Graellsia, 61(2): 151-160 (2005)

TEN CHALLENGES TO TRANSFORM TAXONOMY

Q. D. Wheeler* and A. G. Valdecasas**

ABSTRACT

Taxonomy is at a crossroads. Although taxonomy has an impressive past, having documented and organized knowledge of nearly two million species, most of the basic work required to describe Earth's biodiversity remains undone. Factors that guide the choices of research topics in science are considered. Ten challenges are presented to the taxonomic community that we believe will accelerate its revitalization.

RESUMEN

Diez retos para transformar la Taxonomía

La Taxonomía se encuentra en una encrucijada. Con un admirable pasado que ha permitido documentar y organizar un inmenso conocimiento sobre casi dos millones de especies, sin embargo, la tarea básica de describir la Biodiversidad sobre la Tierra está por hacer. Se examinan los factores que guían la elección de líneas de investigación en la ciencia y se propone a la comunidad taxonómica, diez retos que consideramos acelerarán su revitalización.

Introduction

Taxonomy faces unprecedented challenges and opportunities. In order to succeed, taxonomy must overcome a protracted period of quiescence and neglect, construct a new research paradigm and infrastructure, and take command of its priorities and future. Following a brief discussion of the current situation and factors that have contributed to it, we propose ten action items for the taxonomic community that we believe will contribute to its transformation into a respected, well resourced, leading modern science. Because human actions are contributing to rapid degradation and loss of unique habitats around the globe and we stand to lose a large volume of irreplaceable evidence of species and phylogenetic diversity, such a transformation has become essential. Fortunately, technological and theoretical advances have positioned the field to do just that (Wheeler, 2004; Wheeler *et al*., 2004).

Why do scientists study what they do? Answers are more obvious for applied researchers than basic

* Department of Entomology, The Natural History Museum, Cromwell Road, London SW7 5BD, UK. qdw1@nhm.ac.uk
** Departamento de Biodiversidad, Museo Nacional de Ciencias Naturales, c/José Gutiérrez Abascal, 2. 28006-Madrid. Spain. valdeca@mncn.csic.es

researchers for whom trends are more difficult to predict and explain. Fundamental research ultimately gives support to and widens the basis from which applied sciences solve problems and draw inspiration. Though self evident, it is true that scientists study the problems that they can manage (Lewontin, 2000) yet the number of manageable subjects is essentially unlimited. Funds and technology enable research and each on occasion seem to drive rather than merely enable research choices. Many funding bodies understandably prefer to support the cutting edge of science rather than established areas. Observers of modern technology have repeatedly noted the disproportionate focus on means rather than ends; e.g., Orr (2002:63): "*Unable to separate can do from should do, we suffer a kind of technological immune deficiency syndrome that renders us vulnerable to whatever can be done and too weak to question what it is that we should do*".

We are concerned that the growth and testing of taxonomic knowledge, essential for all biological research, conservation, and biodiversity management, has been largely neglected in recent decades (e.g., House of Lords, 2002). In the face of rapidly changing ecosystems, taxonomy is unequivocally a "should do" topic. Why then do we spend so much time and money pursuing "can do" activities instead? For example, rather than continuing to integrate molecular evidence into the proven conceptual framework of taxonomy some advocate a largely DNA-based alternative taxonomy in spite of its theoretical weaknesses compared to the *status quo* (cf. Lipscomb *et al*., 2003; Tautz *et al*., 2003; Barrett & Hebert, 2005; Prendini, 2005; Wheeler, 2005). It is therefore important to ask how trends in biological science funding might be redirected to assure that the taxonomic community is able to pursue its vital missions.

One way to influence research priorities is to persuade the public of the urgency of a problem or of its importance as a key to further progress as was successfully done for the Human Genome Project. Taxonomic research is urgent due to the environmental ravages of the biodiversity crisis (Wilson, 1992) and absolutely necessary for progress in conservation and biological research generally; you can not save or manage or study effectively that which you do not know exists. Another appeal to the public involves inspiration of the human spirit, achieving what might seem an impossibly lofty goal; the "moon shot" by NASA is a good example. Here, too, taxonomy has an opportunity. Exploring all the life forms inhabiting the biosphere of our entire planet within a few decades is as visionary and ambitious as any science project ever conceived; documenting evolutionary diversity for future generations to study and admire is also as selfless and noble as any project ever proposed. Presented intelligently to the public, we believe that widespread support for a revival in taxonomy is achievable… but this will depend upon leadership and vision from the taxonomic community itself.

Words play an important role in the politics of science. Funding trends are often accompanied by "buzz words" as though the mere existence of a new term substantiates a new course of action. Techniques for exploring the genetic diversity of life at the DNA level were well established already when the term "genomics" greatly increased the popularity of, and funds available to, the field of molecular biology. Taxonomy suffers from the antiquity of its name. Biological classification can be traced to ancient Greece and Aristotle. "Modern" nomenclature dates from the 18th century (Blunt, 2001). Our need for credible taxonomic knowledge is greater than ever and rapidly expanding: known species must be critically tested by taxonomic revisions in order to continue to explain patterns in the natural world and the vast majority of Earth's species remain to be discovered, described and made identifiable. Although the word taxonomy is old, the discipline is modern and vibrant: few sciences have witnessed such profound theoretical revolution as taxonomy (Hennig, 1966; Nelson & Platnick, 1981; Schoch, 1986; Schuh, 2000). Some fields with similarly old names do not suffer the same affliction; there are few calls to ignore physics or astronomy or medicine merely because we have known them by the same names for a long time. The problem was exacerbated in the 1940s when taxonomy was described as a technical subset of the putatively comparatively theory-rich "systematics" (e.g., Mayr, 1942). There is currently a digital revolution underway in taxonomy that offers an opportunity for a new name like "cybertaxonomy" to be adopted (see Page et al, 2005). We suggest that such a name change is unnecessary but that changing the image of taxonomy is essential.

Taxonomy was a smart word in the eighteenth and nineteenth centuries when the science was at the forefront of biological research. Its aim now as then is describing and classifying the Earth's biota. Taxonomy was developed as rigorously as human

anatomy or any other descriptive science. However, while the rate of new discoveries in anatomy has slowed that in taxonomy has not. For instance, in zoology, more than 15,000 species new to science are described annually, many representing new genera, families and orders (Valdecasas *et al*., ms). Given present estimates of the world biota, even a doubling of the current rate of species description would not be enough to meet the challenge to discover Earth's species in a reasonable time (Erwin, 1988; May, 1992; Ødegaard, 2000). A comparatively few major groups are becoming reasonably well known; groundbreaking discoveries are increasingly infrequent for groups like birds or mammals. For many other groups, including those that are hyper-diverse like worms, insects, and mites, we are far from having a fundamental understanding of the origin of body plans or diversification of morphology or numbers of living species within an order of magnitude (Wilson, 1985) let alone other aspects of their incredible diversity.

Taxonomy has been under siege for much of the last century. Any substantial accusations that taxonomy is a "soft" science were refuted by Hennig's (1966) rigorous theories and methods. Hypothesis-driven aspects of taxonomy aside, its descriptive aspects are scientific in their own right and worthy of our full support. Intersubjectivity implies that what I see and recognize can be seen and recognized by any other person independently of time and place, keeping conditions equal. Intersubjectivity is a benchmark of scientific observations, including those of taxonomy.

Many contemporary biologists share a false view that in order for a science to be rigorous it must be experimental; from this point of view taxonomy as a descriptive field is of questionable scientific status. Taxonomy is not dissimilar to other non-experimental, descriptive, useful sciences such as palaeontology, astronomy, plate tectonics and meteorology. Such descriptive sciences, including taxonomy, are the foundation for much of the functioning of our society and modern science. Bearing in mind this solid foundation for both descriptive and hypothesis-driven aspects of taxonomy we are forced to conclude that attacks on taxonomy must have more to do with competition for limited resources than with the requirements of what makes a science sound. Although testability is widely accepted as the demarcation between science and non-science, it remains that much of the necessary background knowledge for progress in science is observational and descriptive rather than predictive. Many astronomical predictions were only possible after the description of a heliocentric solar system.

Ultimately, blame for the decline in stature and support for taxonomy must rest with taxonomists themselves. We, as a community, have done a spectacularly poor job explaining why what we do is exciting, relevant, and important; distinguishing basic from applied taxonomic research; and clearly explaining both those rigorously testable and purely descriptive aspects of our science. Following decades of neglect we seem to have lost our confidence to lead and inspire and take responsibility for our own future. In science as elsewhere opportunities are created more often than found. If taxonomy is to enjoy a revival in time to respond to the biodiversity crisis then it must undertake fundamental changes. Those changes must come from and be led by taxonomists themselves. The Systematics Agenda 2000 activity (Anon. 1994) returned focus to the core missions of taxonomy; it is now time to canalize emerging digital tools to fulfill those missions (see Page *et al*., 2005). We propose ten challenges to the taxonomic community that can contribute in measurable ways to the progress of a revival of taxonomy.

Ten Challenges

1.– Adopt New Community Paradigm and a Decadal Research Agenda

The taxonomic community has a long history of fragmentation with scholars working in isolation and collections built with provincial or regional foci. The "big questions" of taxonomy (e.g., Cracraft, 2002; Page *et al*., 2005) cannot be answered by single research scholars nor single institutions nor single countries. Taxonomy at this scale is big science and requires a new cooperative, international, multi-institutional paradigm to succeed. This does not mean that there will not always be a place for individual scholars; there will. It does suggest that if serious progress is to be made exploring species diversity on Earth before many species have become extinct then much of taxonomy will have to be approached on an unprecedentedly large scale. This collaborative paradigm is evidenced in the Planetary Biodiversity Inventory projects of the U.S. National Science Foundation as well as the planning processes for

both the Legacy Infrastructure Network for Natural Environments (LINNE: Page *et al*., 2005) and the European Distributed Institute of Taxonomy (EDIT). A combination of international cooperative and new technologies have the promise to eliminate or reduce virtually every existing constraint on taxonomic research.

One of the most important responsibilities of the taxonomic community, acting as a community, is to set explicit research priorities and goals. We advocate a rolling decadal plan for the taxonomic research agenda. The community should come together and establish a set of ambitious and achievable prioritized goals for the decade ahead that address both new infrastructure and tools as well as explicit goals in species exploration, description and classification. As taxonomists achieve these goals, successes are trumpeted and new goals set in their place so that on a biennial time scale the community always has an explicit list of its next top goals.

We are not naïve enough to suppose that the world's taxonomists would all agree upon any short list of obviously most important priorities. The community must not confuse the kind of discourse necessary and appropriate for any science that progresses and maintains high standards with the notion of expressing agreed goals with a single (and thereby politically efficacious) voice. The clash of ideas has vastly improved the rigor of taxonomy and will continue to do so (examine the current literature on DNA barcoding or the PhyloCode for graphic cases in point); competing theories and concepts can continue to be argued for and won through publications, talks at meetings, etc. The more fighting in fact, the better the outcome. Following such battles, fought within its own community, taxonomy as a whole must present to the outside world of politicians and funders a clear research agenda. By revising the agenda every couple of years, it remains current with events and opportunities and it keeps open the possibility of inclusion of ideas on a list that were excluded only two years previous. Astronomers have succeeded in funding for projects like the Hubbel telescope because they have spoken univocally as a community; never have all astronomers agreed that the Hubbel telescope should have been the community's top choice. Over time such a community strategy can result in a sequence of successes, even if each is disappointing to a minority of the community.

We challenge the presidents of the world's taxonomic professional organizations, editors of taxonomic journals and other journals where taxonomy occupies an important place, worldwide taxonomic database organizations (e.g. GBIF; Zoological Record; etc.), directors of Natural History Museums and Botanical Gardens, and taxonomists themselves to lend the full measure of their political persuasion to the success of such community planning. We challenge the primary funders of taxonomic and biodiversity research to offer funds to the community for this important planning process.

2.– Establish a Federation of Taxonomy Societies and Institutions

Recognizing that taxonomy currently lacks a single strong advocate and voice we challenge the presidents of taxonomic and taxon-focused professional societies and directors of major collections-based institutions to come together and create an international federation of societies whose purpose it will be to promote, lobby, and educate in order to realize the community's research agenda. The federation should include all such taxonomic organizations whether private or public. The federation should articulate the unique contributions and needs of the field and its institutions to both the public and to politicians capable of influencing support for its community's research. Such a federation should be neutral with regard to the usual factions within the community and promote the discipline as a whole, its constituent organizations, and a community adopted decadal research agenda.

Potential roles for such a federation transcend the usual kinds of promotional activities. As one means to promote and acknowledge the importance of taxonomy such an organization (or some other organization or foundation) should establish a prize recognizing meritorious life time contributions to taxonomy, a kind of international Nobel prize for taxonomy. In this century as humanity confronts unprecedented rates of species loss, those who contribute to the exploration, discovery, description and classification of Earth's species deserve special appreciation and recognition. Such prizes raise public awareness and appreciation of such unique contributions to science and society as well as expanding public awareness of the field.

Another potential role for such a federation of societies would be to serve as or create a kind of learned general commission to keep annual critical evaluation and record of progress in taxonomy, issuing an annual state of taxonomy report that summarizes statistics such as known species and clade diversity on a world level, annual progress in exploration and discovery, annual progress in ope-

ning access to taxonomic information, etc. Such a score card would benchmark taxonomy's successes and highlight its challenges and goals.

3.– Increase Kinds and Levels of Outreach and Education

We challenge every taxonomist and taxonomic organization to be vigilant for opportunities to share taxonomy with non-taxonomists, particularly students and the public in general. We challenge every major museum of Natural History to create at least one significant public exhibit whose purpose it is to define for the public what taxonomy is, why it is intellectually exciting, why it is relevant to society, and why collections of such institutions are so vital to advancing taxonomic knowledge and therefore worthy of support. We hear anecdotally that museums do not mount displays about taxonomy because "the public does not understand taxonomy", "taxonomy is not perceived to be exciting", or it is simply not currently popular. Few things invisible or inaccessible or unexplained or misunderstood become popular. If natural history museums as the custodians of specimens and information associated with them are not willing to share the excitement of taxonomic exploration and research with the public, who will? If they are incapable of articulating taxonomy in an exciting and accessible way, who is? Taxonomic exhibits can be engaging and intellectually stimulating, as shown by the recent opening of the Hunter Museum, London (Palmer, 2005), which shows the 18th century collection of the British naturalist and surgeon in a more or less original setting. More effort should be made to link present day taxonomy to its rich past including both its scientific and aesthetic accomplishments, the questions and answers involved in its intellectual and practical advancements, the new ideas and methodologies that have been developed, and the pending questions that portray it as a fully vital biological discipline.

We urge increased communication with the media (newspapers, radio and TV) to ensure a steady flow of coverage for important taxonomic achievements. Taxonomists take for granted discoveries that would amaze the public; species new to science, sometimes filling extremely important gaps in our knowledge of phylogenetic diversity, are reported on a daily basis in the scientific literature but only rarely shared with the public. When news of new species is published it is often received with excitement by journalists and readers alike.

Taxonomists should all accept the responsibility of teaching people about the field. Taxonomy has virtually been eliminated from school and college curricula. If you are a taxonomist in a university, volunteer to teach a class or at least give some lectures in introductory biology classes. Even the most hardened experimental biologist may jump at the chance for a few days off. Alternatively, consider volunteering to visit a high school biology class or giving a talk to a community group. We share a collective responsibility to educate students at all levels about the demanding and provocative intellectual content of taxonomy and to dispel the myth that a taxonomy class consists of little more than rote memory of extensive lists of Latin names. Homology criteria, species concepts, phylogenetic theory, biogeographic analyses, integration of diverse data sets (palaeontology, morphology, molecular, ontogenetic, etc.) and countless other topics make the field conceptually compelling. As pointed out by Estabrook (1986) "…taxonomists must participate themselves in the practice of scientific method to use results of their craft to test and argue the differential credibility of hypotheses to explain pattern, process, adaptation, mechanism, geographic distribution, history, etc. If knowing what things are called and where they live is really important to science, let those who know these things best demonstrate how they can be used to treat ideas that have compelling intellectual content".

4.– Build a New Research Infrastructure

In the United States a major proposal is being developed to support the creation of a new infrastructure for taxonomic research that uses predicted advances in cyberinfrastructure (Atkins *et al*., 2002) to improve and accelerate virtually every step in taxonomic work and to integrate research resources from instruments to specimens to data and literature; this Legacy Infrastructure Network for Natural Environments, or LINNE for short, will function as a species observatory permitting taxonomists to compare patterns of distributions of species across all scales of time and space (Page et al, 2005). LINNE would provide the research platform and environment for taxonomy on unprecedented scales of efficiency; everyone in the U.S. should express their support to the National Science Foundation and their senators and congressmen for LINNE. The European Distributed Institute for Taxonomy (EDIT) plans to reduce

fragmentation of the taxonomy community in Europe and to develop similar "cyber" tools to support web-based taxonomy. The vision expressed in EDIT has enormous potential to eliminate fragmentation in the European taxonomic community as well as providing a new generation of tools to taxonomists. It deserves appropriate recognition and support within the European community and along with CETAF and other community-building activities has the potential to prepare the European taxonomic community to play a leadership role in transforming the science.

These activities are emerging out of political and funding necessity at national and regional levels. All taxonomists involved appreciate of course that good taxonomy cannot be limited by geopolitical boundaries and that the ultimate success of such efforts will depend upon a network that eventually encompasses the whole world. These are necessary political steps toward the needed access to specimens and infrastructure globally. The community should share broadly what is learned through such efforts in order to "export" successful experiences to other countries and regions.

It is vitally important that high quality comparative morphology research be reinvigorated. While molecular data has made the construction and testing of cladograms easier and faster in many respects, cladograms are primarily useful in the evolutionary interpretation of complex characters such as those generated through morphological studies. One tool that would promote morphology is the refinement of a proposed community morphology bank analogous to GenBank; a place where high resolution digital images, computer tomography 3-D images, and other images can be stored and easily accessed. Digital environments make possible the acquisition, analysis and communication of visual knowledge as never before. Several research groups have made strides toward development of such morphology banks and deserve broad support to continue to develop and expand the concept; we urge their cooperation with one another and with the wider community to lead as soon as possible to a single effective repository for morphological data and images. Paper forerunners can be found in groups as distinct as algae and water mites: the Fristch collection holds more than 500,000 illustrations of algae and the Gledhill collection covers around 5,000 Hydrachnidia species worldwide (Freshwater Biological Association, Windermere, UK.).

5.– Create Electronic Publishing Tools and Taxonomic Impact Factors

We challenge major publishers and leading natural history museums to assist the community by demonstrating that taxonomic revisions and monographs can be made openly accessible online and still be produced. Taxonomists should support and help to develop new open access e-publications, contributing descriptive work of the highest calibre. A kind of "PLoS-Taxonomy", similar to PLoS-Biology and PloS-Genetics could provide one model. In this sense, *Zootaxa* is already one successful example.

As taxonomy moves into an open access electronic publication environment it has the opportunity to develop a new kind of impact factor to assess the contributions of taxonomists. Existing journal citation indexes are inappropriate for taxonomy (Valdecasas *et al*., 2000; Krell, 2000). Individual indexes have been proposed when citation is the variable suitable to use (e.g. Hisrch, 2005), but electronic publication opens the prospects for truly novel approaches. There are so many millions of species and so few specialists working upon the majority of them, that expecting broad citation impacts under current metrics is unreasonable; regardless of the quality of the work, its impact appears low. Taxonomic contributions, at least the good ones, have a much longer shelf life than other kinds of biological research. Impact assessments are needed that track the value of taxonomic work and concepts over their life spans rather than for a small arbitrarily number of years. A system is needed, too, that assures that the concepts created by taxonomy are appropriately cited. Many biologists use taxonomic works to determine or verify the identity of species, and all use the names of species, often without citing the primary literature. When publications are primarily accessed in electronic form, it will be possible to more accurately track their use. Elements of such a new impact scheme ought to minimally include the following. When a scientific name is used in any publication it should be linked to its nomenclatural roots and the appropriate taxonomic literature acknowledged. If every use of a species name like *Musca domestica* were tracked, Linnaeus would have the highest impact factor of any biologist. Considering how useful such taxon concepts and names have been to shaping modern biology, this would be appropriate. It will be possible to detect how many visitors use web-based keys and monographs, for example, including the dwell time of users to sort actual users from casual browsers.

6.– Initiate Team Monographs, Revisions and Knowledge Bases

We challenge communities of experts on particular taxa to pool their resources and expertise and to demonstrate that monographs or taxonomic revisions can be done rapidly and efficiently with no compromise in quality. The goals of such community descriptive taxonomy should include accelerated growth of taxonomic knowledge evidenced in part by a (primarily) web-based publication; well curated and databased collections for the focal taxa; high resolution images of all type specimens; and innovative use of varied identification tools. As such studies are done they are likely to gain good publicity for taxonomy and to dispel the myth that a good monograph or revision requires decades to complete. Partnering also with user communities that have special needs for reliable taxonomic information, such works may well find new financial supporters.

We recognize that over the next few years it is likely that how we do revisions and monographs will evolve rapidly. The products of such research will soon be comprised of digital taxon "knowledge bases" that include effectively our sum total knowledge and information about the species of major groups. We can envisage a time when descriptive taxonomy is transformed so extensively that scientists curate both collections and knowledge, individually and particularly as networks of collaborating specialists. Case studies are needed for now to make revisionary work popular again and to demonstrate what can be done by the community. In parallel, projects are already underway that will begin to develop a new generation of digital tools for descriptive taxonomists to employ.

7.– Undertake Species Inventories, floras and faunas

As the last generation with the opportunity to explore and document many of Earth's species and clades we have a special responsibility to assure that species inventories are undertaken in an ambitious and coordinated manner. Varied approaches can compliment one another, achieve particular aims, and appeal to different funding sources. Traditional place-based inventories may be of interest to national governments in particular. Worldwide inventories of particular taxa are an especially efficient use of limited taxonomic expertise as is being demonstrated by Planetary Biodiversity Inventory projects funded by the U.S. National Science Foundation. Alternatively, an ecological guild based approach might be explored that focuses upon particular assemblages of species such as parasites and hosts, aquatic communities, or fungus associated arthropods. Such inventories must be guided by existing taxonomic knowledge so that we prioritize field work to fill gaps in our inventory of species and clades and avoid duplication of efforts. In the long term, nothing that we do will be more important than the specimens that we preserve for future study. These will assist in the best possible decisions and priorities for conservation on the one hand and assure that future scientists have access to the most complete record of life on Earth possible, particularly including those species soon to become extinct.

8.– Expand Identification Tool Chest

We need to maximize the number of taxonomists that we have available for doing taxonomic research rather than identification services. Fortunately, a wide range of options is opening up for a new generation of species identification tools that will assist biologists and natural historians in making accurate identifications. Web based "keys" are often interactive and well illustrated reducing or eliminating the need for jargon or for running specimens through large numbers of couplets in dichotomous keys.

Image recognition software is being developed that permits the user to simply submit a digital photo for comparison against a bank of images in a database. Some of these systems are "intelligent" and capable of "learning" as new images are submitted to them. One such system, SPIDA, at the American Museum of Natural History, is returning impressively high percentages of successful identifications of complex male pedipalps of spider species.

Recent proposals for DNA "barcoding" is yet another promising direction for species identifications by non-specialists. The naïve proposition that a short segment of any single gene will suffice to identify all species of animals has been rejected (e.g., Prendini, 2005; Wheeler, 2005; Will *et al*., 2005) but it remains that DNA evidence will continue to expand in its utility as a species identification tool. Such DNA-based identifications are particularly exciting because of their potential to identify fragments of specimens or previously unassociated immature or strongly sexually dimorphic forms. Their utility lies primarily in the area of applied taxonomy and supposes the existence of already corroborated

species hypotheses and enough knowledge of the taxonomic identity of an "unknown" to select an appropriate gene.

9.– Establish Common Sense Intergovernmental Agreements for Taxonomic Exploration and Knowledge Sharing

Well intended regulations to protect species and to protect the intellectual property rights of sovereign states have unwittingly come to increasingly limit the growth of taxonomic knowledge to everyone's detriment, particularly species-rich, knowledge-poor developing nations. Much of this arose from an emphasis on the search for new and sometimes enormously lucrative drugs through genetic screening of species. In reality few such drugs have emerged since these regulations were put in place, but progress in our growth of taxonomic knowledge has been severely limited. We suggest that government representatives come together to assess in particular the impact of such rules on taxonomy and to set into place international agreements governed by a few common sense measures and outcomes. The most important elements are those of access.

- Access to field sites by professional taxonomists and taxonomic institutions to facilitate species exploration, discovery and description. For such collecting, access should be relatively open but compliant with terms of agreement for deposition of types, duplicate specimens and so forth.
- Access to knowledge. In exchange for the privilege of exploring species diversity, taxonomy institutes would in return assure open access to what they have learned. In the short and long terms developing nations would profit more by access to knowledge of their living resources than by blindly protecting them from discovery or study.
- Property right protection. On those rare occasions when a patentable product emerges from such exploration, provisions could be in place for suitable economic recovery by the state of origin of the discovery. We are now applying such protection to the 99% of species of essentially no economic importance on the outside chance that the 1% might be unethically exploited.
- One world. Taxonomy is like seismology. Good research cannot be artificially constrained to one geographic locality. Species only make sense when their full variation is accounted for and this means comparing specimens and populations from many countries. It is in the interest of good science that every country be part of the global community of taxonomists. This means a relatively open movement of taxonomists to the places where they need to collect (to avoid provincialism), of specimens to and between collections and institutions where they can be studied, analyzed and documented, and movement of data, information and knowledge from such institutes to the users in the field who need it.

10.– Distinguish Pure and Applied Taxonomy

Because accurate species identifications are a prerequisite to credible biology, effective conservation, detection of invasive species and outbreaks of pest species, etc., the distinctions between identification and classification and between applied and basic taxonomy are sometimes overlooked. Many experimental biologists simply need an accurate identification and see taxonomy as a service to them. They mistakenly think that taxonomy exists only to provide or facilitate identifications. To the taxonomist, the motivation is often pure science. The curiosity to discover what species exist, how they are related, the evolution of their unique characters, and changes in their distributions in ecological and geographic space. This basic research results in species hypotheses that are testable; taxonomic revisions and monographs make such tests, detecting new species in the process. Basic research in taxonomy builds a broad understanding of the origin and diversification of life on Earth and provides knowledge of evolutionary patterns in need of process explanations. Accurate species identification results from such taxonomic research but is only occasionally the motivation for it. Taxonomists find that the results of ecological and ecosystem research are often extremely valuable in understanding the distributions of the species they study; they would not presume that ecologists often undertake research as a service to taxonomists.

Taxonomy has also suffered from the current trend in science funding to favor projects that are interdisciplinary or at least multidisciplinary. While such approaches are necessary or desirable for many big questions in biology, including many related to taxonomy (there are exciting prospects for collaborative work between taxonomists and developmental geneticists and morphologists for example in expanding upon existing concepts of "character" and "homologue" for example), there

remains a great body of descriptive work that is largely taxonomic. Add to this the fact that taxonomy is non-experimental, and you begin to appreciate much of the current lack of support to the field. There is nothing wrong with uni-disciplinary science that attains true excellence. It is critical to maintain an appropriate balance between what we might call basic and applied taxonomy. Some taxonomic research should be driven by immediate needs for knowledge to solve problems while other aspects should be allowed to follow curiosity and even serendipity to assure the growth of our knowledge of the evolution of life on Earth in general.

Conclusions

It is time to vindicate taxonomy as the scientific discipline that has accumulated a huge mass of organized data and information about biological diversity, and that has the procedures and methodologies to succeed in completing its ambitious goals to explore, discover, describe and classify the millions of species on Earth. It is time to harness theoretical and technological advances to transform taxonomy into a "big science" capable of meeting its ambitious agenda. Virtually every aspect of biological research and the success of environmental conservation assumes access to reliable taxonomic information, yet funding for taxonomy remains poor and unpredictable. We accept that the taxonomic community must provide the leadership to make the necessary improvements and transformations; in this spirit, we challenge the community with ten action items that can begin its necessary metamorphosis.

ACKNOWLEDGEMENTS

A. G. V. was supported with a grant of the Secretaría de Estado de Universidades e Investigación del Ministerio de Educación y Ciencia.

References

ANON., 1994. *Systematics Agenda 2000: Charting the biosphere: Technical Report*. Systematic Agenda. Washington. 34 pp.

ATKINS, D. E., DROEGEMEIER, K. K., FELDMAN, S. I., GARCIA-MOLINA, H., KLEIN, M. L., MESSERSCHMITT, D. G., MESSINA, P., OSTRIKER, J. P. & WRIGHT, M. H., 2003. *Revolutionizing Science and Engineering through Cyberinfrastructure*. Report of the National Science Foundation Blue-ribbon Advisory Panel on Cyberinfrastructure. U. S. National Science Foundation, Arlington, Virginia. 84 pp.

BARRETT, R. D. & HEBERT, P. D. N., 2005. Identifying spiders thorugh DNA barcodes. *Canadian Journal of Zoology*, 83: 481-491.

BLUNT, W., 2001. *Linnaeus: The Compleat Naturalist*. Princeton University Press. Princeton. 288 pp.

CRACRAFT, J., 2002. The seven great questions of systematic biology: an essential foundation for conservation and sustainable use of biodiversity. *Annals of the Missouri Botanical Garden*, 89: 303-304.

ERWIN, T. L., 1988. The Tropical Forest Canopy: The Heart of Biotic Diversity. In: E. O.Wilson (ed.). *Biodiversity*. National Academy Press. Washington: 123-129.

ESTABROOK, G. F., 1986. Review of: Current Concepts in Plant Taxonomy, by V. H.Heywood and D. M. Moore (Eds.) *Journal of Classification*, 3: 167-168.

FRESHWATER BIOLOGICAL ASSOCIATION. http://www.frits-chalgae.info/

HENNIG, W., 1966. *Phylogenetic Systematics*. University of Illinois Press. Urbana. 280 pp.

HIRSCH, J. E. 2005. An index to quantify an individual's scientific research output. (Available at: http://arxiv.org/abs/physics/0508025).

HOUSE OF LORDS, 2002. *What on Earth? The Threat to the Science Underpinning Conservation*. Select Committee on Science and Technology, Third Report. HL Paper 118(i). HMSO. London. 12 pp.

KRELL, F. T., 2000. Impact factors aren't relevant to taxonomy. *Nature (London)*, 405: 507-508.

LEWONTIN, R., 2000. *The triple helix: gene, organism, and environment*. Harvard University Press. Cambridge. 136 pp.

LIPSCOMB, D., PLATNICK, N. I. & WHEELER, Q. D., 2003. The intellectual content of taxonomy: a comment on DNA taxonomy. *Trends in Ecology and Evolution*, 18: 65-66.

MAY, R. M., 1992. How many species inhabit the Earth? *Scientific American*, 267(4): 18-24.

MAYR, E., 1942. *Systematics and the Origin of Species from the viewpoint of a Zoologist*. Columbia University Press. New York. xiv + 334 pp.

NELSON, G. & PLATNICK, N., 1981. *Systematics and Biogeography: Cladistics and Vicariance*. Columbia University Press. New York. xi + 567 pp.

ØDEGAARD, F., 2000. How many species of arthropods? Erwin's estimate revised. *Biological Journal of the Linnean Society*, 71(4): 583-597.

ORR, D. W., 2002. *The Nature of Design*. Oxford University Press. Oxford. 248 pp.

PAGE, L. M., BART, H. L., JR., BEAMAN, R., BOHS, L., DECK, L. T., FUNK, V. A., LIPSCOMB, D., MARES, M.

A., PRATHER, L. A., STEVENSON, J., WHEELER, Q. D., WOOLLEY, J. B. & STEVENSON, D. W., 2005. *LINNE: Legacy Infrastructure Network for Natural Environments*. Illinois Natural History Survey, Champaign, Illinois. 16 pp.

PALMER, D., 2005. A medical history. *Nature (London)*, 434: 23.

PRENDINI, L., 2005. Comment on 'Identifying spiders through DNA barcodes'. *Canadian Journal of Zoology*, 83: 498-504.

SCHOCH, R. M., 1986. *Phylogeny Reconstruction in Paleontology*. Van Nostrand Reinhold, New York. xii + 353 pp.

SCHUH, R. T., 2000. *Biological Systematics: principles and applications*. Cornell University Press. New York. ix + 236 + [3] pp.

TAUTZ, D., ARCTANDER, P., MINELLI, A., THOMAS, R. H. & VOGLER, A. P., 2003. A plea for DNA-taxonomy. *Trends in Ecology and Evolution*, 18: 70-74.

VALDECASAS, A. G., CASTROVIEJO, S. & MARCUS, L. F., 2000. Reliance on the citation index undermines the study of biodiversity. *Nature (London)*, 403: 698.

WHEELER, Q. D., 2004. Taxonomic triage and the poverty of phylogeny. *Philosophical Transactions of the Royal Society of London (B)*, 359: 571-583.

WHEELER, Q. D., 2005. Losing the plot: DNA "barcodes" and taxonomy. *Cladistics*, 21: 405-407.

WHEELER, Q. D., RAVEN, P. H. & WILSON, E. O., 2004. Taxonomy: impediment or expedient? *Science (Washington)*, 303: 285.

WILL, K. W., MISHLER, B. D. & WHEELER, Q. D., 2005. The perils of DNA barcoding and the need for integrative taxonomy. *Systematic Biology*, 54: 844-851.

WILSON, E. O., 1985. The biodiversity crisis: a challenge to science. Issues in Science and Technology, Fall: 20-29.

WILSON, E. O., 1992. *The Diversity of Life*. Norton. New York. [5] + 424 pp. + [16 pp. of colour plates].