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# A Position Paper on the Electronic Publication of Nematode Taxonomic Manuscripts

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*Abstract:* Several nematode species have now attained 'model organism' status, yet there remain many niches in basic biological inquiry for which nematodes would be ideal model systems of study. However, furthering the model system approach is hindered by lack of information on nematode biodiversity. The shortage of taxonomic resources to inventory and characterize biodiversity hinders research programs in invasion biology, ecosystem functioning, conservation biology, and many others. The disproportion between numbers of species to be described and numbers of available taxonomic specialists is greater for Nematoda than for any other metazoan phylum. A partial solution to the taxonomic impediment is the adoption of recent advances in electronic publishing. Electronic publishing has the potential to increase the rate at which taxonomic papers are published, the breadth of their distribution, and the type, quantity, quality, and accessibility of data. We propose that the Journal of Nematology implement the advantageous aspects of electronic publication as a means to help ameliorate the limitations of an underdeveloped taxonomy and empower the nematological disciplines currently hindered by it.

*Key words:* data integration; digital multifocal images; electronic publication, nematode taxonomy, online descriptions, position paper.

## Position Statement

The Systematic Resources Committee of the Society of Nematologists argues that refereed electronic publishing of nematode taxonomic manuscripts, especially species descriptions, has distinct advantages over print-only publications by potentially accommodating more comprehensive morphological, developmental, biological, sequence and environmental data. Relative to print-only descriptions, the approach enables more rapid communication and broader dissemination of taxonomic information that invites greater input toward quality control of taxonomic research. Electronic publication has the potential to promote increased global involvement in high-quality taxonomic work by increasing the rate of implementation of phylogeny-based and readily testable species delimitation criteria. These advantages of electronic publication will help to address a major challenge with respect to the enormous genetic diversity of Nematoda relative to the small percentage of named species and the disproportionately small number of currently active taxonomists.

## Background and Need

Nematodes, arguably with more than one million species, are one of the most diverse groups of animals (Lambshead, 2004), but this diversity and the urgency for global inventory of nematodes is not matched by our current capacity to describe species. About 27,000 nematode species are known in the literature, and there is a declining trend in new descriptions. An assessment for the last three years (CAB International Abstracts) revealed 172 new species descriptions in 2003, 135 in 2004, and 83 in 2005. During this period only 13 new species (≈3%) were published in the Journal of Nematology (JON). Decline in the number of taxonomic descriptions extends to fields beyond nematology (Disney, 1998; Coomans, 2000) and may reflect attitudes of funding agencies, journals striving to attain higher impact factors, and the recognition of research endeavors and hiring practices of institutions. Institutions that have previously supported taxonomists often are not replacing these positions at retirement (Hugot, 2002), continuing the threat of loss of taxonomic expertise especially for the 'difficult' groups including Nematoda (Godfrey, 2002). In the face of such losses there has been sporadic recognition of the crisis of

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adequate taxonomic resources and particularly so in the context of the challenge to inventory the world's biodiversity (Systematics Agenda 2000, 1994; Convention on Biological Diversity, 2002 http://www.biodiv.org/convention/default.shtml). These challenges are the basis of a number of funding initiatives by the US National Science Foundation including "Partnerships for Enhancing Expertise in Taxonomy (PEET), Biotic Surveys and Inventories, and Tree-of-Life. Nematology has been strongly represented in these programs, but the amount and continuity of support remains inadequate in relation to the size of the task. The most important issues and developments challenging progress in nematode taxonomy include:

1) There is increasing evidence that the number of undiscovered (and often threatened) species on earth is much greater than previously assumed; this is especially so for invertebrates such as nematodes, a large proportion of which are microscopic.
2) Reliable taxonomy is essential to the repeatability of most biological research. Advances in knowledge of the biology and ecology of many little known groups, including nematodes, are critically constrained by their underdeveloped taxonomy (e.g., Janzen, 2004).
3) A sound broadly based phylogenetic framework (including taxa that may not have recognized economic importance) is an essential context for understanding taxa of recognized economic relevance (e.g., plant parasites) and for efficient choice and application of model systems (e.g., *C. elegans*).
4) Expanding taxonomic tools, including use of molecular data and digitized morphology, are increasingly available to the taxonomic community as well as to end-users of taxonomic information.
5) Electronic publishing provides alternatives to high costs, slow processing, and narrow availability, including limitations to type specimens and quantities of data sometimes associated with print-only publications.

Although the urgency to revitalize taxonomy is widely appreciated, proposed solutions are diverse and often controversial (Lipscomb et al., 2003; Tautz et al., 2003; Will and Rubinoff, 2003). This position paper does not attempt to address all relevant issues; instead, it focuses on the methods of publishing taxonomic information.

Traditionally, print-only publications have been the only recognized way to communicate taxonomic descriptions. A new nematode species description typically includes: a) a narrative description of morphology, b) line drawings of key features, c) morphometric data of structures deemed important for identification and d) photomicrographs and scanning electron micrographs. Biological, geographic, developmental, and molecular data are sometimes included, the later being a more recent introduction. The decision to propose a new taxon is assumed to be based on a defensible operational species concept that is expected to include comparisons of the putative new species with type materials of similar and presumed closely related known taxa. It is expected that type specimens of any newly proposed taxon be deposited in one or more curated museums.

Print publications play a central role in the dissemination of taxonomic descriptions, but advances in electronic technology have created new, more rapid, cost-effective and often more appropriate ways (such as alternative data formats, for example) to document and present such information. This technology opens an opportunity that alters the way scientists (and the public) communicate. We propose that the refereed electronic publication of nematode taxonomic manuscripts, particularly species descriptions, will offer the following major advantages:

1) Expanded use of diverse data and metadata.
   a. Morphology: The introduction of Digital Multifocal Images (DMI) (De Ley and Bert, 2002; Eyualem-Abebe et al., 2004) has opened new opportunities in communicating morphology. In this approach, morphological information for nematodes is captured in the form of a stack of high-quality images representing individual focal planes through the nematode body. When these images are converted into video clips, each clip can be viewed by advancing and reversing the movie to represent the process of focusing. As such, the viewer can reconstruct a three-dimensional image of the specimen. This approach, combined with advances in software, provides new possibilities in morphological analysis and enables end-users to reexamine and manipulate virtual digital specimens in light of their own applications and expertise. Electronic formats, unlike print publications, are able to directly incorporate DMI. In contrast to the space constraints of printing, electronic publication also more readily accommodates extensive numbers of photographs, and computer-assisted or conventional scanned drawings.
   b. Molecular phylogenetic information: The important contribution of DNA sequence data to taxonomy and particularly in the context of phylogeny is indisputable. Contemporary species concepts emphasizing phylogenetics (Adams, 1998, 2002; Nadler, 2002) typically extend beyond morphology to employ sequence information as a basis to hypothesize and test hypotheses of species. Furthermore, sequence data often provide an independent character set against which congruence with morphological information and with traditional taxonomies can be tested. Some have proposed that molecular sequence data can

be used taxonomically in the absence of traditional morphological evaluation (Edgcomb et al., 2002; Floyd et al., 2002; López-Garcia et al., 2003), but this disjunction makes it impossible to link such data to taxonomic or bionomic literature. When linked to morphological data, the ready availability of molecular data to end-users supports the process of testing and reanalysis, and ultimately enhances the quality of taxonomic information. Electronic publications relative to print publications enhance this process by allowing molecular sequences to be conveyed in more detail and in a form more useful and directly accessible.

c. Biological data: Beyond morphology, digital technology in publication can accommodate archived movies illustrating aspects of behavior and biology (e.g., feeding, movement, mating) that are otherwise difficult to accurately convey and evaluate with text alone. Compared to print, electronic publications are potentially more dynamic in communicating biological/behavioral processes and in facilitating the integration of various sources for end-users.

d. Environmental data: A framework of geophysical, biological and environmental data to generate ecologically meaningful conclusions often extends from or requires taxonomic information. To this end, electronic publications can be readily integrated within a geographic information system (GIS) and other mapping infrastructures to visualize various layers, including distribution patterns of a taxon/taxa vs. soil, biotic and anthropogenic factors. Undoubtedly, the ability to acquire real-time environmental data will grow and help create a dynamic platform to address broader questions and understand short- and long-term population/community/ecosystem-level changes.

2) Reduced cost of publication: The cost of electronic publishing, especially for manuscripts that contain large amounts of image and sequence data, is much lower than for print publication (http://www.economicsbulletin.uiuc.edu/EPublishing.asp). This is advantageous considering the large amounts of data useful to taxonomic publications but restricted by the high cost of print publications. Globally, cost impedes access to taxonomic literature and this undermines the entire discipline. Free and easy access to taxonomic literature in the public domain is most feasible in the context of electronic publication and would not only advance nematode systematics but, as an extension of JON, would dramatically expand the readership of the journal. Electronic publications, while cost-effective, nevertheless come with the expense of an organizational infrastructure to guarantee continuity and establishing, maintaining and continually updating facilities specific to storage, accessibility and communication of electronic publications.

3) Faster communication among taxonomists and editors promotes a dynamic research environment: Electronic descriptions of species and other taxonomic proposals can be simultaneously accessed by multiple users providing speed and a global context to taxonomic literature. The review process for such manuscripts can be enhanced since electronic submissions allow editors to efficiently tap into unevenly distributed global expertise. Such experts can review manuscripts online including direct access to DMI and/or sequence data that allows a more detailed independent analysis to the editor than would otherwise be possible. Because DMI do not include some of the bias and "editing" of drawings alone, they allow for reevaluation of specimens by experts in a way that enhances quality control. In short, electronic publishing can give editors access to a more informed peer-review process. In a more dynamic research environment, reviewers could consent to publication of their comments in conjunction with the paper, to provide lines of arguments and divergent scientific opinions. (e.g., http://www.ecs.soton.ac.uk/%7Eharnad/Temp/Kata/bbs.editorial.html). We acknowledge that the issue of speed of communication can also be addressed by making pre-press print publications available online.

4) Continuous and timely publication: Completed manuscripts can be published electronically without delay by layout, printing and the overall logistics of putting together a volume. For species descriptions, such timely publication is crucial considering the impact of other descriptions that may appear during the "in press" lag period. Specifically, printed taxonomic manuscripts are expected to be comprehensive and valid at the time of submission, but with typical delays they may be out of date by the time the publication is mailed. Electronic publication expedites an article's usefulness and availability.

5) Enhanced access to descriptions and ultimately improved quality: A concern to most nematode taxonomists is that a taxon one publishes as new may already be described elsewhere in a remote and/or inaccessible journal. Such inaccessibility of literature contributes to the seemingly endless list of synonymies in nematode taxonomy. This problem would be minimized as electronic publications become more widespread. Each new taxon name and a pre-defined set of key information could be directly fed to an openly accessible and searchable central database. Such a service is already provided when new taxa appear in NemAToL (http://nematol.unh.edu/).

The current challenges to nematode taxonomy necessitate implementation of novel strategies that facilitate taxonomic descriptions while promoting depth and quality of information as well as expanded communication to the broadest audience possible. Whereas the problems are not all easily resolved, we propose that the establishment of an electronic taxonomic journal would transcend many limitations imposed by print-only publication and would be an important step toward meeting the challenges.

## Concerns with Electronic Publishing

Despite obvious advantages, there are widely recognized concerns common to all electronic publishing in the areas of archiving and certification. The Economic Bulletin, an online publication established in response to the increasing cost of print journals, deals with the topic in depth, and readers are referred to the article for further discussion (http://www.economicsbulletin.uiuc.edu/EPublishing.asp); key points are summarized here:

1) Archiving: Despite theoretical arguments in support of electronic archiving vs. print, there are legitimate and practical concerns. Experience shows that websites that are vibrant today may not be there tomorrow. This has brought the issue of permanence to the forefront of the discussion on electronic publications, i.e., "Scholars may be concerned that content may disappear or not always be available in the place they expect it to be" (http://www.economicsbulletin.uiuc.edu/EPublishing.asp). Established electronic publications such as the Economics Bulletin have taken two important steps to address this concern. First, the journal has secured a guarantee from a library to "make the archived contents publicly available over the Internet" should the journal ever cease publication. Second, the journal has organized its "database structure so that published articles will continue to be available at the same URL forever." Such a strong assurance is necessary to persuade hesitant scholars. JON has an advantage in that the proposed electronic journal would simply be an extension of the print publication; this has an established website which could host an electronic, taxonomic part of the journal. Furthermore, JON, within the framework of SON, can further ensure the continuous availability of published materials through a close collaboration with an agreed university/regional/national library.

   The global issues of electronic publishing in general and archiving concerns in particular are being heeded by broad coalitions in the field of publishing, including the Scholarly Publishing and Academic Resources Coalition (http://www.arl.org/sparc/) and PubMed Central (http://pubmedcentral.nih.gov), and it would not be surprising to see in a few years these efforts produce national/international electronic archiving platforms whose aim would specifically be to promote global/national electronic publishing. Such steps would give the assurance of permanence and continuity most skeptics want to see.
2) Journal prestige: Journal prestige is a concern primarily for un-established journals because of the reluctance of scholars to submit high-quality manuscripts to un-established journals. JON has established an excellent reputation in nematology, so the issue of quality would not be a problem particular to electronic publication of taxonomic manuscripts. A peer-review process is rigorously practiced by JON, and we are confident it will be so with electronic publication. In fact, we have noted that electronic publications may offer unparalleled opportunity for manuscripts to be reviewed rigorously and by multiple experts. Consequently, lack of established journal prestige and quality control would not be a hindrance to start an electronic publication by JON for taxonomic manuscripts.

An additional issue related to journal prestige is that many institutions base merit and promotion systems on publications in recognized journals, emphasizing those that with higher impact factor. This expectation has already discouraged some from investing efforts in excellent species descriptions that are typically published in specialized journals with smaller circulation. Some authors will be particularly reluctant to publish in electronic journals if their institutions do not appreciate their rigor and equivalence to print publications.

Considering that all aspects of a species description are subject to future testing through new collections and advances in genomics, developmental biology, morphology, phylogenetics, and ecology, it is advantageous that electronic manuscripts be permanent and easily linked to subsequent analyses and re-descriptions.

## Concerns Specific to Nematode Taxonomic Manuscripts

A number of concerns are peculiar to taxonomic manuscripts because the science is governed by specific international rules and because recent methodological changes may have an impact on taxonomic publications.

1) Nomenclatural validity: The most recent Code (ICZN, 1999, Article 8.6) of the International Commission on Zoological Nomenclature broadens the definition of publication to accept works that are produced ′by a method that does not employ printing on paper provided that the work contains a statement that copies have been deposited in at least 5 major publicly accessible libraries which are iden-

tified by name in the work itself.′ The Code specifies that these copies must be in the form in which the work is published; thus, electronic copies could be deposited as a CD or DVD. Although the current Code continues to recommend first publishing a scientific name in a work printed on paper (Recommendation 8B), it does not preclude alternatives. In quick response to the Code's broadened definition of ′publication,′ the first online, electronic-based description of new species appeared (Scott et al., 2000). The new code thus accommodates electronic publication with some stipulations for archiving copies. Nevertheless, the approach apparently most consistent with the stated preference of the Zoological Commission would be to include electronic publication in combination with print publication. From the Code, one might infer that in such cases ideally the print publication should precede the online version, but the practice of most online journals is to leverage the advantage of speed of production, by first publishing the electronic version.

2) Communicating morphological data: are DMI appropriate? Concerns with respect to increasing use of DMI to record and communicate nematode morphological data (De Ley and Bert, 2002; Eyualem-Abebe et al., 2004) include:
   a. DMI as a substitute for line drawings. DMI, with all the advantages in transmitting morphological information, may not be an adequate or complete substitute for conventional illustrations. Aside from overall DMI quality, which can vary with the tools available to produce and convey those images, an issue of greater concern is that movies and photographs are typically presented of a single specimen. Most nematode taxonomists know from experience that some individual specimens, orientations and preparations show certain traits more clearly than others. By contrast, ideally a drawing accurately conveys the author's experience of careful study of a large collection of paratype specimens, and this is not necessarily the case for other approaches. Some suggest that DMI will eventually weaken or eliminate the deposition of type specimens in museums altogether. We argue that there is no substitute for the proper deposition and curation of type specimens and suggest that DMI of type specimens archived on slides in museums will extend their use and value. For example, researchers could rapidly scan a DMI for the structures of a type specimen they wish to observe and only make a formal request to view the actual slide (which risks loss or damage) if they require further observation.
   b. Potential exclusion of some researchers. Some express concern that the wider use of electronic publication of taxonomic work with DMI, especially if required by journals, might exclude researchers who work in research environments that are less conducive to high research costs (e.g., costs associated with image capture systems).
   c. Technical limitations of DMI. One concern that future developments may address is the light environment of DMI images. Current DMI do not provide an option for end-users to modify the light environment of the product images. Such limitations are less of an inconvenience if the images are captured in an optimal light environment appropriate for the specific body parts. However, this limitation may also be a serious disadvantage in cases where the light environment is not ideal, as one light environment may not be uniformly suitable to all users. This, however, soon may be rectifiable in light of the fast pace of software development; it is indeed now conceivable to have DMI that will give the ability to control the light environment of an image by the end-user.

## Response to Some Concerns Specific to Nematode Taxonomic Manuscripts

1) DMI as a substitute for line drawings. DMI potentially provide the most complete morphological data. In the hands of an expert, labeled line drawings are useful in portraying nematode morphological features representative of a species in a simplified way. However, representing a three-dimensional worm in a two-dimensional line drawing from a mosaic of multiple planes introduces unavoidable bias; often the effect is that end-users have access only to a compromise with respect to the complete communication of morphological information.

   Similar to line drawings and still pictures, each digital picture in a DMI is two-dimensional. Quality is ultimately determined by the focal limitations of the light microscope. The file size of images may also become unmanageable when big worms are imaged at the thinnest slice possible. To solve this problem, images archived in databases can be compressed with little if any reduction in quality and original high-quality, uncompressed images can be made accessible upon request.

   Movie clips (QuickTime and other widely available formats) resulting from multiple two-dimensional images enable the user to see multiple images with speed in an integrated form. This helps users reconstruct a three-dimensional image of the nematode at a level that is not possible for conventional line drawings. DMI therefore can provide a representation of the three-dimensional image of a single nematode that enables reanalysis and quality control. Also, similar to line drawings, DMI can be la-

beled clearly to indicate target body parts; such labeling enhances ease of observation and gives additional clarity to the images. On the other hand, unlabeled DMI need to be studied through a simulated focusing process similar to observing any specimen under the microscope; they simply give a relatively complete access to the data for that imaged individual.

With these concerns in mind, we recognize that DMI are a dramatic advance in the availability of morphological information, but they are not a replacement for physical voucher specimens. Furthermore, we recommend that in new species descriptions, DMI and photographs be used as a very important complement, but not a replacement of drawings.

DMI facilitate access to type materials: A factor that can critically affect the decision to propose a taxon as new and the quality of its description is access to relevant type materials and literature. Our assessment of a portion of the nematode taxonomic literature of a period of four years (1999–2003) revealed that of the 61 taxonomic papers published in the two widely distributed nematology journals, Journal of Nematology (JON) and Nematology, one-third reported inadequacy of original descriptions, or unavailability or inaccessibility of type specimens, hindering them from determining the identity of the studied species unequivocally. As a result, most current nematological descriptions are not based on comparisons with type materials.

Digitization including DMI of type specimens already deposited in museums as well as voucher specimens would make such specimens openly accessible in databases. In the context of electronic descriptions, such availability would greatly improve the efficiency and quality of taxonomic descriptions. Indeed, we are pleased to see that encouraging efforts are underway to do exactly that at both UC Riverside and the National Museum of Natural History, Smithsonian Institution. In order to allow collections to document use and claim intellectual guardianship of online images of type specimens, online records need to clearly indicate curatorship, and collections need to be provided with web tracking data. This being so, effort to digitize all type specimens would be the ultimate solution to the problem. Although a combination of actions can be taken to ensure the highest quality possible in capturing DMI, deposition of type specimens in established collections remains imperative for further subsequent examination. We maintain that wider use of DMI will make type specimens and other digitized voucher specimens more accessible to global users.

2) Potential exclusion of some researchers. Would the use of DMI exclude anyone? Research laboratories with image-capturing facilities currently known to us are primarily limited to a few European and North American labs, but encouragingly the cost of such equipment is decreasing. Most researchers who have modern microscopes for describing new species also have computers. The only additional parts of a DMI system needed by most researchers are a camera and software, and high-quality cameras well suited to this purpose are becoming increasingly cost effective. With wider use and the realization of the advantages of DMI, more researchers will be able to justify an image-capturing system. However, SON and individual scientists must take appropriate steps to ensure that these image-capturing facilities offer services to those who may need but lack access to them. Also, curators can make DMI of the slides sent to them for deposition, so even if individual researchers don't have DMI capability in their own labs, DMI can still be made available for the taxon they described.

## Recommendation

We propose that electronic publication of taxonomic manuscripts will accommodate a complete range of integrated data and metadata including comprehensive morphology, development, biology, environmental parameters and molecular sequences in ways that cannot be incorporated in print publications (e.g., DMI, GIS linkage). We also note that this approach is amenable to improved verification, revision and inclusiveness relative to print papers. Electronic publication will better enlist the participation of worldwide experts who otherwise find it difficult and costly to obtain literature, exchange specimens and bear the cost of conventional publishing. Electronic publishing of taxonomic manuscripts is an important step toward better addressing the enormous challenge of nematode diversity by the limited available global expertise. Specifically, we urge that the SON develop an openly accessible electronic publication for nematode taxonomic manuscripts as part of the JON.

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