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Taxonomy at a crossroads: Communicating value, building capability, and seizing opportunities for the future

THOMAS E. SAUNDERS
School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland Mail Centre, Auckland 1142, New Zealand;
tsau017@aucklanduni.ac.nz; https://orcid.org/0000-0003-1780-0314

Evolution has shaped the bodies and habits of life into an exquisite variety of forms, dazzling in their diversity and complexity. Taxonomists dedicate their careers to discovering, classifying, and understanding this tremendous complexity. I can't think of a more inspiring and ambitious field of science, nor one able to draw on a richer heritage. Linnaeus brought order to chaos by naming and categorising what must have seemed like an endless array of different creatures. Darwin revealed the invisible force working with the raw materials of chance and time to birth biological complexity. Hennig (1966) devised a framework within which to map these processes and visualise their results. Countless researchers, less famous but no less important, have inched us closer to a better understanding of life, and our place in the family tree. Taxonomy nurtures a respect for those who came before. It fosters a shared interest between people separated by vast lengths of time. To read a monograph written one hundred years ago while holding one of the original type specimens in your hand is a special experience. But understanding the natural world is crucial for our future too.

Humankind remains ignorant of perhaps 80% of the species on Earth and the wealth of information associated with each one. This should concern anyone who believes that studying what may be the only life in this universe is an important task. In a climate of environmental decay, political instability, and economic uncertainty, anxiety over the future of the biosphere is only natural. Failing to support taxonomy will only exacerbate these issues in the long run. Recent reports by the UK House of Lords (House of Lords 2008), Natural Environment Research Council (Boxshall & Self 2011), and Royal Society of New Zealand (Nelson *et al.* 2015), all echo similar concerns: although taxonomy underpins the life sciences, it is perceived as irrelevant and unimportant; paid full time positions are disappearing; workers are aging and not being replaced when they retire; universities are scrapping specialist courses; institutions are not investing as much in their staff and collections as they need to. I believe the top three questions facing taxonomy today all relate to the health and future of the discipline itself.

1. How do we ensure taxonomy is valued?

One of the most important issues facing taxonomy today must surely be the lack of appreciation for how taxonomy works and what it contributes to a wide array of other fields and endeavours (de Carvalho *et al.* 2014; Wheeler 2009). Taxonomy has its own epistemology and ambitions, as well as important contributions to make to real-world problems. While non-experimental, it is none-the-less hypothesis-driven in the way taxa and their classifications are proposed (Sluys 2013). A phylogenetic classification of all taxa is an impressive goal, for it would allow us to understand the origins and diversity of life on Earth. To achieve this taxonomists need to integrate all the available evidence they can. Names change when enough evidence mounts to favour an alternate grouping. Through this method, clumsy or inconsistent classifications will eventually be addressed and corrected. Taxonomists should be free to go about their work secure in the knowledge they are working towards one of the most important goals in pure science, understanding life on earth, while also laying the foundations that make it possible to apply knowledge about biodiversity to important problems, both now and in the future.

Few people are aware of the central role played by taxonomy in areas such as biosecurity, conservation, and economic prosperity. Taxonomic expertise, or the lack thereof, can have massive impacts on our day to day lives. For example, border authorities around the world rely on taxonomic descriptions and keys to identify pests and diseases. When an unknown stink bug appeared on the doorstep of the United States in the 1990s, it was only through some careful sleuthing by concerned entomologists that the bug was identified as the brown

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marmorated stink bug (*Halyomorpha halys* Stål), a serious horticultural pest native to East Asia (Hoebeke & Carter 2003). How much more damage could it have done if it had gone unidentified for even longer? Or take the case of the common European skate *Dipturus batis* (Linnaeus, 1758). French researchers showed how taxonomic confusion reflected in ambiguous fishery records was likely masking declines in two species, and that the extinction of both may be unavoidable due to sharp declines caused by over-fishing (Iglésias *et al.* 2010). These kinds of examples show how sound taxonomy is critical for maintaining effective biosecurity systems and conserving species that also have economic value.

Structural issues in the way research is commissioned, funded, published, and evaluated act as further roadblocks to greater appreciation and recognition of the work of taxonomists. Taxonomists are inherently disadvantaged when funders or employers rely on metrics such as Journal Impact Factor to divine the quality of research, and hence, to commission research, make hiring decisions, or assess opportunities for career advancement. This is because taxonomic works are usually only cited in other work focussing on a specific taxon. When only a small number of specialists are actively working on a given taxon, the capacity for their work to be cited at all is reduced. Even when other people use primary taxonomic literature during their research, it may not be cited as frequently as it should (Ebach *et al.* 2011). Big grants for descriptive work are almost non-existent, so taxonomy is seen simply as a cost without the promise of bringing the money in. Collaborating with taxonomists and including them as co-authors is an important step in recognising and appreciating their contributions to the projects they work on. Publishing taxonomic works open access to increase citation rates and ensure workers from developing countries can read the primary literature is another important consideration (and need not incur a publication charge through, for example, green open access). Communicating findings outside of academia to a general audience is increasingly important to demonstrate impact, and it brings the additional bonus of raising the profile of taxonomy at the same time.

2. How do we build and maintain taxonomic capability?

Everyone benefits from taxonomy but institutions are increasingly shifting their budgets away from the costs of training and maintaining staff and collections. Universities are cutting specialist courses in which students gain in-depth knowledge of taxonomy and specific taxa. Anatomical and morphological skills form the backbone of an education in taxonomy but students are missing out on these now. As a result, postgraduate qualifications specifically in taxonomy are rarer. The number of jobs available for full-time taxonomists has been in decline for some time. For some taxa, a significant proportion of active workers are retired or volunteers (Coleman 2015). Fewer support staff and increasing administrative burdens make it difficult to focus on core descriptive work. For example, of the taxonomists employed full-time in New Zealand, less than 20% are able to spend at least half their time on research (Nelson *et al.* 2015). When the current cohort of full-time taxonomists retire, what proportion will be replaced? If we want to maintain skills and capacity we need to ensure all the in-depth scientific and institutional knowledge of retiring taxonomists is captured by the next generation through mentoring programmes, rather than allowing it to walk out the door. And we simply need more taxonomists on the ground doing the work they have been trained to do (Sluys 2013).

If taxonomy were funded more generously over longer time frames the return on investment could be enormous. Which other science could provide more bang for buck? Even modest increases in the funds earmarked for taxonomic work would help to speed up the discovery and classification of the world's hidden biodiversity. But because of the competitive disadvantages baked into the scholarly publishing and funding cycle mentioned above, we don't see the same kinds of large research grants for taxonomy as we do for sexier disciplines perceived to be 'cutting-edge' or 'disruptive'. We don't see the same number of scholarships aimed at encouraging the study of taxonomy. Much of the work done by taxonomists around the world is publically funded one way or another, but it's tough to make budgets stretch even further than they are already. For example, in New Zealand, core government funding for research institutes charged with maintaining biological collections and conducting taxonomic research has remained static since it was introduced in 2011 (Anon. 2016). When inflation is taken into account this represents a declining investment on behalf of the government, and the situation is surely not unique to New Zealand.

3. How do we ensure taxonomy benefits from emerging opportunities?

Emerging technologies and greater international collaboration represent exciting opportunities for taxonomy (Wheeler 2010). Cybertaxonomy—the suite of digital tools available to taxonomists including databases, citizen science platforms, image recognition, 3D printing, etc—shows great promise in speeding up workflows, making data easier to access, and helping to reduce research costs, for example those associated with travelling to view specimens (Wheeler *et al.* 2012). These tools also encourage collaboration and make it

easier for large international teams to coordinate their activities. For example, the Distributed European School of Taxonomy (http://taxonomytraining.eu/) offers training in fundamental skills such as nomenclature, illustrations, scientific writing, as well as managing data and using cybertaxonomy infrastructure. The European Distributed Institute of Taxonomy (https://cybertaxonomy.eu/) is a regional hub to coordinate training and research among European taxonomy organisations, and to act as an advocate for taxonomy. The "Creating a Taxonomic e-Science" project aims to corral fragmented descriptions and revisions into a consolidated, web-based taxonomy, which accepts community contributions in the form of proposals to change classifications (Clark *et al.* 2009).

Molecular methods represent a powerful tool in the study of biodiversity, but tensions remain over the appropriate place of DNA within an integrated taxonomy framework (Hamilton & Wheeler 2008; Wheeler 2018; Will *et al.* 2005). One approach is to use as many sources of evidence as possible to characterise the evolution of a species or clade, rather than restrict ourselves to viewing taxa through the lens of a single character. There is no doubt in the utility of DNA to do some very powerful things. For example, it can help to associate sexes, associate parasites with their hosts, associate different life-stages or body parts, flag cryptic species for further investigation, and document the presence of taxa within the environment. Adding sequences to already-described taxa is a welcome source of new evidence to strengthen or refute an existing species hypothesis. But using DNA in isolation to 'describe' new taxa confuses identification with classification and heralds a return to single-character typologies where more is lost than is gained (Wheeler 2005). An integrative approach that respects the lessons of the past is surely the way forward.

Conclusion

Taxonomy has never been more vital and less understood than it is today. I've asked three questions that I believe are important to reflect on. Without better general understanding of the aims and methods of taxonomy it will be difficult to convince people of its value. Safeguarding the skills and resources available today will be important for building capability tomorrow. And making the most of the opportunities on the horizon will represent an important investment in the future of taxonomy. These issues have no simple solutions, but I believe all are worth reflecting on, in order to preserve and strengthen an incredibly important field for future generations.

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