecies of orangutan are sufficiently distinct to take all possible steps to conserve both of them in nature, with viable population sizes.

What makes it to the list?

Not everyone agrees about the importance of taxonomy, or even lists of species. For example, Renner and Ricklefs (1994) suggest that "lists of species have little intrinsic value and little relevance to the practical problems involved in conservation of natural areas". They argue that museums and systematists should not become simply service providers to various groups who want to know which species is which. They are even concerned that the idea of biodiversity might make conservation vulnerable, drawing attention away from the local economic and sociological importance of protected areas and other areas covered in natural vegetation that provide various sorts of ecosystem services (such as watershed protection and carbon sequestration). And they are not convinced that the delivery of such services depends on diversity itself.

But just as geologists do not spend most of their time identifying rocks, neither do systematists spend most of their time identifying specimens. Rather, they are (or should be) looking at the relationships between species, the distribution of biodiversity, the relationships among species that may be of economic value in various ways, and ways to evaluate conservation problems.

Another challenge is that while modern information technology potentially provides an incredibly powerful new tool for taxonomists, it carries considerable complexities with it. "The on-line sources of these data each provide remarkable user interfaces and deeply inter-connected data sets of great richness. Yet each interface is different, both in the subset of data presented and in organisation. The researcher may find herself devoting as much time adjusting to differences in presentation of the data as she does actually thinking about them" (Stein 2002). Too many of the databases have their own type of user interface and format, making it both inefficient and frustrating to try to cross-fertilise the various databases.

Yet another challenge facing taxonomists is the vast expanse of literature involved in taxonomic descriptions. For example, the 11,000 species of ants are described in about 3800 publications in more than 800 serials and monographs, totalling around 100,000 pages (Bolton 1995). Of course, only a few of the largest libraries are able to maintain and manage such vast amounts of information (Agosti and Johnson 2002), meaning that many taxonomists – especially in developing countries – lack the basic reference tools with which to work.

Generation and geographic gaps

It takes many years of experience to become a leading taxonomy authority on a group of species. A taxonomist does not automatically become the world's expert upon receiving a PhD. Acquiring taxonomic expertise is a process that can take decades and often consumes a lifetime. That is why we have the phenomenon of the octogenarian taxonomist who has stupendous knowledge about a group that he or she has been studying for six decades or more (Miriam Rothschild comes to mind). Few developing countries have the institutions, the career structures, the stability, and the incentives for someone to slowly gain taxonomy expertise. Until long-term opportunities and support are available, especially in the countries with rich biodiversity, taxonomy will suffer, along with conservation.

A related issue is that of scope of focus for those in the taxonomic community. As IUCN undertakes the Global Amphibian Assessment, we have become aware that some parts of the developing world, for example in South America, China, and India, support a growing army of taxonomists, at least on certain species groups. However, most of these scientists know very little about what is going on outside their own countries. Therefore, they are unable to take a regional overview, or to look comprehensively at the systematics of a particular clade. In addition to simple geography, we see cultural and language differences that cause taxonomic communities to become isolated from each other. We are almost certain that Chinese and Indian taxonomists have on several occasions unintentionally named the same amphibian species twice simply because they are unaware of each others' research.

The ethics of taxonomy, or how to turn off the public

As our world becomes more urbanised, public attitudes shift, sometimes leading to unanticipated results. For example, following the vigorous conservation campaigns of the past several decades, the general public – living in cities where food comes from the supermarket – is now strongly opposed to killing animals, at least vertebrates. But this ethical concern also extends into scientific research, including collection of specimens, that may ultimately benefit the species concerned (Stuebing 1998). Such shades of morality are challenging to translate into appropriate public policy, though such translation is essential to a productive future for taxonomy.

Of course, the number of specimens collected from a tropical forest for taxonomic work is considerably exceeded by the mortality associated with the conversion of those forests to other habitat types, such as plantations or agricultural lands. In such cases, human interest trumps the impact on native species. It is ironic that governments who stringently police specimen collecting efforts in the name of conservation also grant extensive logging concessions and promote the replacement of natural forests by plantations, taking on an easy target while allowing the real culprits to flourish. This is a classic example of displacement behaviour, or rather distraction of the public policy process. Diamond (1987) suggests four reasons for this sorry state of affairs:

- It takes thought to realise that habitat destruction kills wildlife as surely as guns do;
- Biologists are few, impoverished and politically impotent compared with large forest industries;
- The reasons for scientific collecting make duller newspaper reading than do the arguments of animal-rights lobbies; and
- Harassing scientists offers a cheap way to feign concern for conservation.

On the other hand, museum specimens are increasing immeasurably in importance as governments impose increasingly stringent regulations on the collection of vertebrate specimens and as ever greater areas of habitat are converted to new uses that entail the loss of many of their native species (Foster and Cannell 1990).

A focus on "useful" knowledge?

A serious problem in many parts of the world is that scientists are constantly reminded not to "waste resources on non-useful research" (Ng 2002). Even worse, many scientists in developing countries are discouraged from working on species from adjacent or nearby countries, ensuring that their research is kept very parochial or even nationalistic (a problem we found in our amphibian work mentioned earlier). While considerable emphasis is given to the economic manifestations of new knowledge, it is far more useful to avoid distinctions between "useful" and "useless" knowledge. Building understanding of biodiversity, ecosystem functioning, and so forth requires a universal body of knowledge, which in turn requires continuous research, exploration, and publication. The arrogance of trying to put knowledge into categories of "useful" and "useless" will only take us in a negative direction that assumes that we can predict what is going to be useful at some point in the future, leading to a knowledge system riddled with gaps and inconsistencies.

As we begin the 21st century, the private sector is in the ascendancy, but we cannot expect very much help from them in the field of taxonomy. Frankly, the pure science of taxonomy is not a very profitable undertaking in the short timeframe of the bottom line on a corporate balance sheet. The private sector argues, with some justification, that it pays taxes and generates public welfare by generating employment and producing goods and services that people want. They expect that part of their taxes will go to supporting public sector research and development, while their own R & D remain protected as a commercial secret, or at least under intellectual property rights regimes. And in any case, such commercial secrets are seldom of fundamental scientific importance for taxonomists (though some of the technology may be). In any case, throughout much of the developing world, public institutions do not make sufficient investment into generating public knowledge, and do not require, or even expect, their scientists to be part of the global mainstream of science.

Improving the partnership between conservation and taxonomy

A better institutional basis for supporting taxonomy

We need an institutional revolution in biodiversity conservation in order to provide the level of public benefit that potentially is available. The new institutions need to provide expert systems that will put relevant information on biodiversity into the hands of the people who need this information, and package the information in ways that can be easily used. We recognise that promoting increased taxonomic knowledge is a worthy goal to advance our understanding of biodiversity (e.g., the "Study" emphasis of the Global Biodiversity Strategy). However, we should be cautious of the emphasis that is being given to relying solely on technological advances for naming all species. While we should certainly embrace such advances, they are not a substitute for training more taxonomists in all countries of the world, and especially for developing the kinds of institutions in all countries that allow taxonomists to excel in their careers.

Another aspect of this institutional revolution is a fundamental change in mind-set. The astounding wealth of some individuals and countries seems to have seduced even the most innocent into entering the fatal trap of material acquisitiveness, looking for opportunities to cash in so that they, too, can enter into the golden culture of excessive, and conspicuous, consumption. Thus even indigenous peoples who had been living in a reasonable relationship with the rest of nature have become dominated by the fight for intellectual property rights and "benefit-sharing". This may be driven at least in part by the concern that others are getting rich off of their work, but that sort of envy is not very attractive either.

One illustration of the reality of pecuniary interests is that the great zoological reference collections of Asia have been in steady decline since at least the early 1970s (Stuebing 1998), accompanied by declines in research, field studies, and training, even while national economies in the region were booming. Meanwhile, the herbaria associated with forest departments have continued to flourish, being more closely linked with direct economic applications.

Conservationists must share the blame for this dollar-oriented approach to taxonomy. For tactical reasons we have emphasised the enormous value of tropical biodiversity, implying that significant rewards could follow conservation efforts (see, for example, McNeely 1988). We should have realised that politicians and civil servants would respond by passing restrictive legislation to prevent others from cashing in on this windfall. The unforeseen result so far has been that neither economic benefit nor scientific advance have been forthcoming, in fact quite the opposite in most parts of the world. The effect of "biodiversity" legislation often is to cripple scientific collecting, curbing a few irresponsible scientists while penalising the vast majority of those who are both responsible and lacking any particular interest in commercialisation of their knowledge.

Having complained about our overly-pecuniary approach to biodiversity, we also must be realistic and recognise that most governments express a strong need to make a profit out of nature. However we may feel about this from an ethical perspective, we can still make important contributions from taxonomy, for example in helping to predict where in nature one might look for various chemical compounds of commercial interest, or applications in biological control, or preventing costs of disease through improved understanding of medical entomology.

Better access to the information generated

Many "customers" share an urgent need for taxonomy, and their needs should be met. Examples of those who need taxonomy:

- Parliamentarians, who need to ensure that laws will protect all biodiversity and that their legislation is directed at the top priorities;

• Field biologists, who need to identify the species with which they are working;
• Diplomats, who need to ensure that biodiversity-related conventions are meeting their conservation objectives (McNeely 1995);
• Agricultural scientists, who need to find species useful for integrated pest management (IPM), requiring a good understanding of species relationships;
• Customs and quarantine officials, who should be on the lookout for potentially invasive alien species;
• Eco-tourists, who want to identify the plants and animals they encounter in their travels;
• Planners, who need to carry out EIA for proposed projects that may affect biodiversity;
• Epidemiologists, who need to chart the distribution of diseases that may be transmitted between people and other animals.

Of course, taxonomic databases also have commercial applications, and those whose motivation is financial certainly should be expected to pay appropriately for the valuable information they receive. And some protection needs to be built into the system to avoid unscrupulous users, for example those who are seeking the locations of rare and endangered species for commercial gain. The commercial uses certainly do need to be factored into access regimes, but our focus is primarily on scientific and conservation applications, which serve the public good and are not designed to earn a profit.

The list of potential users could be expanded considerably, because virtually all of humanity depends on biodiversity and will benefit from better understanding of it. After all, biodiversity is a classic "public good", available to all, and whose use by one person does not diminish its utility to others. That said, taxonomy can become more relevant by better serving the needs of its "customers", which requires careful consideration of these needs and better understanding of them.

Generally speaking, the results of taxonomic work should be so accessible that everyone who needs them can have them in a form they can use. The ideal is to establish a "biodiversity commons" where biodiversity information should be dedicated to free and open access for legitimate research, education, and conservation uses (Moritz 2002). This goes against the current mercantile trend, but we support those who argue that taxonomy should be available free (without access charges) to anyone who can log onto the Internet. As Godfray (2002) points out, "This will raise the profile of taxonomy and increase the number of people who actually use the fruits of taxonomic research". He sees a new, young generation of naturalists, stalking their prey using digital cameras, downloading their captures into PCs, then identifying them over the Web. This will expose them to taxonomy as an active discipline, at the heart of modern biology.

One illustration of how to stimulate the exchange of such information is the Inter-American Biodiversity Information Network (IABIN), an internet-based forum for technical and scientific cooperation that seeks to promote greater coordination among western hemisphere countries in the collection, sharing, and use of biodiversity information relevant to decision making and education. A second illustration is IUCN's Species Information Service, which aims to provide current, high-quality, spatially-explicit biodiversity information to support scientific discovery and to make that information available via the Internet.

While collecting new specimens and new data is exciting, the collections in natural history museums and herbaria already contain a massive store of information on biological diversity. Properly-accessed and well-interpreted museum collections can provide important base-line information for designing land-use and agricultural pest-management programmes. For example, Sanchez-Cordero and Martinez-Meyer (2002) used museum specimen data to generate ecological niche models that predicted geographic distributions of native rodent pest species, and related this to the predicted crop damage by these rodents on major crops in Mexico. Thus the fundamental collections that provide some of the working tools for taxonomists can make key contributions to resource management and ultimately to sustainable development.

Conclusions and recommendations

Over two decades ago, IUCN already recognised the importance of taxonomy. The original World Conservation Strategy (IUCN, UNEP, and WWF 1980) said, "The size of the potential genetic loss is related to the taxonomic hierarchy because, ideally at least, different positions in this hierarchy reflect greater or lesser degrees of genetic difference and hence differences in such variables as morphology, behaviour, physiology, chemistry, and ecology. Although the degree of difference (the gap) between genera and between species within genera varies both within and among classes, the current taxonomic hierarchy provides the only convenient rule of thumb for determining the relative size of a potential loss of genetic material".

Taxonomy has become even more important as biodiversity loss haunts our hopes for a productive future. In order to address the current challenges facing taxonomy and to improve the link with conservation, end users need the following:

Improving the institutional base

• A new coalition for the conservation of biodiversity around ecologists, resource managers, and systematists who can collaborate to produce information and analyses for democratic use (Vane-Wright 1993).
• Contract-based funding for sections of major taxonomic projects as a means of stimulating taxonomic infrastructure (Parnell 1993).
• Investment in building institutions in developing countries that will provide a productive livelihood to a new generation of taxonomists who are able to contribute to the development objectives of their respective countries. Biodiversity institutes such as INBio, CONABIO, and the Indonesian Biodiversity Institute, and networks such as SABONET in southern Africa, are indications of how this might be approached.
• Protocols such as those advocated by Foster and Cannell (1990) or the UK Manual on Biodiversity Assessment (Jermy et al. 1995), to ensure that specimens of plant or animal are accompanied by the most complete possible information.
• Partnerships that could offer numerous fellowships to taxonomists from the tropics to work with the great reference collections in North America and Europe, and help to repatriate knowledge from north to south.

Improving access to information

• A code of conduct for bioinformatics data providers, helping to ensure the cross-fertilisation of data and the generation of information relevant to biodiversity conservation (Stein 2002).
• Agreement from publishers to renounce copyright on published taxonomic papers, making them freely available for access to all (Agosti and Johnson 2002).
• Open and free access to reference collections and methods of remote access and repatriation of information back to countries of origin.
• A centralised repository of nomenclature, as part of a one-stop shop for biodiversity information.

Conservationists should value the contributions that taxonomists have made to conserving biodiversity and using biological resources sustainably. Following several decades of senescence or even dormancy, taxonomy could be entering a new flowering that is based on new biotechnology and information technology. In the next phase of its history, taxonomy should continue its focus on pure science while also seeking to apply this science to basic human needs.

Acknowledgements: This paper has greatly benefited from comments on an earlier draft by Sue Mainka, Walt Reid, Richard Smith, Brian Huntley, Dick Vane-Wright, and Martha Chouchena-Rojas.

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Received 05. 07. 02
Accepted 30. 07. 02