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Archives of a small planet: The significance of museum collections and museum-based research in invertebrate taxonomy*

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Abstract

Museum natural science collections are valuable, in many cases irreplaceable, and vital to research in many disciplines including taxonomy. Since 96% of known multicellular animals belong to one or another of the 34 invertebrate phyla, the value of those collections for invertebrate taxonomy (of both living and fossil taxa) is even higher. Systematic work that does not rely on museum specimens to verify or falsify the identities of the taxa studied is not science. Whether the techniques used are molecular or morphological, high tech analysis, or careful observation, systematics is the primary and most essential use of museum invertebrate collections. Their value and the case for their support for this primary and many other compelling reasons has been argued eloquently time after time, yet support still lags far behind needs.

Key words: value of natural history collections, systematics funding

Introduction

Where would an alien scientific visitor go to learn about Planet Earth? Of course, it/she/he would have accessed everything that was available on the Internet during the interplanetary voyage. However, in order to separate fact from fiction the visitor would turn on arrival to the true archives of Earth's history, to the artifacts and specimens found in the world's natural science collections and to the scientists who study them. No doubt the alien scholar would appreciate the cost-effectiveness of way the records were collected, while deploring their geographically scattered nature, and lack of complete accessibility.

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The significance of museum collections

Many reports and reviews have been written on the value of research collections and collections-based research to science and society (Allmon 2005, Cotterill 1999, Dosmann 2006, O'Connell et al. 2004, Page et al. 2004, Schmidly 2005, Suarez and Tsutsui 2004, Wilson 2003, Wyse-Jackson 1999, to mention a few of the more recent examples). Their arguments include the following:

Collections support research in many disciplines: anthropology, archaeology, biology, medicine, paleontology, and geology, and history of science.

Collections are non-renewable resources. Many specimens now existing in museum collections would be impossible to collect again due to destruction of sites or habitats. For example, VMNH invertebrate paleontologist Lauck Ward was part of a team of geologists and paleontologists who studied a deltaic lobe of the Lower Miocene in Delaware. This previously unknown site was exposed as part of the construction of Delaware Route 1 and was only available for study while the highway was being constructed. Prior to this discovery, the only work on Miocene mollusks in Delaware was published in 1841 and included just a few molds and casts. The newly discovered assemblage consisting of well-preserved material of 104 species was identified and described (Ward 1998) and irreplaceable specimens are now preserved in the VMNH invertebrate paleontology collection.

Specimens now in collections may also be irreplaceable today due to restrictions on collecting certain groups or in certain places, restrictions that did not exist when the specimens were collected.

Collections are cost-effective. As Duckworth, et al. (1993) have pointed out "Virtually all explorations during the past 300 years, from discoveries on earth to forays into the solar system, have resulted in additions to the collected resource in the natural sciences." Even in cases where specimens could be recollected, the cost of the doing so each time they were needed to support a research project would be astronomical compared to the cost of maintaining them and adding to them judiciously over time.

Collections play an important role in human medicine, public health, and security. Most frequently they have been used to track the history and epidemiology of viral, bacterial, and parasitic diseases and determine their hosts or reservoirs (e.g., Hanta virus, AIDS, malaria). They are also extremely valuable in forensic science where they are used to solve crimes ranging from murder to illegal wildlife trading.

Collections can be used to monitor climate change and predict its effects on species success. For example, Australian museum collections provided the data for a study of the vulnerability of species three groups of marine invertebrates (echinoderms, mollusks, and decapod crustaceans) along the coastline of Victoria, Australia. Results indicated that 14% of species were confined to cool-temperate waters and an increase of 1-2° C in seawater temperature would make them extinct on that coastline (O'Hara 2002).

Collections can be used to demonstrate biological differences and/or changes in genetic diversity within a species or population. A fisheries example is given in Systematics Agenda 2000 (1994). Fishery managers had planned to use the abundant data on Brazilian populations of Spanish mackerel to manage Spanish mackerel in the Gulf of Mexico and along the U.S. east coast. Systematic studies showed that the Brazilian population belonged to a different species (*Scomberomorus brasiliensis*) than North American populations (*Scomberomorus maculatus*). There are enough biological differences between the two species that a fisheries plan based on the first species would probably not have succeeded for the second.

Collections can be used for research on the history of a discipline. They may help trace dispersed or lost collections, help modern workers understand early terminology, and provide clues to the social networks of collectors and scientists of the past. For example, Wyse Jackson (1999), by using the specimens, their labels, and a handwritten catalogue, was able to discover the donor of specimens from Greenland in the Trinity College, Dublin geological collection, to be the Greenland explorer Sir Charles Lewis Giesecke (1761-1833). Others have pointed out the value of ancillary materials such as such as collectors' field journals, letters, biologists' field notes, photographs, sketches and maps. Such archival material may offer information of use for present-day repeat surveys of a locality, as well as insight into the thoughts of the original owners, useful in historical studies (Beidleman 2004).

Collections can educate new generations of students. This can and does take place from the elementary school to graduate school level. Specimen-based informal science education, either in a museum setting, or taken directly into schools by museum educators or through kits available to teachers, makes it possible for children to see, touch, and work with real natural history specimens. This hands-on approach can stimulate a sense of wonder that may influence a later career choice. For children and adults, exhibits using collections help promote awareness of natural diversity and conservation. At the other extreme, on the graduate and post-doctoral level, working with museum specimens is an important part of the training of new systematists.

Collections have aesthetic importance. Collections of plants and animals, both living in botanical gardens and zoos and preserved in museums, have an aesthetic appeal as well as an educational one. As Wilson (1984) has suggested, the root cause of this appeal may be biophilia, an innate emotional attachment of our species to other living organisms. This inheritance from our primate ancestors continues to influence art, literature, and hobbies, as well landscape and home design. There might be another characteristic of our species coming into play as well—the pleasure of looking at large displays of objects. This is the attraction that draws people to shopping malls, flower shows, boat shows, etc., as well as to museums; the desire to see, even if not to possess, large accumulations of stuff.

Collections are the foundation for taxonomic research and the study of biodiversity. Last, but not least, this is the primary purpose for the existence of natural history collections. Collections-based research in biology most often focuses on taxonomy, identification, and classification. Modern systematists are scientists who seek to document and understand diversity, to explore phylogenetic relationships, and to test evolutionary and ecological hypotheses. The techniques they use may range from the oldest, such as observation in field or lab, to the newest, molecular genetics and genomics. The collections they need to work with may consist of 200 year-old preserved specimens, or modern collections of frozen tissue or germplasm. As Mayr (1946) said, a systematist must also be a morphologist, ecologist, behavioral biologist, geneticist, zoogeographer, statistician and data analyst, using whatever methods are needed to solve the problem under study. The results of the systematists' efforts are essential to further study and understanding of biodiversity and conservation

Importance of Collections in Invertebrate Taxonomy

Museum collections are, of course, important to vertebrate systematists, but, with no disrespect intended to the subphylum Vertebrata, the taxonomy of most vertebrate groups is much better known and better supplied with taxonomic expertise than almost any invertebrate phylum (including the non-vertebrate chordates), especially when size of the group (about 52,000) versus the number of workers is taken into consideration. For example, there are about 4,200–4,500 species of mammals worldwide (Minelli 1993; Margulis et al. 1999) and about 50 mammal taxonomists in the US alone, or fewer than 100 species/taxonomist (Winston 1988). Most invertebrate groups cannot boast that many taxonomists in the whole world (the ratio of species to taxonomists for several invertebrate groups of interest to natural products researchers in 1988 was about 150,000 to 200, or 750/taxonomist (Winston 1988). In the phylum I study, Bryozoa, there are about 5,000 species described so far (with at least that many more estimated to exist), and about 25 people world-wide who study some aspect of their taxonomy (200–400/specialist, making it one of the better studied invertebrate groups).

Since 96% of known metazoan animals belong to one or another of the invertebrate phyla (Brusca and Brusca 2003) the value of museum collections for the taxonomy of both living and fossil invertebrates is even greater than it is for vertebrates. Of the estimated 10 to 200 million species (depending on whether prokaryotes are included) that remain undescribed (Brusca and Brusca 2003), the majority of the metazoans are invertebrates. On land much of invertebrate diversity lies among the arthropods, with over a million species described (Brusca and Brusca, 2003), and the number of species still to be discovered ranging from 10 to 80 million (Minelli 1993). A survey of the status of the systematics of North American insects and arachnids (Kosztarab and Schaefer 1990) estimated that less than half of the insect and arachnid species have been described and named. In the ocean, species diversity may not be as high as that in terrestrial habitats, but overall body plan diversity is much higher. We probably still know less than half of the coastal and shelf marine invertebrate species. Our knowledge of the deep sea fauna is much more incomplete. Estimates for the total numbers of species to be found in the sea range from 500,000 to 10 million (Minelli 1993).

Systematics is a historical science, one in which museum collections are essential. To do a thorough job on a systematics project, it is necessary to find the specimen on which the original description was based, the type specimen, if at all possible, as well as other material of the taxon that may be available for study in museum collections. By linking a name to a specimen through the use of types, biological nomenclature is made objective. Hypotheses of identity and relationships can be tested, verified, or falsified, but only based on examination of type and other specimens of putative species, genera, etc.

The first steps in a systematics project may be the labor-intensive ones of collecting, sorting, identifying and curating specimens (Figure 1). During that process the taxonomist will consult the literature, the original description and those that follow. However, except in the case of common well-know species, specimens must be consulted, both those available at nearby museums and those that must be borrowed from more distance institutions to ensure that results are science, not fantasy. Anyone who has tried to identify a specimen in hand from a vague description or inadequate illustration knows the problem; the answers lie with the specimens themselves. In most museums the most important specimens, types and paratypes, are either segregated from the general collection or marked in some way (as in Fig. 1d).

Modern means of studying morphology such as scanning electron microscopy, confocal microscopy, etc., may reveal new ultrastructural characters of great usefulness that were not available to 18th or 19th century taxonomists. This often leads to the need for later workers to review and revise a group of taxa. Doing so always leads back to the specimens. Figure 2a shows an enlarged original figure from F. A. Smitt's 1873 publication on bryozoans from Florida. Next to the drawing is a portion of a plate using SEM images of the same species (Fig. 2b), taken using a specimen from the original collection studied by Smitt. The modern illustration show details of characters barely visible in the original.

Even when using only molecular methods in a phylogenetic study, it is essential to keep voucher material of each taxon in traditionally recognizable form so that any later questions about identity can be answered. Deposition of voucher specimens is also essential in ecological studies and biological inventories. For invertebrates, especially, because of their number and the incompleteness of our knowledge, this can make the difference between the work being useful to others or wasted effort. If vouchers are deposited then any mistakes in identification can be corrected later.

Invertebrate paleontologists rely on collections as well. Collections existing in museums today provide a record of the history of life on earth. Collections can be used to attack problems such as the triggers and mechanisms of climate change, extinctions, patterns of diversity over evolutionary time, and the role of past environments in creating those patterns (Allmon 1999). For such studies new collections with detailed biostratigraphic data, as well as geochemical data that allow interpretation of the physical and chemical environment, are necessary (Allmon 1999, Jackson and Erwin 2006). The new collections enable to paleontologists to learn much about both ecological and evolutionary processes that could not be learned by studying only living organisms. Success stories include the deciphering of the environment of the Ediacaran-Cambrian animal radiation (Knoll 2003), a story of immense importance for biology.

Yet even the older fossil collections, collected under less rigorous protocols, are valuable today and for the future. According to Allmon (1999) they can be and have been used to document now inaccessible localities, fill in stratigraphic gaps, and provide morphological data for evolutionary studies at a variety of scales, and as sources of undescribed taxa or additional material of rare taxa, as well as serving as the training ground for new systematic paleontologists.

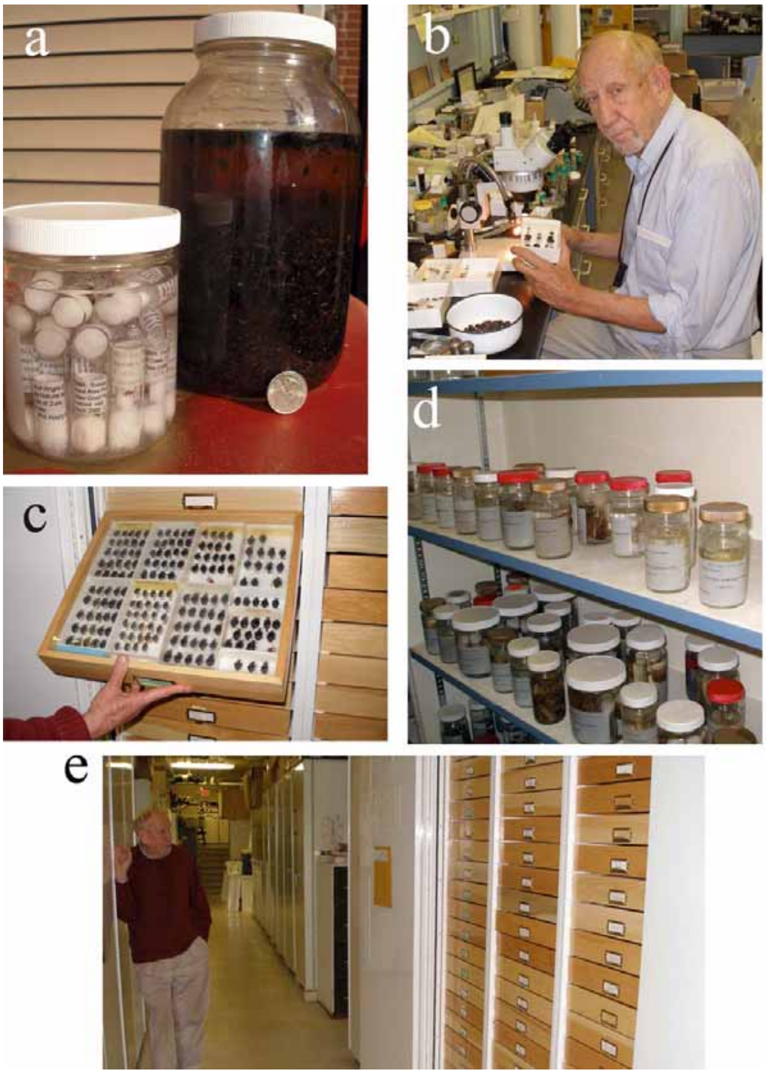

FIGURE 1. a) Jar on the right contains the unsorted arthropods from one night's blacklight trap collection. Insects preserved in alcohol. Jar on left contains specimens which have undergone preliminary sorting to group or species. The white jar top has an alcohol-tight seal that prevents drying out of the contents. US quarter coin for scale. b) Richard Hoffman, VMNH Curator of Recent Invertebrates, identifying and curating insects in his laboratory. c) One drawer of the identified curated VMNH insect collection, stored in Cornell drawers and arranged phylogenetically and geographically to make retrieval easy. d) Types in VMNH arthropod collection. Jars with gold colored tops contain holotypes. Red topped jars are paratype specimens . e) View of some of the VMNH insect collection which is stored in modern steel cabinets that keep specimens dust and pest free.

Conclusions

Over the last 30 years I've read many apologies for the continuing existence of natural history collections and taxonomic research. Every article or report has stressed the need to increase support, training, and products. But, over and over, the recommendations have been ignored. It is clear that well-maintained collections and collections-based research are important to invertebrate taxonomy, indeed to all of biology and paleontology. Logic and reason agree —these are the archives of the planet's past, a palimpsest from which its potential future(s) may be read. The rational approach would be to fund these resources, both the collections and those who study them, so as to best provide for the future of life on earth. It's time to stop apologizing and take a hard look at why the support has not been forthcoming.

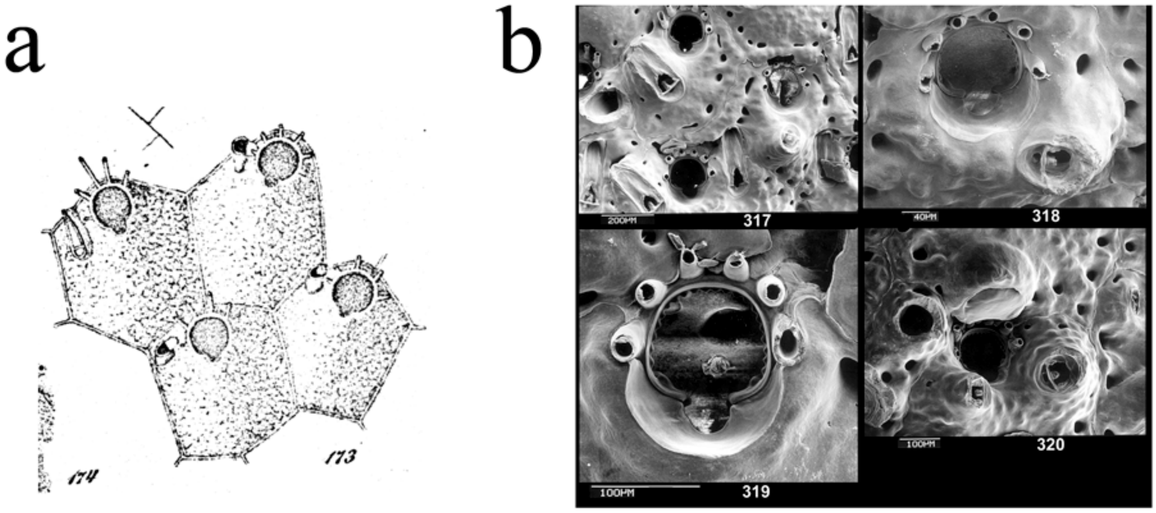

FIGURE 2. a) Enlarged view of Figure 173 from Smitt (1873). He called this and specimens of two other bryozoan species all by the name of a European species, *Hippothoa biaperta* Michelin 1841. b) Several figures from Winston (2005) to show the detailed ultrastructure of zooids of the same species, now identified as *Stephanollona asper* (Canu & Bassler) 1923.

Often this has been blamed on lack of communication by museums and taxonomists, leading to a lack of understanding of the value of taxonomy and collections, as well as of the need to fill in the gaps in those collections. Some potential users may still be ignorant of the usefulness of taxonomic collections, and some parts of the scientific community may still denigrate such research though arrogance, despite the best attempts at communication by some of the most articulate people in the field. In the U.S., at least, any communication problems are not for lack of trying by organizations like the National Science Foundation, the Natural Science Collections Alliance, American Institute of Biological Sciences, and numerous societies built around taxonomic specialties: entomologists, ichthyologists, malacologists, etc. Sure, it is hard to get press headlines as specific as this news article in *Science*, "Human Ancestor Found—In Museum." (Gibbon 1992). However, news of taxonomic discoveries, especially those related to conservation or biodiversity efforts do make the pages of *Nature*, *Science*, and other journals, as well as the science pages of big city newspapers.

Other articles blame the "Taxonomic Impediment"—the slow speed of taxonomic publication and the decreasing numbers of taxonomists (to zero for some groups of organisms already). Meanwhile, the remaining taxonomists consider they are both overworked and underemployed, for lack of what is by current scientific standards, a paltry amount of funding. Those of us who have no technical assistance feel that less than $50,000 a year in funds would quadruple our current productivity. Unfortunately, that may be part of the problem. Taxonomists are cheap dates. That might seem to be a good thing, but trends in academic science have gone in the opposite direction. Laboratory space and jobs go to those who can bring in the largest grants, those which will result in the greatest amount of overhead or profit returned to the university (Schmidly 2005).

Then, too, taxonomic services (as well as curation, maintenance, and preservation of collections) have been traditionally considered to be free services. No one wants to start paying for what's always been provided free. Taxonomic services are not free, of course. In a posting to the TAXACOM listserv Amalie Scheltema (2001) detailed the expenses entailed in morphological taxonomic work: researcher's time, supplies, upkeep, amortization of equipment, charges for use of specialized equipment (SEM and TEM), page charges, shipping, curating, assistants' salaries, training for students and postdocs, development of websites for databases, descriptions, keys, classification, etc. (and salary of a webmaster to produce them). For molecular taxonomic studies, the price is even higher. Either the institution must spend a large amount of money (by museum standards, anyway) to develop and equip an onsite molecular laboratory, or the researcher must pay to have sequencing or other analyses done commercially.

Others have cited the lack of sophisticated and accurate user tools, from complete lists of species, to multi-institutional databases of specimens, to an encyclopedic coverage of not only the name, but the description, illustration and biological information on each species. Why, if librarians have been able to develop such a system as WorldCat (and they started back when mainframe computers used punch card input) haven't taxonomists been able to do the same? Unfortunately, it is a more complicated problem for taxonomy. Most books have one or a few editions, so a single record can be used by many libraries, whereas a database of specimens can have thousands of specimens of a species (each slightly different in its label data), making it much harder to standardize. WorldCat started as a union system to serve a group of Ohio libraries (OCLC); the records they produced saved so much time for catalogers that they had a salable product. Even so, there was a period of at least 10 years when many regional electronic union catalogs were started by libraries, most of them using different database systems. WorldCat won out and now has more than one billion items cataloged and used by 10,000 libraries around the world.

Information technology initiatives now underway may result in a better situation for access and use of collections and taxonomic information. Right now the initiatives are still a patchwork of under- or un-funded projects that duplicate or conflict with each other (e.g., GBIF, ECAT, LINNÉ, FISHBASE, ITIS, ENSHIN, etc.). All of them have accomplished some of their goals. None have yet met all of their goals or timelines and remain pilot projects. Most rely on voluntary un-reimbursed input by those already designated an "impediment"—the taxonomists. Eventually, as with the library initiatives one system may win out (and it may be look a lot more like Wikepedia than any of the current contenders).

Meanwhile, museum collections can provide an incomplete but still useful archive of earth's biological and geological history, but it is still not an inventory. Why run a planet without an inventory?

Not because of other scientists (even though some of them may be oblivious or antagonistic). Not because of the public, who favor protecting the environment and conserving biodiversity. Humans are rational animals (apparently another quality we inherited from our primate ancestors [Wood et al. 2007]). It comes down to a reason that has remained unspoken: to create a world-wide biodiversity inventory would be against the best interests of that short-term oriented, but overwhelmingly effective triumvirate: politics, money, and power. If you don't have an inventory, no one will ever know you've run out of something (say, Indian elephants) that you used to have in stock. It is essential to those whose interests are controlled by greed that nothing block their acquisition or use of property or resources. If we had the knowledge that we already have the power to create, they might sometimes lose out financially. If this sounds unlikely, think of the fate of the whistleblowers of the past ---strikers, miners, social and environmental activists. It may not be nice to fool Mother Nature, but it's downright dangerous to attack Daddy Warbucks. What makes long-term sense for the many may prevent or impede those interested only in their own short-term gains. From that point of view natural science collections and their researchers are dangerous enemies. Asking for support from those in economic and political control is like asking the management of a company to voluntarily bring in a union. This reality has to be accepted and accommodated for any long-term ecological sustainability to be achieved. Can it happen? Or will the more negative primate characters overwhelm our positive qualities, like biophilia and rationality?

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