Recovery Plan for the Endangered Taxonomy Profession

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The worldwide decline in taxonomists has a broad impact on biology and society. Learning from general historical patterns of science and understanding social changes caused by growing economies, we propose changes in priorities for training taxonomists to reverse these losses. Academically trained professionals, parataxonomists (local assistants trained by professional biologists), youths educated with an emphasis on natural history, and self-supported expert amateurs are the major sources of taxonomists. Recruiting effort from each category is best determined by public attitudes toward education, as well as the availability of discretionary funds and leisure time. Instead of concentrating on descriptions of species and narrow studies of morphology and DNA, the duties of the few professional taxonomists of the future also will be to use cyberspace and a wide range of skills to recruit, train, and provide direction for expert amateurs, young students, parataxonomists, the general public, and governments.

Keywords: amateur, parataxonomist, per capita gross domestic product, pro-am, professional taxonomist

The boundaries of the discipline of taxonomy are often vague. They can include studies of anatomical structures, molecules, geographical distributions, behavior, natural history, and higher evolutionary relationships, with goals that some think are better treated as separate fields of study, such as systematics and phylogenetics. To avoid many of these misunderstandings and controversies, we define taxonomy as a field of biology that identifies, describes, classifies, and names living and extinct species and other taxa.

Ecologists, medical researchers, behaviorists, natural resource managers, conservation biologists, policymakers, and the judiciary represent some of the vast array of disciplines that rely heavily on an accurate documentation of taxa and species (Cracraft 2002). Only 2 million of the estimated 7 million to 15 million species on Earth have been described. Despite this obvious taxonomic impediment, we have seen a significant waning of support for taxonomic research over the last decades (Wheeler et al. 2004, Cotterill and Foissner 2010). Taxonomists are an endangered group. As a result, not only are research efforts in many parts of the world at risk but so too is the availability of information on which we rely for medicine, ecosystem and wildlife management planning, and public policy. We propose a recovery plan that combines established patterns from the history of science with present and predicted future economic indicators to help broaden the pool of those who can contribute to taxonomy and resolve the problem of the endangered taxonomist. This plan draws on literature from economics and from recent work on the rise of professional amateur taxonomists to argue for specific changes in the way contributors to the taxonomic enterprise are recruited, trained, and supported in their efforts. As taxonomy transitions from a museum-based science to an information-based science, access to literature and specimens will increase dramatically. New technology presents an opportunity for taxonomy to expand its boundaries by providing a digital infrastructure to a range of participants far beyond the classical model centered on professional taxonomists.

A historical overview of taxonomy

One of the most reliable techniques for answering historical questions and testing for patterns is using insights from one field to tell us something about another—a philosophical technique called consilience by some historians (Gaddis 2002). In so doing, we can make sense of the past and perhaps anticipate the future (Erwin 1985). The historical development of such varied fields as military science, astronomy, archaeology, geology, physics, computer science, horticulture, ichthyology, malacology, ornithology, mammalogy, entomology, and herpetology shares a common pattern with respect to the relationship between experts and amateurs (Leadbeater and Miller 2004). The earliest stages of these fields were dominated by amateurs—there were often no established experts at the time—who described and named component parts such as species, rocks, stars, or bytes of information. As these fields of study solidified, power was transferred from expert amateurs to trained professional scientists, and graduate training for employment in the field became available. In these cases, the maturation of fields led to research that was increasingly conceptual and theoretical, including systems analysis and the use of formal models. As a result, technical terminology and methodology in these

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fields have become so refined that most of what is known about these topics is now accessible to only a narrow audience of trained professionals (Pearson and Cassola 2007).

This trend suggests that theoretical and institutional development in the biological sciences will lead reliably or even inevitably to the exclusion of expert amateurs. Indeed, the 20th century saw a great deal of this, first with the rise of population genetics in the early decades of the century and then with the advent of molecular biology in the 1950s, followed by the push toward mathematical approaches to ecology in the 1970s. This result would be unfortunate in taxonomy, where professional experts are becoming rare and expert amateurs have long made important contributions, and may, with appropriate support from the professional taxonomy community, continue to do so.

Taxonomy has become quite technical and specialized over the nearly 300 years that it has been practiced in its modern form. It requires access to specimens, libraries of historical literature, multiple technical vocabularies, colleagues' expertise, computers for analyzing data, and wet labs for acquiring genetic information. The trend is toward continued professionalization and the exclusion of amateurs. There is little doubt that expert amateurs play a smaller role in taxonomy than they once did. In Europe and the United States, for instance, a significant part of the infrastructure for taxonomy was built by amateurs. It was common for those who assembled research collections in the late 19th and early 20th centuries to rely heavily on large networks of amateur botanists, birders, and mammalogists—examples include Joseph Grinnell, founding director of the Museum of Vertebrate Zoology; C. Hart Merriam, first chief of the Division of Economic Ornithology and Mammalogy of the US Department of Agriculture (later renamed the Bureau of Biological Survey); and Secretary of the Smithsonian Institution Spencer Baird (Kohler 2006). These administrators made extensive use of commercial collectors who were not trained taxonomists, and who today we would call parataxonomists. These collectors contributed tens of thousands of specimens to science and had long careers as freelance naturalists, and some eventually obtained museum or university appointments. These men included well-known natural historians and taxonomists such as Malcolm Anderson, Joseph Dixon, and Rollo Beck.

It would be a mistake to suggest that interactions among professionals, expert amateurs, and commercial collectors in these cases were completely unproblematic, but the fact remains that many who were outside the community of academic professionals made a substantial contribution to natural history infrastructure in the United States and elsewhere, and did so until fairly recently. The trend toward increased professionalization in taxonomy in the second half of the 20th century reduced some problems associated with amateur collecting and description, as well as the problems of excessive for-profit collecting, but it has done so at the cost of the positive contributions of these workers. Our recovery plan includes ideas for encouraging these contributions once again.

Sources of taxonomists

On the basis of a literature review and from discussions with other taxonomists, we conclude that there are four major sources of taxonomists, and that these sources are often interdependent.

Professionals. Taxonomists with university degrees, trained in a setting that includes classical taxonomy, molecular taxonomy, and cybertaxonomy (standardized electronic tools to share and access information), are the dominant source in academia (Wheeler 2008). More and more, taxonomy is conducted by professionals in allied scientific fields such as ecology, genetics, animal behavior, and conservation biology who become part-time taxonomists by necessity (Godfray and Knapp 2004). However, because taxonomy is mistakenly perceived as a weak, descriptive science with no experimentation (Felsenstein 2004), and because comparative morphology, the heart of academic taxonomy, has long been out of favor (Allen 1978), professional taxonomy positions and funding for taxonomic research have waned dramatically since the mid-20th century (Mayr 1942). Hope for a significant resurgence in financial support for professional taxonomy is probably unrealistic (Agnarsson and Kuntner 2007, Packer et al. 2009). Even national and international programs, such as the Global Taxonomy Initiative and the Partnership for Enhancing Expertise in Taxonomy, which are directed primarily toward supporting professional taxonomists, have had little impact in slowing the trend away from professional taxonomists (Boero 2001). Although most of the new professional taxonomists are now receiving training in Europe and the United States, university and museum programs in rising economies such as China's and Brazil's are becoming steadily more important for both science and society.

Amateurs. Many individuals seeking an avocation have chosen to develop their abilities in taxonomy. From marine habitats where millions of amateur shell collectors and scuba club reef photographers investigate sites rarely or intermittently studied by professionals, to tropical forests where bird enthusiasts and insect collectors visit sites seldom inspected by professionals, nonprofessionals have a tremendous potential to help obviate the overwhelming lack of knowledge of taxonomy throughout the world (Pearson et al. 2010). Their interest levels range from those of occasional observers to serious and committed citizen scientists who function at the level of some professionals (pro-ams) but are not paid for their work. The rise in pro-ams in every field generally occurs in societies with growing economies, as measured by gross domestic product (GDP), falling fertility rate, and an increasing middle or leisure class (Leadbeater and Miller 2004). Under ideal circumstances, amateur taxonomists can be mentored and associated with professional taxonomists, museums, or academic institutions. Nevertheless, the work of many amateurs is considered similar to "stamp collecting" and is not readily accepted as reliable by some professionals. Individual amateurs and aspiring pro-ams often need to prove themselves with quality publications and concrete interactions with professionals before they are likely to be accepted by the taxonomy community.

Parataxonomists. Parataxonomists are local paid workers and inventory specialists trained by professionals. Their expertise is in collecting specimens, sorting them into similar-appearing forms (morphospecies), and recording associated habitat and collection information into data format. Because of their narrow training, parataxonomists deliver constrained results (Krell 2004), making their work most appropriate in developing countries with limited economies and few local experts. However, only a small number of these developing countries can provide lasting and secure funding, management personnel, or the nurturing social structure needed to incorporate informally educated individuals into established government and academic social units (Janzen 2004). Parataxonomy, then, requires a new infrastructure, supported by professional taxonomists, perhaps in the ways suggested below.

Natural history education for youth. Numerous studies emphasize the significance of early education in natural history and the environment, along with field trips, for influencing the career goals of people younger than 14 years of age (Rojewski and Kim 2003). Exposure to nature is essential and can range from nonformal (outings with family, friends and colleagues) (Cullen and Mony 2003) and formal school-related field trips (Zoldosova and Prokop 2006) to informal programs (sponsored by community, regional, national, or international groups, such as nongovernmental nature organizations) (Haigh 2006). This exposure to the natural world can be reinforced by Web sites such as the Encyclopedia of Life (EOL; *www.eol.org*). Youth-based nature programs can promote the interests that lead to taxonomic professional careers; such programs also develop outlets for avocations as taxonomic amateurs (Dillon et al. 2006). Formal, informal, and nonformal levels of education, however, are restricted by economic factors, such as a low per capita GDP of a country or region (La Belle 2000).

National and regional economic influence

The economy of a country or region can influence all the proposed sources for taxonomists, but one should not expect that growing economies will continue to increase their contributions to the pool of professional taxonomists; this is one reason for our focus on amateurs. What kinds of amateurs there are, and where they can be found, are importantly constrained by economics. Some regions rich in biodiversity also have growing economies, and this has an impact on how the professional community might best enable amateurs to contribute.

Although initially, a rise of per capita GDP accelerates pollution, biodiversity loss, and few educational advances (Holland et al. 2009), the rising economy eventually reaches a level associated with higher school enrollment rates, higher science test scores, lower fertility rates, increased political stability (Barro 2001), and greater public awareness of the environment (O'Connor 1998). A less-developed economy will mean little public or government support for primary, secondary, or university education (La Belle 2000); it will also lack a strong middle class with adequate leisure time and the ability to self-fund for avocations. Time, ability, and funding for families or private organizations to support informal education will be deficient. At this level, the training of local parataxonomists by foreign taxonomists may be the only productive way to ensure a supply of budding taxonomists who can continue to help provide the vital information upon which so many areas of society rely (figure 1).

Because one of the first positive responses to a growing economy within a country is the greater funding of primary education (Barro 2001), investment in taxonomists at this time should focus on education of youth (figure 1). As the economy continues to improve, families tend to have fewer children and invest more time and money into each child. These factors will lead to a larger middle class, which usually results in greater

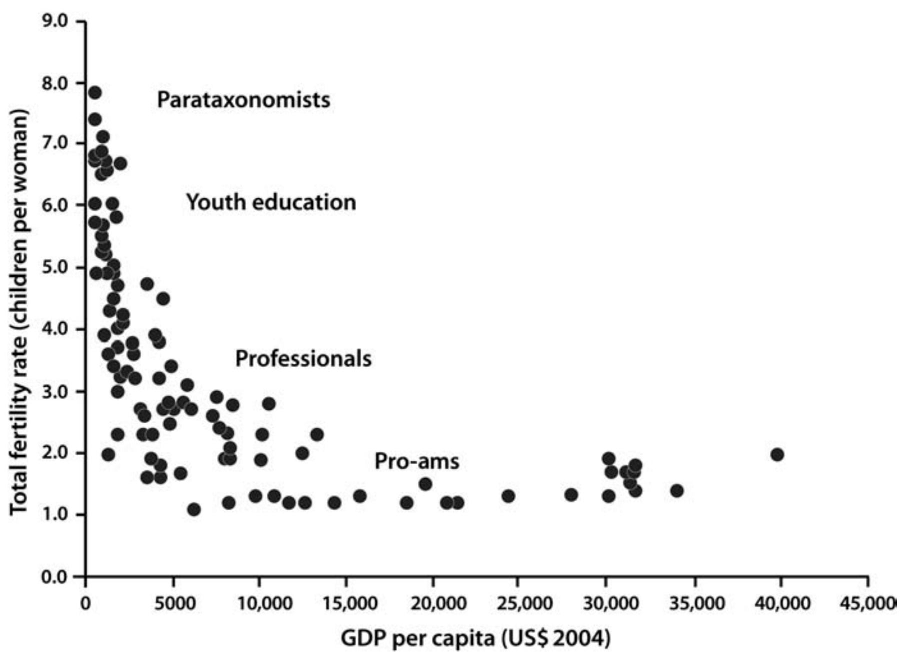

Figure 1. In countries with populations of more than 5 million, relation of growing wealth (gross domestic product per capita) and falling fertility rate (mean number of offspring per female 16 to 38 years old) with approximate points at which support for each of four sources of taxonomists should be emphasized. Data are from the Central Intelligence Agency's World Factbook,* www.cia.gov/library/publications/the-world-factbook/*).

support of higher education, more public citizen-based organizations (nongovernmental organizations [NGOs]), more time and money for avocations (Leadbeater and Miller 2004), as well as heightened concern for the environment (Bhattarai and Hammig 2004). Increased Internet access (Godfray 2007) and more published field guides (Pearson and Shetterly 2006) are especially significant factors in attracting and training taxonomy pro-ams (figure 1). At this stage, however, there is also an increase in the sophistication of scientific study and a rise in the dominance of professionals in the field. At the same time, fewer of these new professionals focus on taxonomy and natural history, largely because of declining employment prospects. With decreasing financial support and perceived need for professional taxonomists, amateurs become, often by default, the major source of taxonomy and associated natural history observations (Leadbeater and Miller 2004).

We queried 35 pro-am colleagues with widely respected publication records in taxonomy, natural history, and the distribution of tiger beetles and birds with the question, "What do you need from professional taxonomists to make yourself more effective and happy as an amateur taxonomist?" The five most common responses were: (1) facilitate specimen loans from museums and collections; (2) help obtain collecting and research permits; (3) share information about local contacts, specialists, and habitats; (4) provide educational opportunities to learn about new procedures, techniques, and literature; and (5) help with page costs in publishing monographs and field guides, although pro-ams generally do things for the love of it even at personal expense.

We are fortunate that strides are being made to build capacity for some of these needs through a new digital infrastructure for taxonomy and for bioinformatics, generally. There have been large-scale efforts at the Smithsonian Institution, Missouri Botanical Garden, the New York Botanical Garden, Arizona State University, and elsewhere to produce high-quality images of type specimens. Meanwhile, the Global Names Architecture and the Universal Biological Indexer have made great advances in indexing and organizing taxon names; the Global Biodiversity Information Facility is databasing and sharing museum records; and the Biodiversity Heritage Library has digitized and shared entire libraries of taxonomic information free of charge under Creative Commons licensing.

These are important tools for pro-ams, but more infrastructure and encouragement is necessary. The EOL is building a set of "LifeDesks" pages through which amateurs will be able to contribute their knowledge. Expert amateurs will also be able to curate EOL pages. Open-access online taxonomic journals, such as ZooKeys, PhytoKeys, and PLoS ONE, make describing new species a faster process without sacrificing peer review and quality control. These are steps in the right direction, but they do not fully address professional acceptance of amateurs or new ways of inviting amateurs into taxonomy and providing them with the training they will need if they are to make a difference.

In their book on the rise of pro-ams and the emerging impact of pro-ams on the economy, Leadbeater and Miller (2004) pointed out five additional ways to help pro-ams become more involved and interested in their avocation: (1) develop government pro-am fellowship programs; (2) declare pro-am days for employees to volunteer or engage in their avocation; (3) prepare volunteers for life beyond employment; (4) encourage professionals to share the stage and limelight with pro-ams in planning, publications, and innovation; and (5) facilitate socialization that will attract an increasing number of participants as pro-ams.

These goals can all be addressed by a willing community, most of them at relatively low costs. However, doing so will require a concerted effort and coordinated action on the part of the taxonomic community, professional societies, and funding agencies.

Recommendations

Although there are exceptions, many professional taxonomists appear to be seeking goals no broader than training more professional taxonomists and convincing funding agencies to support taxonomic research. In a recent volume summarizing a symposium on goals for the new taxonomy (Wheeler 2008), parataxonomists and the training of youth are not mentioned, amateurs and volunteers are cursorily mentioned only three times, and no reference is made to the growing impact of part-time professional taxonomists from allied fields (Valdecasas and Camacho 2003). Instead, article after article in this symposium volume focused on new technology, developing teams of professionals, and ways to make taxonomy more respected as an independent scientific endeavor and not just a service for other fields. Although these considerations are important, they also illustrate the limitations that dominate current thinking. Some taxonomists are already changing the ways in which they function and train new taxonomists, but we believe that there is not yet a critical mass of taxonomists willing to expand their range of goals and consider the full suite of opportunities available. It may be time for taxonomists to adopt a completely new tack and make better use of what is known about the relationships between national and regional economies and their effects on education and the career choices of newly trained professionals.

The precise combination of rising economic indicators, fertility rates, and resultant educational and avocational levels that determine the optimal time to invest in the various sources of taxonomists should be tested and determined accurately (figure 1). These types of tests are already under way by economists (Barro 2001), and with collaboration from biological historians and taxonomists the results could be readily extended to validate the most effective sequence of taxonomist training.

Professional taxonomists must also continue to diversify their duties, which should include (a) directing teams training parataxonomists in remote parts of the world; (b) supporting the quality training of professional foreign taxonomists in the United States and Europe, as well as in the national institutions of countries with rising economies (Wheeler et al.

2004); (c) developing curricula at the primary and secondary levels that will excite and attract students to taxonomy; (d) advising NGOs on research plans; (e) writing grant proposals that may be more likely to be funded by a wider range of private and government agencies through emphasizing support of youth education and cost effective pro-ams; (f) recruiting and mentoring amateur enthusiasts; and (g) sponsoring workshops and symposia in which professionals and pro-ams can interact and socialize with one another (Mallet and Willmott 2003). These activities constitute a return, in a new way, to much of the successful collecting and taxonomic tactics used by interdependent amateurs, parataxonomists, and professionals in the 19th and early 20th centuries.

In addition, taxonomists must engage a wide range of young people. Communicating with increasingly computer-savvy youth commonly requires clever use of interactive Web sites that attract and train students in the latest techniques and technology of taxonomy. For example, Arizona State University's Ask A Biologist program (*askabiologist.asu.edu*) began more than 13 years ago with a simple Web tool to send questions to biology experts. Since then it has grown to more than 2000 pages of content, attracting more than a million visitors each year. The primary goal of the Ask A Biologist site is to capture the imagination of future scientists and amateurs to inspire them to explore the living world. The program is constructed to meet class-plan criteria and to be teacher friendly. Students of all ages encounter a wide range of activities and materials encompassing key taxonomic concepts pertinent to botany, biology, conservation, ecology, biochemistry, genetics, molecular biology, oceanography, and species identification and discovery.

We believe the public should be provided several ranges of opportunities for hands-on experiences with taxonomy. In a recent report on public participation in scientific research, the Center for the Advancement of Informal Science Education proposed that professionals develop three levels of public participation: (1) contributory projects designed by scientists, with participants involved primarily in collecting samples and recording data; (2) collaborative projects in which the public is also involved in analyzing data, refining project design, and disseminating findings; and (3) cocreated projects designed by scientists and members of the public working together, with at least some public participants in all aspects of the work.

As the general historical trend of advancing professionalization of science in rising economies reduces the number of positions and research support for professional taxonomists (Hopkins and Freckleton 2002), the few remaining such experts need to seek ways in which their efforts can have a multiplier effect. This includes broadening and enhancing ideas of what it is to do taxonomy. As taxonomy continues to transition out of the museum and into cyberspace, the skills of the taxonomist and the informatician will resemble one another more than they do now. One effect of this change will most likely be that the taxonomists' skills will be in higher demand for the kind of biodiversity informatics projects mentioned above, with funding coming from large, integrated initiatives for biodiversity, ecotourism, or science education. Academic taxonomists will no longer focus their time and efforts on only a single, museum-based taxon and comparative morphology, but will instead develop goals that include computer imaging of specimens (Wheeler 2008), interpreting molecular and mathematical modeling results, advising developers of taxonomic curricula, and leading teams that include nontaxonomists and amateurs (Cohn 2008). One of the most important functions of professional taxonomists will be assessing and prioritizing the needs for taxonomic work in various regions of the world. Professionals can provide budding pro-ams with alternative possibilities to become experts on taxa that are poorly studied and would otherwise languish in obscurity (Russell 2010). Professional taxonomists will become critical to information science and will be responsible for maintaining broad lines of communication among all the participants—amateur, professional, public, and government.

At all costs, academic taxonomists must avoid the narrow and defensive mentality that characterizes all fields and professions to some degree (Greenwood 2007). As Leadbeater and Miller (2004, p. 16) pointed out: "Some professionals will seek to defend their endangered monopoly. The more enlightened will combine the know-how of professionals and amateurs to solve complex problems. That is true in astronomy, software development and online games. It should be the path that our health, education and welfare systems follow as well."

Furthermore, professional taxonomists must become effective advocates for increasing the demand for taxonomy and taxonomists across all levels of society, from legislators and judges to reporters and the general public. Unfortunately, a simple argument that conservation biology or biodiversity studies cannot advance without taxonomists is unlikely to produce an adequate increase in public funding and broad support (Mace 2004). However, if the economic losses associated with having fewer taxonomists can be made personal to the public and decisionmakers, the pro-taxonomist argument will be stronger and broader. Powerful legislation, such as the Endangered Species Act in the United States, or international treaties such as CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is partly based on accurate taxonomy, and the economic impact of these laws is in the millions of dollars annually (Brown and Shogren 1998). Moreover, the economic and social necessity of taxonomy and taxonomists in fields such as biochemical prospecting among plants by pharmaceutical companies, the study of impacts on health of disease vectors, and inspection and interception activities at ports and national border stations (including the interdiction of invasive species) are needs that public and government officials will better understand and support.

We conclude that an appropriate recovery plan for taxonomy involves a two-step initiative. By consciously focusing time and energy on multiple ways to efficiently expand the supply of taxonomists, and simultaneously influencing public policy so that the economic needs for the profession become obvious, taxonomists need not go extinct (Evans et al. 2005).

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