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Biology Needs a Modern Assessment System for Professional Productivity

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Stimulated in large part by the advent of the Internet, research productivity in many academic disciplines has changed dramatically over the last two decades. However, the assessment system that governs professional success has not kept pace, creating a mismatch between modes of scholarly productivity and academic assessment criteria. In this article, we describe the problem and present ideas for solutions. We argue that adjusting assessment criteria to correspond to modern scholarly productivity is essential for the success of individual scientists and of our discipline as a whole. The authors and endorsers of this article commit to a number of actions that constitute steps toward ensuring that all forms of scholarly productivity are credited. The emphasis here is on systematic biology, but we are not alone in experiencing this mismatch between productivity and assessment. An additional goal in this article is to begin a conversation about the problem with colleagues in other subdisciplines of biology.

Keywords: academic assessment, systematic biology, scientific productivity, digital objects, curation of natural history collections

The nature of research productivity in many disciplines has changed dramatically over the last two decades and will continue to evolve. However, change in the modes and venues of scholarly productivity comes with the attendant risk of a mismatch between the nature of this productivity and the assessment and reward structures that govern professional success. At a recent series of four workshops on the future of systematics and biodiversity research, participants discussed the remarkable mismatch between professional productivity in systematics—both traditionally and in the twenty-first century—and the prevailing academic assessment system. Here, we describe the problem and also present some potential solutions. We know that the systematics community is not alone in experiencing this mismatch, and we invite our colleagues in other subdisciplines of the biological sciences to join us in seeking solutions.

Peer-reviewed publications are a major form of productivity in systematics, but systematic biologists increasingly contribute knowledge in nontraditional ways as well. Systematists contribute actively to the Tree of Life Web Project (<http://tolweb.org>), the Encyclopedia of Life (<http://eol.org>), and other Web-based compendia of systematic knowledge. They also submit data to central repositories from which data can be retrieved and used by others; these include GenBank (www.ncbi.nlm.nih.gov/genbank) and Morphbank (<http://morphbank.net>), as well as distributed biodiversity database initiatives (e.g., the Global Biodiversity Information Facility [GBIF], www.gbif.org), among other types of initiatives. Frequently, data are made available even before they are formally published. These biodiversity data provide the critical factual basis for addressing societal challenges (e.g.,

species conservation, invasive species, infectious diseases, climate change), and access to these data empowers research and discovery across a broad disciplinary spectrum.

Systematic biologists also contribute in other nontraditional ways common to all sciences. Many now maintain Web sites on which research results are reported; many also create and maintain other digital resources (e.g., databases, online keys, identification aids) and teaching aids. Some write software or devise laboratory tools that are extensively used by a diversity of scientists and educators. Many produce scholarly contributions that appear only online (e.g., the new generation of “Red List” assessments of species status led by the International Union for Conservation of Nature [IUCN]). Some develop interdisciplinary and transdisciplinary research programs that bind heretofore disparate fields of science (e.g., proteomics, genomics, bioinformatics, systematics). These kinds of research productivity are increasingly contributed by the rising generation of students and postdoctoral scholars, as well as by more established professionals.

However, somewhat remarkably, systematic biologists continue to compete for jobs and strive toward tenure and promotion in academia largely under the model for professional credit used during the last century. This model counts peer-reviewed publications and calculates “value” using some function of the number of publications, the quality of the journals in which those publications appear, and the impact of the publications on the field as measured by citation indices. These metrics have some merit, but we believe that our academic assessment system requires urgent updating to reflect the nature of systematic biologists’ contributions to biodiversity research in the twenty-first century. It is clear that achieving success in our discipline

now requires productivity in nontraditional modes such that we undervalue them at the peril of early career scientists and of the discipline as a whole.

Not only are these novel forms of productivity undervalued in academic assessment, but so are some traditional contributions in systematic biology. For example, collecting biological specimens for natural history collections (often including organisms that one does not study) and adding to the value of publicly available museum holdings by providing correct taxonomic names are essential scholarly activities to which many systematists devote considerable time. Far more than “service,” these activities require considerable knowledge and constitute research productivity. These specimens, their identifications, and associated data (e.g., DNA tissue, host-plant data, parasite data) are increasingly made available on public databases and are essential resources for conservation planning (Kress et al. 1998, Funk et al. 1999), documenting biotic response to climate change (Moritz et al. 2008), predicting the geographic potential of invasive species (Peterson and Vieglais 2001), understanding disease transmission patterns (Yates et al. 2002), informing forensic science (Dove 1999), and bioprospecting for new materials (Soejarto 1996)—to name just a few uses. Collecting and curating biological specimens builds and strengthens the basic infrastructure on which biodiversity knowledge is built, and this knowledge provides data critical for many disciplines beyond systematic biology.

We note that these traditional kinds of productivity are often explicitly valued for systematists employed at public and nonprofit museums and botanic gardens, at least locally. However, when being externally evaluated for promotion, competing for external funding, or seeking new professional opportunities, these systematists confront the expectations of the broader community, which, in our experience, is dominated by academics at research universities where such contributions are often undervalued or even ignored. In fact, systematists who curate university-based museums may be among the most at risk from the mismatch between the work required to fulfill their curatorial responsibilities on one hand and the demands of their academic department on the other.

We know of no formal study to address the problems in systematic biologists’ careers caused by the mismatch between productivity and assessment, but anecdotal evidence abounds. For example, one of us (DRM), as an assistant professor in 1997, was told by an administrator that two major efforts—the software program MacClade (Sinauer Associates, Sunderland, MA), already a community standard in systematics, and the Tree of Life Web Project, also widely used in the field—would not be considered in his tenure package, because they were not peer-reviewed publications. These products were eventually considered, but the initial threat could have led to their abandonment. Two of us (one as recently as 2010) have been assistant professors who, despite job descriptions specifying roughly one-quarter of effort as curatorial, were told that curatorial productivity would not count toward tenure and that only the traditional

measures based on peer-reviewed publications and grant funding would. In the 2010 tenure guidelines of at least five of our institutions, there is no mention of online publication, databases, software, or museum curation as acceptable avenues of scientific contribution.

It is vital, then, for the assessment system to change so that systematic biology can flourish in today’s world. Below, we first explore how the model of evaluating contributions can be changed, attempting to establish at least some of the problems that will be confronted and presenting some ideas for solving them. We follow with more radical speculation about possible future assessment models. We close with a description of what we commit to do ourselves to help bring about this change.

Adjusting the assessment model

If academia were to adopt an evaluation system that expanded the metrics now associated with traditional publications, how might this work? The products of a modern systematist can now include traditional publications, digital objects (e.g., data matrices, images, text, videos, databases, expert networks, blogs), digital systems that contain objects (e.g., Web sites, blogs, databases) with their own unique and valuable architecture and vision, services and tools (such as analytical software), and biological specimens (figure 1). To accommodate all of these valuable contributions to the field, the metrics that are now used for the various dimensions—in particular, the quantity, quality, and impact—of traditional publications might be extended.

Quantity can be measured for any of the new modes of productivity (e.g., Web-based contributions, data sets, software packages) and for traditional activities that have historically been undervalued (e.g., specimens added to collections, specimens identified). However, what constitutes a unit of quality will not always be clear (e.g., is a specimen easily collected in a city park equal to a specimen collected in a remote part of the Amazon basin? Does one Web page devoted to a plant family equal one contribution, or do the sections of that page each constitute a contribution?), nor will their relative weights be clear (e.g., is a Web page equal to a data matrix?). This problem has its parallel in current practice in that our evaluation system encompasses publications of a range of scales and scopes, from brief communications to major reviews, synthesis papers, and books.

The *quality* of a publication has at least two components in the current system. First, peer-reviewed journal (and book) publications are viewed as higher-quality work than those published without peer review. Peer review is currently applied to several nontraditional forms of research productivity (e.g., although they are published only online, IUCN Global Assessments of species are peer reviewed, scholarly products; the Tree of Life Web Project [<http://tolweb.org>] has peer reviewed some pages). Although peer review may be difficult to apply to other nontraditional contributions, doing so may help to bring about recognition of their worth. A nationwide project called Merlot (www.merlot.org) provides

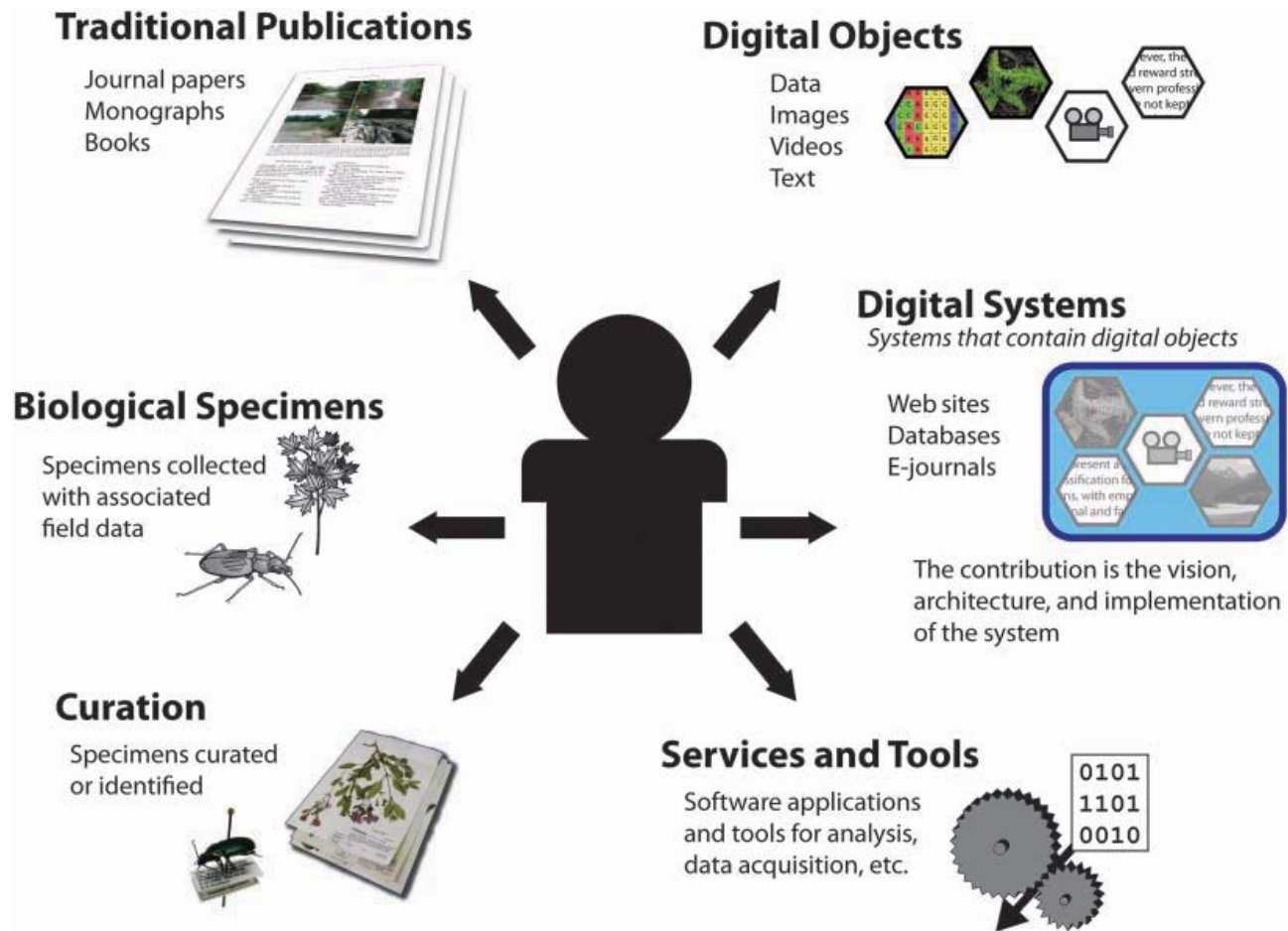


Figure 1. Some contributions made by systematic biologists and some metrics for judging the quality and impact of these works. For all categories, quantity can also be measured. Note that overlap exists between categories (e.g., objects in the physical world [publications on paper, biological specimens] can be represented by an object in the digital world [e.g., a database record] or by an actual digital version [e.g., publications]). The boundaries between some categories are blurred (e.g., an animation, as a digital object, can have interactivity added to it; as the interactive capabilities increase, it could take on the role of a service or tool).

peer review of online teaching content, using the same criteria that are used for journal articles (Young 2002). In addition, the American History Association and the Modern Language Association have approved guidelines for evaluating digital media (Young 2002). Similar guidelines and peer-review systems could be developed for biological resources. We note that writing peer reviews is its own form of research contribution; several communities are experimenting with open peer review to provide recognition for this work (Godlee 2002).

A second, often-applied metric of the quality of a publication is the quality or impact of the journal in which the article is published; this is often interpreted as an indirect indication of the article's quality. For example, the Thomson Reuters Impact Factor (IF) is used to rank peer-reviewed journals. The IF is a metric of mean citations per article in a given journal and is calculated annually on the basis of the number of citations in a given year of those citable articles that were published during the two preceding years. As the sole arbiter

of journal quality, such a metric has many shortcomings (Seglen 1997, Krell 2009, Neff and Olden 2010), including the simple fact that not all journals are in the system. Particularly, within organismal biology and systematics, citation databases are deficient in journal coverage (Krell 2000, Valdecasas et al. 2000, Krell 2009), which has the effect of artificially reducing the estimated scientific impact of biodiversity publications. As a measure of the quality of any given article, the IF is very flawed. The quality of an article is not necessarily correlated with the quality of the journal in which it is published; many superb articles in systematics are published in low-IF journals, and weak or problematic articles have been published in journals with very high IF ratings.

Although impact factors might be devised for other traditional forms of contributions and for newer forms of productivity, this will not always be easy or necessarily sensible. Should specimens deposited in the Natural History Museum in London, which sends out many loans per year and has

many visitors, be considered of higher quality than those deposited in a smaller museum? Should images deposited to Flickr (<http://flickr.com>) be considered of higher quality than those deposited to MorphoBank (<http://morphobank.org>), simply because the former has vastly greater usage and is more commonly cited on the Web?

Many aspects of quality simply cannot be assessed by a metric of this sort. Determining the quality of most products, including that of traditional publications, requires that a human examine the contribution, compare it to other contributions, and make a judgment about the product. This is, of course, why peer review in advance of publication exists. These judgments will also be needed for contributions that have been made without peer review, if their quality is to be assessed in a valid manner.

The *impact* of a publication on the field is often evaluated as the number of times it is cited in other articles, as reported by the Thomson Reuters Science Citation Index (SCI). Impact and productivity can also be measured cumulatively over a systematist's career using measures such as the *h*-index. A researcher with an index value of *h* has published *h* articles that have each been cited at least *h* times. Such cumulative measures have been touted as a means of objectively assessing achievement for the purposes of tenure, promotion, and distinction (Ball 2005, Hirsch 2005) within a field. Both metrics share with journal IF the shortcoming that not all serials are indexed by the system; notably, a number of important journals in systematic biology, especially those that publish monographs, are not included. Books—whether edited volumes or individual contributions—are likewise not included in the SCI. Furthermore, cultural differences among disciplines in terms of the patterns of citation will systematically yield fewer citations for certain kinds of publications (e.g., those that deal with a particular group of organisms may be cited almost exclusively by authors who study the same organisms). Ironically, the style used by systematists to cite works in which species were described (along with publications in which changes were made to taxonomic names) leads to undercitation of these important publications. These are traditionally cited in sections of a systematics paper that deal with the names of taxa and are not included in the list of cited references. Therefore, these citations are omitted from metrics reported by the SCI, and the journals in which such publications appear do not benefit in terms of a higher IF score.

Some modification and expansion of the SCI might enhance its power to measure impact. Public Library of Science (PLOS) journals provide multiple metrics for individual articles beyond traditional citations (e.g., reader rankings, number of comments, blog coverage, number of times bookmarked within online bibliometric libraries [e.g., CiteULike]; Neylon and Wu 2009). In addition, because works in systematics often remain in use for decades, longevity of impact may be a particularly valuable metric. (Note that longevity is measured by the Thomson Reuters system for whole journals but not for individual articles.)

Some of us already track coverage of our work in traditional media, but the newer media (e.g., blogs, online discussion forums) have increasingly large impacts. Reports and discussion of publications and discoveries in these newer media can be monitored through online technologies. One example is using backlinks to track the popularity of articles in newer media (*backlinks*—also termed *incoming* or *inbound links*—are links to the article from an external Web site). Recording the source and date of backlinks provides documentation of the blogs, tweets, and Web sites that mention a scientist's work and can indicate the volume, breadth, and longevity of the impact of the article. Another example is the use of PageRank (Page et al. 1999) to measure an article's impact. The PageRank algorithm combines backlinks with a measure of rank of the link originator: Incoming links from influential resources count most highly.

Impact metrics can be extended to accommodate forms of productivity other than articles published in indexed journals. The number of times a page is accessed and the number of downloads and citations are excellent indicators of the degree to which the community values software, for example. For Web-based contributions, the number of hits, the number of unique visitors, and the number of countries of origin of visitors are already measured by many sites; time spent on the site is also often measured (although this can reflect that a site is difficult to use). New assessment techniques should capture a wide variety of these measurements (Chavan and Ingwersen 2009, Priem and Hemminger 2010); with time, the most useful of these (or equations to combine them) may become clear.

We warn, however, that measures of use by others are deeply flawed as primary metrics of the value of systematic contributions: In our field, research that illuminates poorly studied groups in the dark corners of biodiversity is valued. These contributions are critical to our field's overall goal of discovering and documenting biodiversity. Products related to these groups will almost certainly be cited rarely—in part, because few people study them. If citation indices play a dominant role in assessment in systematics, the only systematists who will prosper are those who study “popular” organisms or model systems (e.g., birds, *Drosophila*, *Arabidopsis*). Therefore, we must not rely on use by others as the primary arbiter of a researcher's productivity; contributions to scientific knowledge must be judged and valued, even if a researcher's products see relatively little use by others as estimated by the number of citations.

Technical and social changes required for a new assessment model

Automation will facilitate the tracking of all forms of productivity. Although the metrics mentioned above are straightforward, reliable automated tracking of these usage metrics will require both technological and social change. We need to build systems to automate the tracking of these metrics so that they can be easily reported on curricula vitae (CVs) and as part of tenure and promotion packages.

Without such systems, administrators and our colleagues in other subdisciplines of biology will likely underappreciate both nontraditional and traditional but untracked forms of research productivity.

Unambiguous tracking will require that all research products have a permanently associated unique identifier (ID), such as a GUID (globally unique identifier), LSID (life science identifier), or DOI (digital object identifier). This unique ID would move with the object through cyberspace, permitting the object to be located and its use to be tracked and counted. Several repositories currently provide DOIs or GUIDs to submissions, including ZooKeys (Penev et al. 2009), Dryad (Vision 2010), and Scratchpads (Smith et al. 2009). Contributions that are not inherently digital (e.g., specimens in museums) would ideally have a virtual counterpart, a digital object that itself contains a unique ID, so that usage can be tracked.

Unambiguous author IDs also need to be linked to the contributions so that contributors receive credit; this can be in the form of an identification code for each researcher (e.g., <http://researcherid.com>; Bourne and Fink 2008; Cals and Kotz 2008). Botanical systematists have recognized the need for unique researcher codes and have devised them for those who describe new plant taxa (Brummitt and Powell 1992). This system will enable works in botany to be relatively easily included in a new assessment system, once researchers' botany-specific codes are cross-referenced to universal codes for all researchers. One system that will support mapping to past unique author codes is ORCID (<http://orcid.org>), an effort already supported by many major scientific initiatives, including PLoS, the European Molecular Biology Organization, and Thomson Reuters.

Museums that house biological collections should also have unique IDs, so that they can receive credit and can document the value of their contributions. Such systems already exist for herbaria (i.e., Index Herbariorum, <http://sciweb.nybg.org/science2/IndexHerbariorum.asp>) and are under development for others (e.g., Registry of Biological Repositories, www.biorepositories.org). One could imagine unique IDs for other entities, such as funding agencies and grants, so that research output can be linked to funding sources.

In addition to unique IDs, evaluators need consistent practices and infrastructure to automatically discover these IDs within attributions. Authors must cite the resources they use, but this is not always practiced (Sieber and Trumbo 1995). Ideally, data sets and other research outputs would be cited directly (Dryad database citation policy; Penev et al. 2009) along with literature citations. Furthermore, attributions must be both machine readable and in a portion of the resource that is machine accessible: Attributions within the formal citation bibliography are much preferred to mentions in an acknowledgments section that lies behind a subscription pay wall. Machine-readable citation lists and metadata are even better (Shotton et al. 2009). The maintainers of a few databases currently attempt to collect and display reuse information (e.g., the Gene Expression Omnibus,

www.ncbi.nlm.nih.gov/geo/info/citations.html; the Distributed Active Archive Center for Biogeochemical Dynamics, <http://daac.ornl.gov>); however, their collection processes are manual and time consuming. Infrastructure must be built to harvest this information automatically and to provide it in a form that can be easily embedded in CVs and research assessments.

Although attribution systems that track and document contributions to electronic resources will surely emerge as a result of pressures from multiple fields of science, systematic biologists must help develop them within our field. There have been numerous calls for systems to manage data attribution (Nature Genetics 2007, 2008, 2009, Costello 2009, Nature Biotechnology 2009, Thorisson 2009), in part so that data producers receive quantitative credit for the use of their published data accessions (Nature Genetics 2007, Smith et al. 2009). Such systems would be valuable but would not accommodate the variety of contributions made by systematists. In particular, we must not lose sight of the need to document contributions that are traditionally nondigital, such as the collection, curation, and identification of specimens. For example, specimen-level database records should ideally have a field for the ID of the collector so that their contributions can be tracked, and we should cite, in a machine-parsable section, the IDs of specimens that we use in our contributions.

Such an accounting system would facilitate a richer and more realistic view of accomplishment and credit. If these tools are automated and provide a publicly available accounting of productivity, we expect that administrators will embrace these numbers as they have embraced measures that are derived from traditional publications.

A more progressive assessment model

As we imagine a world in which digital systems contain more and more of our systematics knowledge and in which technology makes it easy for many to add content to this knowledge base, the question of who might or should contribute becomes relevant, and that leads to additional questions about assessment mechanisms. Over the last century or so, the gatekeeping system that determines who contributes to our scientific knowledge base has been fundamentally based on peer review and the reputations of scientists that are thereby built. Peer review, however, becomes very cumbersome when contributions are extremely numerous and small, as is likely to be the case for biodiversity databases. Although crowd-sourced projects such as Wikipedia (<http://wikipedia.org>) are valuable, it is unlikely that the scientific community would embrace the anyone-can-contribute model for our community databases (e.g., Pennisi 2008). A gatekeeping system that relies solely on the contributor's holding of a professional position will not be successful, because more and more amateurs (i.e., people without careers in systematic biology) are becoming significant contributors to biodiversity knowledge. Some other method of vetting and filtering contributions is needed.

Our field could consider a model in which assessment is done interactively, by the community, in a style similar to that used on some Web sites today. For example, we might devise a system similar to that used by Stack Overflow (<http://stackoverflow.com>) or the intelligent wiki implemented by the Biofinity Project (<http://biofinity.unl.edu>), which uses Adaptive Knowledge Assistants to provide customized support for human users. Imagine that anyone could contribute images, identification of specimens in those images, species diagnoses, searchable text tags for images, links to relevant literature, and so on to a central biodiversity database. Other contributors could vote up or down on the contribution, with the community itself judging the most-valued contributions. Both the contribution and the contributor would be so judged. Contributors who, through time, were judged by the community to have contributed value to the knowledge base would have many votes and could gain privileges (such as the ability to remove poor contributions) as their vote tally increased. One could imagine that votes by such esteemed contributors would themselves be granted greater weight. To alleviate concerns about poor contributions, one of the publicly available listings of such a database could be of only the data vetted through the accumulation of a large number of positive votes or votes from people who have gained many votes and contributions made by those with many previous votes. The system could be built to allow only one vote per researcher ID per contribution. Overly negative participants could be deterred by having negative votes negatively affect the voter's own score (Stack Overflow employs this method). A reputation system based on votes of contributors, although seemingly radical, is not that different from how science currently works. However, this new assessment model would be more explicit, open, and quantifiable. If such a system were built, votes that a contributor gained could be one measure to assess the researcher in an academic setting. Such an assessment model for systematics, however, would have to accommodate, in a sensible fashion, contributions on groups of organisms so rarely studied that only a very small community of people would vote. Advantages of this type of system include validation by scholars as well as the power to vet resources broadly across the sciences, including identification guides, genomics resources, comparative image resources, teaching aids, and interactive lab modules.

“We must become the change we want to see”

—Mohandas Gandhi

Change must begin with us. Fundamentally, change will result from the amalgamation of the practices of individual scientists. We can start immediately on the path to achieving a better match between patterns of productivity and metrics for professional achievement. The authors and endorsers (a list of endorsers can be found in the online supplementary materials at <http://dx.doi.org/10.1525/bio.2011.61.8.8>) of this essay commit to taking the following steps immediately:

Add nontraditional forms of productivity to our CVs, job applications, and tenure and promotion packages. Include

software developed; Web site contributions; openly archived data sets; identification of organisms; numbers of specimens collected, curated, identified; digitized or georeferenced historical museum specimen collection records. Include usage data for these contributions where they are available. Count these annually just as we count other more traditional forms of accomplishment. Encourage junior scientists to do the same.

Write favorably about alternative forms of productivity in letters of recommendation and letters of evaluation. Speak directly to the importance of a person's curation efforts; collecting activities; and sharing of images, data, and specimens as appropriate. Commend those who make their products available in the most usable formats for people inside and outside the sciences.

Value these alternative forms of productivity when we sit on departmental promotion and tenure committees. Strive to make sure that they are included in reporting on the outcome of our committees' deliberations.

Broaden job descriptions so that they better correspond to the ways in which modern systematic biology operates.

Cite all forms of research reuse in our publications, including published articles, preprints, blogs, data sets, databases, and software. Attribute the original products (and not just secondary publications that describe them) in the formal citations list. As reviewers and editors, remind colleagues about best-practice attribution practices.

As authors, reviewers, and editors, work to achieve the citation of publications in which taxa are described, as well as of revisionary and floristic or faunistic works that enabled the identification of the organisms. Ideally, these should appear in the literature cited along with other contributions that critically underpin the new publication.

Formally acknowledge collectors whose efforts support systematics research; include them as coauthors when appropriate. Acknowledge collections from which we borrow material using collections IDs when they are available. If collections data from portals (e.g., GBIF) are used, cite both the portal and the individual collections that provided those data.

Seek the implementation of peer-review systems for non-traditional publications and digital resources.

Finally, educate administrators about the value of an improved assessment model.

The news that many contributions of systematic biologists are undervalued in the academic assessment system is not, in fact, news. Systematists have been collecting, curating, and naming organisms for hundreds of years. As the academic credit system “matured” in the second half of the twentieth century, these forms of productivity were largely left out of the credit equation. Is it possible that the lack of recognition in the academic assessment system of these forms of productivity has contributed to the diminished status—indeed even the near disappearance from many academic departments—of traditional systematics over this same time period? As systematists take on ever-expanding kinds of

productivity, from Web sites to uploaded images and DNA sequences, we do so at our peril if we do not work in parallel to ensure that we—and our junior colleagues—receive the professional credit that these achievements merit.

The academic assessment system requires both updating and remodeling, and this must be done in the context of a broad and deep understanding of productivity across scientific disciplines, including but certainly not limited to systematic biology. We invite our colleagues in other subdisciplines of biology to join us in taking active steps to ensure that the professional reward system encompasses all forms of productivity that are vital to progress in science.

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