

MODERN METHODS AND TECHNOLOGY FOR DOING CLASSICAL TAXONOMY

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ABSTRACT — Significant advances in disseminating taxonomic knowledge are pressing the boundaries of traditional techniques and challenging researchers to upgrade their methodology. Detailed herein are three major developments. First, field emission low temperature scanning electron microscopy (FE-LTSEM) is a contemporary tool for imaging mites that retains body turgor, setal position, and captures a snap-shot of the animal in vivo. Examples are given to illustrate the superiority of this method over conventional SEM in mite taxonomy. Second, digital illustration techniques designed to speed up the species-description process are discussed. Line drawings are created by drawing on top of a montaged photograph on a touch sensitive tablet. Necessary equipment/software and a workflow are provided with the intention of proposing new standards for creating line drawings in acarology. Third, trends in cybertaxonomy, which are raising publication standards for all taxonomists, are discussed with the hope that future acarological work will incorporate such trends and increase the accessibility of information both to taxonomists and non-taxonomists worldwide. Cybertaxonomic topics suggested here include embedding hyperlinks and e-references such as images deposited on MorphBank and sequences on GenBank. One can also contribute elements to the Encyclopedia of Life (EOL), register new species with ZooBank, and share collection data with the Global Biodiversity Inventory Facility (GBIF). Particularly useful are KML files for viewing distribution records interactively with Google Earth. Finally, it is recommended that Web presence should be expanded by contributing taxon pages to the Tree of Life Web Project, and creating independent webpages on the taxon of interest that can act as the central hub of information for that group.

KEYWORDS — low temperature scanning electron microscopy (LTSEM); digital illustration; cybertaxonomy; taxonomy

INTRODUCTION

Acarologists have been describing species for many centuries, but a tremendous number of new species await discovery (Walter and Proctor 1999). Unfortunately, federal funding programs worldwide typically do not fund such research, instead focusing more on multi-disciplinary and highly collaborative projects aimed at addressing large scale questions across biology. Researchers are often left to work on species descriptions as side projects and have responded by seeking new methods to increase time-efficiency, quality, accessibility, and attractiveness

of taxonomic work. This paper details three major advances in taxonomic research: 1) field emission low temperature scanning electron microscopy (FE-LTSEM), 2) digital illustration techniques, and 3) cybertaxonomy.

FIELD EMISSION LOW TEMPERATURE SCANNING ELECTRON MICROSCOPY (FE-LTSEM)

Ambient temperature scanning electron microscopy (ATSEM) has been used by acarologists for

the past 40 years. The increased magnification and depth of field attained from ATSEM have enabled researchers to investigate mite morphology far beyond what was previously possible (e.g., Baker et al. 1987, Baker 1995, de Lillo 1994, Doudrick et al. 1986, Evans 1992, Gibson 1974, Halliday et al. 1998, Otto 1999, Thomson 1987). Field emission (FE) ATSEM greatly improves the magnification and resolution beyond that attainable with conventional ATSEM. However, soft-bodied mites imaged with ATSEM usually lose body turgidity during specimen preparation, leaving much information to be gained from magnified living mites.

A solution pioneered by Ronald Ochoa, Gary Bauchan, William Wergin, and Eric Erbe at the USDA ARS is FE low temperature SEM (FE-LTSEM). Using this technique, living mites are instantly frozen with liquid nitrogen so a snap-shot of the mite in vivo is available for microscopy (see Wergin et al. 2000 for procedure). The technique was developed for slow-moving mites on a substrate, like plant feeders or parasites attached to the host (Figure 1), but has also recently been used to investigate free-living mites. Free-living mites (especially fast-movers) can be very difficult to freeze on the imaging plate, but the images are rewarding if this can be accomplished (Figure 2).

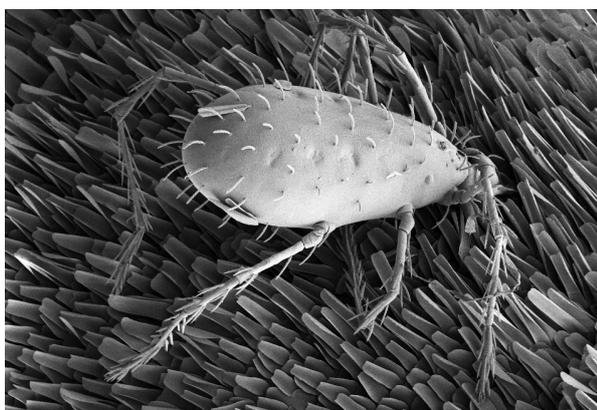


FIGURE 1: *Leptus* (Erythraeidae) attached to a bristletail. (Mounting by R. Ochoa, image by G. Bauchan, USDA ARS).

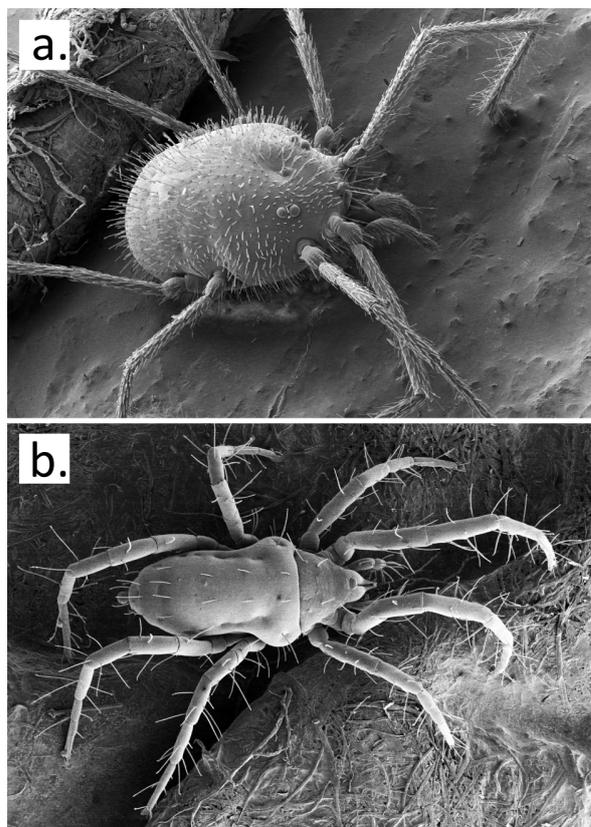


FIGURE 2: FE-LTSEM image of soft-bodied fast moving mites frozen in living postures: (a) – Erythraeidae, and (b) – Rhagidiidae. Mounted by R. Ochoa, image by G. Bauchan, USDA ARS.

Achor *et al.* (2001) compared LT to ATSEM and found LTSEM to outperform ATSEM when investigating mite morphology. Since then, many mites and other arthropods have been investigated continuously with stunning results. Magnification limits have been successfully tested for vibration and artifacts at 35,000x (Bauchan and Ochoa pers. comm.), though nearly all arthropod morphological investigations require far less magnification. No unwanted artifacts specific to LTSEM have been identified (Achor *et al.* 2001, Ochoa and Bauchan pers. comm.). The only known disadvantages to LTSEM are higher initial and maintenance costs, and scarcity of trained personnel. These disadvantages may be overcome with increased demand if acarologists widely seek LTSEM for their own research.

Recent unpublished experimentation at the USDA ARS has shown that specimens frozen for

LTSEM can be thawed after imaging, repositioned, and then refrozen for further imaging (e.g. only one specimen is necessary for both dorsal and ventral imaging). Furthermore, these frozen specimens have been shown to contain usable, extractable DNA (Dowling unpublished), in other words, only one specimen is necessary for complete body imaging and molecular investigation.

Besides the ability to view the animal in a life-like pose, and with normal turgidity, important information can be obtained like setal position (Figure 3a), behavior (Figure 3b), and functional morphology (Figure 3c). An example involves a currently undescribed species of *Trachymolgus* Berlese (Bdellidae). Unlike all other bdellids, *Trachymolgus* is equipped with a sclerotized cuticle with reticulate patterning (Figure 4a). However, when investigated with FE-LTSEM, the cuticle was found to be composed of reticulated ridges forming polygonal hollows, with pits bordering the hollow (Figure 4b). These pits have an unknown function, but current work is attempting to elucidate their use. These characteristics would be visible through standard ATSEM techniques, but not through light microscopy alone, highlighting the importance of incorporating scanning electron microscopy into taxonomic work. Of course, standard SEM techniques should be employed when LTSEM is not available.

Finally, structures too soft to be preserved during the slide-mounting process, or that shrivel during conventional SEM specimen preparation are viewable with LTSEM. For example, smaridids are known to have a gnathosoma capable of being retracted within the idiosoma. However, when we investigated the gnathosoma using FE-LTSEM, we found the fleshy gnathosoma forms a sucker or gasket at the distal end out of which the chelicerae protrude (Figure 4c-d). Past species descriptions of smaridids have never displayed this structure because it is not observable on slide-mounted specimens. Another example is the peritreme present in erythraeids (Figure 4e-f). The morphology of peritremes of this size, raised on tubercles, was previously unknown for erythraeids.

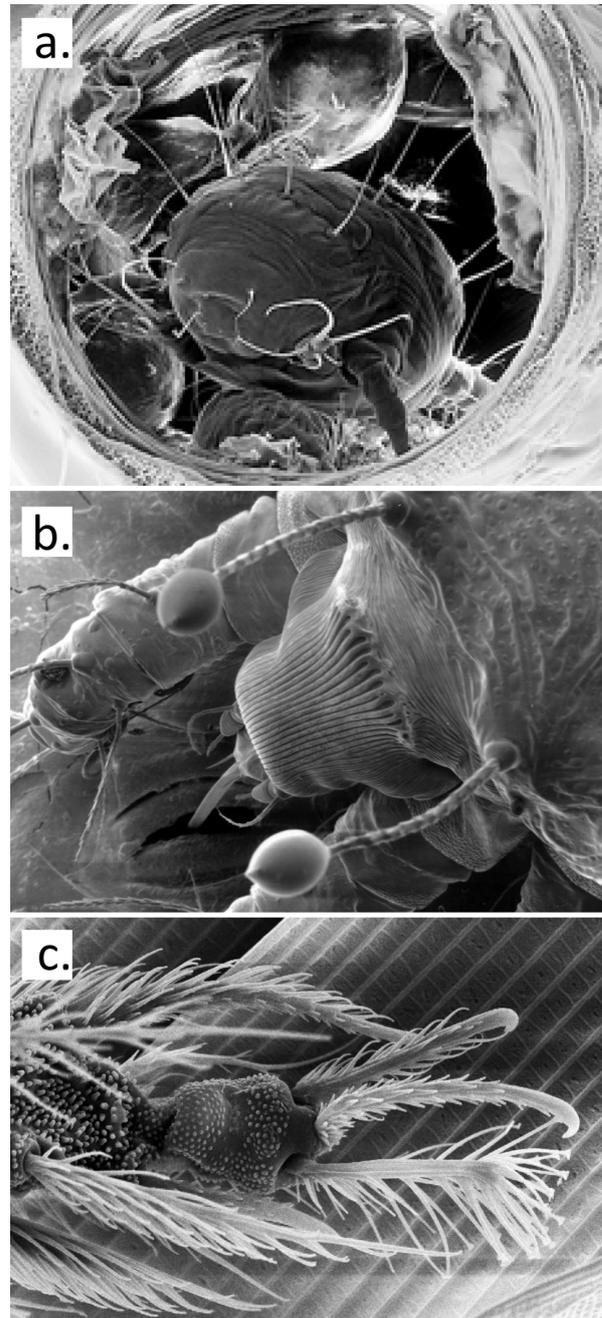


FIGURE 3: (a) – Mites frozen *in situ* allow investigators to observe structures in their natural positions. *Acaropsis woodi*, shown here in a cross-sectioned honeybee (*Apis mellifera*) trachea, was not known to position itself using its setae. Larger individuals are able to occupy larger diameter tracheae, but not able to accompany smaller individuals in smaller diameter tracheae. (b) – Frozen mites allow investigators to capture behaviors as they were occurring, such as feeding from a leaf. (c) – *Leptus* (Erythraeidae) larva foretarsus clinging to scales of a bristletail host. (a) mounted by R. Ochoa and J. Pettis, (b) and (c) by R. Ochoa; (a) and (b) imaged by E. Erbe, (c) by G. Bauchan; USDA ARS.

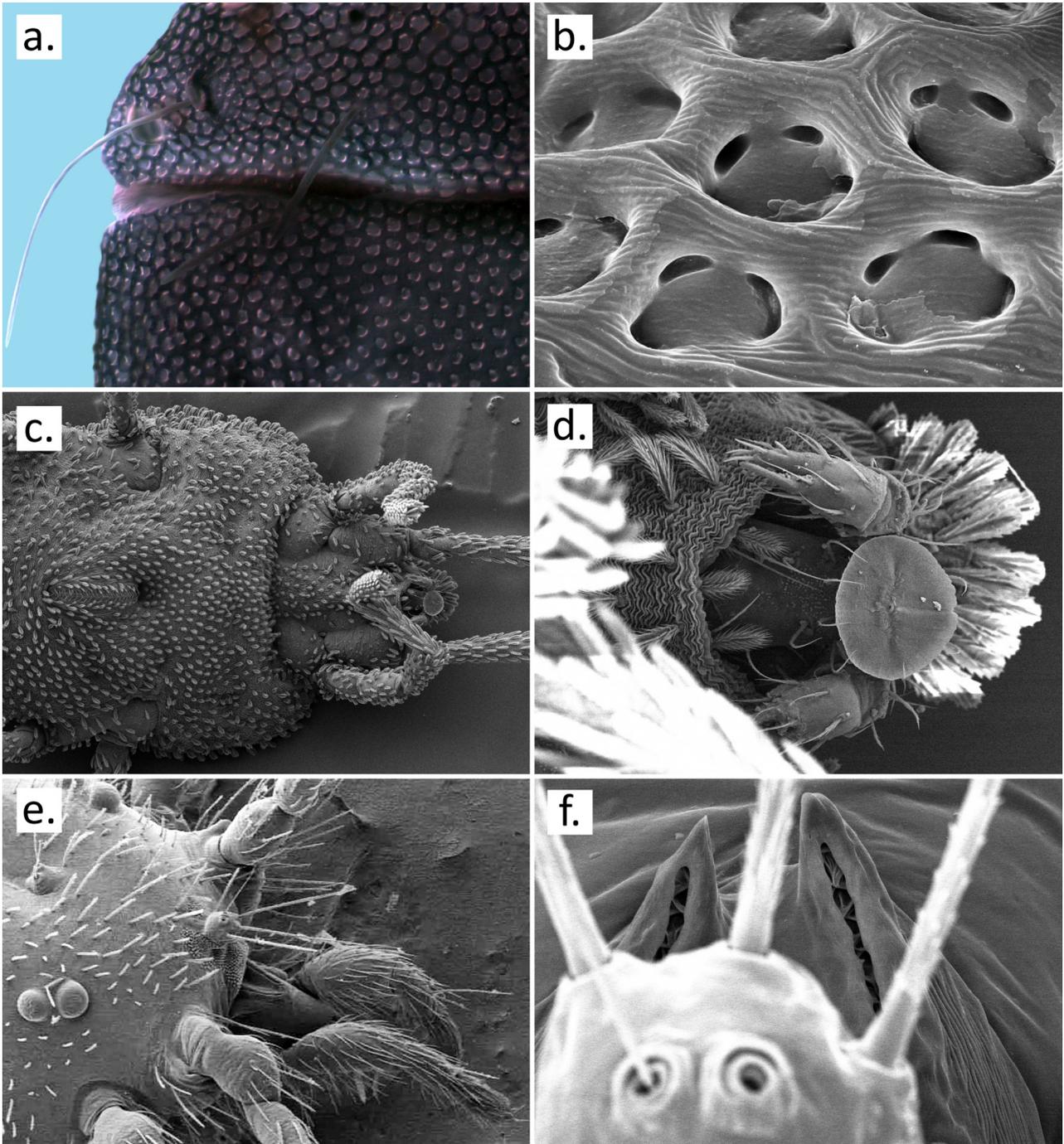


FIGURE 4: (a) – Montaged compound micrograph of *Trachymolgus* (Bdellidae). (b) – FE-LTSEM of *Trachymolgus* (Bdellidae) cuticle showing pits. (c) – *Trichosmaris* (Smarididae), ventral full view. (d) – *Trichosmaris*, ventral magnified view. (e) – *Erythraeus* (Erythraeiidae), fronto-lateral view of proterosoma. (f) – *Erythraeus peritremes* magnified, visible on two dorso-gnathosomal tubercles. (b) - (f) mounted by Ron Ochoa and imaged by Gary Baughan, USDA ARS).

Despite the great utility of LTSEM, there are currently not enough microscopes available to raise this technique to a standard in acarology. Moreover, there is increasing pressure to redirect personnel in the most active FE-LTSEM (USDA-ARS, Beltsville, MA). However, recognizing the potential of LTSEM, and using the images wherever possible only increases the likelihood of raising their popularity and, consequently, availability. There are so many basic questions in mite natural history left to be answered, and so much new information available with every specimen subjected to LTSEM. It is our hope this call for action incites the acarological community into investigating the basic natural history of mites by proposing FE-LTSEM as a vibrant and unique method, worthy of integrating into future research.

MONTAGED PHOTOGRAPHS AND DIGITAL ILLUSTRATION

Traditionally, to create line drawings for publication mite taxonomists sketch mites on paper using an ocular grid, camera lucida, or merely by-eye. To incorporate more detail, the artist draws highly enlarged sketches, often taking several sheets of large paper. These sheets are then scanned into a computer, arranged (some illustrators arrange prior to scanning), and edited. This process is time consuming and does not produce images that translate easily to publication, particularly due to line quality and size reductions.

Scientific illustrators in arthropod biology have solved this problem by replacing paper-driven illustration with drawings created directly on the computer from photographs on a touch sensitive tablet. Below we list the necessary equipment, propose an efficient workflow for making digital illustrations, and discuss key benefits of this system.

Equipment necessary for creating digital line drawings

1. Computer, microscope, and camera

There are many microscope and camera combinations utilized in labs worldwide and just about any

setup that allows the user to take digital pictures of magnified slide mounted specimens will work. As long as the images from the camera are crisp, a user will be able to illustrate from them. Almost any camera produced during the last few years will certainly satisfy this criterion. The computer used should possess enough processing power to run the illustrating program of choice. Minimum requirements for this will depend on the illustration program used as they can have different requirements.

2. Montage software

There are many programs available for creating montaged images, i.e., produced by merging multiple images captured at different focal planes through the z (vertical) axis. Some software is accompanied by an automatic z-stepper, which is connected to the compound microscope, allowing photographing a series of focal planes automatically. While the automatic z-stepper is useful, it is not essential.

Montage software often deletes desired portions of an image (e.g., setae occurring minimally on each focal plane), dramatically reducing the utility of drawing from montaged photographs (especially with cleared, slide-mounted mites). To completely overcome this disadvantage, especially for acarologists whose species descriptions are almost entirely from slide-mounted specimens, the montage software should include the option for *quickly* incorporating these portions from the parent images into the montaged image. Perhaps most montage software have this capability, but very few are user friendly enough to be time-savers. Thus, it is important to always investigate demo versions of the software and check for this capability before purchasing.

3. Live feed

A live feed from the microscope is helpful for producing an accurate line drawing. Some characters are poorly rendered after merging focal planes (e.g., long setae traversing the z-axis), and others require more detail than that shown in the original image (e.g., greater magnification). Hence, consulting the specimen on a monitor adjacent to the drawing tablet acts as a continuous and necessary check

for accuracy. Of course, simply checking the specimen under a microscope can substitute for a second monitor. However, if another monitor is used, the artist is more able to readily take additional photographs (at any magnification level) and incorporate those into the line drawing with great speed.

4. Vector-based illustration software

Vector lines are mathematical formulae representing a line. This enables the illustrator to zoom in without losing crispness and to change the thickness, texture, and curves in the line with a few mouse clicks. The alternative to vector-based software is raster (bitmap)-based software. Raster lines are similar to lines drawn on paper, because they lose resolution when magnified (Figure 5). Though raster-based software is fantastic for creating many types of art, the final line drawing should be created using vector-based software due to the crisp, clean image, and ease of editing.

The illustration software must have layering capabilities. Layers should have the capabilities of being viewed or hidden, locked or unlocked, merged, sorted, and named. The goal should be to draw each major structure (body outline, chelicerae, Leg I, Leg II, plates, eyes, body setae, trichobothria, etc.) on separate layers, then lock that layer so it cannot be accidentally selected.

The illustration software should preferably have a brush function that can be used to quickly produce replicate structures of different curvatures. This is especially useful when drawing setae (see Figure 6 and Coleman 2009). To use this function, draw a symmetrical representation of the seta of interest, complete with setal socket. A white shape can be added behind the seta and socket to create a break in any line it crosses (as in Figure 5b, mag. view). After the brush is created, others of approximate size can be drawn to exactly match the size, curvature, and position of setae on the photographs (Figure 6f). This radically speeds the drawing process. All illustration software have copy and paste, or symbol functions which can act as alternatives, but the ease, time saved, and accuracy of brushes are worth the expense.

5. Digital sketching software (optional)

Occasionally, drawing vectored lines on top of a photograph can be difficult due to the quality of the photograph, or complexity of the specimen. The illustrator may prefer creating a sketch in a raster-based program first, and import that sketch into a vector-based program so vector lines may be drawn on top of the sketch instead of a photograph. Many online tutorials and illustrators recommend always creating line drawings from paper sketches. Though the sketch is created at the same speed, digital sketching is still much faster than paper sketching because the scanning step is eliminated. Furthermore, to maximize time efficiency, sketching in general should be minimized or eliminated and replaced with creating line drawings directly from photographs (Coleman 2006). Of course, raster based illustration programs are not only useful for digital sketching, but are often preferred when shading, coloring, or creating backgrounds.

6. Touch sensitive drawing tablet

The best way to maximize time efficiency and accuracy is to invest in a touch sensitive digital tablet with draw-on-screen capability. Less expensive touch sensitive tablets exist without draw-on-screen capability, but the utility of the tablet should be to save time and maximize accuracy, so the extra expense is worthwhile. Likewise, on smaller budgets, drawing can be accomplished with a mouse, thus alleviating the necessity of purchasing a tablet. Although some illustrators are very skilled with the mouse, the authors have personally found the stylus and tablet approach to be much more efficient and accurate.

7. Shortcuts and a wireless keyboard

Learning shortcut keys for any drawing software can be frustrating, but the time saving benefits of using the keyboard in combination with the stylus make this skill an absolute necessity. For maximum efficiency, the drawing stylus should be held in one hand, while the other controls keyboard shortcuts. Wireless keyboards that can be held in your lap simply make this process easier.

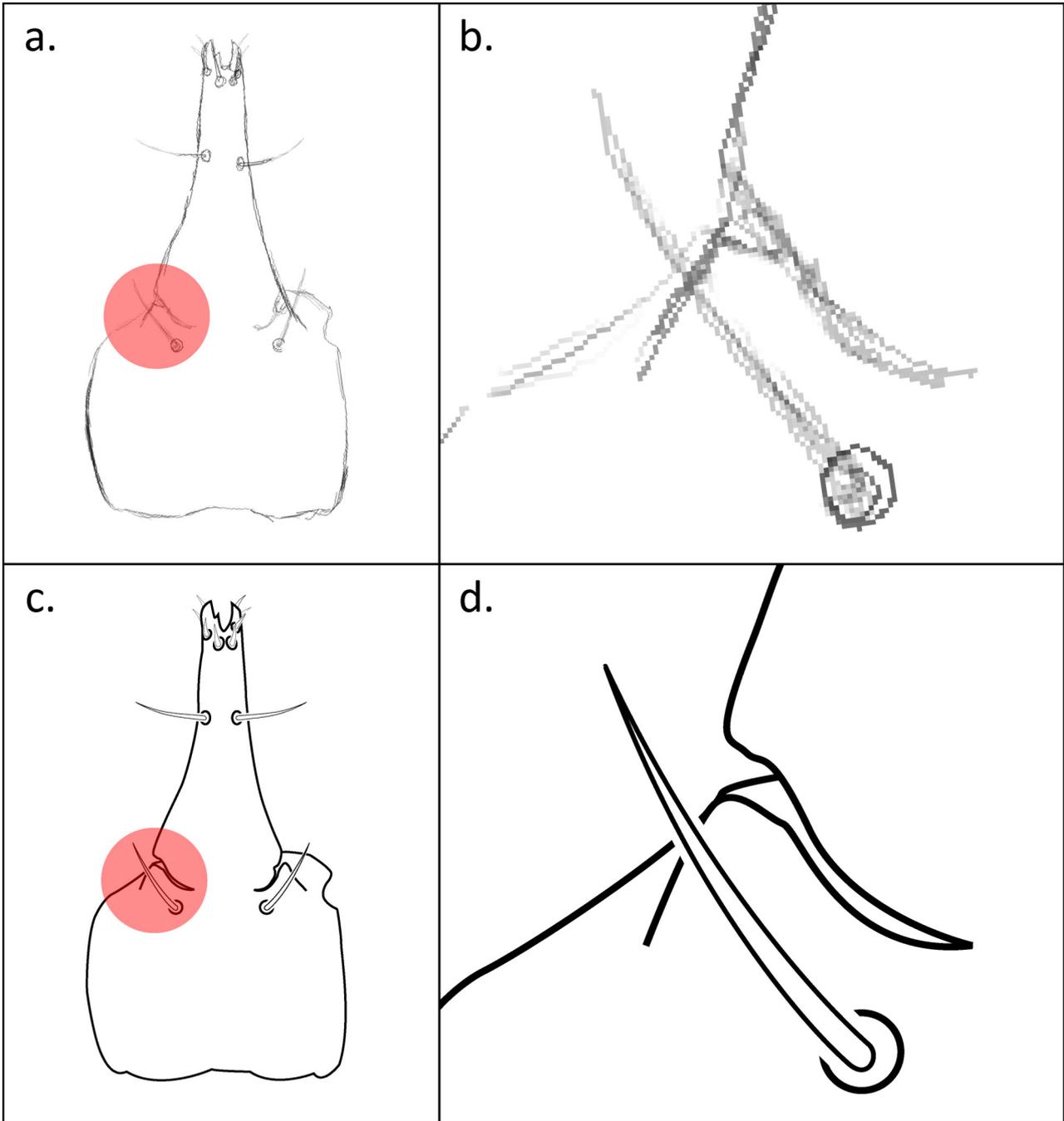


FIGURE 5: Raster vs. vector lines. (a) – raster lines lose resolution when magnified (shown here zoomed at 20x, or 2000% of the original size), (b) – whereas vectored lines do not. The drawing depicts a cunaxid hypostome created with Adobe Photoshop® (a) and Adobe Illustrator® (b).

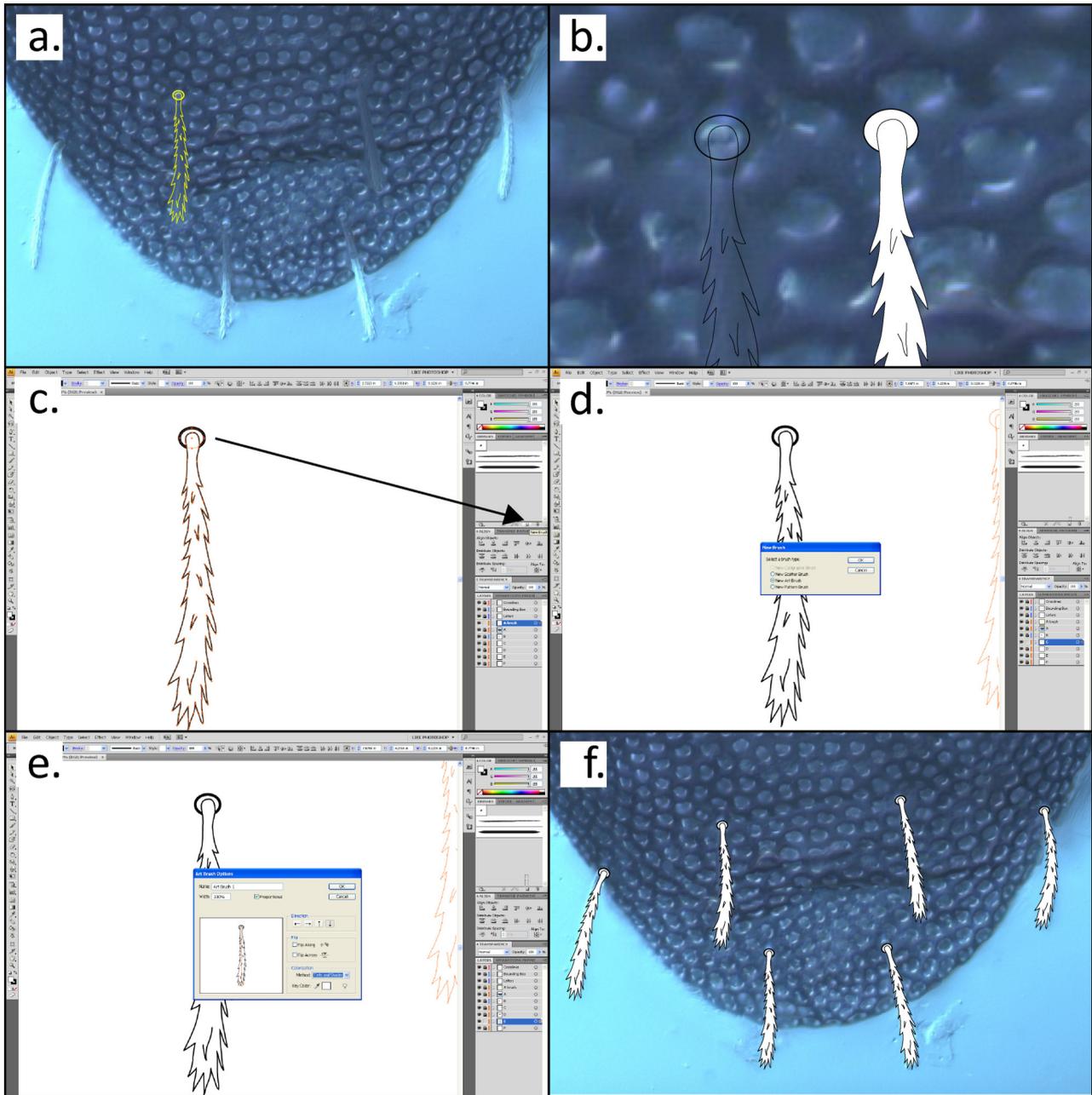


FIGURE 6: Instructions for creating a setal brush in graphics software, Adobe Illustrator® is shown. (a) – First, a seta complete with socket is drawn at the same scale as an on the photograph. (b) – Fill in seta and setal socket white to hide overlapping lines. (c) – Next, a new brush is created by simply dragging the setal complex to the New Brush icon on the Brushes Menu. (d) – This will bring up the New Brush window, select New Art Brush and click OK. (e) – This will bring up the Art Brush Options window, select Proportional in the Size box and choose the arrow in the direction from socket to tip of seta and select OK. (f) – The new setal brush now appears in the Brushes Menu on the right. Choose the Paintbrush Tool on the left, select your setal brush on the right and now each stroke you make with the paintbrush will produce the entire seta. Notice that you can draw seta in any direction and with any amount of curve. The mite depicted is an undescribed species of *Trachymolgus* (Bdellidae).

Basic workflow for creating digital line drawings

The workflow provided here is not meant to replace the existing tutorials on creating line drawings in arthropods, but rather to outline the steps and highlight key elements during the process. A few tutorials we highly recommend are listed below.

- (<http://www.entomology.umn.edu/museum/links/coursefiles/ENT%205051/PDF%20documents/AI%20for%20Entomologists.pdf>) - Ralph Holzenthal's (University of Minnesota) tutorials for digitally illustrating insects are unmatched and an invaluable resource.
- Charles Coleman (Museum für Naturkunde, Berlin, Germany) has published several tutorials (Coleman 2003, 2006, 2009) that have become the standard in many systematics labs.
- (<http://www.nhm.ku.edu/illustration/index.html>) - Daci Kampschroeder's (University of Kansas) tutorial offers excellent instruction on habitus drawings, photo illustration and editing, and line drawings.
- (<http://hymenoptera.tamu.edu/illustration/index.htm>) - This site, written by Junwook Kim (Texas AandM), offers a nice outline with screen-captured images, which are useful to beginners.

Almost any graphics software problem has been discussed at length in many online forums accessible by simple Google searches. We recommend both these forums as well as video searches for online tutorials anytime there is a question or problem. The best formula for success is using the workflow provided below as a guideline, online tutorials as thorough lessons, and general online searches for problem solving or troubleshooting.

1. Create a template in your drawing software with a visible boundary box equal to the plate submission size, and lock the layer. Unlike paper drawing, digital line drawings can be drawn at submission size (due to the zoom function), to ensure minimal distortion when the drawing is reduced for publication.
2. Obtain an image (montage, photograph, SEM, raster-based sketch, etc) of the structure of interest. Most tutorials (including those previously listed above) insist on creating paper sketches first, and scanning those into the drawing software. We have found this to be unnecessary, and prefer to draw from photographs to increase speed and accuracy.
3. Place (usually a specific command rather than cut and paste or import) the image(s) into your drawing software in a new layer, and lock that layer. The boundary box layer and image(s) layer are your background layers, and should not be edited after the drawing begins. If necessary, multiple images representing sections of an entire image can be taken and arranged into a complete picture in the drawing software. When multiple images are used, each image should reside in a separate layer. When arranging multiple images, increase the transparency of the top image to make it easier to place. A lower magnification image (e.g., from the stereoscope) may be useful for outlining the structure (or habitus) and organizing higher magnification images. NOTE: always lock all layers not currently in use to avoid selection accidents resulting in moving or editing an unintended item or layer.
4. Draw vector-based outlines of major regions (idiosoma, hypostome, leg, etc). Each region should reside in a separate layer, named according to the structure drawn on that layer. NOTE: more accuracy and detail are possible at higher zoom levels.
5. Color fill objects (usually with white) on each layer as desired to hide overlapping lines (as in Figure 6b). Open shapes (e.g., drawing a "C" instead of a circle) that you intend to fill should be avoided because open shapes cannot be completely filled.
6. Add setae. As previously mentioned the brush function is preferred because it is most accurate and time efficient (see Figure 6).

However, if your drawing software lacks this function, symbols or cut and paste are alternatives.

7. Continually save the file as you draw.
8. Know how to use the undo function (e.g., Ctrl-z), as well as all keyboard shortcuts.
9. Be prepared for computer crashing and always save a backup copy!

Key benefits of creating line drawings digitally

1. Submission size pallet and the power of vectors

A great benefit to eliminating the paper steps of illustration is the ability to draw and edit the exact image of submission throughout the drawing process. Vectors are not actual lines, but mathematical formulae representing lines. Therefore, unlike paper drawn lines (or raster lines), vectors do not lose resolution/crispness when the user zooms closer (Figure 5b). This quality allows the illustrator to draw at high magnification and create minute detail previously unattainable with pen and paper on submission size images. Additionally, drawing on submission size pallets eliminates the possibility for line distortion when the image is reduced for publication. Furthermore, the ability to zoom to any magnification puts much less strain on your eyes while drawing.

2. Workspace

Traditional drawing techniques monopolize workspace and time. The illustrator must dedicate a significant segment of time and space for drawing, and other activities must be put aside. Digitally illustrating from photographs takes no more space than the normal workstation plus a drawing tablet. The illustrator is free to work on the drawing (or many drawings) for small or large segments of time, freeing both time and space for other tasks.

3. Ease of incorporating new information

Images from multiple sources can easily be incorporated into the digital line drawing by simply placing such images into new layers in your graphics software. For example, species descriptions of mites

are usually drawn from slide mounted specimens, which are often dissected, crushed, or dismembered by the slide mounting process. A lower magnification habitus image taken from the stereoscope could be placed into your graphics software onto a background layer and act as a template for the body outline, with all structures intact and in natural position. Then, images containing useful morphological information from higher magnification (i.e. from compound or scanning electron microscopes) could be placed onto other layers and organized appropriately on top of the stereomicroscope photograph. The product would be a composite line drawing depicting a naturally positioned animal with standard morphological detail.

4. Editing

The immediacy and simplicity of editing a digital line drawing is a major selling point for completely digitized illustration techniques. Line thickness, color, size, shape, and position are easily adjusted to correct mistakes, reflect greater accuracy or more information, or increase aesthetics. Whole shapes can also be edited just as easily. For example, to change the position of a leg without altering the shape of the segments and position of setae, simply select that leg layer and move/flip/rotate the segments to their desired position (Figure 7). Using paper techniques, this process would have required redrawing the entire leg and then rescanning the new drawing.

5. Speed

The greatest advantage to the drawing techniques detailed here, is the speed in which drawings can be created and edited. After all, Michael, Berlese, Grandjean, and others were able to create masterful drawings without any of this equipment. However, more accurate line drawings can be made in just fractions of that amount of time using digital techniques. If widely accepted, digital line drawings will speed the species descriptions process so much that the annual number of species described could be radically increased.

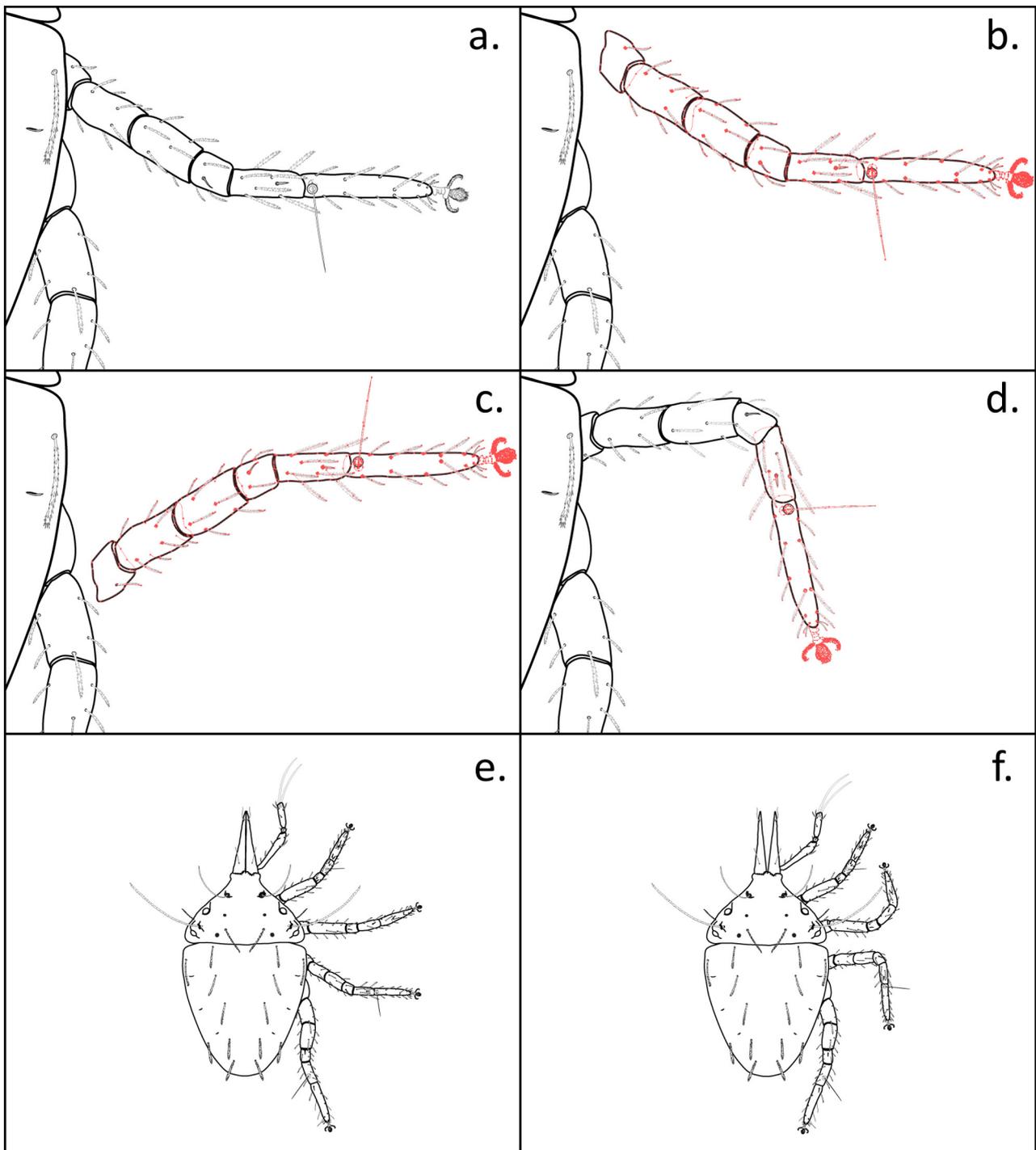


FIGURE 7: Editing leg position in graphics software, Adobe Illustrator® is shown. (a) – starting with the leg in the original position, (b) – the leg is selected and moved away from the body, (c) – then flipped (d) – and repositioned on the body where distal podomeres can be selected and rotated downward. (e) – (f) – show the dorsal habitus before and after editing. All appendages have been modified in (f). The mite depicted is an undescribed species of *Trachymolgus* (Bdellidae).

6. Cost

Drawing tubes are becoming increasingly difficult to purchase, and many microscope companies have stopped manufacturing them (e.g., Zeiss). While digital illustration is more expensive initially, the difference is made up almost immediately based on the time saved.

Given the superiority of digitally illustrating line drawings from photographs to paper methods, it is our hope these techniques will become new standards for acarological laboratories. By working toward a more efficient, fast workflow for species descriptions, we are one step closer to meeting the biodiversity crisis head-on.

CYBERTAXONOMY

In 2008, the taxonomic community began a paradigm shift in the manner species descriptions and revisions should be published. It began with Pyle *et al.* (2008) who, when describing new species of *Chromis* Cuvier, extensively used internal and external hyperlinks to additional electronic content, including images, references, species names, and email addresses. Zhang (2008) showcased Pyle *et al.* (2008), listing major advancements. The list of concepts below is an expansion of Zhang's (2008) list, incorporating more trends in cybertaxonomy. In the same year, two additional papers used Pyle *et al.* (2008) as a model (Johnson *et al.* 2008, Deans and Kawada 2008). Those three papers have acted as a springboard into "taxonomy of the future" (Penev *et al.* 2008), setting higher standards for taxonomic publications.

An important development was a revision by Winterton (2009), which acted as a test case and highly supported the movement proposed by previous papers by producing the publication in a highly standardized and in one-third of the time normally taken to publish a revision of equivalent size (La Salle *et al.* 2009). The primary time-saving element was the use of automated natural language species descriptions parsed from matrix based character data generated with Lucid Builder (Winterton 2009). One of the most integrated examples of web-based taxonomy is Miller *et al.* (2009). Since then,

many others are joining the cybertaxonomic movement (e.g., Blagoderov *et al.* 2010, Brake and von Tschirnhaus 2010, Mengual and Ghorpade 2010, Stoev *et al.* 2010). These papers offer key innovations to publishing taxonomic work and should be consulted for empirical examples. Major concepts derived from these papers are discussed below.

1. MorphBank and GenBank

Data should be deposited in online sources that can be accessed by collaborators worldwide during the project, and hyperlinked throughout the text upon the project's publication. Images should be deposited in MorphBank (<http://www.morphbank.net>), an online database which allows deposition of images and private or public access to those images based upon the desire of the researchers. Suggested images include character states, habitus drawings/photographs, and measuring techniques. Sequences should be deposited in GenBank (<http://www.ncbi.nlm.nih.gov/>).

2. Mark ups

Descriptive data relating both to the newly described species and other species for comparisons can be marked up according to biodiversity information standards Taxonomic Database Working Group (TDWG, <http://www.tdwg.org/activities/sdd/>) for descriptive data. This allows raw data to be downloaded directly in markup languages (computer languages that annotate text and determine how that text is structured, formatted, etc.), like Extensible Markup Language (XML), that will facilitate dissemination of information through the web and numerous other digital resources. Many papers are also marking up species descriptions themselves using standards in TaxonX (<http://research.amnh.org/informatics/taxlit/schemas>) and taXMLit11 (<http://www.sil.si.edu/digitalcollections/bca/documentation/taXMLitv1-3Intro.pdf>).

3. ZooBank and LSIDs

A recent amendment of the International Code of Zoological Nomenclature (ICZN 2008) proposed the registration of new species names in ZooBank (<http://www.zoobank.org/>) (Polaszek 2005a, 2005b), the official online registration system for ICZN. Prospective (newly described species) and retrospective (currently described species) registration of species is recommended upon publication of revisions. In addition, references cited can be registered with ZooBank, many of which can also be hyperlinked and viewed through the Biodiversity Heritage Library (BHL, <http://www.biodiversitylibrary.org/>).

4. Datasets and georeferencing

Following the example of Miller *et al.* (2009), collection data should be shared with the Global Biodiversity Information Facility (GBIF, <http://www.gbif.org/>) and made available in the manuscript. A Keyhole Markup Language (KML) file should be included with the online edition of the publication for viewing distribution records interactively with Google Earth (<http://earth.google.com/>). Using this file, collection data, linked MorphBank images of the specimens, and other information can be accessed directly from Google Earth! Furthermore, collection datasets should be available with the manuscript so future researchers can supplement and manipulate the dataset. Miller *et al.* (2009) provided a template file (in Microsoft Excel format) which should be used as a model for this procedure.

5. Electronic keys

Interactive keys, popularly created by Lucid software (<http://www.lucidcentral.com/>), have been used for a decade and have greatly increased in popularity. Publishing these keys online, especially when combined with taxon pages described below, are becoming the norm in zoological research.

6. Taxon webpages

Information submitted with the manuscript should be contributed to the Encyclopedia of Life (EOL:

<http://www.eol.org/>), which some journals are already doing automatically (e.g., ZooKeys). Web presence can be extended by establishing taxon pages for the Tree of Life Web Project (ToL, <http://tolweb.org/tree/>) (Maddison and Shultz 2007). Additionally, taxon specific web portals act as a hub for all information and keys, but can also act as a source of popularizing information and provoking future research. Examples include AmphibiaWeb (<http://amphibiaweb.org/>), AntWeb (<http://antweb.org>) and WaspWeb (<http://waspweb.org/>) from the California Academy of Sciences, as well as Evanioidea Online (<http://evanioida.info/>) or Homepage of the Arachnid Order Solifugae (<http://solpugid.com>). These pages greatly extend the Web presence of both your lab and the taxon of interest, making the field more attractive to incoming students.

CONCLUSION

Despite the mega-diversity of Acari, the amount of annual research devoted to mites is minimal compared to many less diverse groups. Mite taxonomists are dwindling and too few new students are being introduced to the field to make up for the deficiency. The time is now to double our efforts in describing species, implement new technologies, and overall making the field more attractive to incoming students. This paper details three modern advances in acarology that could springboard the discipline into the future.

The imaging methods discussed (FE-LTSEM) allow the researcher to investigate snap shots of living mites in their natural setting, and overcome common problems of investigating mite morphology using ATSEM. Modern illustration techniques are detailed that speed the species description process, potentially allowing taxonomists to describe more species annually, as well as producing more accurate, crisper images. Also discussed are cyber-taxonomic methods designed to increase Web presence, include more information in taxonomic publications, and make taxonomic and biogeographic information more accessible and attractive.

These methods are vital in attracting future generations of acarologists, and raising standards in acarology to meet those embraced by researchers in other disciplines. As workers of an underrepresented taxon, the onus rests on our shoulders to change our current tactics, and incorporate aggressive methods of reinvigorating the field into our research programs.

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