# Journal of Natural Science Collections

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NatSCA

Natural Sciences Collections Association

## The Natural Sciences Collections Association

The Natural Sciences Collections Association (NatSCA) is a UK based membership organisation and charity which is run by volunteers elected from the membership.

NatSCA's mission is to promote and support natural science collections, the institutions that house them and the people that work with them, in order to improve collections care, understanding, accessibility and enjoyment for all.

More information about NatSCA can be found online at: **natsca.org**

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NatSCA membership is open to anyone with an interest in natural science and/or collections that contain natural materials. There are many benefits of being a member, including; availability of bursaries, discounted annual conference rates, discounted training seminars and workshops, participation in the natural science collections community, friendly and helpful network for information and skill sharing and subscription to the *Journal of Natural Science Collections*.

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## *Journal of Natural Science Collections*

*Aims and scope*

The *Journal of Natural Science Collections* is a place for those working with these collections to share projects and ways of working that will benefit the museum community. The Journal represents all areas of work with natural science collections, and includes articles about best practice and latest research across disciplines, including conservation, curatorial methods, learning, exhibitions, and outreach. Articles in the Journal should be relevant and accessible to all of our diverse membership. Submissions are peer reviewed, resulting in high quality articles.

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## Editorial Board



**Front cover image:** Fossil specimen of *Sinosauropteryx* (IVPP V12415) with fuzzy integument preserved. Slab = 127 cm long. ©IVPP See Smith, Wang, and Evans, 2020 (pp.3-16 of this volume).

# Editorial

Jan Freedman

Welcome to Volume 7 of the *Journal of Natural Science Collections*. I am delighted to stand in as the Editor for the greatest Journal for those working with natural science collections again. Thank you to the previous editor, Rachel Jennings, for all her handover notes and assistance. Thank you also to the Editorial Board for their expertise in finding peer reviewers for each of the articles, and to the many referees who have spent a lot of time ensuring that all the articles are to the highest quality and standard.

This volume can be divided into three sections. First, we see articles focusing on museum practice. **Smith and Qi** provide background to their incredible successful exhibition, *Dinosaurs of China*, from the development to the public reactions. **Jennings** uses her experience to provide information about the process and advice for applying for an Article 60 certificate for CITES Annex A listed specimens. Finally, **Jackson** describes the process that the Tully House Museum and Art Gallery underwent to apply for Designation. This trio of articles all share relevant skills which readers of this journal can put into practice.

The next section focuses on collections history, where three more articles explore the role of collections and collectors from the past. An important paper by **Callaghan *et al.*** provides a thorough update of all the taxonomic names of the historically significant Blaschka models. **Hancock and Ryder** detail the history, and rarity, of silver pins in entomology collections. Finally, **Smith** makes a valuable case for under-appreciated collections, which focuses on fungi, demonstrating the real value of *all* types of collections in museums.

The final section concentrates on collections conservation. An interesting, and transferable, method using LEGO® to safely hold bound herbaria pages open, is given by **Dupont and Prakesh**. An extremely useful article by **Holloway and Pinniger** provides a guide on hoe to identify different *Anthrenus* Linnaeus, 1761 species in museum collections. Next, **Muñoz-Saba *et al***. outline the best methods and procedures needed to keep the flesh eating beetle, *Dermestes* Linnaeus, 1758 to prepare osteological material. **Allington-Jones** describes the conservation of a meteorite specimen, which is unusual in its chemical make-up, providing difficult challenges. Finally **Chitimia-Dobler and A. Dunlop** describe a method to clean tick specimens using an ultra-sonic cleaner.

I hope you enjoy this Volume, and find the articles interesting and relevant to your own roles.

## View from the Chair

Paolo Viscardi

This will be the last view from this particular Chair, as I hope to be handing over the reins of NatSCA to Isla Gladstone in 2020. It has been an honour working on your behalf for the last few years, through some hard times in the sector and in society as a whole.

2019 has been yet another uncertain year, with the implications of Brexit still being identified. NatSCA has been helping to support the natural science collections sector by liaising with Defra to help inform them of the needs of museums with scientific collections with regards to Brexit & CITES legislation.

To help address some of the other bigger picture issues surrounding the decline of subject specialist expertise in the museums sector we have been working with other Subject Specialist Networks (SSNs). A large part of this work involves us being on the steering group for the SSN Consortium. This is an important group, as it joins together the voices of around 40 SSNs similar to NatSCA, amplifying the message that museum collections need knowledge to unlock their potential. Through the Consortium we have an opportunity to engage more effectively with sector bodies, and we have already helped inform the Art Fund and Arts Council England about how the wider museums sector is supported by specialist groups and how they as funders can better support the work we do. This has resulted in a new funding strand from the Art Fund and we are in discussion with Arts Council England about how SSNs might be better supported to increase capacity for developing and delivering resources for our members.

We had good uptake of our conference bursaries this year, after increasing the award from a maximum of £100 to £250. Our 2019 Bill Pettit Memorial Award went to two projects. The Dorman Museum "Leo the Lion conservation project" and the Victoria Gallery, Liverpool "Primate skeleton conservation project". Both will have the results reported on our blog.

Training delivered this year included "Finding Funds for Fossils, Ferns and Flamingos: how to secure money for museum collections" run in partnership with the World Museum Liverpool; a "Care and Conservation of Insect Collections" workshop was run in partnership with The Oxford University Museum of Natural History, and "An introduction to mobilising your collection's biodiversity data" workshop in partnership with Bristol Culture and NMH London. This training ties in with our aim of facilitating the integration of the UK national dispersed collections with the European Distributed System of Scientific Collections (DiSSCo) programme. DiSSCo looks to become an increasingly important initiative for mobilising collections data and improving access to collections around the UK and Europe.

Our AGM and conference was on the theme of "Dead Interesting: Secrets of Collections Success" which was generously hosted by the National Museum of Ireland with additional tours kindly provided by the National Botanic Gardens of Ireland. At the AGM the membership voted for a proposed change in NatSCA's status to a Charitable Incorporated Organisation (CIO). This is a step that many SSNs are undertaking since the CIO status was introduced by the Charities Commission in 2013, since it confers 'legal personality' allowing entry into contracts on behalf of the organisation rather than individual trustees.

We had several committee members stepping down at the end of their term or due to capacity issues this year. I would very much like to thank Roberto Portela-Miguez, Miranda Lowe, Rachel Jennings, and Emma Nicholls for all their valuable efforts in supporting NatSCA over the years. While we're sad to lose such wonderful members of our committee, we are delighted to welcome Jen Gallichan, Glenn Roadley, Amanda Callaghan and Kirsty Lloyd who have joined us. Speaking of welcome additions, I would like to congratulate NatSCA's Conservation Rep Lucie Mascord on the birth of her daughter.

Finally, I would like to offer my deep gratitude to the whole of the NatSCA committee and the excellent volunteers who help us in our mission. That includes: the Conservation Group (Natalie Jones, Emilia Kingham, Julian Carter, Bethany Palumbo, Arianna Bernucci, Vicen Carrio, Nigel Larkin, Gill Comerford, Simon Moore and Vicky Purewal); the Editorial Board (Bethany Palumbo, David Notton, Matthew Parkes and Rob Huxley); and our operational support team who help us deliver events, projects, the conference and the essential work involved in keeping things running (Justine Aw, Lily Wilks, Natalie Jones, Sam Barnett, Antoinette Madden and Erin McNulty). As ever, I want to end with a special vote of thanks to our Treasurer Holly Morgenroth, whose support enables everything we do.

# From China to Nottingham: The making of Dinosaurs of China

Adam S. Smith[1*], Wang Qi[2], and Rachael Evans[1]

[1]*Nottingham Natural History Museum, Nottingham City Museums and Galleries, Wollaton Hall, Nottingham, NG8 2AE, UK*

[2]*Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, Nottingham, NG7 2RD, UK*

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**Corresponding author: adam.smith@nottinghamcity.gov.uk*

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**Abstract**

'Dinosaurs of China: Ground Shakers to Feathered Flyers' was an exhibition of Chinese dinosaur fossils and casts that provided visitors with a unique opportunity to explore the scientific evidence that connects large, scaly ground-shaking dinosaurs to their feathered relatives – modern birds. The main exhibition at the Nottingham Natural History Museum, Wollaton Hall, included original holotype specimens of feathered dinosaurs and the tallest dinosaur skeleton ever displayed in the UK. A smaller satellite exhibition at Nottingham Lakeside Arts, University of Nottingham, focussed on palaeo-art. During its four-month duration from July to October 2017, the exhibition at Wollaton Hall received 115,000 visitors, while Lakeside Arts received 30,000 visitors. The exhibition was the outcome of a multi-partnership between the University of Nottingham, Nottingham City Council, the Institute of Vertebrate Paleontology and Paleoanthropology, and the Longhao Institute of Geology and Paleontology Inner Mongolia. The project provides a case study for collaboration between subject specialisms as varied as architecture, palaeontology, history, and theatre.

**Keywords:** Dinosaurs, China, spatial narrative, temporary exhibition, partnership

## Introduction

In the summer of 2017, Nottingham hosted the world exclusive exhibition 'Dinosaurs of China: Ground Shakers to Feathered Flyers' hereafter referred to as 'the exhibition' (Smith and Wang, 2017). The exhibition included fossils and casts of Chinese dinosaurs including original holotype specimens of feathered dinosaurs and the tallest dinosaur skeleton (a cast) ever displayed in the UK. This provided visitors with a unique opportunity to explore the scientific evidence that connects large, ground-shaking dinosaurs to modern birds.

The exhibition was the outcome of a multi-partnership between the University of Nottingham (UoN), Nottingham City Council (NCC), the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), and the Longhao Institute of Geology and Paleontology Inner Mongolia (LIGP). The project provides a case study for collaboration between subject specialisms as varied as architecture, palaeontology, history, and theatre.

The exhibition was not the first exhibition of Chinese dinosaurs in the UK, but it was the first of its kind in several aspects. It follows in the footsteps of two previous temporary exhibitions. 'Dinosaurs from China' was an exhibition of dinosaurs developed by the National Museum Cardiff and later toured to other venues in the UK in the late 1980s and early 1990s (Saunders and Engesser, 1990). It contained fossil skeletons loaned by the IVPP of some of the ground-shakers on show (as casts) in the Nottingham exhibition, for example, the large sauropod *Mamenchisaurus* Young 1954, and the smaller 'prosauropod' *Lufengosaurus* Young 1941. More recently, 'Dino-Birds: The Feathered Dinosaurs of China' exhibited fossils of feathered dinosaurs at the Natural History Museum, London, in 2002-2003. Those fossils were loaned from the Geological Museum of China and it was the first UK exhibition to display non-avian feathered dinosaurs (Prudames, 2002; and see Milner, 2002 for details). The Nottingham exhibition was different because it was the first of its kind to combine large dinosaurs *and* feathered flyers. It was also the first exhibition in the UK to display feathered dinosaurs from the collections of the IVPP, and the first anywhere in the world to display a key LIGP s pecimen – *Gigantoraptor* Xu *et al.*, 2007 – in the public museum sector. Dinosaurs of China also included recent discoveries made subsequent to those earlier exhibitions, so it was the first time many of the specimens were displayed outside of Asia. The exhibition was not a touring exhibition and was designed specifically for Nottingham.

This paper describes the content of the exhibition, recounts how the exhibition came about, and explains how the project team worked together to overcome the challenges of designing, curating, transporting, and installing a major international exhibition in the unusual setting of an Elizabethan mansion. The Dinosaurs of China project as a whole provides a case study to help demonstrate the benefits of multi-partner collaborations between local authorities and universities, and the positive impact exhibitions and collections can have on the local economy.

*Why China?*

The last few decades have seen dramatic developments in Chinese palaeontology (Conniff, 2018). Key discoveries of feathered dinosaurs in China have drastically changed our understanding of dinosaur appearance, evolution, and behaviour (Benton *et al.*, 2008; Pickrell, 2014). Most of the dinosaurs in the exhibition were discovered and excavated within the last 30 years. Many Chinese deposits, such as those of the Yixian Formation of Liaoning Province, consist of fine sediments of volcanic ash, which buried the dinosaurs and other organisms in the ecosystem quickly, preserving their anatomy, including soft parts, in incredible detail (Zhou *et al.*, 2003). Importantly, the deposits are dated to the Late Jurassic and Early Cretaceous, so they are also just the right age to preserve key events in dinosaur evolution (Zhou 2006, 2014; Benton *et al.*, 2008).

*Why Nottingham?*

The UoN and NCC have worked together closely for over a decade to build trade and cultural links with China. In 2006, the UoN became the first university in the UK to establish an independent campus in China. Ningbo, now Nottingham's twin city, hosts the campus, which - together with campuses in Malaysia and Kuala Lumpur - grants the University of Nottingham international status. These strong connections to China proved instrumental in bringing the exhibition to Nottingham. To highlight the collaborative nature of the project the exhibition was divided across two Nottingham venues.

## The partners

*The University of Nottingham's Lakeside Arts*

The UoN's Lakeside Arts comprises a theatre, several galleries, a recital hall, and artist studios, and delivers an annual programme of exhibitions and events across the visual and performing arts. To reflect the partnership between the UoN and NCC, a small satellite exhibition was located in the Angear Gallery of Lakeside Arts within the University Park campus, immediately south of the main exhibition at Wollaton Park.

*Nottingham Natural History Museum, Wollaton Hall*

At the heart of Wollaton Park in Nottingham sits Wollaton Hall, built in 1588. Wollaton Hall has housed the collections of the Nottingham Natural History Museum (NOTNH) since 1926. Part of the Nottingham City Museum and Galleries service (NCMG) run by NCC, the museum contains 750,000 specimens, including many birds and fossils, which make it one of the largest provincial natural history collections in the UK. Additionally, the exhibition spaces inside Wollaton Hall, including the ornate 15-metre-high central hall and a cluster of galleries surrounding it, offer a creative space for exhibition narrative. This combination of relevant collections and grand architecture, together with the museum's location in a country park occupied by waterfowl and other wildlife, made Wollaton Hall a fitting venue for an exhibition about how dinosaurs evolved into the birds that live among us today (Figure 1).


*Figure 1. Wollaton Hall, Nottingham, showing the entrance to the Dinosaurs of China exhibition at the Nottingham Natural History Museum.*


*Figure 2. The Institute of Vertebrae Paleontology and Paleoanthropology, Beijing.*

*Institute of Vertebrate Paleontology and Paleoanthropology*

The IVPP in Beijing is part of the Chinese Academy of Sciences (CAS) and one of the world's leading dinosaur research centres, dating back to 1929 (Xu and Chen, 2018). Its scientists have discovered, described, and named many new prehistoric species (Xu and Chen, 2018). The IVPP has a public-facing museum, the Paleozoological Museum of China (PMC) (Figure 2). Of the 26 Chinese specimens in the exhibition, 25 were loaned from the collections of the IVPP to represent the most important findings from three generations of Chinese palaeontologists, from Prof. C. C. Young, the founder of Chinese palaeontology, to Prof. Dong Zhiming who was prolific during the late 20th century, to the renowned contemporary researcher Prof. Xu Xing.

*The Longhao Institute of Geology and Paleontology Inner Mongolia*

The LIGP is the only private institute in China that focusses on palaeontology and geology. It was established in 1996 and has made important scientific contributions. Its scientists, led by Prof. Tan Lin, have named more than ten new dinosaur species, including the world-renowned *Gigantoraptor* – the largest bird-like dinosaur ever found and one of the stars of the exhibition.

*The project team*

The Dinosaurs of China project was overseen by an executive group of staff from the two UK partners. In particular, logistics were managed by Rachael Evans, Museum Development Manager at NCMG, in conjunction with Gemma Morgan-Jones, SME Engagement Manager at UoN. The exhibition was the brainchild of Dr Wang Qi, Associate Professor of Architecture in the Department of Architecture and Built Environment at UoN, who co-wrote and curated the final exhibition between 2015 and 2017 with Dr Adam Smith, Curator of Natural Sciences at NCMG. The exhibition was designed by a freelance interpretive designer – Robert Harris – in close collaboration with the curators. Installation was undertaken by a team of technicians from the IVPP and LIGP, supported by NCC and UoN staff together with contracted scaffolders, fabricators, and manual handlers.

## Timeline

*Origin of the project*

Dr Wang Qi first had the vision to bring an exhibition of Chinese dinosaurs to Nottingham following his first successful cooperation with the IVPP – a project to revitalise the PMC in Beijing (Wang, 2012). With the support of the IVPP, Dr Wang approached Wollaton Hall in May 2013 to arrange a meeting to pitch the idea to NCMG. This round table meeting took place between Dr Wang, several NCMG staff members, and (remotely) Zhang Ping, Deputy Director of the PMC, on 31 July 2013 at Wollaton Hall. The proposal was formally approved by NCC in December 2015 and a memorandum of understanding was signed by the four partners in February 2016. This MoU formed the basis for the first press release announcing the exhibition to the public. A formal contract was signed in Beijing in September 2016, by Councillor Trimble representing the NCC.

*Front-end evaluation*

Between 2013 and 2015, the concept of a 'Dinosaur Vision for Wollaton' was formed as a framework for student projects, front-end evaluation, and public engagement. Postgraduate students from the Department of Architecture and Built Environment, University of Nottingham, contributed potential design ideas to the exhibition though student projects. In the autumn semester of the 2013-14 academic year, a group of Master students designed visions for such an exhibition, and these were used to conduct front-end evaluation (Zhang *et al.*, 2016). The four best projects were displayed in Wollaton Hall during the summer of 2014, along with a ballot box to collect public responses to the question "Would you like to see a dinosaur exhibition inside Wollaton Hall?". Of the 558 votes cast, 495 (89%) were positive, 16 (2.8%) were neutral, 42 (7.5%) were negative, and 5 (<1%) were invalid (Zhang, 2016). Comments were also collected, and those on negative votes mainly reflected people's concern about the suitability of the exhibition narrative and contents for such a historical building. This is because Wollaton Hall has a rich history and some visitors relate more strongly to its Elizabethan mansion or stately home identity than its natural history museum identity. However, the results demonstrated overwhelming public support for a dinosaur exhibition, and the curators were able to take account of the concerns raised. This evaluation also formed part of the PhD research of Dr Zhang Licheng, one of Wang Qi's students, who studied the early stages of public engagement during the Dinosaurs of China project under the title 'Towards Conflict Resolution and Consensus-making: a participatory approach to architecture design in the Nottingham Natural History Museum, Wollaton Hall' (Zhang, 2016, Zhang *et al.*, 2016).

During the autumn semester of 2016-17, another group of Masters students and PhD students took an active part in the design process. This group focused on the palaeo-art exhibition in the Angear Gallery, Lakeside Arts. This involved collaboration with two external specialists who formed part of the student project review panel: Robert Harris, the Dinosaurs of China freelance interpretive designer, and Richard Fallon, whose own PhD was being conducted at the University of Leicester at the time on the topic of 'Reshaping Dinosaurs: The Popularisation of Palaeontology in Anglo-American Culture, 1877-1921' (Fallon, 2019). In addition to providing feedback on the student designs, he worked on the exhibition narrative and co-wrote interpretation with the curators. Fallon's invaluable input into the exhibition at Lakeside Arts was supported by a Midlands 3 Cities student placement. His design concepts strongly influenced the final exhibition.

*Object selection*

The object selection process began with a generous shortlist of 46 potential Chinese dinosaurs (fossils and casts of fossils) provided by the IVPP. The curators visited the IVPP in March 2016 to finalise the object list and inspect selected objects. During this trip, the IVPP offered other specimens not on the original list to fit the specific themes of the exhibition and space of the hall. Additional object-specific stories were gathered during interviews with Xu Xing, leading vertebrate palaeontologist at the IVPP, and Wang Yuan, the director of the Paleozoological Museum of China.

*Loaned specimens*

The curators selected 26 specimens to fulfil the exhibition narrative based on the theme hierarchy (see below) and available space inside Wollaton Hall. Table 1 provides a full list of specimens and the main justification for their selection. The list included an impressive array of feathered species to demonstrate a modern picture of dinosaur diversity. To fulfil our objective of giving visitors an "…opportunity to explore the scientific evidence with your own eyes" (Smith and Wang, 2017, p. 4), it was crucial that as many of the specimens as possible were original fossils. While replicas are important and can provide valuable information and experiences (Foster and Curtis, 2014), they are also intrinsically different from original objects (Veldcamp, 2014). As Lawton (2017a) put it in his New Scientist review of Dinosaurs of China: "No amount of studying reproductions quite prepares you for the original…This is a once-in-a-lifetime opportunity". This is why the concept of "'Authenticity' is to a large extent at the heart of museums' concerns in their displays, collections, and interactions with visitors" (Broekhoven, 2013, p. 151). Without the original fossils it is unlikely the exhibition would have received the critical acclaim and media exposure it did (e.g. Caethoven, 2017; Lawton, 2017a&b; Smith, 2017a; Smith, 2017b; Smith, 2017c; Smith, 2017d; Squires, 2017; Smith and Wang, 2018), or the corresponding visitor numbers.

However, this requirement for original fossils had to be balanced against the costs of object hire, insurance, and other practicalities. About one third (eight) of the specimens in the exhibition were original fossils including two type specimens. Most of these were skeletons preserved in single slabs of matrix. However, one fossil was a three-dimensional skeleton embedded in a block of matrix, and two fossils were isolated three-dimensional specimens free of matrix (one a bone, the other an egg in two parts). Approximately another third of the specimens (nine in total) in the exhibition were replicas in the form of casts (seven) and 3D prints (two) of fossils preserved on single slabs or blocks surrounded by matrix. The final third of the objects (nine in total) were three-dimensional mounted casts of skeletons.

| Name | Specimen number | Type | Justification for selection |
|---|---|---|---|
| *Mamenchisaurus hochuanensis* | IVPP TMP CV001 | 3D mounted skeleton cast | Typical sauropod, 'ground-shaker' and the tallest dinosaur displayed in the UK |
| *Lufengosaurus huenei* | IVPP TMP CV002 | 3D mounted skeleton cast | First dinosaur discovered, named, and mounted by Chinese palaeontologists |
| *Protoceratops andrewsi* | IVPP TMP CV003 | 3D mounted skeleton cast | Early discovery in China, represents a horned dinosaur |
| *Sinraptor dongi* | IVPP TMP CV004 | 3D mounted skeleton cast | Large theropod, a carnivorous 'ground shaker' |
| *Guanlong wucaii* | IVPP TMP CV005 | 3D mounted skeleton cast | Size comparable to an ostrich, related to *T. rex* |
| *Mamenchisaurus* thigh bone | IVPP V23344 | Fossil (isolated bone) | Handling object |
| *Pinacosaurus* | IVPP V16854 | Fossil skeleton in block | Represents an armoured 'ground shaker' |
| *Ovaloolithus chikang-kouensis* | IVPP V732 | Fossil (isolated egg, sliced into two parts) | Fossil dinosaur eggs to highlight bird-like nesting behaviour |
| *Oviraptor* sp. | IVPP TMP CV006 | 3D mounted skeleton cast | Story connected to bird-like nesting behaviour |
| *Mei long* | IVPP CV12733 | 3D print of fossil skeleton in block | Curled up with its head under its arm, demonstrates bird-like behaviour in dinosaurs. Also is a tiny fossil to contrast with 'ground shakers'. |
| *Sinosauropteryx prima* | IVPP V12415 | Fossil skeleton on slab | Fossil with fuzzy feathers preserved. Represents the first feathered dinosaur species ever found. |
| *Gigantoraptor erlianensis* | LIGP no number | 3D mounted skeleton cast | Largest bird-like dinosaur ever found, first time displayed in public museum |
| *Dilong paradoxus* | IVPP CV14243 | Cast of fossil skeleton on slab | Tyrannosauroid – evidence suggests *T. rex* might have had feathers. |
| *Epidexipteryx hui* | IVPP CV15471 | Cast of fossil skeleton on slab | Bizarre dinosaur with feathers for display |
| *Caudipteryx dongi* | IVPP V12344 | Fossil skeleton on slab (type specimen) | Type specimen with bird-like feathers preserved and gastroliths in stomach. Related to *Gigantoraptor* and so suggests it had feathers, also. |
| *Sinornithosaurus millenii* | IVPP CV12811 | Cast of fossil skeleton on slab | Feathered dromaeosaurid – suggests *Velociraptor* had feathers |
| "Archaeoraptor" | IVPP CV12444 | Cast of fossil skeleton on slab | Black market and fake fossils |
| *Linheraptor exquisitus* | IVPP CV16923 | Cast of fossil skeleton on slab | *Velociraptor*'s 'big brother' |
| *Yanornis martini* | IVPP V14426 | Fossil skeleton on slab | Fossil bird with feathers preserved. Species makes up part of 'Archaeoraptor' |
| *Microraptor gui* | IVPP V13352 | Fossil skeleton on slab (type specimen) | Type specimen of dinosaur with bird-like feathers, proves that some non-avian dinosaurs could fly. Species makes up part of 'Archaeoraptor'. |
| *Protopteryx fengningensis* | IVPP CV11665 | Cast of fossil skeleton on slab | Shows transitionary characteristics between non-avian dinosaurs and birds |
| *Confuciusornis sanctus* | IVPP V11640 | Fossil skeleton on slab | Shows transitionary characteristics between non-avian dinosaurs and birds |
| *Yi qi* | IVPP FV2108 | 3D print of fossil skeleton on slab | Shows that flight evolved multiple times in dinosaurs |
| *Wukongopterus lii* | IVPP CV15113 | Cast of fossil skeleton on slab | Pterosaur to demonstrate that flight evolved multiple times in vertebrates |
| *Alxasaurus elesitaiensis* | IVPP TMP CV007 | 3D mounted skeleton cast | Therizinosaur – a bizarre type of feathered dinosaur |
| *Sinosaurus triassicus* | IVPP TMP CV008 | 3D mounted skeleton cast | Previously known as 'Dilophosaurus', a star of Jurassic Park |

*Table 1. Full list of loaned specimens with justifications for their selection.*

*Domestic collections*

The exhibition provided an opportunity for the NOTNH and the UoN to showcase their own existing collections to a new audience. At Wollaton Hall, an ostrich skeleton, a locally collected fossil reptile footprint, a cast of an *Archaeopteryx* Meyer 1861, and a Wollaton Hall building stone were incorporated into the exhibition to supplement the story and add value to the user experience, by giving them more to see and experience than just the loaned specimens. Entire existing galleries were also incorporated into the exhibition route. Specimens from the UoN's teaching collections supplemented the satellite exhibition at Lakeside Arts, including a range of bird skeletons, a fossil ichthyosaur skeleton, and casts of dinosaurs and other Mesozoic vertebrates.

*Theme hierarchy*

A theme hierarchy was developed early in the process to provide focus during the object selection stage. Identifying key themes in this way was also crucial to rationalise interpretive text and stay focussed on high-level narrative during the design and writing process. Text was minimised to keep objects the stars of the show.

*Spatial narrative*

The main exhibition was located in a spectacular venue – the architectural magnitude of Wollaton Hall certainly matches the magnitude of the dinosaurs. However, the building presented special challenges. When Robert Smythson (1535 – 1614) designed and built this mansion in the 16th century (the building was completed in 1588) (Marshall, 1999), he surely never envisioned its reincarnation as the Nottingham Natural History Museum 300 years later. At the centre of Wollaton Hall is an ornate Great Hall, 15.4 metres long and 9.1 metres wide, which rises dramatically to a height of 15.3 metres. A five-metre-high balcony at the west end of the space overlooks the Great Hall. A series of corridors and smaller rooms surround the Great Hall on both ground and first floor (Marshall, 1999). The floors are connected by two grand wooden staircases on opposite sides of the building. The rooms surrounding the Great Hall are currently used as themed galleries of natural history and history.

One key challenge was how to organise the objects and themes in the building to tell a cohesive narrative. Three key elements were considered together to meet this challenge: space, circulation, and exhibits. This approach draws from 'spatial narrative', the concept that architectural space can be used to communicate messages. The principle behind spatial narrative is that "…both built spaces and languages could be described as socially structured systems that we have to actively 'take up'…" (Hale, 2017, p27). As Wang and Heath (2011) put it: "architectural language is an interaction between mental thoughts and concrete constructions" (p416). The field stems from theories of architectural language and structural linguistics put forward in publications by Barthes (1964) on semiology, by De Saussure (1915) on structural linguistics, and by Merleau-Ponty (1962) on phenomenology. Furthermore, in the circle of exhibition design, museum exhibition designer Kathleen Mclean has argued that exhibition space could be a vessel in which objects, ideas, and people are brought together and transformed (Falk and Dierking, 2000). In practice, during the design of the exhibition we adopted a spatial narrative approach to guide visitor circulation and exhibit arrangement.

The overarching story of dinosaur evolution was supported in the exhibition by two other themes. Geological time was an important consideration and so we placed the oldest dinosaurs at the start of the exhibition and the youngest dinosaurs later in the exhibition. The history of discovery was another important theme, so we presented the specimens in roughly the order of their discovery by palaeontologists, with the earliest discoveries located at the start of the exhibition and the most recent discoveries at the end of the exhibition. Conveniently, it was possible to arrange the objects to support all three of these themes in parallel to create a journey through evolution, geological time, and history of discovery.

The spatial narrative at Wollaton Hall helped to communicate the evolutionary message in two main ways. Firstly, the exhibition led visitors upwards from 'ground shakers' on the ground floor to 'feathered flyers' on the first floor, a metaphor for the evolution of flight from the ground to the sky. Secondly, the fossil birds were located on the balcony at the end of the exhibition, overlooking the 'ground shakers' to reinforce the message about the evolutionary origins of birds. Essentially, the spatial narrative allowed visitors to experience the 'ground shakers' section from two perspectives, a 'traditional' perspective at the start of the journey, and a new perspective at the end of the journey: a bird's eye view both literally and conceptually.

*One-way system*

A separate entrance and exit for visitors was implemented for the first time in the history of the NOTNH at Wollaton Hall. This one-way circulatory route was designed to lead visitors on a journey through five gallery spaces to retrace the evolution of dinosaurs to birds. Although there was definite linear order from gallery to gallery, the spaces were designed to allow free flow and exploration within each gallery.

A small elevator in Wollaton Hall allows disabled and push-chair access to each floor. However, its location in the North West tower, a corner of the building far away from public stairwells, meant that we had to incorporate a separate one-way return route back to the elevator at transition points on each floor. Because of the limited capacity of the elevator, visitors with push-chairs were encouraged to leave them in a dedicated area at the exhibition entrance, so the elevator could be prioritised for those who needed it the most. At the transition points (at stairwells), able-bodied visitors could ascend the staircase to the next section, while other visitors could make their way to the same section via the elevator, without having to go back on themselves against the unidirectional visitor flow. This way, all visitors were able to experience the 'gallery to gallery' spatial narrative in the same order.

**Installation**

The dinosaurs were shipped in 17 crates (15 from IVPP and two from LIGP) by Corten Logistics. All of the crates were stored in a single shipping container for their journey by sea and transferred into lorries for the road legs of their journey. After a 50-day journey, the dinosaurs arrived in Nottingham on 9th June 2017. The same day, a team of six technicians arrived separately via air from IVPP and LIGP to begin the installation immediately. Since Wollaton Hall has no dedicated service entrance, another difficulty was getting the crates and dinosaurs into the building. Casts were opened outside and the individual bones moved into the hall. However, fossil specimens had to be opened inside (Figure 3). A special platform was built outside the rear entrance, so that the bones and crates could be lifted onto them mechanically and moved in through the narrow door (Figure 4).

The curatorial team used masking tape to test out the layout well in advance, during the design phase. Masking tape was also used as a guide during installation to make the process as efficient as possible, allowing key objects to be dropped into the correct position immediately. The Chinese technicians constructed the skeletons and moved the fossils into secure storage. All of the objects were condition checked and documented upon arrival. The largest dinosaurs were built from the ground up, with scaffolding being erected along with the dinosaurs by contract scaffolders. Specialist exhibition fabricators (J Birchwood) were contracted to build the bases, cases, barriers, and other non-collections structures. The dinosaurs were all in place at both sites by 19th June, and the IVPP and LIGP technicians returned to China, allowing the fabricators to complete the barriers, interpretation panels, and other superficial structures of the exhibition. Installation was completed by the end of June.

**Elements of design**

*Brand, logo and colours*

The exhibition title was selected by a public vote on Facebook, in which the public were given a multiple choice of three pre-selected alternatives. A feather icon was used to represent the new view of dinosaurs and was also a subtle nod to a Nottingham icon, Robin Hood, who happens to wear dinosaur integument in his cap (Figure 5). Feathers also appeared on the curtains to the

*Figure 3. Crates containing fossils inside Wollaton Hall.*

*Figure 4. Scaffold platform built on the rear of Wollaton Hall during the installation (and deinstallation).*

*Figure 5. Dinosaurs of China logo. The feather is red and the word 'China' is gold.*

Great Hall, scanned from feathers collected from the grounds of Wollaton Park and elsewhere. The primary logo and marketing colours were selected to echo the gold and red of the Chinese flag, and this colour scheme was also adopted in the exhibition itself. The colour palette of the plinths and panels transitioned through the exhibition from yellow and orange, representing the golden age of ground-shaking dinosaurs, to yellow and green, representing feathered dinosaurs, and eventually to blue, a subtle metaphor for the evolution of flight. #Chinasaurs17 was used as a hashtag for social media. A series of animated gifs was commissioned, each showing a dinosaur from the exhibition in a different Nottingham tourist attraction, to help promote the exhibition through social media. Additionally, the NOTNH museum mascot, @George_Gorilla, took on the persona of 'George the Gorilla-saurus' in the build up to, and during, the exhibition. George the Gorilla's Twitter account was run by ASS, while all other dedicated Dinosaurs of China social media accounts were managed by the NCC's marketing team.

*Plinths and barriers*

The crates the dinosaurs were shipped in were incorporated into the exhibition. This solved the problem of where to store them, and also provided authenticity to the design. This decision – approved by the IVPP – influenced other design choices such as the text font and barrier style. About half of the crates were used as plinths in the exhibition, while the rest were kept in the Dino-Explorer Zone (see below), where they were used as set dressing and surfaces for activities.

*Interpretation*

Each dinosaur was accompanied by three levels of object-specific interpretive text below a main heading that gave the name of the dinosaur in English and Chinese: 1. a tagline to summarise the main take-home message, 2. a panel with an object-specific story, 3. A table of key facts. Separate narrative text was arranged on walls throughout the exhibition to provided context for the object-specific stories.

*Artwork*

Each specimen in the exhibition was also accompanied by a large painting depicting its possible appearance in life. This important visual interpretation helped to bring the fossils to life. Due to the rapid speed at which palaeontology has moved, some of the restorations contained anatomical inaccuracies. For example, the arrangement of wing feathers on some of the depictions was wrong. To commission new artwork was not feasible due to budget and time constraints, so we knowingly included these artworks as a pragmatic compromise. Overall, the paintings satisfied the main requirement of depicting many dinosaurs as feathered and bird-like, and the inaccuracies were relatively minor. These paintings by Zhao Chuang were provided by the Beijing-based Peking Natural Science and Art Organisation (PNSO), and so also reinforced the exhibition's connection to China. The PNSO also provided immersive landscape backdrops for the main gallery spaces. The smaller paintings were printed on canvas and fixed onto panels with Velcro, while the expansive panoramas were printed on self-adhesive vinyl wallpaper and hung by digital print specialists (John E. Wright & Co. Ltd). Each artwork consisted of several vertical strips. Once in rough position, the backing was first removed from the very top of the strip and the adhesive vinyl pressed into place with a squeegee. The rest of the backing was then gradually pulled down as the lower parts of the strip were fixed into place. Once the first strip was hung, the adjacent strip could then be aligned and hung in a similar way to traditional wallpaper, repeating the process until the entire wall was filled.

*Dinosaurs of China trail*

An exhibition trail was developed as an interactive element and was integrated directly into the exhibition during the design phase. The choice to use a recurring egg motif for the trail provided young visitors with a dinosaur egg hunt. The trail asked visitors to gather the evidence that connects dinosaurs to birds, mirroring the key narrative of the exhibition. The free trail sheet consisted of 20 short statements with one word left blank to be filled in by finding the corresponding trail stop in the exhibition. The trail was intentionally divided between the two venues to encourage visitors at one site to visit the other.

## Costs, launch and visitor figures

Ticket prices for the main exhibition at Wollaton Hall were £7 per adult and £5 per child, while entry to the smaller satellite exhibition at Lakeside Arts was free. This helped to improve accessibility for the exhibition as a whole. Wollaton Hall is normally free to enter, but it was necessary to charge an entry fee during the exhibition to cover the costs. The total project budget for the Dinosaurs of China project, including loan fees, shipping, marketing, and exhibition development and fabrication, was approximately £500,000. Arts Council England (ACE) contributed towards the development phase, and since revenue from ticket sales exceeded the total project budget, the exhibition was cost neutral. The exhibition launched to the public on 1st July 2017 and ran until 29th October 2017. The main exhibition at Wollaton Hall received 115,000 visitors during its four-month duration, while Lakeside Arts received 30,000 visitors. This met the predetermined target for Wollaton Hall of 100,000 to 150,000 visitors.

## Description of the exhibition

*Lakeside Arts – The Science of Palaeo-art*

The satellite exhibition at Lakeside Arts focused on palaeo-art – the science of depicting the likely life appearance of prehistoric organisms in art. This theme worked as a stand-alone exhibition, but also fit with the main Dinosaurs of China narrative. In particular, the satellite exhibition considered how depictions of dinosaurs have changed over the decades and how feathered dinosaurs from China have influenced modern palaeo-artists. Two dinosaurs from IVPP were displayed here because of their connection to this topic. A cast specimen of *'Dilophosaurus sinensis'* Hu 1993 (=*Sinosaurus triassicus* Young 1940) was selected because it is a star of Jurassic Park (Figure 6). In the film, it has a frilled neck and is toxungenous i.e. it spits a toxic substance (toxungen) at its prey (Nelsen *et al.*, 2014). There is no fossil evidence for this, but speculation is a necessary and fun part of palaeo-art. Additionally, a cast of *Alxasaurus* was selected because it represents a key group of feathered dinosaurs, therizinosaurs, not represented elsewhere in the exhibition. Lakeside Arts also hosted a series of ten free palaeo-talks given by palaeontologists, curators, and palaeo-artists.

*Wollaton Hall*

*Ground shakers*

The first gallery of the main exhibition was located in the Great Hall and contained all of the 'ground shaker' exhibits. This was a Jurassic hall with skeletons of a variety of large, scaly species, which fit a traditional view of dinosaurs.

It contained typical plant-eating 'ground shakers' including one of the earliest (i.e. from the early Jurassic) large dinosaurs from China (*Lufengosaurus*). This important genus was also the first Chinese dinosaur discovered and named by Chinese palaeontologists, in 1941 (Young, 1941). An immense *Mamenchisaurus* dominated the centre of the space, leaning back onto its strong hind limbs and tail, with its front limbs and neck raised up (Figure 7). This rearing posture made the skeleton 13.7 metres tall - the tallest dinosaur skeleton ever displayed in the UK. Below the cast, a *Mamenchisaurus* femur allowed visitors to touch, and compare their height to, a fossil dinosaur bone.

Two armoured dinosaurs (*Protoceratops* Granger and Gregory 1923 and *Pinacosaurus* Gilmore 1933), also early discoveries (Granger and Gregory, 1923; Gilmore, 1933), were also on display here. Sneaking up on the *Mamenchisaurus* from the far end of the Great Hall was one of the largest predatory dinosaurs from China, *Sinraptor* Currie and Zhao 1994 (Currie and Zhao, 1994) (Figure 7). A painted panorama in the Great Hall depicted a Jurassic encounter between a herd of *Mamenchisaurus* and a pack of *Sinraptor*, to help set the scene and interpret the two largest skeletons in the gallery.

In addition to the ground-shakers on display in this gallery, similarities were also highlighted here between the bones of dinosaurs and birds. Specifically, *Guanlong* Xu *et al.*, 2006 was displayed face to face with an ostrich skeleton under the heading 'Spot the similarities'. Lastly, Wollaton Hall is built from Jurassic-aged Ancaster stone (Marshall, 1999), so a piece from the NOTNH collection was also displayed and interpreted here as a handling object.


*Figure 6. Skeleton of* 'Dilophosaurus sinensis' *(=*Sinosaurus triassicus*) (cast) on display in the Angear Gallery at Nottingham Lakeside Arts, University of Nottingham.*

*Figure 7. A predatory* Sinraptor *(cast) sneaks up on the unsuspecting* Mamenchisaurus *(cast) in the Great Hall.*

*Dinosaurs behaved like birds*

After observing the similarities between the skeletons of dinosaurs and birds, visitors were directed from the Great Hall into the Bird Room on the same floor. This permanent gallery of taxidermy bird dioramas was a perfect setting to consider the topic of dinosaur behaviour. Three Chinese dinosaur specimens were displayed here to provide evidence for bird-like behaviour in dinosaurs. A fossil dinosaur egg and a cast of an *Oviraptor* skeleton were used to tell the story of dinosaur nesting behaviour. A locally collected Permo-Triassic fossil footprint from the NOTNH collection was displayed here to explain how trace fossils provide information on behaviour. Also displayed in this gallery was a 3D-printed replica of a tiny *Mei long* Xu and Norell 2004 skeleton, preserved coiled up into a bird-like sleeping pose with its head tucked under its forelimb (Xu and Norell, 2004) (Figure 8). This room also represented a move forward in time to the Cretaceous Period.

*A new view of dinosaurs*

After seeing evidence for bird-like dinosaur bones and behaviour on the ground floor, visitors could then 'fly' to the first floor via a grand staircase to see the 'smoking gun' evidence – precious fossils of feathered dinosaurs. This material included two authentic holotype specimens of the feathered dinosaurs *Microraptor gui* Xu *et al*., 2003 and *Caudipteryx dongi* Zhou and Wang 2000 (Figures 9 and 10). Two other important fossils were in this gallery: a referred specimen of *Sinosauropteryx* Ji and Ji 1996, the first feathered dinosaur species ever described by palaeontologists in 1996 (Figure 11), and a referred specimen of *Yanornis* Zhou and Zhang 2001, an early true bird fossil. These four fossil specimens, all from the Cretaceous Jehol biota of Liaoning Province, provided examples of four key categories of feathered dinosaurs: *Sinosauropteryx* had fuzzy feather-like integument ('protofeathers') (Zhang *et al*., 2010), *Caudipteryx* had bird-like feathers but was flightless (Zhou and Wang, 2000), *Microraptor* had wing feathers and was capable of flight (Xu *et al*., 2003), and the bird *Yanornis* had wings and an advanced bird tail, which gave it the same flight capabilities as modern birds (Zhou and Zhang, 2001).

*Figure 8.* Mei long*, the sleeping dragon, is only 15 cm long in this curled up pose. A 3D print of this tiny fossil was a highlight for many visitors. ©IVPP*

*Figure 9. Holotype specimen of the flying dinosaur* Microraptor gui *(IVPP V13352) with wing feathers preserved. Slab = 86 cm long. ©IVPP*

Another key specimen among the ten feathered dinosaur genera in this gallery was a mounted cast of the eight-metre-long *Gigantoraptor* from Inner Mongolia, the largest bird-like dinosaur in the world (Xu *et al*., 2007) (Figure 12). This was also significant because it was the first time this dinosaur had been displayed in a public museum anywhere in the world.

Panoramas on the end walls in this gallery depicted an ecosystem of the Cretaceous Period. Specifically, it represented the Jehol biota located in the western area of Liaoning Province, where most of the feathered dinosaurs in this gallery were found.

An interactive in this space provided an opportunity for visitors to create their own dinosaur name and pose as a feathered dinosaur. This was designed and created as an integral part of the exhibition to invite visitors to think creatively about the process of naming dinosaurs in a fun and engaging way. It consisted of a wooden panel depicting two life-sized feathered dinosaurs with the head cut out, so visitors could poke their own heads through. Next to the dinosaurs was a tray of loose acrylic letters that could be placed on a series of hooks to complete a dinosaur name ending in either "-raptor" or "-saurus" (Figure 13).

*Figure 11. Fossil specimen of* Sinosauropteryx *(IVPP V12415) with fuzzy integument preserved. Slab = 127 cm long. ©IVPP*

*Figure 10. Holotype specimen of* Caudipteryx dongi *(IVPP V12344) with bird-like feathers preserved. Slab = 88 cm long. ©IVPP*

This was an incredibly popular interactive and photo-opportunity, but also noisy because of the sound of the acrylic letters constantly being shuffled and hooked into place.

*Figure 12. Mounted cast of* Gigantoraptor*, the largest bird-like dinosaur in the world.*


Figure 13. Design for an interactive used in the 'New view of dinosaurs' section of the exhibition. Visitors could use acrylic letters to create their own dinosaur name.

*Feathered flyers*

A fourth gallery of Chinese specimens was set up on a balcony overlooking the ground shakers in the Great Hall. This section celebrated the capability of flight. Here, specimens of more Cretaceous birds (*Protopteryx* Zhang and Zhou 2000 and *Confuciusornis* Hou *et al.*, 1995) were displayed to complete the evolutionary picture. Also, a bizarre flying dinosaur (*Yi qi*) and a pterosaur *Wukongopterus* Wang *et al.*, 2009) were displayed to show different types of flying animals. *Yi qi* was discovered in 2015 and had bat-like wings (Xu *et al.*, 2015), so the exhibition ended with one of the most recent dinosaur discoveries from China. From this high vantage point visitors again encountered the gigantic *Mamenchisaurus* to reinforce the message of the exhibition: "*Mamenchisaurus* rises up to meet her modern relatives – the birds!".

*Africa Gallery*

Visitors exited the exhibition via a permanent Africa Gallery. A question was posed here: "What happened next?". The taxidermy specimens of African animals in this gallery, including George the Gorilla and a giraffe, represented animals that could only evolve into niches left vacant following the extinction of certain types of dinosaurs. The centrepiece of this gallery, however, is an African waterhole diorama, which contains some modern-day dinosaurs – ostriches and crowned cranes. These birds were a fitting punctuation mark to the exhibition to reinforce one of the fundamental messages; that dinosaurs evolved into birds so not all dinosaurs are extinct.

*Exit through the gift shop*

The Dinosaurs of China exhibition route led visitors out of the exhibition through the gift shop towards an outdoor activity area (Dino Explorer Zone).

The educational remit of a museum should extend into the gift shop, but often doesn't (ASS, pers. obs.). In some respects, an exhibition shop can be regarded as the final gallery, perhaps even the most important gallery, since visitors might literally take parts of it home with them. It was therefore crucial that the key messages of the exhibition were reinforced and not contradicted by the merchandise in the shop. It would be counter-productive, for example, to sell toys of outdated scaly Jurassic Park-style 'raptors' in an exhibition intended to change visitor perceptions of dinosaurs. However, accurate feathered dinosaur toys are rare and expensive. Since retail and curatorial teams will have different priorities and objectives, compromise is necessary. The exhibition curators were able to input into stock decisions to ensure a range of accurate dinosaur merchandise was available, including accurate feathered dinosaur models and up-to-date dinosaur books, which might have been omitted otherwise. More affordable plastic 'chinasaurs' were still available as pocket-money purchases, along with plush toys. All of the toys sold well, and other big sellers included exhibition-branded products, fossil ammonites, dinosaur-themed games, and the exhibition guide-book (Smith and Wang, 2017).

*Dino Explorer Zone*

Outside of Wollaton Hall, a large marquee was erected on the lawn to host daily free dinosaur-themed activities and interactives. This was necessary because of the lack of space for many activities inside the museum. An animatronic life-size puppet, Hunter the *Sinraptor*, was an essential part of the interactive experience outside. Hunter, operated by a professional puppeteer and accompanied by handlers, brought an element of theatre and performance to the exhibition. This played an important role in marketing and education, including school visits in the build up to and during the exhibition (Nunn and Smith, 2018).

## Legacy and impact

A three-dimensional virtual Dinosaurs of China experience was created from laser scans of the exhibition and can be explored for free at: https://v21artspace.com/dinosaurs-of-china. This makes the exhibition accessible to visitors who did not visit in person, and it also preserves it in digital form for perpetuity. The work was undertaken by V21 Productions at a cost of approximately £1000, paid for from the project budget. The data was collected on two separate days before and after museum opening hours.

The exhibition has helped promote international academic links and research cooperation and has set a precedent for Nottingham museums as a venue for world-class exhibitions. One outcome was the exhibition's selection as the venue for the SVPCA 2017 annual meeting field trip, which saw dozens of vertebrate palaeontologists visit Wollaton Hall (Martin-Silverstone, 2017). The exhibition has also helped to foster Nottingham's reputation as a venue for natural science in general (e.g. Lawton, 2017a,b), and the NOTNH is working towards hosting other major temporary exhibitions in the future. The Dinosaurs of China project also helps to demonstrate the value of natural history collections and the huge audience they are capable of generating, even in provincial museums. It also shows the outcomes possible for museums when they collaborate with outside expertise. The achievements and impacts of Dinosaurs of China have also been recognised with some awards. In 2018 the Palaeontological Society of China awarded the exhibition as one of the 'top 10 excellent science popularisation events of China', and the exhibition was awarded the Judge's Special Prize for 'Excellence in Exhibitions' at the East Midlands Regional Heritage Awards 2019.

Dinosaurs of China benefited the partners, but it also had a wider positive impact on the local econ omy as the "exhibition played [a] part in boosting tourism figures" (Toulson, 2018). The exhibition was reported to have contributed towards a 1.3% increase in visitor numbers to Nottinghamshire and a corresponding growth of 3.6% to the value of tourism in the county in 2017 compared to the previous year (Toulson, 2018).

Plans are now under way to redevelop the permanent gallery spaces at the Nottingham Natural History Museum, Wollaton Hall, to make the most of its own extensive collections.

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# Demystifying CITES: UK museums and commercial use of Annex A specimens

Rachel Jennings

*Curator of Natural History*
*Powell-Cotton Museum, Quex Park, Birchington, Kent, CT7 0BH*

*Email: Rachel.jennings@powell-cottonmuseum.org*

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**Abstract**

CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) aims to ensure that trade in wild animals and plants is sustainable and does not endanger wild populations. It is implemented through national legislation that regulates international trade and commercial use. Most museums with natural science collections will have some CITES-listed specimens. However, the available guidance for museums on how to comply with CITES is not always clear.

A CITES Article 10 or Article 60 certificate is required by EU scientific institutions that use their collections for commercial purposes; this includes charging fees for exhibitions, research visits, and corporate filming and photography. The Powell-Cotton Museum recently successfully applied for an Article 60 certificate. This article will describe the CITES Article 60 certificate application process and the Powell-Cotton's experience, and provide advice for other museums on preparing the application and supporting documentation, including where to find further guidance.

**Keywords**: CITES, Annex A, museums, commercial use, Article 60 certificate, Article 10 certificate, Article 30 certificate

## Introduction

CITES is an international agreement that regulates the movement and trade in endangered species, living and dead, their parts and derivatives. It was drafted by the International Union for the Conservation of Nature (IUCN) and came into force on 1 July 1975. The Regulations aim to protect wild populations from over-exploitation by controlling trade. Species are listed in three appendices according to the degree of protection that they need Appendices I, II and III; CITES, 2019a). The website 'Species+' provides a searchable database of CITES -listed species (UNEP, 2019).

Becoming a Member State (or Party) is voluntary, and there are currently 183 Parties to the Convention (European Commission, 2019; JNCC, 2019). CITES provides a framework, and each Party has to adopt domestic laws that implement CITES nationally. It is legally binding to the Parties that have signed up, but other countries are not subject to it and are thus able to continue trading endangered species without controls. However, non-member states are now are tiny minority worldwide.

In the EU, CITES is legislated through the EU Wildlife Trade Regulations, and species are divided into four annexes (Annex A – D). In some cases, the EU Regulations apply stricter control measures than the CITES Appendices (European Commission, 2017a), and Annex D includes some non-CITES species that are subject to EU regulations for the protection of native species (European Commission, 2019). CITES is enforced through permits and certificates issued by the Management Authority in each State (CITES, 2019b), which controls activities such as import, export, commercial use, and sale of listed species. The UK CITES Management Authority is currently the Department for Environment, Food and Rural Affairs (Defra). The implementation of CITES in the UK is managed by the Animal and Plant Health Agency (APHA), an executive agency of Defra, which is responsible for the issue of guidance and certificates (APHA, n.d.).

In this article I will outline the EU regulations for commercial use of CITES-listed species by museums and discuss the issues with the guidance that is currently available. I will then present a brief case study of my own experience of preparing an Article 60 certificate application on behalf of the Powell-Cotton Museum, and provide some advice for other institutions planning to submit an application.

## CITES: commercial use and museums

The commercial use of Annex A species is prohibited under CITES. Article 8(1) of Council Regulation (EC) No 338/97 defines commercial use:

> "*The purchase, offer to purchase, acquisition for commercial purposes, display to the public for commercial purposes, use for commercial gain and sale, keeping for sale, offering for sale or transporting for sale of specimens of the species listed in Annex A shall be prohibited.*"
>
> European Union, 1996: p.8.

This has implications for museums with endangered species and/or their derivatives in their collections. Holding Annex A specimens is not regulated within the EU, but any use of these specimens for commercial gain is not allowed under Article 8(1). This includes charging entry fees for permanent or temporary exhibitions, events in which Annex A specimens are used or displayed, and fees for research access and corporate photography or filming (AHVLA, 2011a).

No certificate or permit is required for commercial use of specimens that were captive bred, artificially propagated (in the case of plants), or that were acquired and worked before 3 March 1947 (commonly known as the 'antiques derogation') (European Commission, 1996: p.9). However, proof of provenance is required in these cases. Guidance on what is considered a 'worked' or 'unworked' specimen has been published by the European Commission (2017b). Many natural history specimens will be considered 'unworked', and thus subject to Article 8(1) as defined above.

A derogation of Article 8(1) for scientific institutions was introduced in 2006: Article 60 of Commission Regulation (EC) No 865/2006 exempts scientific institutions from the prohibition on commercial use of Annex A species, provided that this use contributes to conservation efforts or education relating to the protection of those species (European Commission, 2006: p.19). EU museums can apply for an Article 60 certificate, which covers all Annex A specimens in their collections and permits commercial use for the purpose of conservation-related research and education. The sale of specimens is only permitted to other scientific institutions holding an Article 60 certificate (European Commission, 2006: p.19). It should also be noted that prior to Article 60, Article 30 certificates were issued for the same purpose. Institutions holding an Article 30 certificate do not need to reapply for an Article 60 unless it has an expiry date (AHVLA, 2011a).

What constitutes a 'scientific institution' is not fully defined in available guidelines, although the following is included in the 'Reference Guide to the EU Wildlife Trade Regulations':

> "*Bone fide zoos, botanical gardens, museums or similar establishments, which are considered to be "scientific institutions" can be exempted from the prohibition on the use of specimens of Annex A species for commercial purposes...*"
>
> European Commission,
> TRAFFIC Europe,
> and WWF, 2017: p.110.

The European Commission's online guidance about wildlife trade states that institutions must register as scientific institutions before they can obtain an Article 60 certificate (European Commission, 2016). However, this is not explicit in the wording of Article 60 itself (European Commission, 2016: p.19), and it has not been administered this way in the UK: the APHA grants certificates to museums without requiring them to register as scientific institutions.

Registration of scientific institutions with a CITES Management Authority serves a different purpose in the Regulations: registered scientific instructions are exempt from the requirement for import and export permits for the purposes of non-commercial loan or transfer of specimens to other registered scientific institutions (Council of the European Union, 1996: p.8; CITES, 2000). In this case, import and export permits are replaced with labels issued by the Management Authority, removing the need to apply for a new certificate each time a specimen is transported.

This example demonstrates the difficulty for users in interpreting the complex EU Wildlife Trade Regulations and highlights a potential for inconsistency in the way they are applied by different Management Authorities. Clarification is required on how the Regulations should be enforced in the case of scientific institutions.

For purely commercial use of Annex A specimens, a second exemption to Article 8(1) exists: Article 10 certificates can be applied for by anyone owning Annex A specimens (not just museums or other scientific institutions) and are issued for single specimens rather than whole collections. These certificates can be issued for the whole 'life' of a specimen (Specimen Specific Certificate (SSC)) or for particular transactions only (Transaction Specific Certificate (TSC)). Examples of transactions in this case include sale, display, or breeding (APHA, 2013).

EU museums wishing to use a single Annex A specimen commercially (for example, in a charged temporary exhibition or commercial event) would require an Article 10 SSC or TSC certificate. While not explicit in the available guidelines, it can be inferred from the Regulations that an Article 60 certificate holder would additionally require an Article 10 certificate for any specimens used purely commercially (i.e. not for the purposes of research or education).

The situation for loans, outside of transfer between scientific institutions, is not covered in the EU Wildlife Trade Regulations or published guidance. However, recent advice from the APHA is that lenders require an Article 10 or Article 60 certificate only if they will commercially gain from a loan. The onus is on the borrower to have the appropriate certificate to cover any items borrowed from other institutions that they will be using commercially (for example, in a charged temporary exhibition) (Nicholls, 2019).

## Applying for an Article 60 certificate

Currently, applications for both Article 60 and Article 10 certificates for commercial use are made through the submission of form FED 1012 to the APHA's Centre for International Trade, based in Bristol (APHA, 2015a; APHA, 2019). Guidance on how to apply for an Article 10 certificate can be found on the UK Government's CITES webpage (APHA, 2013; APHA, 2017; APHA, 2019), but – despite requiring the same form - there is currently no guidance for Article 60 applications published here.

Published Article 60 guidance does exist, but is outdated and not easily accessible: documents GN20 and GN13 contain guidance notes for museums and herbaria, respectively (AHVLA, 2011a; 2011b). These documents were prepared by the predecessor of the APHA, the Animal Health and Veterinary Laboratories Agency (AHVLA), with advice from the Natural Sciences Collections Association (NatSCA). However, they have not been updated since 2011 and are not available on the current UK Government CITES guidance page (APHA, 2019). The documents can be found on a legacy webpage that was archived by National Archives in 2014 (AHVLA, 2013). This archived content is not well optimised for search engine use, and can therefore be hard to find. An older version of GN20 (Animal Health, 2010) was also available on the NatSCA website at the time of writing (June 2019). It should be noted that while much of the guidance in GN20 and GN13 does appear to still be relevant, the section on how to complete form FED 1012 no longer applies as all CITES permit application forms were updated in 2015 (APHA, 2015b).

Further information can be found in Attachment H of the 'Reference Guide to the European Union Wildlife Trade Regulations', which lays out the minimum standards required of scientific institutions holding an Article 60 certificate (European Commission, TRAFFIC Europe, and WWF, 2017: p.191). These standards align closely with best practice in collections management and documentation, and the application should demonstrate that the standards are being met.

The UK authorities (including Border Force and the National Wildlife Crime Unit) do not accept being unaware of guidelines as a reason to not comply with the EU Wildlife Trade Regulations. The APHA, as the relevant Management Authority, can be contacted directly for advice and information (APHA, 2019).

## The Powell-Cotton Museum and Article 60

The Powell-Cotton Museum was created by Percy Powell-Cotton (1866-1940) in the grounds of his family home at Quex Park, Birchington, Kent.

Powell-Cotton travelled and hunted extensively in African countries and on the Indian subcontinent and amassed a large collection of animal specimens and ethnographic objects. He began building a museum in 1896 to house his 'sporting trophies' and expanded it by adding galleries over the years. The Natural History collections at the Powell-Cotton Museum largely reflect Percy Powell-Cotton's interests as a hunter: mainly comprising African mammals, 'big game' animals are well represented.

The natural history displays at the PCM consist of three galleries containing large-scale dioramas in naturalistic settings (Figure 1), created between 1896 and 1939. The taxidermy mounts were created by Rowland Ward Ltd., and Powell-Cotton was in constant correspondence with the firm to ensure that the animals were recreated in accurate anatomical detail and realistic poses.

In addition to these impressive displays, Powell-Cotton developed a large research collection containing flat skins and disarticulated skeletons, which he made available to visiting researchers and is still frequently used by academics and artists (Figure 2). The value of this collection for research lies not only in the large number of specimens available, but also the quantity and quality of data that accompanies it – Powell-Cotton recorded detailed field notes for the majority of his specimens, including accurate locations (with coordinates and sometimes altitude) and dates of collection. The Museum archive also contains diaries, photographs, film footage, and correspondence.

Today, the Natural History collection comprises around 6,500 mammal specimens, plus smaller numbers of birds, reptiles, amphibians, and invertebrates. Over 1,000 of the mammal specimens are currently listed in CITES Annex A. The Museum uses these specimens commercially as defined in Article 8(1) of Council Regulation (EC) No 338/97, in several ways: fees are charged for Museum entry, and also for research access and teaching workshops. The Powell-Cotton Museum has successfully applied for a CITES Article 60 certificate.

*Preparing the Powell-Cotton Museum application*

The application process was begun by the Powell-Cotton Museum's Head of Collections and Engagement, Dr Inbal Livne, and completed by myself. Due to the lack of easily-accessible information online, my colleague had initially sought advice from a wildlife training consultant, Craig Fellowes, and also the Natural History Museum, London (NHM), who hold an Article 60 certificate. This was valuable in giving us both confidence in preparing the application, and the information provided formed the basis of the Powell-Cotton's supporting documentation. I then expanded on this with reference to Attachment H

*Figure 1. Part of the large 'jungle' diorama in Gallery 3 of the Powell-Cotton Museum. Photo circa 1915. Image © The Powell-Cotton Trust.*

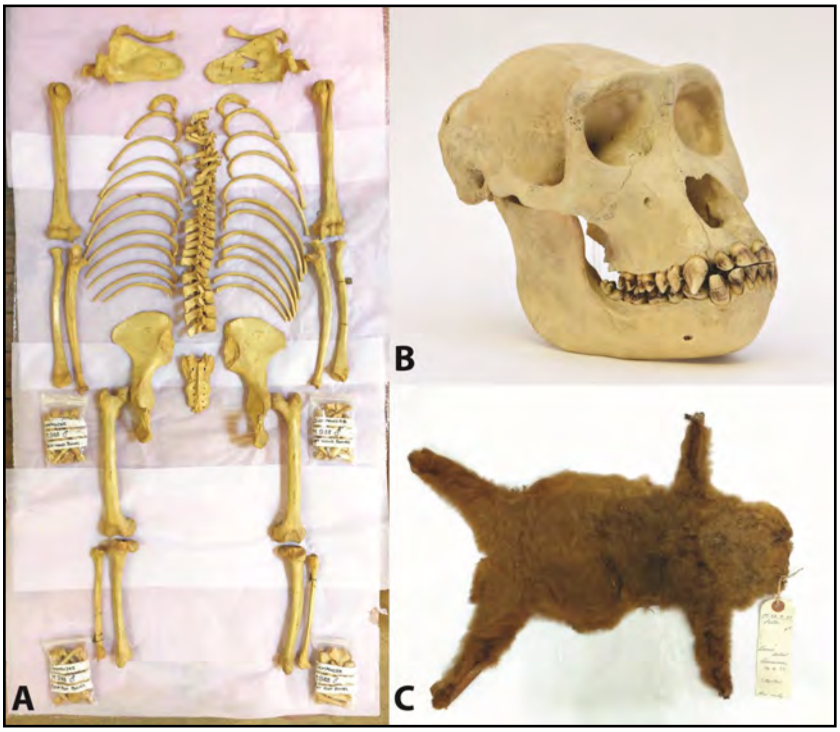

*Figure 2. Examples of the Powell-Cotton Museum's extensive research collection. A) Adult male chimpanzee skeleton (Pan troglodytes troglodytes Blumenbach, 1775; PCM NH.MER32.988). B) Adult female Western gorilla skull (Gorilla gorilla (Savage, 1847); PCM NH.MER35.57). C) Milne-Edwards's potto skin (Perodicticus edwardsi Bouvier, 1879; PCM NH.MER.T1). All images © The Powell-Cotton Trust.*

of the 'Reference Guide to the European Union Wildlife Trade Regulations' (European Commission, TRAFFIC Europe and WWF, 2017: p.191).

Completing the application form FED 1012 itself was a challenge because, as mentioned above, the current guidance only applies to Article 10 applications (APHA, 2018). In my initial completion of the form, I provided detailed responses, but after submission the form was immediately returned with instructions to remove information from several sections; it is a legal requirement that the whole form (including signatures) fits onto one side of A4 paper, but our application had flowed over to a second page because some boxes had been expanded too far. Where names of countries and species were required, I had initially referred the reader to the supporting documentation submitted with the form (e.g. "See Appendix 1"), but was instructed that this was not necessary and that Box 16 (scientific name of species) should read "All Annex A dead specimens".

I had been advised by colleagues in other institutions that the APHA will often request additional information or clarification after the initial submission, but once these few issues with the form had been resolved I was not contacted further regarding the application. The Powell-Cotton Museum's application was successful, and the CITES Article 60 certificate arrived about eight weeks after submission.

**Discussion**

The EU Wildlife Trade Regulations are complex, and they can be daunting for museum professionals to engage with. For institutions considering an Article 60 application, it is advisable as an initial step to contact the APHA to discuss the situation at your institution and to confirm whether a certificate is required. This will provide you with a named contact in the Agency who should be able to supply additional guidance, and to whom you can submit the application. It will also give the Agency notice to expect an application, which may make the process smoother.

It can also be valuable to contact a wildlife consultant for advice and/or training about CITES, as they can provide information tailored to your collection and needs. Other institutions already holding an Article 60 certificate may also be willing to share their experiences.

My experience of the application process on behalf of the Powell-Cotton Museum demonstrates that the key to success with CITES Article 60 is to keep the application form brief, and make the supporting information detailed. I would suggest that it is a good strategy to refer to the standards provided in Attachment H of the 'Reference Guide to the European Union Wildlife Trade Regulations', and to address all of the criteria listed (European Commission, TRAFFIC Europe and WWF, 2017: p.191).

However, it is worth remembering that the submission opens a dialogue: if your application does not initially contain the details necessary to make an assessment, the APHA will request additional information.

Museums and herbaria are important repositories of scientific collections. It is vital to make these collections accessible to the public, researchers, and artists, and to do so in compliance with all relevant legislation. Article 60 allows museums to use their Annex A specimens commercially in ways that contribute to education and research that benefits conservation of species, but clearer published guidance is needed to facilitate museums in complying with the EU Wildlife Trade Regulations and CITES as a whole.

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# Secrets of Designation unlocked: the Tullie House natural science collection and a window into Cumbrian biodiversity

Simon Jackson

*Independent museum freelancer and consultant.*

*Email: drsimonjjackson@gmail.com*

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**Abstract**

In 2018, Tullie House Museum and Art Gallery was awarded Arts Council England's Designated status for its natural science collection, recognising the outstanding quality of the collection to support research and understanding into Cumbrian biodiversity and geodiversity. Arts Council England's Designation Scheme identifies the pre-eminent collections of national and international importance held in England's non-national museums, libraries and archives, based on their quality and significance. This mark of distinction is a key to unlock the research "secrets" and potential of collections, through raising their status and through access to Arts Council funding programmes to develop them and to make them more accessible to researchers and the public. Understanding the content of our collections and their significance is also vital to public engagement. In this paper, the author explores the successful aspects of the Tullie House application, focusing on the collection and how it met the specific Designation criteria. The application focused on voucher specimens, centring on those which are most historically and scientifically important, and which provide key insights into Cumbrian biodiversity and wider UK ecology.

**Keywords**: Designation, Cumbria, Tullie House, biodiversity, geodiversity, collection.

## Introduction

Designated status from the Arts Council England (ACE) was awarded to Tullie House Museum and Art Gallery (TH) for its natural science collection in 2018, and the integral role of the Cumbria Biodiversity Data Centre (CBDC), with its archival data, hosted at the Museum, was acknowledged. It has taken a number of years to achieve this award, and consequently a lot has been learnt about what works and what does not work when applying for Designation. Here, some of the aspects of the successful application are shared, from the position of having written and coordinated the bid, as the previous Curator specialising in the natural science collections.

The paper will include what Designation is, and why it is significant, how Designation works, the collections and context of the application, before laying out how TH addressed the key criteria. The purpose of this paper is not to provide general guidance about the process: for which people should refer to the ACE guidelines (Arts Council England, 2015) or staff at ACE, but instead to elucidate TH's successful approach. Each Designation candidate will have a unique collection and will need to tailor their bid to its strengths, but the author hopes that this article will contain some useful advice for Designation applicants.

*What is Designation and why is it important?*

The Designation Scheme was born out of a commitment in the government review of museum policy, *Treasures in Trust* (Department of National Heritage, 1996), that a system should be created to recognise collections of outstanding quality and importance: this became the Designation Scheme (Mendoza, 2017). Its founding principles were to raise the profile of collections and to encourage their safeguarding (Arts Council England, 2014). It was firstly administered by the Museums, Libraries and Archives Council until 2011, after which the ACE took over and revamped the application process.

The definition of Designation is that the scheme "… exists to identify and celebrate collections of outstanding resonance that deepen our understanding of the world and what it means to be human" (Arts Council England, 2015). Furthermore, a Designated collection is defined as "a nationally significant, coherent assemblage of items; held in trust in the long-term for public benefit… [and]… is an essential research resource for its subject" (Arts Council England, 2015). The scheme is established for non-national, accredited, English museums.

Designation is a mark of distinction, helping to raise the profile of collections nationally and internationally, to researchers, funders and stakeholders: it is something in which donors, affiliated societies and organisations should take great pride. With this accolade, the TH natural science collection is now formally recognised as one of England's most important collections.

In a climate where austerity continues in the museum sector, with a reduction in public funding and shrinkage of museum specialisms (Museums Association, 2019), the continuation of funding for core curatorial work becomes ever more vital. In the 17 year period of the scheme between 1997-2014, financial awards were made to 140 distinct Designated collections with around £32 million invested towards ACE objectives including collections development work, to facilitate the ongoing care and understanding of these collections, whilst ensuring that they are as accessible as possible (Arts Council England, 2014), helping to "unlock" their full potential. More specifically, Designated institutions are able to apply for the Designation Development Fund with grants of £20,000-£90,000 for 2 years (Arts Council England 2019a). Furthermore, Designation, as a mark of prestige, also helps to demonstrate the Excellence strand of the ACE National Portfolio Organisation (NPO) funding (where applicable such as TH), and will help Designated institutions secure further grants.

*How does Designation work?*

The Designation application is a two-stage process, formally assessed by the ACE Designation Panel, which meet twice a year to review applications. These are accepted for a single collection (e.g. natural sciences), although historically organisations could apply for all of their collections to be Designated in a single application. The purpose of Stage I is to demonstrate that the organisation has the potential to meet the definition of a Designated collection (Arts Council England, 2015). After the Panel have formally reviewed and evaluated the application they will then provide feedback to the applicant on if they have been successful. If so, then they will be eligible to apply for Stage 2. The receipt of Designated status is awarded following a successful Stage 2 result (see Arts Council England, 2015 for further details).

*Who has Designation?*

Of 149 museums, libraries and archives that have received this award (Arts Council England, 2019b), 77 (52 %) are accredited museums. There are at least 2,600 museums in England (Mendoza, 2017) which means at the most, 3% of English museums are Designated. 15 of these have natural sciences as a component of their collections.

The only other museum in the North West region to have been awarded Designated status for their natural science collections is the Manchester Museum, University of Manchester. This is significant because in the application TH needed to make extensive comparisons to their nearest Designated natural science collection, both in terms of discussing comparable content, but also how the two organisations work together. The only other Designated collection in Cumbria is Wordsworth House which is associated with William Wordsworth. Therefore, Tullie House is the only Designated natural science collection in the county.

## Tullie House Museum and the context of the application

Tullie House Museum and Art Gallery is a regional museum in Carlisle, to the north of the county of Cumbria. The Museum has mixed collections of natural sciences, archaeology, social history, costume and art. Archaeology and social history document the lives and activities of the people who have settled in Northern Cumbria and include prehistoric, Roman, Viking, medieval and contemporary objects. The fine art collection includes 4,800 objects, mainly British paintings, including works from local artists.

The natural science collection has the greatest breadth and depth, with approximately 320,000 specimens, consisting of a rich variety of material from different disciplines including in order of size; entomology, botany, geology, bird eggs, and vertebrate taxidermy and skins, although the collection also includes a smaller collection of osteology, molluscs, microscope slides and spirit specimens. The greatest strength is its focus on Cumbria (described below), as well as containing material from elsewhere in the UK and overseas. The biological specimens date back to the 18th century, and the significant history of collecting is intertwined with the activities of prominent naturalists across the county and the development of the local Carlisle Natural History Society.

The collection plays a vital part in supporting exhibitions, the public engagement programme and also biological recording. Specimens are used regularly by researchers and artists and they support higher education teaching. With the community at the heart of engagement, the collection has great social impact, improving the lives of local people (e.g. "tactile" sessions for people with visual impairments).

TH had strong resources at hand to tackle the bid. The Museum had specialisms in natural sciences through in-house curatorial positions (the very first application was led by the, then, Curator of Natural Sciences, Stephen Hewitt), and the applications were supported at senior levels, including most notably the Directors (see Acknowledgements). TH is also very fortunate to host the CBDC, which currently houses 2.3 million biological records, and is supported by staff expertise in analysing data, biological recording and ecology: the CBDC was recognised by the Designation Panel as being integral to the work of TH. Through its relationship with the CBDC, but also through its historical relationship with its local natural history Society (the Carlisle Natural History Society), the Museum has always had a strong affiliation with local naturalists and recorders. The research activities and academic impacts of the Museum have always had an excellent track record of internal research and collaboration. These relationships meant that TH had a bounty of expertise on which it could draw upon in developing the Designation bid. TH also a strong public engagement programme, as explained above, which was an invaluable component of the bid.

The first and most important step taken in the Designation process, was to evaluate why the collection was nationally or internationally significant.

*Cumbrian biodiversity and natural science*

In order to demonstrate that a collection is nationally, or even internationally significant, one clear advantage is if the material is from across the world. In the case of natural science, specimens have links to other landscapes, environments and their biodiversity. In the case of human history, objects have links to other societies and cultures. The Manchester Museum, University of Manchester, for instance, has a collection of international scope, both in terms of natural science and human history.

The TH approach, however, was significantly different. Tullie House contains some material from overseas and from across Britain; for instance, the entomology collection contains some 10,000 British species. However, the greatest focus of the collection is undoubtedly on Cumbria and the TH application focused on why Cumbria itself is nationally and internationally significant for understanding natural science.

Cumbria is the most biodiverse county in England, with more priority habitats (24) than any other English county, according to Natural England data (Figure 1) (Eweda and Frost 2014). For instance, Cumbria contains 84% of English willow heath and montane environments; important for the dotterel (*Charadrius morinellus* Linnaeus 1758) and golden eagle (*Aquila chrysaetos* Linnaeus 1758) (JNCC, 2019). The county has more biological Sites of Special Scientific Interest (SSSI) than any other county in England. The outstanding bio and geodiversity is also an integral part of the Lake District, which is now a UNESCO World Heritage Site. Many of the UK endangered and Biodiversity Action Plan species have taken refuge in this region taking advantage of the abundance of natural habitats. Cumbria provides an excellent area for understanding human impacts on wildlife, including environmental pollution, habitat degradation and climate change.

The Museum has also had a long-term association with prominent Cumbrian naturalists. This includes the founder of Cumbrian natural science study, Reverend Hugh Alexander Macpherson who campaigned to have natural science collections at Tullie. His meticulous level of biological recording set the first comprehensive baseline for how species were changing in response to land-use change in the county, culminating in his comprehensive opus *A Vertebrate Fauna of Lakeland* (Macpherson, 1892). When he died, this left a huge gap in biological recording and the world's first natural science records bureau (as far as TH knows) was set up in 1902; today this has evolved to become the CBDC,

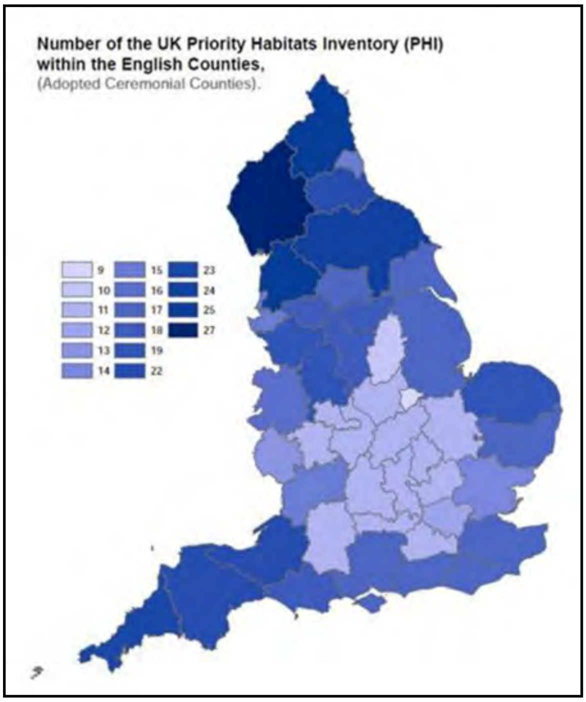


*Figure 1. Map of the number of priority habitats by county. Cumbria has the greatest number of priority habitats (24) in England. © Cumbria Biodiversity Data Centre.*

hosted at the Museum. The Museum has also had a 125 year association with its Carlisle Natural History Society and their collecting efforts have underpinned the development of the collection.

*Number of type specimens: not a barrier*

Voucher specimens are among the most important specimens in a museum, and can be defined in different ways, but with common elements. One of the most comprehensive definitions by Kageyama (2003) starts: "A voucher is a specimen, a sample thereof, or an artefact, and its associated data, that documents the existence of that organism or object at a given place and time in an archival manner, to ensure the repeatability of the study which otherwise could not be adequately reviewed or reassessed." A type specimen is a particular voucher specimen which serves as a vital basis (or taxonomic unit or reference) for describing new species.

Many Designated collections have numerous type specimens, and detailing them can certainly help to demonstrate national and international significance in a Designation bid; indeed, one of the prompts in the Designation guidelines (Arts Council England, 2015) indicates applicants may wish to detail their type specimens to support their application. With a relatively small number of type specimens, TH focused on documenting their impact on the literature. TH also made it clear that the strength of the collection was also the inclusion of other voucher specimens from Cumbrian localities and historical and scientific studies. Examples of these were discussed throughout the application.

**Meeting the criteria**

There are 3 main criteria (national significance, outstanding quality, and research value) to meet in the Designation application (Arts Council England, 2015). The purpose of this paper is to illustrate how TH met the criteria with the strength of its Cumbrian collections, focusing on the Stage 2 bid, where the criteria were addressed most explicitly.

*Criteria 1: national significance*

TH kept the national significance section entirely focused on the subject of Cumbrian biodiversity and geodiversity, by discussing why Cumbria's biodiversity is so special (e.g. number of priority habitats, biological sites as discussed above). More importantly, TH briefly cited a number of examples of how particularly important Cumbrian species (e.g. those that have had strongholds in the county) have been studied upon the basis of the collection, and the impacts the research has made on natural science studies. Some of these examples were discussed in more detail in later sections of the bid.

For example, peregrine falcons (*Falco peregrinus* Tunstall 1771) have historically had one of the world's most important nesting sites, in terms of population density, in the Lake District. In the mid-20$^{th}$ century, across the country, the species was declining dramatically with the eggshells breaking. Famous ecologist and conservationist, Derek Ratcliffe undertook work on TH collections and others including museums and private collections, studying how eggshells were changing in thickness over a period of a hundred years and found a link between the introduction of the pesticide DDT and the thinning of eggshells (Figure 2) (Ratcliffe, 1970). This demonstrated a clear link between environmental pollution and the decline of the species. His
meticulous studies eventually paved the way for a ban on these pesticides so that these birds of prey could recover. This example clearly demonstrates the impact of a collection on the conservation of the species and our understanding of our affects on the environment.

The national significance criterion was explicitly addressed in the first section of the Stage 2 bid, but TH also made sure that the theme underlined


*Figure 2. Bird eggs of the peregrine falcon (*Falco peregrinus *Tunstall 1771) from the Ernest Blezard collection which were studied in Derek Ratcliffe's ground-breaking research. © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

the rest of the application, frequently referring back to the significance of Cumbrian biodiversity and making sure that all examples were relevant to the subject.

*Criteria 2: outstanding quality*

This section looked at the size, scope and coverage of the TH natural science collection, demonstrating that it is a coherent assemblage; part of the definition of a Designated collection (Arts Council England, 2015). This was one of the relatively easiest parts of the TH bid, as it focused on one county. For instance, more than half the specimens are from SSSIs, and of the 288 SSSIs known in Cumbria, 275 are represented by specimens (Cumbria Biodiversity Data Centre, 2017 *pers comm.*). The collection includes almost 200,000 Cumbrian specimens; almost two thirds of the entire natural science collection are from this county.

The collection is also associated with 2.3 million biological records held at the Cumbria Biodiversity Data Centre. These records present some 20,000 species in archival data which includes rare or protected species such as the natterjack toad, *Epidalea calamital* Laurenti, 1768. Both the collection and biological records comprise the pre-eminent resource for understanding the changing Cumbrian biodiversity.

The remaining part of this section was broken down into different discipline areas, in order to provide specific examples from the collection showing how it is comprehensive, and how it is an essential resource for researchers. A few examples from the bid are included below. In each section TH also made frequent comparisons to Cumbrian holdings in other Designated museums, particularly the Manchester Museum which is their closest comparator in the North West.

*The entomology collection*

Entomology is by far the largest part of the collection with around 200,000 specimens, of which 122,000 specimens (c. 6,500 Cumbrian species) represent voucher records for sites in the county. The specimens extend back more than 125 years thanks to the history of past collecting associated with the Carlisle Natural History Society, extending back to George Routledge (collecting period 1890-1930) and Frank Henry Day (1890-1950 collecting period), right up to the present day with the collecting activities of the Cumbria Biodiversity Data Centre, the society and other naturalists.

The key example cited in detail in this section, was that of the marsh fritillary (*Euphydryas aurinia* Rottemburg, 1775) (Figure 3). This species has had an historical stronghold in Cumbria, with the abundant wet grasslands and its larval host food plant, the Devil's Bit Scabious (*Succisa pratensis* Moench). Famous geneticist of Oxford University, Edmund Brisco Ford studied specimens, now in the Tullie House collection, from a population near Carlisle (Orton) between the late 19th and early 20th century with his father HD Ford to investigate the relationship between population size and variation and the affects of bottlenecks on the populations (Ford and Ford 1930). This work significantly contributed to understanding the role of natural selection in ecology and the understanding of natural fluctuations helped to inform the conservation and successful reintroduction of the species to the county in 2007 (Porter, 2007) following its local extinction. This example demonstrates the links not only to a Cumbrian species, and the understanding of evolutionary theory, but also the legacy in terms of impacting conservation science today.

*Vertebrate zoology: the taxidermy and skins collection*

This collection consists of around 4,500 mounts and study skins. Many of these specimens were cited in Macpherson's *A vertebrate fauna of Lakeland* (Macpherson, 1892), which provides a unique window into the fauna of the late 19th century. Many of these were then subsequently incorporated into

*Figure 3. Specimens of the marsh fritillary (*Euphydryas aurinia*) in the George Routledge Collection which were studied by EB Ford (CALMG:1935.28). © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

the 300 mostly Cumbrian habitat cases, modelled on field observations, from Cumbrian sites. These set piece dioramas include sites which are now SSSIs (e.g. St Bee's Head) and nesting localities which can still be observed today (Figure 4).

Of greatest research value, TH cited the red squirrel (*Sciurus vulgaris* Linnaeus 1758) skins (Figure 5). Red squirrels are habitat specialists and excellent markers sensitive to changes in woodland. By studying genetic changes and also changes to skull shape, Dr Peter Lurz and his team were able to identify distinct populations within the species and how they were changing over time in response to our changing land use (Hale *et al.*, 2001, Hale and Lurz 2003). This research also showed that before 1980 there was a distinct West Cumbrian race and a distinct continental one to the north-east. After the Kielder Forest was built this effectively acted as a land bridge joining up previously fragmented populations and allowing these populations to come together to mix. The upside is there is now greater genetic diversity within this region, making the species more immune to local extinction (Lurz, 2018 *pers comm.*), but the West Cumbrian race is now harder to identify. These studies demonstrate the specific changes to populations that occurred due to human impacts. Again this is an example which links to Cumbrian biodiversity, as red squirrels have one of their last English strongholds in the county and the collection will have a considerable and vital part to play in the ongoing conservation of this species.

*The herbarium*

The nationally significant herbarium is a unique research resource for present and future work on the county's flora and underpins nationwide publications. It consists of c. 60,000 specimens,

*Figure 4. Taxidermy mounts of the Atlantic puffin,* Fratercula arctica *Linnaeus, 1758, in their habitat case based on their historical nesting site on new red sandstone at St Bee's Head. Sadly only one pair are left there and the species has considerably declined. (CALMG:2001.784.222, CALMG:2001.784.223, CALMG:2002.1525.391, CALMG:2002.1525.372, CALMG:2002.1525.373). © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

*Figure 5. Study skins of red squirrel (*Sciurus vulgaris *Linnaeus 1758) are an important source of genetic material for studying populations of the species. CALMG: 1949.122, CALMG: 1937.10, CALMG: 1963.4). © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

some dating back to the 18th century, from Cumbria, but also from the UK and beyond. The application emphasised the importance of a recent significant acquisition, from the University of Lancaster in 2015 (Figure 6) consisting of c approximately 35,000 sheets, containing invaluable voucher specimens from the most comprehensive floral surveys to date of the county, and their floral compendium, *A Flora of Cumbria* (Halliday, 1997). This indispensable voucher collection, with the survey data held in the CBDC, provides the baseline for understanding the exceptional Cumbrian flora.

*Figure 6. Herbaria sheets such as this specimen of lesser water parsnip* Berula erecta *(Hudson) Coville, in the ex-University of Lancaster herbarium are invaluable voucher specimens for Cumbrian biological records including county surveys. (CALMG:2015.14). © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

*The geology collection*

This consists of c.10,000 specimens showing how Cumbria's environments have changed over a period of 300 million years (Lower Ordovician-Lower Jurassic). After Cornwall and Devon, Cumbria is the next most mineral rich area in the UK (Rumsey, 2016) and the outstanding geodiversity across the county underpins the rich variety of habitats. The TH geological collection has had a strong track record of research.

The main example TH cited was the fossil collection of Professor Robert Harkness, which is the largest geological collection at TH. Harkness had a significant impact on the 19th century palaeontological literature and was able to show that the oldest rocks in the Lake District, the Skiddaw Slates were far richer in fossils than previously thought, using his observations and the TH collection itself (Harkness, 1863, Salter, 1863). His collection includes type specimens including *Ormathops nicholsoni* Salter, 1866, the earliest record of trilobites from the Skiddaw Slates (Whiteside, west of Braithwaite and Keswick) (Figure 7). The Harkness collection also includes Permian Hilton Plant Bed specimens of the Eden Valley, one of the few localities in the British Isles to have Permian plant fossils (Worley, 2016 *pers comm.*). It was important to emphasise the rarity of assemblages to help demonstrate their significance.

*Figure 7. Fossil specimen of* Ormathops nicholsoni *Salter, 1866 in the Professor Harkness Collection, the earliest trilobite record from the Skiddaw Slates (CALMG:1978.126.99). © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

### Criteria 3: research value

*Research*

This section was framed around the type of people TH works with and focused on how research is facilitated. Throughout this section, TH referenced their Research Framework. The application addressed how research has been undertaken historically in-house at the Museum including former Curator, Ernest Blezard's 1943 *Birds of Lakeland*. TH also focused on collaborative work, including the example of the red squirrel research (Hale *et al.*, 2001), noting that it was published in the peer-reviewed, high-impact journal, *Science*.

It was important to highlight TH's current collaboration in a NERC-funded Imperial College London and Natural History Museum led project; investigating how bumblebees are changing in response to land-use change. Using the Museum's 18 bumblebee species from Cumbria, TH is able to contribute unique data to the project for the far North West (Cumbrian) area of England (Figure 8). This project combines the latest genetic sampling technology and imaging to build the most comprehensive picture to date of how these vital pollinator species are changing, and will enable the team to investigate why some species are declining (e.g. moss carder bee: *Bombus muscorum* Linnaeus, 1758) whilst others are not (e.g. common carder bee: *Bombus pascuorum* Scopoli, 1763) and will hopefully provide useful insights into the future conservation of the species.

TH also discussed the central role of the Cumbria Biodiversity Data Centre has in working with taxonomic specialists and biological recorders across the county to promote and support research into Cumbrian species and habitats. For instance, working with the Cumbria Wildlife Trust, the CBDC has made data from the Uplands for Juniper survey freely accessible to all providing a comprehensive assessment for a species under pressure from disease and climate change.

*Contribution to public understanding*

TH framed this section based on the audiences with which they worked. This included the exhibitions programme, for instance, Eden Rivers Wonder World was a 2018 exhibition developed in partnership with the Eden Rivers Trust exploring the exceptional biodiversity of the River Eden and its catchment area.

The application addressed TH's work using the collection in both in-house and outreach workshops for primary schools and how they collaborate with external partners including Natural England. TH also detailed how they use the collection to develop their input into the University of Cumbria zoology course, in particular focusing on the taxidermy and osteology to investigate anatomy and evolution. A key strength of this section was the work of the CBDC and its relationship with recorders. The CBDC provides opportunities for specialists and amateurs to enhance their knowledge of the county and its species and to facilitate surveying special, under-recorded sites. For instance, in 2018 the Bowkerstead Bioblitz was organised in partnership with the Rusland Horizons HLF project. 100 individuals in family groups attended, collecting 609 records representing 443 species including 99 that are rare or protected. Prior to this event the number of recorded species held at the centre for the area was only 22 (Muscat, 2019 *pers comm.*).

*Figure 8. Specimen of red-tailed bumblebee (*Bombus lapidarius *Linnaeus, 1758) used in the NERC- funded project investigating how bumblebees are changing in response to land-use change. (CALMG:1935.28). © Tullie House Museum and Art Gallery (photograph by Guy Broome).*

TH also emphasised their work with their closest comparator collection, Manchester Museum, delivering a joint workshop in geological collections care, as part of the Museum Development North-West initiative providing training for smaller museums in the region.

## Conclusions

This paper charts the key elements of TH's successful application which will hopefully provide some insights into the process of Designation and how TH developed a strong bid. Designation is a highly prestigious award, and achieving it has been a challenging process. The successful bid entailed a large amount of resources, in terms of expertise and time, which is something a potential applicant should consider when embarking on their journey towards Designation. TH was fortunate in its expertise at hand, in terms of existing and also previous curatorial staff. The expertise from the in-house CBDC, but also affiliated societies and naturalists and researchers was also invaluable; this meant therefore that there was a community to support the application. Furthermore, the process was also supported at senior levels of the organisation.

The most significant step in developing the application for TH was to determine the subject of national significance. This was Cumbrian biodiversity and geodiversity, a subject which underpinned the application, and allowed the collection to be considered a coherent assemblage. However, as most of the material is from this one region, it was crucial to the bid to determine why this area was of national or international significance. As well as explicitly addressing this in the 'national significance' section, examples were used throughout the bid which linked back to the subject. The author subsequently selected and researched a number of suitable research examples, which had considerable impact, and linked to contemporary issues including climate change, environmental pollution and conservation efforts. This included going back to the researchers, including face-to-face meetings, to obtain more detail on the impacts of their work and why the TH collection was vital. In some cases, this also culminated in letters of support.

Of course, each applicant will have different subjects of national significance, and will need to tailor their application to their collection and work of their organisation. The ACE guidelines and staff provide a crucial reference for the development of the application.

Designation has been a long process for TH, but the successful achievement of Designated status, has now opened up the Designation Development Fund income stream, as well as supporting future funding applications. However, the application has "evolved" over the 3 versions, incorporating new research and knowledge about the collections, a broader understanding of how they fit in with the wider picture of other museums across the country, and deeper relationships with users of the collections. Therefore, Designation is just as much a 'journey' as well as a 'destination' (modified from a quote often attributed to Ralph Waldo Emerson).

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# Taxonomic revision of Leopold and Rudolf Blaschkas' Glass Models of Invertebrates 1888 Catalogue, with correction of authorities

Eric Callaghan[1], Bernhard Egger[2], Hazel Doyle[1], and Emmanuel G. Reynaud[1*]

[1]School of Biomolecular and Biomedical Science, University College Dublin, University College Belfield, Dublin 4, Ireland.
[2]Institute of Zoology, University of Innsbruck, Austria

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*Corresponding author: Emmanuel.reynaud@ucd.ie

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**Abstract**
The glass models of invertebrates crafted by Leopold and Rudolf Blaschka were made between 1863 and 1889. Production ceased when the glassmakers turned their attention to what is now known as the Ware Collection of Blaschka Glass Models of Plants, created for the Harvard Museum of Natural History. More than 130 years have passed since their last published catalogue of species in 1888 and the nomenclature they applied is now a confusing mix that includes many junior synonyms and unavailable names. This is an issue for many museums and universities which own Blaschka models, as uncertain identifications may compromise interpretation of this rediscovered legacy. Today, many museums and universities hold collections of those glass invertebrates but rely on labels that have outdated taxonomy, or may be misspelled. Here, we provide a valuable resource for curators and enthusiasts alike. We studied and updated the final catalogue of 1888 from the Blaschkas' Dresden-based workshop. We first focused on major taxonomical changes from taxa to species, as well as on an analysis of the acknowledged authorities. We found that only 35.3% of the taxonomic names applied to the 1888 models are currently used, while 3.7% lack any known synonym and their identity remains open to interpretation. Finally, two of the authorities listed in the catalogue, Ernst Haeckel and Philip Henry Gosse, were incorrectly acknowledged as authors for taxa that were applied to an extensive range of models. This study is the first of its kind on the taxonomy used for the 1888 Blaschka catalogue, and it will help in the identification and naming of Blaschka models worldwide.

**Keywords:** Invertebrate, Blaschka, museum, collection, taxonomy

## Introduction

During the 18th century, the Swedish botanist Carl von Linné (Carolus Linnaeus) established a "two-term naming system", also known as binomial nomenclature to provide a standardised name for each species. This system is now governed by international codes of rules such as the *International Code of Zoological Nomenclature* (ICZN). Binomial nomenclature encompasses terrestrial as well as marine species and became the reference for describing and naming any new species discovered, including those from terrestrial and marine the expeditions of the 19th century. From François Auguste Péron's jellyfish drawings (Péron, 1816) to Ernst Haeckel's radiolarian engravings (Haeckel, 1887), alongside the massive 35 volumes from the HMS *Challenger* expedition reports (1872–1876), a new world was opened up to the masses.

This enabled people to see these creatures both in books and in prints. The newly established French and British museums were keen to show what the world had to offer, and exploit (Das and Lowe, 2018), through the display of skeletons and exotic stuffed animals. However, the marine world, other than fishes and dolphins, remained difficult to #present as many of those marine species could not withstand taxidermy (e.g. jellyfish) and deteriorated rapidly when preserved in spirit usually fading, or shrinking in preservatives.

One workshop, based in the German town of Dresden, found a solution to the challenge of displaying the newly described marine invertebrates. The lampworkers Leopold and Rudolf Blaschka, father and son, used their knowledge of glass and its translucent qualities, as well as pigments to create artificial jellyfishes and other soft-bodied invertebrates that could be exhibited easily (Reiling,, 1998; Reiling2000). However, they relied on books, lithographs, and sometimes live creatures kept in tanks to produce their models (Dohrn A. 1877). Many different books and monographs were used as source illustrations such as Philip Henry Gosse's *Actinologia Britannica: A History of the British Sea-Anemones and Corals* (Gosse, 1860), Haeckel's *Das System der Medusen* (Haeckel, 1879) or Jean Baptiste Vérany's *Céphalopodes de la Méditerranée* (Vérany, 1851). The Blaschkas manufactured models of invertebrates that they sold worldwide through their own workshop and through three distributors: Robert Damon (United Kingdom and Ireland), Václav Frič (Austria and Hungary), and Henry Augustus Ward (North America). These models are quality representations, and they are often referred to as masterpieces in which their art matches their true biological nature (Sheets-Pyenson, 1988; Dyer, 2008; Callaghan *et al.*, 2014). Since the production of these magnificent models ended in 1889, a wealth of marine biological data has accumulated, and there have been many taxonomic changes. In addition, challenges to established ideas and concepts have led to the extensive reorganization of the Tree of Life (e.g., the Archean Kingdom). However, the name "glass models of invertebrates," which has been consistently applied to the Blaschkas' creations, has never been challenged, presumably because these models were extremely accurate, and little has been published about their taxonomy. Although some work has been done on the origin of their designs and their sources of inspiration, it is often very general and incomplete (Reiling; 1998).

We decided to investigate the taxonomy of the Blaschkas' glass models of invertebrates listed in the two English catalogues (1878;1888) published by Ward's Natural Science Establishment. We used archives such as the Rakow Research Library of The Corning Museum of Glass (which contains the archives of the Blaschkas' workshop), as well as the large digitized holdings of the online Biodiversity Heritage Library (BHL). The authority for each species and the taxonomic validity of the original species' name versus the currently established one was assessed through the World Register of Marine Species (WoRMS). We thus established a new version of the Blaschkas' 1888 catalogue, with the correct modern taxonomy and authority for each species, along with a unique set of "Blaschka species" that exist only as models (the species they described are no longer considered valid). Finally, we uncovered a bias toward citing British naturalist Philip Henry Gosse and Ernst Haeckel as recognized taxonomic authorities.

## Methods

### *Archival material*

The original catalogues that describe the invertebrate models sold by the Blaschkas' workshop in Dresden were obtained from the following sources: Blaschka workshop early catalogues in German (Three editions between 1871 and 1876) "Wenig Bekannte Seethiere…" The first edition has not been found yet while the second version has been provided to us as a transcript from Chris Meechan, National Museum of Wales while the third Edition has been purchased from the British Library [**Identifier:** 000373688; **UIN:** BLL01000037368]; Ward's Natural Science Establishment catalogue in English (1878): Reese Library of the University of California. [online access: https://babel.hathitrust.org/]; Blaschka 1885 catalogue in German "Katalog über Blaschka's Modelle von Wirbellosen von Leopold Blaschka" was obtained from the Corning Museum of Glass Library [OCLC Number: 70272726; it was originally obtained from Chris Meechan, National Museum of Wales. It is a copy of a catalogue own by Robert Damon the British Blaschka Dealer and heavily annotated]; Ward's Natural Science Establishment catalogue in English (1888): River Campus Libraries, University of Rochester, Rochester, New York, Henry Augustus Ward Papers (1840–1933), reference A.W23.

### *Analysis of Data*

Because of the extent of the species and phyla covered by the Leopold and Rudolf Blaschka models, as well as the evolution of the taxonomical nomenclature with the passing of time (150 years), we had to work, for the most part, on well-established and curated online databases to ascertain that each model represented a valid species. All the species names were checked, and the taxonomy, from phylum to species, was updated as much as possible.

The principal databases consulted were: World Register of Marine Species (WoRMS), www.marinespecies.org; Marine Species Identification Portal, species-identification.org; and the Catalogue of Life, www.catalogueoflife.org.

The Biodiversity Heritage Library (www.biodiversitylibrary.org) was also used. This holds scanned original books with chromolithographies, that can be compared to Blaschka drawings and final models to confirm or reject the binomial nomenclature used.

These databases were used consistently and, depending on the final established taxonomy, we applied the following taxonomic terms: "*nomen dubium*" (Latin, "doubtful name," indicating that the taxonomic validity is uncertain or disputed by various experts); "*nomen nudum*" (Latin, "naked name," indicating a name that has been published without an adequate description), and "*species inquirenda*" (Latin, "species of doubtful identity, requiring further investigation"). In cases where no matching entry could be found in any of these databases, an online search was conducted to cross-reference other sources, which often clarified the identification or suggested a possible alternative. For several models, despite our best efforts no valid current identification, inclusive of synonymies, could be found. These models are designated as "ND" (No Data) in the updated version of the catalogue.

## Results

*General Catalogue Analysis*

The Dresden Blaschka workshop sold the models by the means of catalogues. Three early catalogues published between 1871 and 1875 were in German and directly distributed by Leopold Blaschka [Third edition: 392 items]. The items were not numbered, but only described by three elements: species name, price and the author. Rarely was there any indication of the number of parts per item (e.g. two polyps). Size, weight, material and so on were never indicated. Numbering of each item available first appeared in the catalogue published by one of their distributors: Henry Augustus Ward in 1878 [630 items]. This catalogue, in English, was sold by Ward Establishment and promoted through their publications. Each item was numbered and this is now commonly referred to as the Ward Number when describing a Blaschka model. Each number was associated with a species, a reference, a price and sometimes additional indications such as: developmental stages, male, female. There were no indications of the number of parts per item, size, weight, colour, material and additionally there were no drawings, illustrations or sketches. In 1885, the Blaschka workshop published a new version of their improved offer of models in a new German catalogue [697 items] mainly based on taxonomical classification, from Protozoa to Salps while the translated Ward catalogue from 1888 used a numerical ranking from 1 to 704 irrespective of taxonomy [704 items]. This was to be the last ever published catalogue. However, the 1878 and 1888 Ward catalogue have three items which numbers have been duplicated in comparison to the 1885 Blaschka catalogue bringing the total number listed to 707 items:

1885 – Blaschka catalogue in German
- 141. *Cladonema radiatum* (juvenile and adult medusa)
- 191. *Tubularia indivisa*
- 219. *Rhizophysa Eysenhardti*

1878/1888 Ward catalogue in English
- 141. *Cladonema radiatum* (stages of development)
- 141a. *Cladonema radiatum* (adult medusa
- 191. *Tubularia indivisa* (stages of development)
- 191a. *Tubularia indivisa* (male colony)
- 219. *Rhizophysa Eysenhardti*
- 219a. *Rhizophysa helianthus*

It is important to agree on the terms used to describe the models. We assume that number referred to an item linked to a species and a price as they were models sold through a catalogue. Some items may consist of a number of parts and so one catalogue number may correspond to several sub-elements or parts. For example, some models such as *Caryophilla Smithii* [sic] is either a single polyp or two polyps depending if they are an early model (<1878) or a late model (>1878) but both will be numbered identically (n. 122). Similarly, the *Aurelia aurita* (n. 225) is an item that consists of up to 14 parts. Therefore, the numbers referred to an item in the catalogue regardless of the numbers of parts produced by the Blaschka workshop. Moreover, some species may not be represented by a single number as some species appeared multiple times across the catalogue as adult, juvenile, and developmental stages and even by a dissection. So even though the last catalogue published in 1888 lists 704 items, it does not consist of 704 species and offers more than 704 elements. Based on our practice with various collections, many items have been split and renamed as the curators were not aware of the number of parts per item/number.

The Blaschkas were lampworkers, not taxonomists, and they had to rely on the limited taxonomic literature available at the time and especially chromolithographic plates that helped them produce coloured models. The best-known example are the anemones based on lithographies illustrated by P.-H. Gosse (Gosse; 1860). Henry Ward, who produced his catalogues, was a geologist not a zoologist. At that time, it was customary to assign a specific status to organisms based on minor differences that would today be regarded as a subspecies at best, and therefore some of the items in the catalogues represent "species" that are no longer considered valid. In addition, it is possible that some of the species were incorrectly identified in the first place.

None of the two catalogues follow established taxonomic conventions, in that the generic and specific names are not italicized. Specific names were also capitalized when they referred to persons, as was common practice in the literature of the time (e.g., item n. 30, *Actinoloba Paumotensis*, and item n. 43, *Bunodes Ballii*).

There are spelling errors throughout the German and English catalogues. These may have been a fault of the typesetters, who were not experts in the field (e.g. item n. 20 is listed as *Actinaria* rather than *Actiniaria*). The mistakes may indicate that neither Ward nor the Blaschkas corrected their manuscripts before they were printed.

*Analyzing Ward's 1888 Catalogue*

We used Henry Ward's 1888 catalogue as the last available catalogue to establish a reference of the complete Blaschka marine invertebrate collection. Seven hundred and four items are sequentially numbered, but three items [ns. 141, 191 and 219] were subdivided into two items each [ns. 141a, 191a and 219a] so the complete set of items offered to customers was 707. However, the distribution is highly variable across phyla, classes, and orders (Table 1).

Of the 707 items, 19 (2.6%) are of varieties no longer considered valid, although three of these are now regarded as full species in their own right where the variety named has been recognized as the species under a different name; 10 (1.4%) represent developmental stages of species (note that there are no adult forms of items 252 and 669 listed in the catalogue); 12 (1.7%) are dissections presenting the internal anatomy of mainly Gastropoda, three of which are not otherwise included in the catalogue; and four (0.6%) represent male and female specimens of two species. Therefore, the 707 items represent 694 species as recognized at that time.

*General Changes in Taxonomy (from the 1888 Ward Catalogue)*

At the phylum level, three phyla are still valid (Echinodermata, Mollusca, and Porifera) and two phyla (Coelenterata and Vermes) are obsolete, while Tunicata is now a subphylum of Chordata. The Protozoa, introduced in 1818 as a taxonomic class, has been and remains a problematic area of taxonomy, but is currently considered a subkingdom in the kingdom Protista. Coelenterata now encompasses the current phyla Ctenophora (comb jellies) and Cnidaria. Platyhelminthes, Annelida and Nemertea are now three phyla that cover the obsolete Vermes phylum. (In the catalogues, the term "Phylum" does not appear; instead, the now obsolete "Type" is found.)

At the Class level, eight classes are still valid (Anthozoa, Crinoidea, Asteroidea, Holothuroidea, Gastropoda (originally Gasteropoda), Cephalopoda, Thaliacea, and Turbellaria), and one is obsolete (Gephyrea). However, because of the reorganization of phyla and subphyla, many classes are now assigned to various phyla and subphyla (e.g., Anthozoa is now a class of the phylum Cnidaria) (Table 2). Three classes used names that can be commonly found with different spellings: Hydromedusae (Hydroidomedusae, now accepted as Hydroidolina), Gasteropoda (Gastropoda), and Tethyodea (Tethioidea). This could be based on the original book used for the species' name or eventually some printing errors or transcription.

At the Order level, there have been extensive changes, as noted in Table 2. Three orders are now obsolete (Calycozoa, Hydroidea, and Acalephae), while many orders are now regarded as classes, infraclasses, subclasses, or families. Only two orders remain valid today (Zoantharia and Siphonophorae).

Concerning the Species taxonomic classification of the Blaschka marine invertebrate models, 240 (33.7%) are unchanged, 400 (56.1%) have changed (this includes the variations that are no longer recognized), and 40 (5.6%) have been only tentatively identified. For 25 (3.5%), no data can be located (this includes one model that bears the name of a plant species). Finally, four (0.56%) are described as "*nomen dubium*," two (0.28%) are termed "*nomen nudum*," and two (0.28%) are

*Table 1: Taxonomic Distribution of Invertebrate Models in Henry Ward's 1888 Catalogue.*

| ***Phylum*** | ***Class*** | ***Order*** |
|---|---|---|
| Coelenterata (258) | Anthozoa (133) | Alcyonaria (19) |
| | | Zoantharia (107) |
| | | Madreporaria (7) |
| | Hydromedusae (117) | Hydroidea (71) |
| | | Siphonophorae (26) |
| | | Lucernaria (3) |
| | | Acalephae (17) |
| | Ctenophora (8) | |
| Echinodermata (48) | Crinoidea (4) | |
| | Asteroidea (11) | Ophiuridae (10) |
| | Holothuroidea (33) | |
| Mollusca (276) | Gasteropoda (226) | Opisthobranchia (158) |
| | | Prosobranchia (12) |
| | | Pteropoda (9) |
| | | Pulmonata (44) |
| | Cephalopoda (50) | |
| Vermes (68) | Platyhelminthes (36) | Turbellaria (6) |
| | Gephyrea (3) | |
| | Annelida (29) | |
| Tunicata (33) | Tethyodea (24) | |
| | Thaliacea (9) | |
| Protozoa (16) | Rhizopoda (16) | Protoplasta (3) |
| | | Heliozoa (3) |
| | | Radiolaria (10) |
| Porifera (5) | Calurea | Leucosolenida (1) |
| | Hexactinellida | Lychniscosida (2) |
| | | Hexactinosida (2) |
| MODELS: 704 items | | |

regarded as "*species inquirenda*." Interestingly, 60 items (8.4% of the catalogue) are of species that had been described within the preceding 30 years (i.e., since 1858), and 17 of those (2.4% of the catalogue) had been described within the preceding 20 years (i.e., since 1868).

*Authority*

According to the International Code of Zoological Nomenclature (ICZN), it is common practice to identify a species using the established binomial name, followed by the "authority". It is a way of identifying the person who first published the name, and it is a very important component of the species' nomenclature. We identified 136 naming authorities, but 22 of these accounted for 64 percent of the names. They include such well-recognized naturalists as Carl von Linné and Jean-Baptiste Lamarck, but also some authors who are regarded as experts in specific branches of invertebrate studies: Louis Agassiz and Edward Forbes (Cnidaria), Jacques Philippe Raymond Draparnaud (Gastropoda), and Otto Friedrich Müller (Actiniaria).

*Table 2: Corrected Taxonomic Distribution at the Class and Order Levels of Marine Invertebrate Models in the 1888 Ward Catalogue .*

| ***Class*** | ***Current Status/Rank*** | ***Comments*** |
|---|---|---|
| Anthozoa | Class | Class in Phylum Cnidaria |
| Hydromedusae (Hydroidomedusae) | Class (Hydroidolina) | Subclass of Hydrozoa, phylum Cnidaria |
| Crinoidea | Class | Class in Subphylum Crinozoa, phylum Echinodermata |
| Asteroidea | Class | Class in Subphylum Asterozoa, phylum Echinodermata |
| Holothuroidea | Class | Class in Subphylum Echinozoa, phylum Echinodermata |
| Gasteropoda | Class (Gastropoda) | Class in Phylum Mollusca |
| Cephalopoda | Class | Class in Phylum Mollusca |
| Gephyrea | Obsolete | Modern sub class Echiura [Phylum: Annelida], Phyla Sipuncula and Priapulida |
| Tethyodea (Tethioidea) | Division | Division of Subphylum Tunicata |
| Thaliacea | Class | Class of Subphylum Tunicata |
| Turbellaria | Class | Class in Phylum Platyhelminthes<br>Some species of this group are now in the Phylum Nemer-tea |
| Alcyonaria | Subclass (Octocorallia) | Subclass of Anthozoa |
| Zoantharia | Order | Order of Subclass Hexacorallia, class Anthozoa |
| Calycozoa | Obsolete | |
| Hydroidea | Obsolete | |
| Siphonophorae | Order | Order of Class Hydrozoa |
| Acalephae | Obsolete | |
| Ophiuridae | Family | Family of Order Ophiurida |
| Opisthobranchia | Infraclass | Infraclass of Class Gastropoda |
| Prosobranchia | Subclass | Infraclass of Class Gastropoda (Prosobranchia is no longer accepted as a valid subclass see Ponder & Lindberg, 1997) |
| Pulmonata | Infraclass | Infraclass of Subclass Heterobranchia |

Philip Henry Gosse, the English naturalist and popular nature writer, is the principal naming authority quoted, with 59 species in the catalogue attributed to him. However, the identification of 50 of these species has been revised. Twelve were reassigned to species already described by Gosse, and 38 were reclassified as species previously identified by other authorities. Only nine were retained as genuinely new species described by Gosse.  Another frequently quoted authority is Ernst Haeckel. Twenty-one species are attributed to Haeckel in the catalogue, 13 of which have been reclassified (four as species previously described by Haeckel, and nine as species previously identified by other authorities). The remaining eight are unchanged as genuinely new species described by Haeckel.

**Discussion**

The Blaschka workshop, based in Dresden, developed a unique series of invertebrate models between 1863 and 1890, using as reference zoological illustrations such as those contained in Gosse's *Actinologia Britannica* or Ludwig Schmarda's *Neue wirbellose Thiere* (1859–1861). Although the current use of Blaschka models by many museums and universities is to highlight invertebrate biology, interpretation of this rediscovered legacy is compromised by uncertain identifications. With the passing of time and new discoveries, the extent of knowledge of the biological world increased, as did the complexity of the Tree of Life and the taxonomic keys required to identify every single species.

We investigated the taxonomy of the Blaschkas' entire zoological production (707 items) to correct any taxonomical inaccuracies that may have occur over the last 131 years (1888–2019). We established the modern taxonomy of as many models as possible to provide every Blaschka collection curator with a reference table (Appendix 1), to properly label models with accurate taxonomic identification. But this table will not be the final one because we still have a series of models for which only limited information can be located. Two models (0.28%) are "*species inquirenda*" (Table 3). Forty models (5.6%) have been only tentatively identified (Table 4), no data can be located for 25 others (3.5%) (Table 4), four (0.56%) are described as "*nomen dubium*," two (0.28%) are termed "*nomen nudum*,". All of these will require further research.

It is interesting to note that of the 630 items presented in the 1878 Ward catalogue and the 707 in Ward's 1888 edition, we can identify only 694 species. Because of the invalidation of 25 variations of some species and the paucity of firm data, we could finally retrieve only 621 valid and fully identified species, with 400 (64%) being unchanged since the last catalogue was published in 1888. The occurrence of those variations in the Blaschka catalogue relate biologically to the fact that environmental conditions can exert a significant influence on the physical appearance of some species. In the past, it was common practice to identify and name animals and plants exhibiting these effects as distinct varieties within a species - a practice that is no longer considered valid. For example, item n. 122, *Caryophyllia smithii var. clara*, and item n. 123, *var. castanea*, are no longer separated, but are listed as *Caryophyllia smithii* in Appendix 1.

*Table 3: Species with no identification information (Note:* Actinia chiococca*, has no number but it Is from an earlier catalogue, 91863, which has no number.)*

| No. | Original Species Name | Authority |
|---|---|---|
| 12 | *Renilla violacea* | Quoy & Gaimard |
| 15 | *Sympodium purpurascens* | Ehrenberg |
| 60 | *Edwardsia vestita* | Forbes |
| 70 | *Paractis adhaerens* | Ehrenberg |
| 72 | *Paractis olivacea* | Ehrenberg |
| 87 | *Saccanthus purpurascens* | Milne Edwards |
| 148 | *Cunina campanulata* | Eschscholtz |
| 160 | *Liriope appendiculata* | Forbes |
| 168 | *Obelia sphaerulina* | Péron |
| 175 | *Polyxenia Alderii* | Forbes |
| 176 | *Rhegmatodes (Aequorea) forbesianus* | Gosse |
| 190 | *Trachynema ciliatum* | Gegenbaur |
| 194 | *Turris neglecta* | Forbes |
| 196 | *Zygodactyla crassa* | Agassiz |
| 198 | *Abyla pentagona* | Eschscholtz |
| 199 | *Agalma rigidum* | Haeckel |
| 207 | *Halistemma punctatum* | Kolliker |
| 209 | *Hippopodius gleba* | Leuckart |
| 211 | *Physalia pelagica* | Eschscholtz |
| 233 | *Holigocladodes lunulatus* | Pennant |
| 368 | *Aeolis militaris* | Alder & Hancock |
| 392 | *Cratena longibursa* | Bergh |
| 442 | *Facellina Drummondii* | Thompson |
| 697 | *Paludina achatina* | Sowb |
| | *Actinia chiococca* | Cocks |

*Table 4: Species with uncertain or tentative identifications*

| No | Original Species | Original Authority | Potential Identification | Potential Authority | Year |
|---|---|---|---|---|---|
| 3 | *Alcyonium stellatum* | Milne Edwards | *Sarcophyton stellatum* | Kükenthal | 1910 |
| 6 | *Gorgonia verrucosa* | Pallas | *Eunicella verrucosa* | **ND** | 1766 |
| 21 | *Actinia concentrica* | Risso | *Actinia cari* | Delle Chiaje | 1822 |
| 30 | *Actinoloba Paumotensis* | (Couthouy) Dana | *Heteractis crispa* | Hemprich & Ehren-berg in Ehrenberg | 1834 |
| 71 | *Paractis erythrosoma* | Ehrenberg | *Entacmaea quadricolor* | Ruppell and Leukart | 1828 |
| 99 | *Sagartia rosea* | Gosse | *Sagartia elegans* | Dalyell | 1848 |
| 100 | *Sagartia rubus* | Drayton | *Nemactis rubas* | Drayton in Dana | 1846 |
| 112 | *Tealia gemma* | Drayton | *Actinia gemma* | Drayton in Dana | 1846 |
| 120 | *Balanophyllia italica* | Michelin | *Balanophyllia europaea* | Risso | 1826 |
| 135 | *Aequorea violacea* | Milne-Edwards | *Distichopona violacea* | Pallas | 1766 |
| 145 | *Clytia aeronautica* | Forbes | *Phialella quadrata* | **ND** | 1848 |
| 169 | *Oceania phosphorica* | (Péron) Agassiz | *Olindias phosphorica* | Delle Chiaje | 1848 |
| 181 | *Stomobrachium octocostatum* | Sars | *Melicertum octostatum* | **ND** | 1835 |
| 182 | *Stomotoca dinema* | (Forbes) Agassiz | *Amphinema dinema* | Péron & Lesueur | 1810 |
| 185 | *Tiara conica* | (Quoy & Gay-mard) Agassiz | *Pandea conica* | Quoy & Gainard | 1827 |
| 197 | *Zygodactyla vitrina* | Gosse | *Aequorea vitrina* | **ND** | 1853 |
| 210 | *Physalia Caravella* | Eschscholtz | *Caravella maxima* | Haeckel | |
| 237 | *Polyclonia frondosa* | (Pallas) Agassiz | *Cassiopea frondosa* | Pallas | 1774 |
| 251 | *Comatula Novae Guineae* | Müller | *Phanogenia novaeguineae* | **ND** | 1841 |
| 260 | *Ophiothrix serrata* | Kuhl & Hasselt | *Ophiomastus serratus* | Mortensen | 1936 |
| 265 | *Chiridota purpurea* | Lesson | *Trochodota purpurea* | Pawson | 1969 |
| 279 | *Sporadipus impatiens* | (c) Semper | *Holothuria (Thymiosycia) impati-ens* | Forsskål | 1775 |
| 312 | *Proceros clavicornis* | Schmarda | *Pseudoceros clavicornis* | (Schmarda) | 1859 |
| 313 | *Proceros cornutus* | Müller | *Eurylepta cornuta* | (Müller) | 1776 |
| 314 | *Proceros latissimus* | Schmarda | *Pseudoceros latissimus type A* | (Schmarda) | 1859 |
| 315 | *Proceros viridis* | Schmarda | *Pseudobiceros viridis* | Kelaart | 1858 |
| 330 | *Pontobdella vittata* | Chamisso | *Calliobdella lophii* | von Benden & Hesse | 1863 |
| 335 | *Hesione Schmardae* | Quatrefages | *Myriocyclum schmardae* | Grube | 1880 |
| 469 | *Placobranchus gracilis* | Pease | *Thuridilla gracilis* | Risbec | 1928 |
| 483 | *Trevelyana cristata* | Bergh | *Nembrotha cristata* | **ND** | 1877 |
| 484 | *Trevelyana nigerrima* | Bergh | *Nembrotha cristata* | **ND** | 1877 |
| 500 | *Syphonota punctata* | Pease | *Aplysia punctata* | Cuvier | 1803 |
| 517 | *Clausilia bidens* | Draparnaud | *Papillifera papillaris* | Müller | 1774 |
| 539 | *Philomycus carolinensis* | Binney | *Philomycus carolinianus* | Bosc | 1802 |
| 561 | *Loligo Bianconii* | Vérany | *Onchyoteuthis banksii* | Leach | 1817 |
| 562 | *Loligo Meneghini* | Vérany | *Teleoteuthis meneghini* | **ND** | 1851 |
| 618 | *Phallusia pustulosa* | Alder | *Ascidiella aspersa* | Müller | 1776 |
| 619 | *Phallusia callosa* | Stimpson | *Ascidia callosa* | Stimpson | 1852 |
| 643 | *Eucecryphalus schultzei* | Haeckel | *Lampromitra schultzei* | **ND** | 1862 |
| 655 | *Actinoloba senile* | de Blainville | *Metridium senile* | Linnaeus | 1761 |

The Blaschka father and son based their work on illustrations and relied on the book plate legends and descriptions for the names and descriptions, as they were not trained taxonomists. We believe that they simply copied the variations cited in the book without further considerations for the biological debate on species variation and plasticity.

One particularly interesting part of our research is related to the naming authorities cited. In taxonomy, a species name is always linked to the name of the person who originally named it and the year when this occurred. Philip Henry Gosse had always been an important influence on both Blaschkas (Meechan and Reiling, 2002) as a well-established marine invertebrate expert, even though he was not a zoologist, but rather a naturalist and popularizer of natural science. We have noted that the Blaschkas wrongly attributed many species (38 out of 59) to Gosse. Another great influence on the workshop also misidentified some species: Ernst Haeckel. We looked in detail at *Actinologia Britannica*, one of the major books known to have been used by the two glassworkers, and found that the identification of the authority is quite difficult to find and may have been the source of the mistaken identities. In some instances, the Blaschkas listed Gosse himself as the naming authority, but Gosse did not list the actual naming authorities in his illustrations. Wherever a species can be clearly identified, we have retrieved the correct authority (Appendix 1).

Our work represents an important step toward establishing a complete descriptive database of the Blaschkas' glass invertebrate models, enabling us to identify models and their names in accordance with both the original documents and current taxonomic knowledge. We have already helped the curators of several European Blaschka collections by correcting identification errors that were usually related to the loss of original labels or the mixing of those labels during curation, repair, or display. Appendix 1 will likely be updated, because more taxonomists will be able to access the relevant taxonomic information to confirm or correct the identification of the models, and to allow for the taxonomic identification of models for which we have no data (Table 3).

We will continue to use the information gathered during our research to link every model to the original documentation and lithograph used, alongside the drawings held at the Rakow Research Library of The Corning Museum of Glass. We believe that, although the Blaschkas' invertebrate models are often described as unique art pieces, they were originally zoological specimens that need to be curated taxonomically and clearly identified and labelled, even if the species are no longer recognized. We hope that our work will help the Blaschka-related community to curate their collections in a taxonomically correct manner.

## Appendix 1:

This is available online. Please visit natsca.org/publications/Callaghan_et_al-2020-Appendix1

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F. Welter Schultes [Last modified 15-03-2011; Accessed 24/01/2020]
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**TABLE 3** – Callaghan et al.

| TAXONOMY | WARD N° | ORIGINAL SPECIES NAME | AUTHORITY (Ward Catalogue 1888) | REVISED SPECIES NAME | REVISED AUTHORITY |
|---|---|---|---|---|---|
| **Coelenterata<br>Anthozoa<br>Alcyonaria** | **1** | *Alcyonium digitatum* | Linnaeus, 1758 | | |
| | **2** | *Alcyonium palmatum* | Pallas, 1766 | | |
| | **3** | *Alcyonium stellatum* | Milne-Edwards | **[?]** *Sarcophyton stellatum* | Kükenthal, 1910 |
| | **4** | *Anthelia glauca* | Savigny | | Lamarck, 1816 |
| | **5** | *Corallium rubrum* | Lamarck | | Linnaeus, 1758 |
| | **6** | *Gorgonia verrucosa* | Pallas, 1766 | **[?]** *Eunicella verrucosa* | |
| | **7** | *Kophobelemon (Umbellularia) stelliferum* | Müller, 1766 | | |
| | **8** | *Paralcyonium elegans* | EdwardsandHaime | *Paralcyonium spinulosum* | Delle Chiaje, 1822 |
| | **9** | *Pennatula phosphorea* | Ellis | | Linnaeus, 1758 |
| | **10** | *Pennatula rubra* | Ellis, 1761 | | |
| | **11** | *Ptero**e**ides griseum* | Bohadsch | | Linnaeus, 1767 |
| | **12** | *Renilla violacea* | Quoy and Gaimard | **ND** | |
| | **13** | *Spongodes cel**lios**a* | Lesson, 1834 | | |
| | **14** | *Sympodium c**a**eruleum* | Ehrenberg, 1834 | | |
| | **15** | *Sympodium purpurascens* | Ehrenberg | **ND** | |
| | **16** | *Tubi**p**ora Hemprichii* | Ehrenberg, 1834 | | |
| | **17** | *Veretillium cynom**o**ium* | Pallas, 1766 | | |
| | **18** | *Virgularia mirabilis* | Müller, 1766 | | |
| **Coelenterata<br>Anthozoa<br>Zoantharia** | **19** | *Xenia umbellata* | Savigny | | Lamarck, 1816 |
| | **20** | *Actinaria Hemprichii* | Ehrenberg, 1834 | *Megalactis hemprichii* | |
| | **21** | *Actinia concentrica* | Risso | **[?]** *Actinia cari* | Delle Chiaje, 1822 |
| | **22** | *Actinia mesembrianthemum var rubra* | Forbes, 1758 | *Actinia equina* | Linnaeus, 1758 |
| | **23** | *Actinia mesembrianthemum var fragacea* | Gosse, 1829 | *Actinia fragracea* | [Tugwell, 1856] |
| | **24** | *Actinia diaphana* | Rapp | *Aiptasia diaphana* | [Rapp, 1829] |

| | | | | | |
|---|---|---|---|---|---|
| | **25** | *Actinia chromatodera* | Schmarda | *Paranthus chromatoderus* | [Schmarda, 1852] |
| | **26** | *Actinia Contarinii* | Heller | *Paranemonia cinerea* | Contarini, 1844 |
| | **27** | *Actinoloba Dianth Ellis var rubida* | Gosse | Synonym for *Metridium senile* | Linnaeus, 1767 |
| | **28** | *Actinoloba Dianthus Ellis var brunnea* | Gosse | Synonym for *Metridium senile* | Linnaeus, 1767 |
| | **29** | *Actinoloba Dianthus Ellis var sindonea* | Gosse | Synonym for *Metridium senile* | Linnaeus, 1767 |
| | **30** | *Actinoloba Paumotensis* | (Couthouy) Dana | **[?]** *Synonym for Heteractis crispa* | Hemprich and Ehrenberg in Ehrenberg 1834 |
| | **31** | *Actinoloba reticulata* | (Couthouy) Dana | *Antholoba achates* | Drayton in Dana, 1846 |
| | **32** | *Actinoloba achates* | (Drayton) Dana 1847 | *Antholoba achates* | |
| | **33** | *Adamsia palliata* | Johnston | | Fabricius, 1779 |
| | **34** | *Aiptasia Couchii* | Gosse | *Aiptasia mutabilis* | Gravenhorst, 1831 |
| | **35** | *Anthea Cereus, Johnst. var amaragdina* | Gosse | *Anemonia sulcata* | Pennant, 1777 |
| | **36** | *Anthea Cereus var maxima* | Gosse | *Anemonia viridis* | Forsskål, 1775 |
| | **37** | *Anthea Cereus var alabastrina* | Gosse | *Anemonia sulcata* | Pennant, 1777 |
| | **38** | *Arachnactis albida* | Sars, 1846 | | |
| | **39** | *Aureliana Augusta* | Gosse | *Ambiguous synonym for A. heterocera* | Forbes, 1841 |
| | **40** | *Aureliana heterocera* | Gosse | *Capnea sanguinea* | Forbes, 1841 |
| | **41** | *Bolocera Eques* | Gosse | *Synonym for Urticina felina* | Gosse, 1860 |
| | **42** | *Bolocera Tuediae* | (Johnston) Gosse | | Johnston, 1832 |
| | **43** | *Bunodes Ballii, Cocks, var. rosea* | Gosse | *Anthopleura ballii* | Cocks, 1851 |
| | **44** | *Bunodes Ballii, Cocks, var. dealbata* | Gosse | *Anthopleura ballii* | Cocks, 1851 |
| | **45** | *Bunodes crispa* | Ehrenberg | *Synonym for Heteractis crispa* | Hemprich and Ehrenberg in Ehrenberg, 1834 |
| | **46** | *Bunodes cruentata* | (Couthouy) Dana, 1846 | *Parantheopsis cruentata* | |
| | **47** | *Bunodes coronata* | Gosse, 1858 | *Hormathia coronata* | |
| | **48** | *Bunodes gemmacea* | (Ellis) Gosse | *Aulactinia verrucosa* | Pennant, 1777 |
| | **49** | *Bunodes gemmacea var* | Sowerby, Gosse | *Aulactinia verrucosa* | Pennant, 1778 |
| | **50** | *Bunodes thallia* | Gosse, 1854 | *Anthopleura thallia* | |
| | **51** | *Calliactis decorata* | (Couthouy) Dana, 1846 | *Calliactis polypus* | |
| | **52** | *Capnea sanguinea* | Johnston | | Forbes, 1841 |
| | **53** | *Cerianthus Lloydii* | Gosse, 1859 | | |
| | **54** | *Cerianthus membranaceus* | Haime | | Spallanzanii, 1784 |

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|---|---|---|---|---|---|
| | **55** | *Corynactis clavigera* | Drayton | *Staurachis clavigera* | [Drayton in Dana, 1846] |
| | **56** | *Corynactis quadricoloor* | Leuckart and Rüppell | *Entacmaea quadricolor* | Ruppell and Leukart, 1828 |
| | **57** | *Corynactis viridis* | Allman 1846 | | |
| | **58** | *Edwardsia (Milnea) callimorpha* | Gosse | *Edwardsia claparedi* | Panceri, 1869 |
| | **59** | *Edwardsia (Milnea) carnea* | Gosse, 1856 | *Edwardsiella carnea* | |
| | **60** | *Edwardsia vestita* | Forbes | **ND** | |
| | **61** | *Evactis artemisia* | Drayton | *Anthopleura artemisia* | Drayton in Dana, 1846 |
| | **62** | *Gregoria fenestrata* | Gosse, 1860 | | |
| | **63** | *Halcampa chrysanthellum* | Gosse | | Peach in Johnston, 1847 |
| | **64** | *Heterodactyla Hemprichii* | Ehrenberg 1834 | | |
| | **65** | *Hormanthia Margaritae* | Gosse | *Hormathia digitata* | Muller, 1776 |
| | **66** | *Ilyanthus Mitchelli* | Gosse | *Mesacmaea mitchelli* | |
| | **67** | *Ilyanthus scoticus* | Forbes 1840 | | |
| | **68** | *Nemactis primula* | Drayton | | [Drayton in Dana,1846] |
| | **69** | *Palythoa auricula* | Lesueur, 1817 | **Species inquirenda** | |
| | **70** | *Paractis adhaerens* | Ehrenberg | **ND** | |
| | **71** | *Paractis erythrosoma* | Ehrenberg | **[?]** *Synonym for Entacmaea quadricolor* | Ruppell and Leukart, 1828 |
| | **72** | *Paractis olivacea* | Ehrenberg | **ND** | |
| | **73** | *Peachia hastata* | *Gosse* | *Peachia boeckii* | Danielssen Koren, 1856 |
| | **74** | *Peachia triphylla* | Gosse | *Peachia boeckii* | Danielssen and Koren, 1856 |
| | **75** | *Peachia undata* | Gosse | *Peachia boeckii* | Danielssen and Koren, 1856 |
| | **76** | *Phellia Brodrichii* | Gosse, 1859 | *Cataphellia brodricii* | |
| | **77** | *Phellia gausapata* | Gosse, 1858 | | |
| | **78** | *Phellia murocincta* | Gosse, 1858 | | |
| | **79** | *Phellia picta* | Gosse | *Sagartiogeton laceratus* | Dalyell, 1848 |
| | **80** | *Phyllactis praetexta* | Couthouy in Dana 1846 | | |
| | **81** | *Phymactis florida* | (Drayton) Dana | *Phymactis clematis* | Drayton in Dana, 1846 |
| | **82** | *Phymactis clematis* | Drayton | | Drayton in Dana, 1846 |
| | **83** | *Phymactis pustulata* | Couthouy | | Couthouy in Dana, 1846 |
| | **84** | *Phymactis diadema* | Drayton | *Bunodosoma diadema* | Drayton in Dana, 1846 |

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|---|---|---|---|---|---|
| | **85** | *Phymanthus loligo* | Ehrenberg | | Hemprich and Ehrenberg in Ehrenberg, 1834 |
| | **86** | *Rhodactis rhodostoma* | Ehrenberg | | Hemprich and Ehrenberg in Ehrenberg, 1834 |
| | **87** | *Saccanthus purpurascens* | Milne-Edwards, 1857 | Cerianthus membranaceus | [Gmelin, 1791] |
| | **88** | *Sagartia bellis E, var tyriensis* | Gosse | *Cereus pedunculatus* | Pennant, 1777 |
| | **89** | *Sagartia bellis E, var punctata* | Schmarda | *Cereus pedunculatus* | Pennant, 1777 |
| | **90** | *Sagartia fuegiensis* | (Couthouy) Dana | *Antholoba achates* | Drayton in Dana, 1846 |
| | **91** | *Sagartia impatiens* | (Drayton) Dana | *Choriactis impatiens* | [Couthouy in Dana, 1846] |
| | **92** | *Sagartia chrysosplenium* | Gosse | *Chrysoela chrysoplenium* | Cocks in Johnston, 1847 |
| | **93** | *Sagartia coccinea* | Gosse | *Sagartiogeton laceratus* | Dalyell, 1848 |
| | **94** | *Sagartia ichthyostoma* | Gosse, 1858 | | |
| | **95** | *Sagartia miniata* | Gosse | *Synonym for Sagartia elegans* | Dalyell, 1848 |
| | **96** | *Sagartia nivea* | Gosse | *Sagartia elegans* | Dalyell, 1848 |
| | **97** | *Sagartia pallida* | Gosse | *Metridium senile* | Linnaeus, 1761 |
| | **98** | *Sagartia parasitica* | Gosse | *Calliactis parasitica* | [Couch, 1842] |
| | **99** | *Sagartia rosea* | Gosse | **[?]** *Sagartia elegans* | Dalyell, 1848 |
| | **100** | *Sagartia rubus* | Drayton | **[?]** *Nemactis rubas* | [Drayton in Dana, 1846] |
| | **101** | *Sagartia sphyrodeta* | Gosse, 1858 | *Actinothoe sphyrodeta* | |
| | **102** | *Sagartia troglodytes var aurora* | Gosse, 1853 | *Sagartia aurora* | |
| | **103** | *Sagartia troglodytes var melanoleuca* | Gosse | *Sagartia troglodytes* | Price in Johnston, 1847 |
| | **104** | *Sagartia ornata* | Holdsworth, 1855 | | |
| | **105** | *Sagartia venusta* | Gosse | *Sagartia elegans* | Dalyell, 1848 |
| | **106** | *Sagartia viduata var aleurops* | Gosse | *Sagartiogeton viduatus* | Müller, 1776 |
| | **107** | *Sagartia viduata var anguicoma* | Price | *Sagartiogeton viduatus* | Müller, 1776 |
| | **108** | *Stomphia Churchiae* | Gosse | *Urticina felina* | Linnaeus, 1767 |
| | **109** | *Tealia crassicornis var purpurea* | Gosse | *Urticina crassicornis* | Müller, 1776 |
| | **110** | *Tealia crassicornis var meloides* | Gosse | *Urticina crassicornis* | Müller, 1776 |
| | **111** | *Tealia crassicornis var rubrocincta* | Gosse | *Urticina crassicornis* | Müller, 1776 |
| | **112** | *Tealia gemma* | Drayton | **[?]** *Actinia gemma* | [Drayton in Dana, 1846] |
| | **113** | *Tealia digitata* | Gosse | *Hormathia digitata* | [Müller, 1776] |
| | **114** | *Tealia pluvia* | Drayton | *Phymanthea pluvia* | [Drayton in Dana, 1846] |

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|---|---|---|---|---|---|
| | **115** | *Thalassianthus aster* | Klunzinger | | Rüppell and Leuckart, 1828 |
| | **116** | *Ulactis muscosa* | (Drayton) Dana, 1846 | *Oulactis mucosa* | |
| | **117** | *Zoanthus Couchii* | Gosse | *Epizoanthus couchii* | [Johnston in Couch, 1844] |
| | **118** | *Zoanthus SolanderI* | Lesueur, 1817 | | |
| | **119** | *Astroides calycularis* | Pallas, 1766 | | |
| | **120** | *Balanophyllia italica* | Michelin | **[?]** *Balanophyllia europaea* | Risso, 1826 |
| | **121** | *Balanophyllia regia* | Gosse, 1853 | | |
| | **122** | *Caryophyllia Smithii var clara* | Gosse | *Caryophyllia Smithii* | Stokes and Broderip, 1828 |
| | **123** | *Caryophyllia Smithii var castanea* | Gosse | *Caryophyllia Smithii* | Stokes and Broderip, 1829 |
| | **124** | *Cladocora cespitosa* | Lamarck | | Linnaeus, 1767 |
| | **125** | *Dendrophyllia ramea* | Blainville | | Linnaeus, 1758 |
| **Coelenterata Anthozoa Calycozoa** | **126** | *Lucernaria auricula* | [Fabricius, 1780] | *Manania auricula* [alternate representation] | |
| | **127** | *Lucernaria campanulata* | Lamouroux, 1815 | *Leucernariopsis campanulata* [alternate representation] | |
| | **128** | *Lucernaria quadricornis* | Müller 1776 | | |
| **Coelenterata Hydromedusae Hydroidea** | **129** | *Aegina citrea* | Eschscholtz, 1829 | | |
| | **130** | *Aegina rosea* | Eschscholtz | *Aegina citrea* | Eschscholtz, 1829 |
| | **131** | *Aegineta sol maris* | Gegenbaur, 1856 | | |
| | **132** | *Aequorea cyanea* | Peron and Lesueur | **ND** | Blainville, 1834 |
| | **133** | *Aequorea albida* | Agassiz, 1862 | | |
| | **134** | *Aequorea Forskalea* | (Peron) Forbes | | Péron and Lesueur, 1810 |
| | **135** | *Aequorea violacea* | Milne-Edwards | **[?]** *Distichopona violacea* | [Pallas, 1776] |
| | **136** | *Bougainvillia fruiticosa* | Allman | *Bougainvillia muscus* | Allman, 1776 |
| | **137** | *Bougainvillia superciliaris* | Agassiz, 1849 | | |
| | **138** | *Carmarina hastata* (male) | Haeckel | *Geryonia proboscidalis* | Forsskål, 1775 |
| | **139** | *Carmarina hastata* (female) | Haeckel | *Geryonia proboscidalis* | Forsskål, 1775 |
| | **140** | *Carmarina hastata* (development stages) | Haeckel | *Geryonia proboscidalis* | Forsskål, 1775 |

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|---|---|---|---|---|---|
| | **141** | *Cladonema radiatum* (development stages) | Dujardin, 1843 | | |
| | **141a** | *Cladonema radiatum* (adult medusa) | Dujardin, 1843 | | |
| | **142** | *Clava squamata* | (Müller) Allman | *Clava multicornis* | Forsskål, 1775 |
| | **143** | *Clavatella prolifera* | (Hincks) Allman | *Eleutheria dichotoma* | De Quatrefages, 1842 |
| | **144** | *Clytia poterium* | Agassiz | *Orthopyxis integra* | MacGillivray, 1842 |
| | **145** | *Clytia aeronautica* | Forbes, 1848 | **[?]** *Phialella quadrata* | |
| | **146** | *Corymorpha nutans* | Sars 1835 | | |
| | **147** | *Crematostoma flava* | Agassiz | *Aequorea victoria* | Murbach andShearer, 1902 |
| | **148** | *Cunina campanulata* | Eschscholtz | **ND** | |
| | **149** | *Cunina vitrea* | Gegenbaur, 1856 | | |
| | **150** | *Eirene viridula* | Eschscholtz | | Péron and Lesueur, 1809 |
| | **151** | *Eudendrium ramosum* | Linnaeus, 1758 | | |
| | **152** | *Garveia nutans* | Wright, 1859 | | |
| | **153** | *Glossocodon eurybia* | Haeckel | *Liriope tetraphylla* | Chamisso and Eysenhardt, 1821 |
| | **154** | *Gossea Corynetes* | Agassiz | | Gosse, 1853 |
| | **155** | *Heterocordyle Conybearei* | [Allman, 1864] | *Dicoryne conybearii* | |
| | **156** | *Hydractinia echinata* | Fleming, 1828 | | |
| | **157** | *Lafoea calcarata* | Agassiz | *Laodicea undulata* | Forbes and Goodsir, 1853 |
| | **158** | *Laodicea cellularia* | [Agassiz, 1862] | *Earleria cellularia* | |
| | **159** | *Laomedea amphora* | Agassiz, 1862 | | |
| | **160** | *Liriope appendiculata* | Forbes | **ND** | |
| | **161** | *Liriope tetraphylla* | Chamisso | | Chamisso and Eysenhardt, 1821 |
| | **162** | *Lizzia blondina* | Forbes, 1848 | | |
| | **163** | *Lizzia Koellikerii* | Gegenbaur | *Koellikerina fasciculata* | Péron and Lesueur, 1810 |
| | **164** | *Lizzia octopunctata* | Forbes | *Rathkea octopunctata* | [Sars, 1835] |
| | **165** | *Melicertum campanula* | Eschscholtz | *Melicertum octocostatum* | M. Sars, 1835 |
| | **166** | *Modeeria formosa* | Forbes | *Modeeria rotunda* | Quoy and Gaimard, 1827 |
| | **167** | *Obelia dichotoma* | Linnaeus, 1758 | | |
| | **168** | *Obelia sphaerulina* | Peron | **ND** | |
| | **169** | *Oceania phosphorica* | (Peron) Agassiz | **[?]** *Olindias phosphorica* | [Delle Chiaje, 1848] |

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|---|---|---|---|---|---|
| | **170** | *Pandea flavidula* | Peron and Lesueur | *Aurelia aurita* | Linnaeus, 1758 |
| | **171** | *Pandea globulosa* | Forbes, 1848 | *Oceania globulosa* | |
| | **172** | *Perigonimus vestitus* | Allman | *Leuckartiara octona* | Fleming, 1823 |
| | **173** | *Podocoryne carnea* | Sars, 1846 | | |
| | **174** | *Polyorchis penicillatus* | Agassiz | | Eschscholtz, 1829 |
| | **175** | *Polyxenia Alderii* | Forbes | **ND** | |
| | **176** | *Rhegmatodes (Aequorea) Forbesianus* | Gosse | **ND** | |
| | **177** | *Rhegmatodes tenuis* | [Agassiz, 1862] | *Aequorea tenuis* | |
| | **178** | *Rhopalonema velatum* | Gegenbaur, 1857 | | |
| | **179** | *Slabberia halterata* | Forbes, 1846 | | |
| | **180** | *Staurophora laciniata* | Agassiz | *Staurophora mertensii* | Brandt, 1838 |
| | **181** | *Stomobrachium octocostatum* | [Sars, 1835] | **[?]** *Melicertum octostatum* | |
| | **182** | *Stomotoca dinema* | (Forbes) Agassiz | **[?]** *Amphinema dinema* | Péron and Lesueur, 1810 |
| | **183** | *Syncoryne frutescens* | [Allman, 1872] | *Sarsia frutescens* | |
| | **184** | *Syncoryne implexa* | [Alder, 1857] | *Zanclea implexa* | |
| | **185** | *Tiara conica* | (Quoy and Gaimard) Agassiz | **[?]** *Pandea conica* | Quoy and Gaimard, 1827 |
| | **186** | *Tiara octona* | Forbes | *Leuckartiara octona* | Fleming, 1823 |
| | **187** | *Tima Bairdii* | Forbes | | Johnston, 1833 |
| | **188** | *Tima flavilabris* | Eschscholtz | *Neotima lucullana* | Delle Chiaje, 1822 |
| | **189** | *Tima formosa* | Agassiz, 1862 | | |
| | **190** | *Trachynema ciliatum* | Gegenbaur | **ND** | |
| | **191** | *Tubularia indivisa (development stages)* | Linnaeus, 1758 | | |
| | **191a** | *Tubularia indivisa (male colony)* | Linnaeus, 1758 | | |
| | **192** | *Tubularia bellis* | Allman | *Ectopleura larynx* | Ellis and Solander, 1786 |
| | **193** | *Turris digitale* | Forbes | *Neoturris pileata* | Forsskål, 1775 |
| | **194** | *Turris neglecta* | Forbes | **ND** | |
| | **195** | *Willia stellata* | [Forbes, 1846] | *Proboscidactyla stellata* | |
| | **196** | *Zygodactyla crassa* | Agassiz | **ND** | |
| | **197** | *Zygodactyla vitrina* | Gosse, 1853 | **[?]** *Aequorea vitrina* | |

**TABLE 3** – Callaghan et al.

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|---|---|---|---|---|---|
| **Coelenterata Hydromedusae Siphonophorae** | **198** | *Abyla pentagona* | Eschscholtz | **ND** | |
| | **199** | *Agalma rigidum* | Haeckel | **ND** | |
| | **200** | *Agalmopsis Sarsii* | Kolliker | *Agalma elegans* | Sars, 1846 |
| | **201** | *Apolemia (Stephanomia) uvaria* | (Lesueur) Eschscholtz | *Apolemia uvaria* | Lesueur, 1815 |
| | **202** | *Athorybia rosacea* | Eschscholtz | *Melophysa melo* | Quoy and Gaimard, 1827 |
| | **203** | *Diphyes Sieboldi* | Kolliker | *Chelophyes appendiculata* | Eschscholtz, 1829 |
| | **204** | *Diphyes quadrivalvis* | Lesson | *Sulcoleolaria quadrivalvis* | de Blainville, 1830 |
| | **205** | *Forskalia contorta* | Milne-Edwards | | |
| | **206** | *Forskalia Edwardsii* | Kolliker | | |
| | **207** | *Halistemma punctatum* | Kolliker | **ND** | |
| | **208** | *Halistemma rubrum* | Vogt, 1852 | | |
| | **209** | *Hippopodius gleba* | Leuckart | **ND** | |
| | **210** | *Physalia Caravella* | Eschscholtz | **[?]** *Caravella maxima* (not in WoRMS) | Haeckel |
| | **211** | *Physalia pelagica* | Eschscholtz | **ND** | |
| | **212** | *Physophora hydrostatica* | Forsskål, 1775 | | |
| | **213** | *Physophora magnifica* | Haeckel | *Physophora hydrostatica* | Forsskål, 1775 |
| | **214** | *Physophora magnifica* (development stages) | Haeckel | *Physophora hydrostatica* | Forsskål, 1775 |
| | **215** | *Praya cymbiformis* | Leuckart | *Rosacea cymbiformis* | Delle Chiaje, 1830 |
| | **216** | *Porpita mediterranea* | Eschscholtz | *Porpita porpita* | Linnaeus, 1758 |
| | **217** | *Porpita umbella* | Eschscholtz | *Porpita porpita* | Linnaeus, 1758 |
| | **218** | *Rhizophysa filiformis* | Forsskål, 1775 | | |
| | **219** | *Rhizophysa Eysenhardti* | Gegenbaur, 1859 | | |
| | **219a** | *Rhizophysa heliantha* | Quoy and Gaimard | *Anthorybia rosacea* | Forsskål, 1775 |
| | **220** | *Stephanomia canariensis* | Haeckel | *Nannomia bijuga* | Delle Chiaje, 1844 |
| | **221** | *Velella lata* | Chamisso | *Velella velella* | Linnaeus, 1758 |
| | **222** | *Velella spirans* | Forsskål | *Velella velella* | Linnaeus, 1758 |
| | **223** | *Velella spirans* (2 stages of growth) | Forsskål | *Velella velella* | Linnaeus, 1758 |

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|---|---|---|---|---|---|
| **Coelenterata Hydromedusae Acalephae** | **224** | *Aurelia aurita* | Linnaeus, 1758 | | |
| | **225** | *Aurelia aurita* (history of development) | Linnaeus, 1759 | | |
| | **226** | *Aurelia limbata* | Brandt, 1835 | | |
| | **227** | *Chrysaora hysoscella* | Linnaeus, 1767 | | |
| | **228** | *Chrysaora melanaster* | Brandt, 1838 | | |
| | **229** | *Cotylorhiza borbonica* | Delle Chiaje | *Cotylorhiza tuberculata* | Macri, 1778 |
| | **230** | *Crambessa Tagi* | Haeckel | *Catostylus tagi* | [Haeckel, 1869] |
| | **231** | *Pennatula phosphorea* | Linnaeus, 1758 | | |
| | **232** | *Dactylometra quinquecirra* | Agassiz | *Chrysaora quinquecirrha* | [Desor, 1848] |
| | **233** | *Holigocladodes lunulatus* | Pennant | **ND** | |
| | **234** | *Pelagia cyanella* | (Peron and Lesueur) Agassiz | | |
| | **235** | *Pelagia noctiluca* | Peron and Lesueur | | Forsskål, 1775 |
| | **236** | *Pelagia tuberculosa* | Couthouy, 1862 | | |
| | **237** | *Polyclonia frondosa* | (Pallas) Agassiz | **[?]** *Cassiopea frondosa* | [Pallas, 1774] |
| | **238** | *Rhizostoma pulmo* | Linnaeus | | Macri, 1778 |
| | **239** | *Stomaster canariensis* | (Til) Agassiz | *Cassiopea canariensis* | [Tilesius, 1829] |
| | **240** | *Stomolophus meleagris* | Agassiz, 1862 | | |
| **Coelenterata Ctenophorae** | **241** | *Beroe punctata* | Chamisso | *Beroe ovata* | Bruguière, 1789 |
| | **242** | *Cestum Veneris* | Lesueur, 1832 | | |
| | **243** | *Gegenbauria cordata* | (Kolliker) Agassiz | *Callianira bialata* | Delle Chiaje, 1841 |
| | **244** | *Hormiphora plumosa* | Agassiz,1860 | | |
| | **245** | *Idyia roseola* | Agassiz | *Beroe cucumis* | Fabricius, 1780 |
| | **246** | *Mertensia ovum* | Lesueur | | Fabricius 1780 |
| | **247** | *Pleurobrachia pileus* | Fleming | | O.F. Müller, 1776 |
| | **248** | *Pleurobrachia rhododactyla* | Agassiz, 1860 | | |
| **Echinodermata Crinoidea** | **249** | *Comatula hamata* | Kuhl and Hasselt, 1870 | *Actinometra hamata* | |

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|---|---|---|---|---|---|
| | **250** | *Comatula mediterranea* | Lamarck, 1816 | *Antedon mediterranea* | |
| | **251** | *Comatula Novae Guineae* | O.F. Müller, 1841 | **[?]** *Phanogenia novaeguineae* | |
| **Echinodermata Asteroidea Ophiuridea** | **252** | *Amphiura filiformis* (stages of development) | Müller, 1776 | | |
| | **253** | *Hemipholis cordifera* | Lyman | | Bosc, 1802 |
| | **254** | *Ophiocoma picta* | Kuhl and Hasselt | | Muller and Troschel, 1842 |
| | **255** | *Ophiocoma nigra* | O.F. Müller | *Ophiocomina nigra* | Abildgaard in O. F. Muller, 1789 |
| | **256** | *Ophiomastix annulosa* | Lamarck, 1816 | | |
| | **257** | *Ophiopholis (ophiothrix) aculeata* | Müller, 1767 | | |
| | **258** | *Ophi**a**rachna incrassata* | Lamarck, 1816 | | |
| | **259** | *Ophiothrix longipeda* | Lamarck, 1816 | *Macrophiothrix longipeda* | |
| | **260** | *Ophiothrix serrata* | Kuhl and Hasselt | **[?]** *Ophiomastus serratus* | Mortensen, 1936 |
| | **261** | *Ophiothrix fragilis* | O.F. Müller | | Abildgaard in O.F. Muller, 1789 |
| **Echinodermata Holothuroidea** | **262** | *Anapta gracilis* | Semper, 1867 | | |
| | **263** | *Chir**i**dota rigida* | Semper, 1867 | | |
| | **264** | *Chir**i**dota discolor* | Eschscholtz, 1829 | | |
| | **265** | *Chir**i**dota purpurea* | Lesson | **[?]** *Trochodota purpurea* | Pawson, 1969 |
| | **266** | *Colochirus quadrangularis* | Lesson | | [Troschel, 1846] |
| | **267** | *Cucumaria Hyndmannii* | Thompson, 1840 | *Panningia hyndemannii* | |
| | **268** | *Cucumaria tergestina* | [Sars, 1857] | *Leptopentacta tergestina* | |
| | **269** | *Holothuria atra* | Jaeger, 1833 | *Holothuria (Halodeima) atra* | |
| | **270** | *Holothuria coluber* | Semper, 1868 | *Holothuria (Acanthotrapeza) coluber* | |
| | **271** | *Holothuria edulis* | Lesson, 1834 | *Holothuria (Halodeima) edulis* | |
| | **272** | *Holothuria immobilis* | Semper, 1868 | *Holothuria (Lessonothuria) immobilis* | |
| | **273** | *Holothuria maculata* | Kuhl and Hasselt, 1869 | | |
| | **274** | *Holothuria tubulosa* | Tiedmann | | Gmelin, 1791 |
| | **275** | *Holothuria tubulosa* (anatomy) | Tiedmann | | Gmelin, 1791 |
| | **276** | *Phyllophorus urna* | Grube, 1840 | *Phyllophorus (Phyllophorus) urna* | |

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|---|---|---|---|---|---|
| | **277** | *Psolus phantapus* | Strussenfeldt, 1765 | | |
| | **278** | *Psolus boholensis* | Semper, 1867 | *Psolidium boholensis boholensis* | |
| | **279** | *Sporadipus impatiens* | (Forsskål) Semper | **[?]** *Holothuria (Thymiosycia) impatiens* | Forsskål, 1775 |
| | **280** | *Sporadipus tremula* | Gunnerus, 1767 | *Parastichopus tremulus* | |
| | **281** | *Stichopodes monocaria* | Lesson, 1830 | *Holothuria (Merstensiothuria) hilla* | |
| | **282** | *Synapta Beselii* | Jaeger | *Synapta maculata* | Chamisso and Eysenhardt, 1821 |
| | **283** | *Synapta fasciata* | Kuhl and Hasselt | **ND** | |
| | **284** | *Synapta glabra* | Semper, 1867 | *Opeodesoma glabra* | |
| | **285** | *Synapta inhaerens* | O. F. Müller, 1776 | *Leptosynapta inhaerens* | |
| | **286** | *Synapta (Chirodota) lumbricoides* | Eschscholtz | *Polyplectana lumbricoides* | |
| | **287** | *Synapta maculata* | Chamisso and Eysenhardt, 1821 | | |
| | **288** | *Synapta mamillosa* | Eechscholtz 1829 | *Synapta maculata* | Chamisso and Eysenhardt, 1821 |
| | **289** | *Synapta oceanica* | Lesson 1830 | *Synapta maculata* | Chamisso and Eysenhardt, 1821 |
| | **290** | *Synapta (Chirodota) verrucosa* | Eschscholtz, 1829 | *Leptosynapta verrucosa* | |
| | **291** | *Thyone fusus* | O.F. Müller, 1776 | | |
| | **292** | *Thyone peruana* | Lesson, 1830 | | |
| | **293** | *Thyone raphanus* | Duben and Koren, 1846 | *Pseudothyone rapharus* | |
| | **294** | *Thyonidium pellucidum* | Fleming | *Ekmania barthi* | Troschel, 1846 |
| **Vermes** **Platyhelminthes** **Turbellaria** | **295** | *Borlasia trilineata* | [Schmarda, 1859] | *Lineopsella trilineata* | |
| | **296** | *Borlasia unilineata* | Schmarda, 1859 | *Lineus vittatus* | Quoy and Gaimard, 1832 |
| | **297** | *Centrostomum polycyclium* | [Schmarda, 1859] | *Leptoplana polycyclia* | |
| | **298** | *Euryle**pt**a rubrocincta* | Schmarda, 1859 | *Pseudobiceros rubrocinctus* | |
| | **299** | *Euryle**pt**a superba* | Schmarda, 1859 | *Pseudobiceros undulatus* | Kelaart, 1858 |
| | **300** | *Eurylepta miniata* | Schmarda, 1859 | *Pseudobiceros miniatus* | |
| | **301** | *Euryle**pt**a auriculata* | O.F. Müller, 1788 | *Vorticeros auriculatum* | O.F. Müller, 1784 |
| | **302** | *Leptoplana gigas* | [Schmarda, 1859] | *Ilyella gigas* | |
| | **303** | *Leptoplana lanceolata* | Schmarda, 1859 | *Stylochoplana chilensis* | |

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|---|---|---|---|---|---|
| | **304** | *Leptoplana purpurea* | [Schmarda, 1859] | *Ilyella purpurea* | |
| | **305** | *Leptoplana ot**ophora*** | [Schmarda, 1859] | *Notocomplana otophora* | |
| | **306** | *Meckelia macrorrhochma* | [Schmarda, 1859] | *Cerebratulus macrorrhochmus* | |
| | **307** | *Nemertes flaccida* | O.F. Müller, 1774 | *Carinella annulate* [Nemertea] | Montagu, 1804 |
| | **308** | *Planaria lactea* | [O.F. Müller, 1776] | *Dendrocoelum lacteum* [Nemertea] | Ørsted, 1844 |
| | **309** | *Planaria torva* | O.F. Müller, 1773 | | |
| | **310** | *Polycelis microsora* | Schmarda, 1859 | *Notocomplana microsora* | |
| | **311** | *Polycelis orbicularis* | [Schmarda, 1859] | *Postenterogonia orbicularis* | |
| | **312** | *Prostheceraeus clavicornis* | Schmarda, 1859 | *Pseudoceros clavicornis* | |
| | **313** | *Prostheceraeus cornutus* | O.F. Müller, 1776 | *Eurylepta cornuta* | |
| | **314** | *Prostheceraeus latissimus* | Schmarda, 1859 | *Pseudoceros latissimus type A* | |
| | **315** | *Prostheceraeus viridis* | Schmarda, 1859 | *Pseudobiceros viridis* | Kelaart, 1858 |
| | **316** | *Stylochus dictyotus* | [Schmarda, 1859] | *Planocera dictyota* | |
| | **317** | *Stylochus oxyceraeus* | Schmarda, 1859 | *Callioplana marginata* | Stimpson, 1857 |
| | **318** | *Tetracelis marmor**osa*** | O. F. Müller, 1773 | | |
| | **319** | *Thysanozoon brocchii* | Risso, 1818 | | |
| | **320** | *Thysanozoon discoideum* | Schmarda, 1859 | | |
| | **321** | *Thysanozoon ovale* | [Schmarda, 1859] | *Acanthozoon ovale* | |
| | **322** | *Typhloplana fulva* | Ehrenberg, 1837 | *Mesostoma griseum* [Nomen dubium according to Luther, 1904] | O.F. Müller, 1789 |
| | **323** | *Typhloplana viridata* | Abildgaard, 1789 | | |
| **Vermes Gephyrea** | **324** | *Bonellia viridis* | Rolando, 1821 | | |
| | **325** | *Phascolosoma vulgare* | Dies | *Golfingia (Golfingia) vulgaris vulgaris* | Blainville, 1827 |
| | **326** | *Priapulus caudatus* | O.F. Müller | | Lamarck, 1816 |
| **Vermes Annelida** | **327** | *Clepsine bioculata* | Bergm | *Helobdella stagnalis* | Linnaeus, 1758 |
| | **328** | *Clepsine marginata* | [O.F. Müller, 1774 ] | *Hemiclepsis marginata* | |
| | **329** | *Clepsine sanguinea* | De-Filippi, 1837 | | |
| | **330** | *Pontobdella vittata* | Chamisso | **[?]** *Calliobdella lophii* | von Benden and Hesse, 1863 |
| | **331** | *Arenicola marina* | Linnaeus, 1758 | | |

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|---|---|---|---|---|---|
| | **332** | *Audouinia Lamarckii* | Milne-Edwards | *Cirratulus tentaculata* | Montague, 1808 |
| | **333** | *Branchiomma vesiculosum* | Montagu, 1815 | | |
| | **334** | *Eunice norvegica* | O.F. Müller | | Linnaeus, 1767 |
| | **335** | *Hesione Schmardae* | Quatrefages | **[?]** *Myriocyclum schmardae* **[ND]** | Grube, 1880 |
| | **336** | *Hydroides norvegic**us*** | Gunnerus, 1768 | | |
| | **337** | *Nereis margaritacea* | Leach | *Perinereis cultrifera* | Grube, 1840 |
| | **338** | *Notocirrus Hilairii* | Claparede | *Arabella iricolor* | Montague, 1804 |
| | **339** | *Phyllodoce Paretti* | [Blainville, 1828] | *Nereiphylla paretti* | |
| | **340** | *Phyllochaetopterus major* | Claparede, 1869 | | |
| | **341** | *Pista (Terebella) cristata* | O.F. Müller, 1776 | | |
| | **342** | *Sabella penicillus* | Linnaeus | *Sabella spallanzanii* | Gmelin, 1791 |
| | **343** | *Serpula contortuplicata* | Linnaeus, 1767 | *Serpula vermicularis* | |
| | **344** | *Siphonostoma diplochaitos* | Otto, 1821 | *Flabelligera diplochaites* | |
| | **345** | *Spirographis Spallanzanii* | Vivani | *Sabella spallanzanii* | Gmelin, 1791 |
| | **346** | *Spirorbis nautiloides* | Lamarck | *Spirorbis spirorbis* | Linnaeus, 1758 |
| | **347** | *Sternaspis scutata* | Malmgren | | Ranzani, 1817 |
| | **348** | *Terebella conchilega* | Pallas, 1776 | *Lanice conchilega* | |
| | **349** | *Terebella conchilega* (larvae stages) | Pallas, 1776 | *Lanice conchilega* | |
| | **350** | *Terebella Emmalina* | Quatrefages | *Pista cretacea* | Grube, 1860 |
| | **351** | *Trophonia plumosa* | O.F. Müller, 1776 | *Pherusa plumosa* | |
| **Mollusca** **Gastropoda** | **352** | *Clio borealis* | Pallas | *Clione limacina* | Phipps, 1774 |
| | **353** | *Clionopsis Krohnii* | Troschel, 1854 | *Cliopsis krohnii* | |
| | **354** | *Clionopsis Krohnii* (Anatomy) | Troschel, 1854 | *Cliopsis krohnii* | |
| | **355** | *Clionopsis flavescens* | Gegenbaur, 1855 | *Paraclione flavescens* | |
| | **356** | *Cymbulia Peronii* | Cuvier | | Blainville, 1818 |
| | **357** | *Cymbulia quadripunctata* | Gegenbaur | *Cymbulia peronii peronii (see 356 and 357)* | Blainville, 1818 |
| | **358** | *Pneumoderm**a** violaceum* | D'Orbigny, 1776 | | |
| | **359** | *Tiedamannia neapolitana* | Beneden | *Gleba cordata* | Forsskål in Niebuhr, 1776 |
| | **360** | *Tiedamannia neapolitana* (development history) | Beneden | *Gleba cordata* | Forsskål in Niebuhr, 1776 |

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| **Mollusca**<br>**Gastropoda**<br>**Opisthobranchia** | **361** | *Actinodoris australis* | Angas | *Dendrodoris nigra* | Stimpson, 1855 |
| | **362** | *Aeolis alba* | Alder and Hancock | *Fiona pinnata* | Eschscholtz, 1831 |
| | **363** | *Aeolis despecta* | Johnston | *Tergipes tergipes* | Forsskål, 1775 |
| | **364** | *Aeolis diversa* | Couthouy | *Coryphella verrucosa* | M. Sars, 1829 |
| | **365** | *Aeolis exigua* | Alder and Hancock, 1848 | *Eubranchus exiguus* | |
| | **366** | *Aeolis Foulisi* | Angas | *Anteaeolidiella cacaotica* | Stimpson, 1885 |
| | **367** | *Aeolis gymnota* | Couthouy, 1838 | *Cuthona gymnota* | |
| | **368** | *Aeolis militaris* | Alder and Hancock | **ND** | |
| | **369** | *Aeolis papillosa* | Linnaeus, 1761 | *Aeolidia papillosa* | |
| | **370** | *Aeolis rufibranchialis* | Johnston | *Flabellina verrucosa* | M. Sars, 1829 |
| | **371** | *Alderia (Cantopsis) Harvardiensis* | Agassiz | *Alderia modesta* | Lovén, 1844 |
| | **372** | *Ancula cristata* | Loven | *Ancula gibbosa* | Risso, 1818 |
| | **373** | *Beccaria tricolor* | Trinchese | *Caliphylla mediterranea* | Costa, 1867 |
| | **374** | *Bornella arborescens* | Pease | *Bornella stellifer* | A. Adams and Reeve in A. Adams, 1848 |
| | **375** | *Bornella digitata* | Alder and Hancock | *Bornella stellifer* | A. Adams and Reeve in A. Adams, 1848 |
| | **376** | *Bornella Hermanii* | Angas, 1864 | | |
| | **377** | *Caecinella luctuosa* | Bergh, 1870 | | |
| | **378** | *Casella philippinensis* | Bergh | *Doriprismatica atromarginata* | Cuvier, 1804 |
| | **379** | *Ceratosoma gracillimum* | Semper | | Semper in Bergh, 1876 |
| | **380** | *Chromodoris Bennetti* | Angas, 1864 | *Hypselodoris benneti* | |
| | **381** | *Chromodoris Crossei* | Angas | *Hypselodoris obscura* | Stimpson, 1855 |
| | **382** | *Chromodoris festiva* | Angas, 1864 | *Mexichromis festiva* | |
| | **383** | *Chromodoris lentiginosa* | Pease, 1871 | | |
| | **384** | *Chromodoris Loringi* | Angas, 1864 | *Goniobranchus loringi* | |
| | **385** | *Chromodoris maculosa* | Pease, 1871 | *Hyselodoris maculosa* | |
| | **386** | *Chromodoris rufomaculata* | Pease, 1871 | *Goniobranchus rufomaculatus* | |
| | **387** | *Chromodoris variana* | Pease, 1871 | *Nournea varians* | |
| | **388** | *Chromodoris variegata* | Pease | *Mexichromis lemniscata* | Quoy and Gaimard, 1832 |

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| | **389** | *Chromodoris Tryonii* | Garrette, 1873 | *Hypselodoris tryoni* | |
| | **390** | *Coryphella (Eolis) Bostoniensis* | Couthouy, 1838 | *Facelina bostoniensis* | |
| | **391** | *Coryphella (Eolis) salmonacea* | Couthouy, 1838 | *Flabellina salmonacea* | |
| | **392** | *Cratena longibursa* | Bergh | ***ND*** | |
| | **393** | *Cyerce elegans* | Bergh, 1870 | | |
| | **394** | *Cyerce nigra* | Bergh, 1871 | | |
| | **395** | *Dendronotus arborescens var carneus* | Müller | *Dendrodoris frondosus* | Ascanius, 1774 |
| | **396** | *Dendronotus arborescens var brunneus* | Müller | *Dendrodoris frondosus* | Ascanius, 1774 |
| | **397** | *Doriopsis atromaculata* | Alder and Hancock | *Peltodoris atromaculata* | Bergh, 1880 |
| | **398** | *Doriopsis clavulata* | Alder and Hancock | *Dendrodoris krustensternii* (see 398, 399, 411) | Gray, 1850 |
| | **399** | *Doriopsis gemmacea* | Alder and Hancock | *Dendrodoris krustensternii* (see 398, 399, 411) | Gray, 1850 |
| | **400** | *Doriopsis nigra* | Stimpson, 1855 | *Dendrodoris nigra* | |
| | **401** | *Doriopsis rubra* | Kelaart, 1858 | *Dendrodoris rubra* | |
| | **402** | *Doriopsis scabra* | Pease, 1860 | *Doris granulosa* | |
| | **403** | *Doriopsis tuberculosa* | Quoy and Gaimard | *Dendrodoris tuberculosa* | Quoy and Gaimard, 1832 |
| | **404** | *Doris arbutus* | Angas, 1864 | *Rostanga arbutus* | |
| | **405** | *Doris areolata* | Alder and Hancock, 1864 | *Dendrodoris areolata* | |
| | **406** | *Doris bilamellata* | Linnaeus, 1767 | *Onchidoris bilamellata* (see 406, 407) | |
| | **407** | *Doris bilamellata var coronata* | Agassiz, 1860 | *Onchidoris bilamellata* (see 406, 407) | |
| | **408** | *Doris compta* | Pease | *Doriopsis herpetica* **[taxon inquirenda]** | Bergh, 1879 |
| | **409** | *Doris concinna* | Alder and Hancock, 1864 | *Montereina concinna* | |
| | **410** | *Doris debilis* | Pease | *Dendrodoris nigra* | Stimpson, 1855 |
| | **411** | *Doris Denisoni* | Angas | *Dendrodoris krustensternii* (see 398, 399, 411) | Gray, 1850 |
| | **412** | *Doris diademata* | Agassiz | *Onchidoris diademata* | Gould, 1870 |
| | **413** | *Doris Elliotii* | Alder and Hancock, 1864 | *Platydoris ellioti* | |
| | **414** | *Doris flammea* | Alder and Hancock, 1844 | ***ND*** | |
| | **415** | *Doris formosa* | Alder and Hancock, 1864 | *Sebadoris fragilis* | |
| | **416** | *Doris fragilis* | Alder and Hancock | *Jorunna funebris* | Kelaart, 1859 |
| | **417** | *Doris funebris* | Kelaart, 1859 | *Jorunna funebris* | |
| | **418** | *Doris grisea* | Stimpson | *Dendrodoris grisea* | Kelaart, 1858 |

| | | | | | |
|---|---|---|---|---|---|
| | **419** | *Doris muricata* | O.F. Müller, 1776 | *Orchidoris muricata* | |
| | **420** | *Doris nodulosa* | Angas, 1864 | *Hoplodoris nodulosa* | |
| | **421** | *Doris nubilosa* | Pease, 1871 | *Sebadoris nubilosa* | |
| | **422** | *Doris pallida* | Agassiz | *Glossodoris pallida* | Ruppell and Leuckart, 1830 |
| | **423** | *Doris pantherina* | Angas, 1864 | *Jorunna pantherina* | |
| | **424** | *Doris pardalis* | Alder and Hancock, 1864 | *Montereina pardalis* | |
| | **425** | *Doris pilosa* | Abildgaard | *Acanthodoris pilosa* | Abildgaard in O. F. Muller, 1879 |
| | **426** | *Doris repanda* | Alder and Hancock | *Cardina laevis* | Linnaeus, 1776 |
| | **427** | *Doris rubrilineata* | Pease | *Dendrodoris nigra* | Stimpson, 1855 |
| | **428** | *Doris striata* | Kelaart, 1858 | *Platydoris striata* | |
| | **429** | *Doris variabilis* | Angas | *Apheldoris varia* | Abraham, 1877 |
| | **430** | *Doris villosa* | Pease | *Thordisa villosa* | Alder and Hancock, 1864 |
| | **431** | *Doto coronata* | Alder and Hancock | | Gmelin, 1791 |
| | **432** | *Elysia chlorotica* | Agassiz | | Gould, 1870 |
| | **433** | *Elysia grandis* | Bergh, 1872 | | |
| | **434** | *Elysia viridis* | Montagu, 1804 | | |
| | **435** | *Embletonium fuscata* | Gould, 1870 | *Tenellia fuscata* (see 406 and 407) | |
| | **436** | *Embletonium pallida* | Alder and Hancock | *Tenellia adspersa* | Nordmann, 1845 |
| | **437** | *Embletonium remigata* | Gould, 1870 | *Tenellia fuscata* (see 406 and 407) | |
| | **438** | *Ercolania Pancerii* | Trinchese | *Ercolania viridis* | A. Costa, 1866 |
| | **439** | *Ercolania Siottii* | Trinchese, 1872 | | |
| | **440** | *Ercolania Uziellii* | Trinchese | *Ercolania viridis* | A. Costa, 1866 |
| | **441** | *Facelina coronata* | Forbes | *Facelina auriculata* | O.F. Müller, 1776 |
| | **442** | *Facellina Drummondii* | Thompson | **ND** | |
| | **443** | *Flabellina ianthina* | Angas, 1864 | *Pteraeolidia ianthina* | |
| | **444** | *Flabelina Newcombi* | Angas, 1864 | | |
| | **445** | *Flabellina ornata* | Angas, 1864 | *Australeolis ornata* | |
| | **446** | *Glaucilla briarens* | Reinhardt | *Glaucus atlanticus* (see 446, 447, 449 and 450) | Forster, 1777 |
| | **447** | *Glaucilla marginata* | Reinhardt | *Glaucus atlanticus* (see 446, 447, 449 and 450) | Forster, 1777 |
| | **448** | *Glaucus atlanticus* | Forster, 1777 | | |

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|---|---|---|---|---|---|
| | **449** | *Glaucus lineatus* | Reinhardt | *Glaucus atlanticus* (see 446, 447, 449 and 450) | Forster, 1777 |
| | **450** | *Glaucus longicirrus* | Reinhardt | *Glaucus atlanticus* (see 446, 447, 449 and 450) | Forster, 1777 |
| | **451** | *Goniobranchus albomaculatus* | Pease, 1886 | | |
| | **452** | *Goniodoris citrina* | Alder and Hancock, 1864 | | |
| | **453** | *Goniodoris erinaceus* | Crosse | *Atagema intecta* | Kelaart, 1859 |
| | **454** | *Goniodoris modesta* | Alder and Hancock, 1864 | | |
| | **455** | *Goniodoris verrucosa* | Crosse | *Thordisa verrucosa* | Crosse in Angas, 1864 |
| | **456** | *Janus sanguineus* | Angas, | *Madrella sanguinea* | |
| | **457** | *Kalinga ornata* | Alder and Hancock, 1864 | | |
| | **458** | *Kentrodoris rubescens* | Bergh, 1876 | *Jorunna rubescens* | |
| | **459** | *Lomanotus (Eumenis) marmoratus* | Alder and Hancock, 1845 | *Lomanotus marmoratus* | |
| | **460** | *Melibe fimbriata* | Alder and Hancock | *Melibe viridis* | Kelaart, 1858 |
| | **461** | *Melibe australis* | Angas, 1864 | | |
| | **462** | *Miamira nobilis* | Bergh | *Melibe sinuata* | van Hasselt, 1824 |
| | **463** | *Montaguia picta* | Alder and Hancock, 1864 | | |
| | **464** | *Phyllobranchus orientalis* | Kelaart, 1858 | *Polybranchia orientalis* | |
| | **465** | *Phyllobranchus prasinus* | Bergh, 1871 | *Polybranchia prasinus* | |
| | **466** | *Plocamopherus ceylonicus* | Kelaart, 1858 | | |
| | **467** | *Plocamopherus imperialis* | Angas, 1864 | | |
| | **468** | *Placobranchus argus* | Bergh, 1872 | *Plakobranchus ocellatus* | van Hasselt, 1824 |
| | **469** | *Placobranchus gracilis* | Pease | **[?]** *Thuridilla gracilis* | Risbec, 1928 |
| | **470** | *Placobranchus variegatus* | Pease, 1871 | *Plakobranchus ocellatus* | van Hasselt, 1824 |
| | **471** | *Polycera Lessonii* | D'Orbigny | *Pallio dubia* | M. Sars, 1829 |
| | **472** | *Polycera ocellata* | (Alder and Hancock) Meyer and Mobius | *Pallio nothus* | Johnston, 1838 |
| | **473** | *Polycera quadrilineata* | (O.F. Müller) Meyer and Mobius | | O.F. Müller, 1776 |
| | **474** | *Pontolimax capitatus* | O.F. Müller, 1774 | *Limapontia capitata* | |
| | **475** | *Pterogasteron marginata* | Pease | *Elysia ornata* | Swainson, 1840 |
| | **476** | *Pterogasteron nigropunctata* | Pease, 1871 | *Elysia nigropunctata* | |
| | **477** | *Pterogasteron rufescens* | Pease, 1871 | *Elysia rufescens* | |
| | **478** | *Scyllaea marmorata* | Alder and Hancock | *Scyllaea pelagica* | Linnaeus, 1758 |

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|---|---|---|---|---|---|
| | **479** | *Stiliger (Calliopea) fuscatus* | Gould, 1870 | *Ercolania fuscata* | |
| | **480** | *Stiliger Mariae* | Meyer and Mobius | *Calliopaea bellula* | d'Orbigny, 1837 |
| | **481** | *Stiliger ornatus* | Ehrenberg, 1828 | | |
| | **482** | *Tethys leporina* | Linnaeus, 1767 | *Tethys fimbria* | |
| | **483** | *Trevelyana cristata* | Bergh, 1877 | **[?]** *Nembrotha cristata* (see 483 and 484) | |
| | **484** | *Trevelyana nigerrima* | Bergh, 1877 | **[?]** *Nembrotha cristata*( see 483 and 484) | |
| | **485** | *Tridachia crispata* | Oersted, 1863 | *Elysia crispata* | Morch |
| | **486** | *Triopa claviger* | (O.F. Müller) Alder and Hancock | *Limacia clavigera* | O. F. Muller, 1776 |
| | **487** | *Triopa gracilis* | Pease, 1871 | *Palio gracilis* | |
| | **488** | *Triopa Yatesi* | Angas, 1864 | *Kaloplocamus yatesi* | |
| | **489** | *Aplysia Inca* | D'Orbigny, 1837 | | |
| | **490** | *Aplysia leporina* | Linnaeus | *Aplysia depilans* | Gmelin, 1791 |
| | **491** | *Dolabrifera fusca* | Pease, 1868 | | |
| | **492** | *Dolabrifera tahitensis* | Pease, 1868 | | |
| | **493** | *Lobiger picta* | Pease | *Lobiger souverbii* | P. Fischer, 1857 |
| | **494** | *Lophocereus viridis* | Pease, 1861 | *Oxynoe viridis* | |
| | **495** | *Pleurobranchus delicatus* | Pease | *Berthellina citrina* | Ruppell and Leuckart, 1828 |
| | **496** | *Pleurobranchus grandis* | Pease, 1868 | | |
| | **497** | *Pleurobranchus ovalis* | Pease, 1869 | | |
| | **498** | *Pleurophyllidia pallida* | Bergh, 1874 | | |
| | **499** | *Pleurophyllidia Semperii* | Bergh, 1861 | *Armina semperi* | |
| | **500** | *Syphonota punctata* | Pease | **[?]** *Aplysia punctata* | Cuvier, 1803 |
| | **501** | *Syphonota viridescens* | Pease | *Aplysia dactylomela* | Rang, 1828 |
| **Mollusca Gastropoda Prosobranchia** | **502** | *Cyclostoma elegans* | Draparnaud | *Adeorbis elegans* | A. Adams, 1850 |
| | **503** | *Paludina achatina* | Sowerby [No date] | **Not in WoRMS** | |
| **Mollusca Gastropoda Pulmonata** | **504** | *Limnaeus auricularius* | Draparnaud | *Radix auriculata* | Linnaeus, 1758 |

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|---|---|---|---|---|---|
| | **505** | *Limnaeus stagnalis* | O. F. Muller | *Lymnaea stagnalis* [also listed as no. 698] | Linnaeus, 1758 |
| | **506** | *Limnaeus palustris* | Draparnaud | *Stagnicola palustris* | O. F. Muller, 1774 |
| | **507** | *Planorbis corneus* | Linnaeus, 1758 | | |
| | **508** | *Amalia marbinata* | Draparnaud | | Lessona and Pollonera, 1882 |
| | **509** | *Arion albus* | O. F. Muller, 1774 | | |
| | **510** | *Arion empiricorum var aster* | Ferussac. Linnaeus | *Arion ater* (see 510, 511, 512 and 513) | Linnaeus, 1758 |
| | **511** | *Arion empiricorum var rufus* | Ferussac. Linnaeus | *Arion ater* (see 510, 511, 512 and 513) | Linnaeus, 1758 |
| | **512** | *Arion empiricorum var marginatus* | Moquin-Tandon | *Arion ater* (see 510, 511, 512 and 513) | Linnaeus, 1758 |
| | **513** | *Arion empiricorum (Anatomy)* | Moquin-Tandon | *Arion ater* (see 510, 511, 512 and 513) | Linnaeus, 1758 |
| | **514** | *Arion hortensis* | Ferussac, 1819 | **ND** | |
| | **515** | *Bulimus detritus* | O. F. Muller, 1774 | | |
| | **516** | *Bulimus montanus* | Draparnaud, 1801 | *Ena montana* | |
| | **517** | *Clausilia bidens* | Draparnaud | **[?]** *Papillifera papillaris* | O. F. Muller 1774 |
| | **518** | *Clausilia similis* | Charp | | Hartmann, 1821 |
| | **519** | *Daudebardia rufa* | Draparnaud, 1805 | | |
| | **520** | *Helix arbustorum* | Linnaeus | *Arianta arbustorum* | O. F. Muller, 1774 |
| | **521** | *Helix hortensis* | O. F. Muller, 1774 | *Cepaea hortensis* | |
| | **522** | *Helix incarnata* | O. F. Muller, 1774 | *Monachoides incarnatus* | |
| | **523** | *Helix lapicida* | Linnaeus | *Helicigona lapicida* | |
| | **524** | *Helix nemoralis* | Linnaeus, 1758 | *Cepaea nemoralis* | |
| | **525** | *Helix pomatia* | Linnaeus, 1758 | | |
| | **526** | *Helix pomatia (Anatomy)* | Linnaeus, 1758 | | |
| | **527** | *Limax agrestis* | Linnaeus, 1758 | | |
| | **528** | *Limax alpinus* | Férussac | *Limax sarnensis* (see Reference weblink A) | Hein and Nitz, 2009 |
| | **529** | *Limax arborum* | Bouch-Chant | *Lehmannia marginata* | O. F. Muller, 1774 |
| | **530** | *Limax brunneus* | Draparnaud | *Deroceras laeve* | O. F. Muller, 1774 |
| | **531** | *Limax cinctus* | O. F. Muller, 1774 | | |
| | **532** | *Limax corsicus* | Moquin-Tandon, 1855 | | |
| | **533** | *Limax gagates* | Ferussac | *Milax gagates* | Draparnaud, 1801 |
| | **534** | *Limax maximus* | Linnaeus, 1758 | | |

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|---|---|---|---|---|---|
| | **535** | *Limax variegatus* | Draparnaud | *Limax flavus* | Linnaeus, 1758 |
| | **536** | *Parmacella Valenciennii* | Moquin-Tandon | | Web and Vanbenenden, 1836 |
| | **537** | *Parmarion pupillaris* | Humbert, 1864 | | |
| | **538** | *Philomycus bilineatus* | Bens. | *Tebennophorus bilneatus* | Benson, 1842 |
| | **539** | *Philomycus carolinensis* | Binney | **[?]** *Philomycus carolinianus/Tebennophorus c* | Bosc, 1802 |
| | **540** | *Succinea amphibia* | Draparnaud | *Succinea putris* | Linnaeus, 1758 |
| | **541** | *Testacella haliotidea* | Cuvier | | Draparnaud, 1801 |
| | **542** | *Vaginulus Moreleti* | Fischer and Crosse, 1872 | *Veronicella moreleti* | |
| | **543** | *Vaginulus occidentalis* | Guilding, 1825 | *Diplosolenodes occidentalis* | |
| | **544** | *Vaginulus siamensis* | Martens, 1867 | *Valiguna siamensis* | |
| | **545** | *Vaginulus Sloanei* | Ferussac | | Cuvier, 1817 |
| | **546** | *Carinaria mediterranea* | Lamarck | *Carinaria lamarckii* | Blainville, 1817 |
| | **547** | *Pterotrachea mutica* | Lesson | *Pterotrachea hippocampus* | Phillipi, 1836 |
| | **548** | *Pterotrachea scutata* | Gegenbaur, 1855 | | |
| **Mollusca Cephalopoda** | **549** | *Argonauta Argo* (female) | Linnaeus, 1758 | | |
| | **550** | *Argonauta Argo* (male 2 stages) | Linnaeus, 1758 | | |
| | **551** | *Eledone Aldrovandi* | Delle Chiaje | *Eledone cirrhosa* | Lamarck, 1798 |
| | **552** | *Eledone Genei* | Verany | *Eledone cirrhosa* | Lamarck, 1798 |
| | **553** | *Eledone moschata* | Leach | | Lamarck, 1798 |
| | **554** | *Enoploteuthis Owenii* | Verany, 1846 | | |
| | **555** | *Enoploteuthis Veranii* | Ruppell, 1844 | *Abralia veranyi* | |
| | **556** | *Histioteuthis Bonelliana* | Ferussac, 1834 | *Histioteuthis bonnellii* | |
| | **557** | *Histioteuthis Riippelii* | Verany | *Histioteuthis bonnellii* | Ferussac, 1834 |
| | **558** | *Loligo vulgaris* | Lamarck, 1798 | | |
| | **559** | *Loligo Alessandrini* | Verany | *Ancistrocheirus lesueurii* | d'Orbigny, 1842 |
| | **560** | *Loligo Berthelotii* | Verany | *Loligo vulgaris* | Linnaeus, 1798 |
| | **561** | *Loligo Bianconii* | Verany | **[?]** *Onchyoteuthis banksii* | Leach, 1817 |
| | **562** | *Loligo Meneghini* | Verany 1851 | **ND** | |
| | **563** | *Loligo Marmorae* | Verany | *Loligo media* | Linnaeus, 1758 |

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|---|---|---|---|---|---|
| | **564** | *Loligopsis Veranii* | Ferussac, 1834 | *Chiroteuthis veranii* | |
| | **565** | *Loligopsis vermicularis* | Ruppell | *Chiroteuthis veranii* | Ferrusac, 1834 |
| | **566** | *Loligopsis Zygaena* | Verany, 1847 | **Nomen dubium** | |
| | **567** | *Octopus Alderii* | Verany | *Callistoctopus macropus* | Risso, 1826 |
| | **568** | *Octopus Cocco* | Verany | *Pteroctopus tetracirrhus* | delle Chiaje, 1830 |
| | **569** | *Octopus De-Filippii* | Delle Chiaje | *Macrotritopus defilippi* | Vérany, 1851 |
| | **570** | *Octopus Fontanianus* | D'Orbigny, 1834 | | |
| | **571** | *Octopus Koellikerii* | Verany | *Tremoctopus violaceus* | Delle Chiaje, 1830 |
| | **572** | *Octopus macropus* | Risso, 1826 | *Callistoctopus macropus* | |
| | **573** | *Octopus Salutii* | Verany, 1836 | | |
| | **574** | *Octopus tetracirrhus* | Delle Chiaje, 1830 | *Pteroctopus tetracirrhus* | |
| | **575** | *Octopus tetracirrhus var* (Verany) | Verany | *Pteroctopus tetracirrhus* | Delle Chiaje, 1830 |
| | **576** | *Octopus tuberculatus* | Blainville | *Octopus vulgaris* | Cuvier, 1797 |
| | **577** | *Octopus vulgaris* | Lamarck | | Cuvier, 1797 |
| | **578** | *Ommastrephes sagittatus* | Lamarck, 1798 | *Todarodes sagittatus* | |
| | **579** | *Ommastrephes (Loligo) todarus* | Delle Chiaje | *Todarodes sagittatus* | Lamarck, 1798 |
| | **580** | *Ommastrephes aequipodus* | Ruppell | **[?]** *Todarodes saggitatus* | Lamarck, 1798 |
| | **581** | *Ommastrephes (Loligo) Pillae* | Verany, 1839 | *Illex coindetii* | |
| | **582** | *Ony**k**ia platyptera* | D'Orbigny, 1834 | | |
| | **583** | *Onychoteuthis Lichtensteini* | Ferussac | *Ancistroteuthis lichtensteinii* | Férrusac in Férrusac and d'Orbigny, 1835 |
| | **584** | *Onychoteuthis Krohnii* | Verany | ***Species Inquirenda,*** **Possible synonym for *O. Banksii*** | Leach, 1817 |
| | **585** | *Philonexis catenulatus* | Ferussac | *Ocythoe tuburculata* | Rafinesque, 1814 |
| | **586** | *Philonexis Carenae* | Verany | *Ocythoe tuburculata* | Rafinesque, 1814 |
| | **587** | *Rossia dispar* | Ruppell, 1844 | *Heteroteuthis dispar* | |
| | **588** | *Rossia macrosoma* | Delle Chiaje, 1828 | | |
| | **589** | *Sepia officinalis* | Lamarck | | Linnaeus, 1758 |
| | **590** | *Sepia elegans* | Blainville, 1827 | | |
| | **591** | *Sepia bisserialis* | Montf | *Sepia elegans* | Blainville, 1827 |
| | **592** | *Sepiola Rhondeletii* | Delle Chiaje | | Leach, 1817 |
| | **593** | *Sepioteuthis sicula* | Ruppell | *Chtenopteryx sicula* | Vérany, 1851 |

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|---|---|---|---|---|---|
| | **594** | *Verania sicula* | Krohn | *Octopoteuthis sicula* | Ruppell, 1844 |
| | **595** | *Tremoctopus Quoyanus* | D'Orbigny | *synonym for Tremoctopus violaceus* | Delle Chiaje, 1830 |
| | **596** | *Tremoctopus velifer* | Ferussac | *synonym for Tremoctopus violaceus* | Delle Chiaje, 1830 |
| | **597** | *Tremoctopus violaceus* | Delle Chiaje, 1830 | | |
| **Tunicata Tethyodae** | **598** | *Appendicularia cophocerca* | Gegenbaur, 1855 | *Oikopleura (Vexillaria) cophocerca* | |
| | **599** | *Appendicularia flagellum* | Chamisso | *Oikopleura (Vexillaria) dioica* | Fol, 1872 |
| | **600** | *Amaroecium Normannii* | Milne-Edwards, 1841 | *Aplidium nordmannii* | |
| | **601** | *Botryllus bivittatus* | Milne-Edwards | *Botryllus schlosseri* | Pallas, 1776 |
| | **602** | *Botryllus gemmeus* | Milne-Edwards | *Botryllus schlosseri* | Pallas, 1776 |
| | **603** | *Botryllus Schlosseri* | Savigny | | Pallas, 1776 |
| | **604** | *Botryllus amaragdus* | Milne-Edwards | *Botryllus schlosseri* | Pallas, 1776 |
| | **605** | *Botryllus violaceus* | Milne-Edwards | *Botryllus schlosseri* | Pallas, 1776 |
| | **606** | *Syntethys hebridicus* | Forbes | *Diazona violacea* | Savigny, 1816 |
| | **607** | *Boltenia Burkhardti* | Agassiz | *Botryllus ovifera* | Linnaeus, 1767 |
| | **608** | *Boltenia clavata* | Stimpson | *Botryllus ovifera* | Linnaeus, 1767 |
| | **609** | *Boltenia rubra* | Stimpson | *Boltenia ovifera* | Linnaeus, 1767 |
| | **610** | *Ciona canina* | (Müller) Kupffer | *Ciona intestinalis* | Linnaeus, 1767 |
| | **611** | *Ciona intestinalis* | Fleming | | Linnaeus, 1767 |
| | **612** | *Ciona fascicularis* | Hancock, 1870 | | |
| | **613** | *Clavellina lepadiformis* | Savigny | | Müller, 1776 |
| | **614** | *Corella (Ascidia) parallelogramma* | Müller, 1776 | *Corolla paralellogramma* | |
| | **615** | *Cynthia pyriformis* | Rathke, 1806 | *Halocynthia pyriformis* | |
| | **616** | *Cynthia (Microcosmia) echinata* | Linnaeus, 1767 | *Boltenia echinata* | |
| | **617** | *Molgula producta* | Stimpson | *Mogula complanata* | Alder and Hancock, 1870 |
| | **618** | *Phallusia pustulosa* | Alder | **[?]** *Ascidiella aspersa* | Müller, 1776 |
| | **619** | *Phallusia callosa* | Stimpson | **[?]** *Ascidia callosa* | Stimpson, 1852 |
| | **620** | *Pyrosoma atlanticum* | Savigny | | Péron, 1804 |
| **Tunicata Thaliacea** | **621** | *Doliolum mediterraneum* | Krohn | **Not in WoRMS** | Otto |

| | | | | | |
|---|---|---|---|---|---|
| | **622** | *Salpa africana-maxima* | Forsskål, 1775 | | |
| | **623** | *Salpa aspera* | Chamisso, 1819 | | |
| | **624** | *Salpa bicornis-vaginata* | Chamisso, 1819 | | |
| | **625** | *Salpa cordiformis-zonaria* | Chamisso | **[?]** *Soestia zonaria* | Pallas, 1774 |
| | **626** | *Salpa democratica-mucronata* | Forsskål, 1775 | *Thalia democratica* | |
| | **627** | *Salpa pinnata* | Forsskål, 1775 | *Cyclosalpa pinnata* | |
| | **628** | *Salpa punctata* | Forsskål, 1775 | *Ihlea punctata* | |
| | **629** | *Salpa runcinata-fusiformis* | Chamisso. Cuvier | *Salpa fusiformis* | Cuvier, 1804 |
| | **630** | *Salpa ferruginea* | Chamisso | *Pegea socia* | Bosc, 1802 |
| **Protozoa Rhizopoda Protoplasta** | **631** | *Amoeba proteus* | Pallas | | |
| | **632** | *Difflugia pyriformis* | Perty | *Difflugia linearis* | (Penard, 1890) Gauthier and Lievre, 1958 |
| | **633** | *Euglypha ciliata* | Leidy | | Dujardin, 1841 |
| **Protozoa Rhizopoda Heliozoa** | **634** | *Actinophrys sol* | Ehrenberg, 1830 | | |
| | **635** | *Clathrulina elegans* | Cienkowski, 1867 | | |
| | **636** | *Raphidiophrys elegans* | HertwigandLesser, 1874 | | |
| **Protozoa Rhizopoda Radiolaria** | **637** | *Actinomma asteracanthion* | Haeckel, 1862 | | |
| | **638** | *Aulacantha scolymantha* | Haeckel, 1862 | | |
| | **639** | *Aulosphaera elegantissima* | Haeckel, ? No date | | |
| | **640** | *Cladococcus cervicornis* | Haeckel, 1860 | | |
| | **641** | *Dictyopodium trilobum* | Haeckel, 1860 | *Pterocanium charybdeum* | |
| | **642** | *Dorataspis diodon* | Haeckel, 1862 | | |
| | **643** | *Eucecryphalus schultzei* | Haeckel, 1862 | **[?]** *Lampromitra schultzei* **[Not in WoRMS]** | |
| | **644** | *Eucyrtidium cranoides* | Haeckel, 1861 | | |
| | **645** | *Heliosphaera actinota* | Haeckel, 1860 | *Acanthosphaera actinota* | |

**TABLE 3** – Callaghan et al.

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|---|---|---|---|---|---|
| | **646** | *Spongosphaera streptacantha* | Haeckel, 1860 | | |
| **Porifera**<br>**Calurea**<br>**Leucosolenida** | **647** | *Sycandra raphanus* | Schmidt, 1862 | *Sycon raphanus* | |
| **Cnidaria**<br>**Anthozoa**<br>**Actiniaria** | **648** | *Aiptasia mutabilis* | Gravenhorst, 1831 | | |
| | **649** | *Bunodes balli var funesta* | Cocks, 1851 | *Anthopleura ballii* | |
| | **650** | *Cereactis aurantiaca* | delle Chiaje, 1825 | *Condactylis aurantiaca* | |
| | **651** | *Sagartia troglodytes striata* | Price in Johnston, 1847 | *Sagartia troglodytes* **[no ssp listed]** | |
| | **652** | *Sagartia troglodytes fusca* | Price in Johnston, 1847 | *Sagartia troglodytes* **[no ssp listed]** | |
| | **653** | *Sagartia troglodytes* | Price in Johnston, 1847 | | |
| | **654** | *Actinia equina* | Linnaeus, 1758 | | |
| | **655** | *Actinoloba senile* | de Blainville | **[?]** *Metridium senile* | Linnaeus, 1761 |
| **Cnidaria**<br>**Hydrozoa**<br>**Anthoathecata** | **656** | *Codonium codonoforum* | Haeckel | *Codonium proliferum* | Forbes, 1848 |
| | **657** | *Sarsia siphonophora* | Haeckel | *Stauridiosarsia gemmifera* | Forbes, 1848 |
| **Echinodermata**<br>**Crinoidea**<br>**Comatulida** | **658** | *Comatula mediterannea* | Lamarck, 1816 | *Antedon mediterranea* | |
| **Echinodermata**<br>**Asteroidea**<br>**Forcipulatida** | **659** | *Asteracanthion pallidus* | Agassiz, 1866 | ***Nomen nudum*** | |
| **Platyhelminthes**<br>**Rhabditiphora**<br>**Rhabdocoela** | **660** | *Mesostom**a** ehrenbergii* | Focke, 1836 | | |
| | **661** | *Mesostoma rostratum* | Ehrenberg, 1836 | *Rhynchomesostoma rostratum* | O.F. Müller, 1773 |
| | **662** | *Prostomum lineare* | Schultze and Müller, 1857 | *Gyratrix hermaphroditus* | Ehrenberg, 1831 |
| | **663** | *Schizostomum productum* | Schmidt, 1848 | *Mesostoma productum* | |

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|---|---|---|---|---|---|
| **Platyhelminthes**<br>**Rhabditiphora**<br>**Polycladida** | **664** | *Cryptocelis compacta* | Lang, 1884 | | |
| | **665** | *Leptoplana tremellaris* | O.F. Müller, 1773 | | |
| | **666** | *Stylostomum variabile* | Lang, 1884 | *Stylostomum ellipse* | Dalyell, 1853 |
| **Annelida**<br>**Clitellata**<br>**Rhynchobdellida** | **667** | *Hirudo medicinalis* | Linnaeus, 1758 | | |
| **Annelida**<br>**Polychaeta** | **668** | *Arenicola marina* (anatomy) | Linnaeus, 1758 | | |
| **Annelida**<br>**Polychaeta**<br>**Phyllodocida** | **669** | *Autolytus cornutus* (5 stages)7 models present in museum | Agassiz, 1884 | *Proceraea cornuta* | |
| **Annelida**<br>**Polychaeta**<br>**Sabellida** | **670** | *Sabellaria alveolata* | Linnaeus, 1767 | | |
| **Mollusca**<br>**Bivalvia**<br>**Veneroida** | **671** | *Cardium edule* | Linnaeus, 1758 | *Cerastoderma edule* | |
| **Mollusca**<br>**Bivalvia**<br>**Limoida** | **672** | *Lima squamosa* (anatomy) | Lamarck | *Lima lima/ Lima vulgaris* | Linnaeus, 1758 /Link, 1807 |
| **Mollusca**<br>**Bivalvia**<br>**Mytiloida** | **673** | *Mytilus edulis* | Linnaeus, 1758 | | |
| **Mollusca**<br>**Bivalvia**<br>**Pectenoida** | **674** | *Pecten opercularis* | Linnaeus, 1758 | *Aequipecten opercularis* | |
| **Mollusca**<br>**Bivalvia**<br>**Veneroida** | **675** | *Scrobicularia piperata* | Poiret | *Scrobicularia plana* | Da Costa, 1778 |

**TABLE 3** – Callaghan et al.

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|---|---|---|---|---|---|
| **Mollusca**<br>**Bivalvia**<br>**Euheterodota** | **676** | *Solen vagina* | Linnaeus, 1758 | | |
| **Mollusca**<br>**Bivalvia**<br>**Veneroida** | **677** | *Tapes decussata* | Linnaeus, 1758 | *Ruditapes decussatus* | |
| | **678** | *Venus gallina* | Linnaeus, 1758 | *Chamelea gallina* | |
| **Mollusca**<br>**Bivalvia**<br>**Pectenoida** | **679** | *Vola jacobea* | Linnaeus, 1758 | *Pecten jacobaeus* | |
| **Mollusca**<br>**Gastropoda**<br>**Sacoglossa** | **680** | *Limapontia capitata* (anatomy) | Müller, 1774 | | |
| | **681** | *Elysia viridis* (anatomy) | Montagu, 1804 | | |
| **Mollusca**<br>**Gastropoda**<br>**Nudibranchia** | **682** | *Phylliroe bucephala* | Lamarck, 1816 | | |
| | **683** | *Aeolis papillosa* (anatomy) | Linnaeus, 1761 | *Aeolidia papillosa* | |
| | **684** | *Tritonia hombergii* | Cuvier, 1803 | | |
| | **685** | *Doris formosa* | Alder and Hancock, 1864 | *Platydoris formosa* | |
| **Mollusca**<br>**Gastropoda**<br>**Anaspidea** | **686** | *Aplysia leporina* (anatomy) | Blumenbach | *Aplysia depilans* | Gmelin, 1791 |
| **Mollusca**<br>**Gastropoda**<br>**Pleurobranchomorpha** | **687** | *Pleurobranchus aurantiacus* (anatomy) | Risso | *Berthellina citrina* | Abbott, 1949 |
| **Mollusca**<br>**Gastropoda**<br>**Littorinimorpha** | **688** | *Aporrhais pespelecani* | Linnaeus, 1758 | | |

**TABLE 3** – Callaghan et al.

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|---|---|---|---|---|---|
| **Mollusca Gastropoda Caenogastropoda** | **689** | *Buccinium undatum* | Linnaeus, 1758 | | |
| **Mollusca Gastropoda** | **690** | *Cassidaria echinophora* | Linnaeus, 1758 | *Galeodea echinophora* | |
| | **691** | *Cerithium vulgatum* | Bruguière, 1792 | | |
| | **692** | *Glyphis italica* | Agassiz | *Diodora italica* | Defrance, 1820 |
| | **693** | *Gibbula albida* | Gmelin, 1791 | | |
| | **694** | *Haliotis tuberculata* | Linnaeus, 1758 | | |
| **Mollusca Gastropoda Neogastropoda** | **695** | *Murex brandaris* | Linnaeus, 1758 | *Bolinus brandaris* | |
| **Mollusca Gastropoda** | **696** | *Astralium rugosum* | Linnaeus, 1767 | *Bolma rugosa* | |
| | **697** | *Paludina achatina* | Sowerby | **ND** | |
| | **698** | *Limnacus stagnalis* | O. F. Muller | *Lymnaea stagnalis* | Linnaeus, 1758 |
| | **699** | *Glandina truncata* | Gmelin, 1791 | *Euglandina truncata* | |
| **Mollusca Cephalopoda Sepiida** | **700** | *Sepia officinalis* (anatomy) | Linnaeus, 1798 | | |
| **PoriferaHexactinellida Lychniscosida** | **701** | *Aulocystis zitteli* | Marshall and Meyer, 1877 | *Neoaulocystis zitteli* | |
| **PoriferaHexactinellida Lyssacinosida** | **702** | *Caulophacus latus* | Schulze, 1886 | **Alternate representation** *Caulophacus (Caulophacus) latus* | |
| **PoriferaHexactinellida Hexactinosida** | **703** | *Eurete semperii* | Schulze, 1886 | *Pararete semperi* | |
| | **704** | *Farrea occa* | Bowerbank, 1862 | | |

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|---|---|---|---|---|---|
| **Mollusca**<br>**Gastropoda** | | *Fissurella costaria* | Deshayes, 1824 | | |
| | | *Turbo rugosus* | Linnaeus, 1767 | *Bolma rugosa* | |
| **Cnidaria** | | *Actinia chiococca* | Cocks | **ND** | |
| **Cnidaria**<br>**Anthozoa**<br>**Zoantharia** | | *Zoanthus alderi* | Gosse, 1860 | | |
| | | *Zoanthus sulcatus* | Gosse, 1860 | *Isozoanthus sulcatus* | |
| **Cnidaria**<br>**Anthozoa**<br>**Actinaria** | | *Halcampa microps* | Gosse, 1856 | *Edwardsiella carnea* | |

# Silver and nickel pins in entomology: historical attempts at combating corrosion problems in insect collections

E Geoffrey Hancock[1*] and Suzanne Ryder[2]

[1]The Hunterian, University of Glasgow. Glasgow, G12 8QQ

[2]Department of Entomology, The Natural History Museum, London, SW7 5BD

*Corresponding author: geoff.hancock@glasgow.ac.uk

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**Abstract**

We describe some examples of silver and nickel entomological pins and provide the context for their promotion and use. Insects pinned with these silver pins have been identified and an example of subsequent corrosion illustrated. The aim is to highlight the possible existence of silver in this context, which generally has not been considered in historical collections. This is compared in appearance with other kinds of metal corrosion that can occur in museum insect collections. Pins made from other materials are referred to.

**Keywords**: collections, historical, entomology; metallic corrosion, sulphides, verdigris, rust

## Introduction

On a few occasions silver pins were promoted for entomological use with some enthusiasm but they do not seem to have been generally adopted. Until the invention of stainless steel and its subsequent recognition of value for making insect pins, silver did offer some advantages over plated or lacquered brass or mild steel. There is an obvious disadvantage of softness and difficulty in producing a sharp point needed particularly for piercing harder integuments. This might have been sufficient disinclination to use silver pins. There seems to have been little or no reaction or feedback following this suggestion as an answer to pin corrosion problems and so it would seem silver pins were not widely perceived as valuable in this context. The existence of samples of unused silver pins still in their packets and finding some in collections that had been deployed provides an opportunity to analyse the situation. Pure nickel pins have also been investigated in a similar manner and their use described.

## Historic accounts of promoting the use of silver pins

David Sharp (1840-1922), was employed as Curator of Insects at Cambridge University Museum of Zoology from 1890 to 1909 (Clark, 2004). While there he wrote how silver wire was "the best material to use" for pinning small insects (Sharp, 1892). He had been using it for twenty years and originally made his own pins by hand. In this published note he announced they were being sold by Watkins & Doncaster, the natural history dealers then based in The Strand, London. They were available in a number of sizes that Sharp had recommended to them. He compared silver pins favourably with those made of brass and steel, which were prone to degradation by corrosion. Such problems often manifest themselves today when dealing with old insect collections (e.g. Garner, *et al*., 2011).

Sharp pointed out silver that was used in the arts was annealed and un-annealed metal should be used for pins as it was harder. Nevertheless, to counter the relative softness of silver he described how for some insects he used another pin to make a small hole prior to insertion of the silver one. This would have been necessary with beetles, Sharp's speciality, although he did not say if he actually used silver pins for Coleoptera. In fact, it is unlikely as he said that small insects were staged on small cork blocks covered in paper. Except for very large species which are direct-pinned, beetles were traditionally glued on card, a technique still widely used even though it renders the ventral surface impossible to see. Some examples of Sharp's specimens are illustrated by Foster and Close (2014).

William Farren (1836-1887) also claimed he had been using silver pins for several years and he stuck them into elder pith rather than cork to avoid any possibility of bending (Farren, 1892). He expressed surprise that complaints about rusting of steel "minutien nadeln" (i.e., micro pins) were not consistently avoided by the use of silver pins for smaller microlepidopterans such as the Nepticulidae. Farren was known for his work as a Cambridgeshire dealer/naturalist (C[arrington], 1888).

It seems that the value of silver pins was promoted and they became commercially available so might have been used by other collectors but with what frequency is not known. After these two articles appeared no further mention of silver pins appears for a number of years although the merits and demerits of other kinds of pins were regularly the subject of discussion in the various popular British entomological journals.

Forty years elapsed before another recommendation for silver was made. Austen and Hegh (1922) stated "pins made of silver wire have the great advantage of never becoming corroded, but, owing to their softness, need to be used with special care; for tsetse flies the most suitable sizes are "0" and "3" costing in each case about 8s. 6d. per 1,000." They do not refer to a supplier but in the same paragraph allude to D.F. Tayler with reference to "pins of the ordinary type". D.F. Tayler of Newhall Works, Birmingham, England, manufactured a range of entomological pins and in 1939 did include pure silver pins in their advertising. What date they were first offered for sale has not been established (pers. comm., Brian Jowett, October 2010). In addition to silver they made pins of pure nickel, black (tempered) carbon steel, stainless steel and brass. In 1960, silver pins were only available in one size, No.16 with a length of $1\frac{3}{8}$ inch and a gauge, or diameter, of 0.024 inch. This is larger than sizes suggested by Austen and Hegh (1922) and would seem inherently unsuitable for use with smaller insects.

As the discussion by Austen and Hegh (1922) was embedded in a monograph of medically important insects it is unlikely to have reached the community of British amateur naturalists with an interest in preserving their specimens. It seems to have had little detectable impact on preferred practices.

In the Hunterian Museum collection of historical entomological collecting and preserving equipment and materials are two batches of unused silver pins (Figure 1 and 2). They were originally obtained by one of the authors (EGH) from John Heath (1922-1987). They are both labelled by parts of gummed labels with "Quick Lab., Cambridge" printed on them and some handwritten notation. In a glass tube are some marked "0" and in a small metal glass-topped box are paper packets marked "0" and "3". As quoted above, these clearly conform to those recommended by Austen and Hegh (1922). Heath lived in the area and worked for the

*Figure 1. Tube of silver pins, size "0" and 15 mm long, labelled as suitable for Tinea moths (The Hunterian, University of Glasgow).*


*Figure 2. Pill box with packets of silver pins, sizes "0" and "3" (The Hunterian, University of Glasgow).*


*Figure 3. One of two boxes of silver pins (Hope Department, OUMNH).*

Biological Records Centre at Monkswood Research Station, Huntingdonshire. This involved data processing at Cambridge University prior to distribution map printing and so he may have obtained the silver pins at that time. But earlier, from 1947 to 1952, he had been employed by the Biological Research Department of Pest Control, near Cambridge and so could have got them during that period (Anon., 1988). One of Heath's specialities was the study of the tiny moths in the family Micropterigidae so he may have considered trying silver for pinning his specimens. The Hope Department, Oxford University Museum of Natural History, also has some unused silver pins in their historical collection (Figure 3).

## Corrosion of silver pins

Analysis of an unusual kind of corrosion on a pin in the Natural History Museum, London (Figure 4), proved to be crystals of silver sulphide and the specimen was illustrated by Selwyn (2004; fig. 11.7, p. 138). There are a few other examples of silver pin corrosion in the same part of the collection, drawers that include type specimens of Hymenoptera from the collection of Peter Cameron (1847-1912). His collection was acquired in 1914 and the specimen figured here was collected in 1906. The corrosion presents a dramatic appearance from which, in technical literature, the word whiskers has been adopted. The silver sulphide crystals sprout radially from the pin and are very different in form from other kinds of metal corrosion products seen in entomology collections. Selwyn (2004) groups corrosion products according to their situation, in this case as "Corrosion Indoors", separate from either outdoor or burial conditions. This sulphide is typical of indoor corrosion found in a variety of stored museum artefacts.

An attempt to find more examples in other principal British entomology collections produced no results. Some searching was made through specific areas of collections such as tsetse flies in several museums also with negative results. Their use appears to have been transient. Sharp (1882) described how the pins turned black but said that this was merely an initial effect of no further detriment; he clearly regarded it as cosmetic.

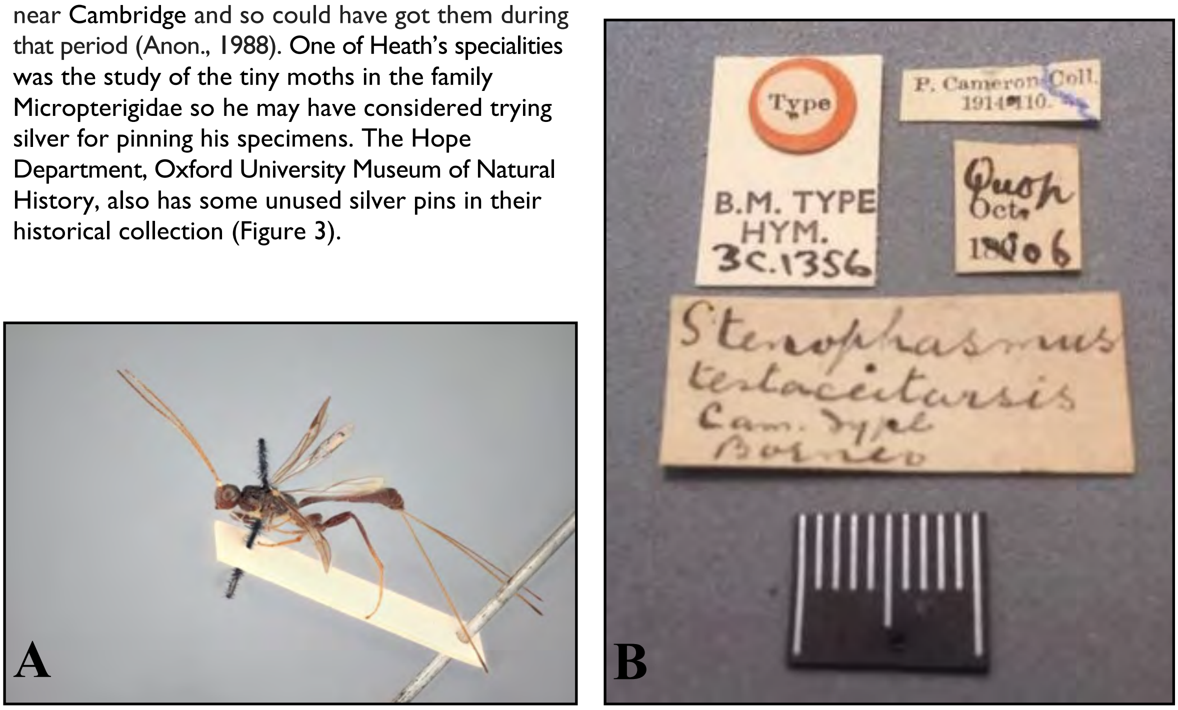


*Figure 4a & b. Corrosion of a silver pin on a parasitic hymenopteran showing silver sulphide whiskers; with data labels (Cameron collection, NHM, London).*

This characteristic of silver means that that such pins would be difficult to find when scanning by eye down rows of small insects as they would appear similar to black-varnished steel pins. It may be that conditions under which the pins developed a fine growth of silver sulphide whiskers, were in some way abnormal, but any relevant history has not been established.

### Nickel pins

Pure nickel pins were made and advertised by D.F. Tayler. Theoretically, nickel would have been a good material for pins before stainless-steel became the choice material (Figure 5). The earliest mention of nickel pins having been tested and then marketed was made by Emile Deyrolle, Paris (Anon., 1895). Pure nickel was said to be too brittle to be drawn into wire so a "secret alloy" had been made in order to do so. It claimed that a successful search had been made "to produce a pin which should be as nearly perfect as possible". Two boxes labelled "Pure Nickel" are in Oxford alongside the silver ones, also dating from the mid twentieth century (Figure 6). Any lack of purity in the nickel may compromise them, as with any metal product. To test this both nickel and silver unused pins have been analysed (see below). No pins that could be identified as nickel could be found when looking through collections and no published statement on their use by any British entomologist has been traced. However, a corroded pin that looked slightly different from the "normal" verdigris as often seen in museum insect collections was tested and its metallic spectrum is that of nickel. The corrosion products of nickel are also green and may be hydrated carbonate with an organic addition (Faithfull, 2019 *pers comm.*). This serendipitous discovery may make it possible to visually identify nickel pins from the different appearance of the green coating.

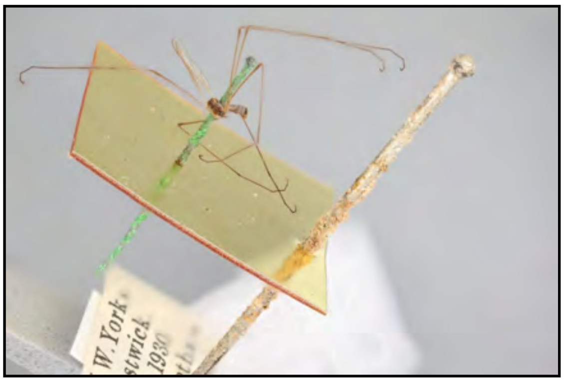


*Figure 5. A cranefly specimen, one of the first examples of* Dicranomyia aperta *Wahlgren, 1904 to be collected in Britain in 1926, on a pin with green corrosion. Analysis proved it to be nickel.*

### Purity of the silver and nickel pins

The historic unused silver and nickel pins in Glasgow and Oxford were tested by EDS (Energy Dispersion X-ray Spectroscopy) with a Stereoscan Electron Microscope. The results show the level of purity. The silver ones are between 82-89% silver with some metallic copper and carbon present. Nickel pins were 92-95% pure with some carbon present. One sample from Oxford although labelled as such but did not look like silver was tested and confirmed as tin-plated brass.

### Other pin types and corrosion problems in insect collections

The main purpose of this paper is to report the existence and use of silver and nickel pins. Any conservation issues that might arise have not been addressed. If the strength of the silver metal is not materially compromised by the growth of whiskers and that simple black tarnishing is a superficial surface affect it may be best not to attempt remedial conservation. Examination of specimens in most museums will usually reveal more familiar examples of corrosion. The most obvious is brass pin corrosion in which verdigris is formed, usually in the form of irregular green growths from the point of contact between pin and insect (Figure 7). These can often burst apart the specimen (Garner, et al., 2011; page 52, figures 5 and 6). According to Selwyn (2004) verdigris can be an organic compound arising from the interaction of fatty acids with copper hence its irregular growth form. It is noticeably waxy when rubbed between the fingers. This seems to be in contrast to the harder green coating on the nickel pin which is evenly distributed along the shaft and has not formed any outgrowth from the surface.

The use of mild steel pins or even sewing needles was common in the eighteenth and early nineteenth century before mass production techniques meant tin-plated brass pins could be produced specifically


*Figure 6. Boxes of nickel pins (Hope Department, OUMNH).*

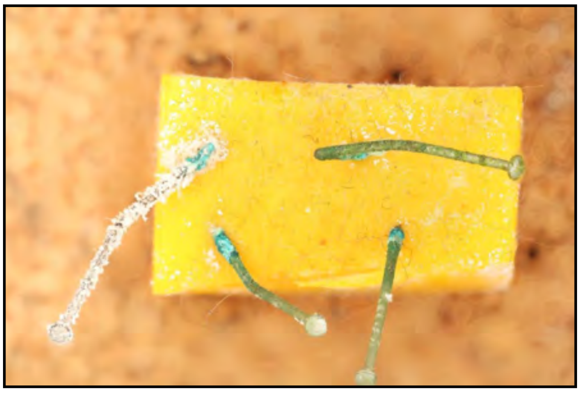

*Figure 7. Verdigris on brass pins that had been used to hold down an organic insecticide product within a collection. The analysis in addition to copper and zinc showed phosphorus, a component of the pesticide.*

for insects (Hancock, *et al.* 2011; Hancock (2015). They were prone to rusting and the formation of ferrous oxide, just as does verdigris in brass, compromises pin strength. Breaks can occur both inside the insect or at the level of the papered cork. Many old collections have insects on soft iron wire that had been cut into suitable lengths and a rough point made by filing or grinding. Sometimes an angled cut was sufficient to use without bothering to make a point. These wire pins easily bend in use and require careful handling. Rust on pins is figured also by Garner, et al., (2011). There are varying qualities of stainless steel - not all stainless-steel pins currently offered on the market are satisfactory (see Walker, *et al.*, 1999) plus variation in sharpness during manufacture that proves annoying when trying to pin certain groups of Coleoptera and Hymenoptera with hard integuments. Despite the adoption of so-called "Continental" pins as a museum standard there is a variety of manufacturers and suppliers and different numbering systems. In reality there is no specific standard as shown by those made in central Europe being 38 mm long but some sold under the trade name 'Asta' (which might be of English manufacture and remnants of old stock) are 1.5 inches which is 38.1 mm. Imports from China are 40 mm and Japanese ones are 42 mm long.

In severe instances of verdigris or rust corrosion remedial conservation such as pin replacement becomes necessary. Our conclusion in the case of silver and nickel pins is that their different properties and restricted adoption means they appear to present little problem for the well-being of entomological collections.

**Acknowledgements**

Curatorial staff at Oxford University Museum of Natural History facilitated a loan of some unused pins. Brian Jowett, formerly of D.F. Tayler & Co., Birmingham, from his own research into the history of pin-making as part of a degree research project, has supplied many interesting facts concerning pin manufacture and the kinds of stock items that were made and sold. Dr Peter Chung, Earth Sciences, Glasgow University, kindly found time to analyse the unused silver and nickel pins and Innes Clatworthy, of the Imaging and Analysis, Core Research Laboratories of NHM provided those for pinned specimens in London. Dr John Faithfull, Curator of Mineralogy at The Hunterian, provided valuable insight into interpreting the spectroscopy results from the SEMs.

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# Minority Taxa, Marginalised Collections: A focus on Fungi

Nathan Smith

*Department of Zoology, University of Cambridge Downing St, Cambridge, CB2 3EJ, UK*

*Email: cwe.smith@gmail.com*

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**Abstract**

Minority taxa, such as fungi, algae, lichens, ferns, and mosses, are taxa that receive a disproportionately small amount of public and curatorial interest. Whilst present in museums, they often form only a small part of an overall collection and possess characteristics that present barriers to engagement and, as such, are more likely than others to be neglected and suffer marginalisation. This paper explores how we can best handle minority taxa collections, using fungi as an example, in light of limited funding. It provides definitions for 'minority taxa' and 'marginalised collections' and gives a brief history of mycological collection within the UK before going on to make a case for the importance of these collections, both scientific and historical, showing practical examples for each. It assesses the likely impact of several potential pathways for management of these collections, given both limited staff and funding levels as well as the need to find a balance between a collection's utility and its durability, and gives resources to enable curators and collection managers to make the most of their fungal collections. This is done with the ultimate aim of increasing curator's confidence in working with unfamiliar material within an unfamiliar scientific landscape.

**Keywords**: mushrooms, fungi, mycology, volunteers, local authority museums, British Mycological Society

## Introduction

How do we curate collections that we are not specialists in? Most museums possess such a diversity of specimens that no individual, or small group, can be expected to have sufficient knowledge or interest to maximise the potential of all of them. Furthermore, time and resource commitments are limited, often severely, and as such collections have to be prioritised. However, this prioritisation often disproportionately marginalises collections belonging to 'minority taxa'.

Minority taxa, such as fungi, algae, lichens, ferns, and mosses, usually form only a small part of an overall collection. They are likely to spend the majority of their existence in storage and often share practical characteristics that impede curation and create barriers to exhibition. They may be aesthetically unassuming and often presented in uncommon preparations (such as packets or slides). They often require microscopic or chemical work for accurate identification, particularly to species level, and their associated disciplines are usually extremely young, particularly relative to zoology and botany: both the British Mycological Society and British Bryological Society will celebrate its 125th anniversary in 2021 and the British Lichen Society and British Phycological Society were both only founded in the 1950's. The expert group associated with the taxa is more likely than not to be amateur rather than professional. Biologically, they are often phylogenetically basal and their lifecycles may differ substantially from the perceived norm associated with mammalian and angiosperm reproduction, for example. These practical characteristics, combined with understaffed and overworked curators with little to no personal experience in any minority taxa, lead to these collections being marginalised, ignored and, in the worst-case scenarios, falling into disrepair.

This paper, through focusing on non-lichenised fungi and fungal-like organisms (hereafter referred to as fungi unless stated otherwise as lichens have historically been treated as a separate group from fungi with a different cultural history and taxonomic practice), explores how curators can begin to manage minority taxa in their collections to get the best out of them without becoming specialists overnight. It aims to do this through providing a terminology that both helps us understand the problem and realise solutions. It provides a brief history on mycological collection within Great Britain and in doing so attempts to demystify collections and highlight potential narratives through which curators and visitors can connect to the collections. It discusses the practical values of fungal collections, both for curators and researchers. Finally, it takes a realistic approach to how fungal collections can be effectively and efficiently curated to maximise utility whilst minimising losses.

## A Note on Terminology

Here, I introduce and adapt respectively the terms minority taxa and marginalised collections for use in natural history collections. The former has been used on occasion (Field Studies Council, 2011), though with no clear definition or assessable #characteristics, whilst the latter has seen some use in museum studies focused on collections #outside of natural history (Rohde, 2010). In this paper, minority taxa are defined here as 'taxa that consistently receive a disproportionately small amount of public and curatorial interest on a #national or international scale relative to their species abundance and diversity.' and marginalised collections defined here similarly as 'collections likely to suffer curatorial neglect'. These terms are beneficial for several reasons. As previously detailed, many unrelated taxa can be seen to share numerous practical characteristics and, importantly, face many of the same problems in museum representation. By grouping these taxa together under a single banner, they form a larger group and are thus more capable and deserving of attracting attention and resources.

The second, more fundamental, reason is that the language we use informs our understanding of the problem and guides us to certain conclusions regarding potential solutions. A negative example of this can be seen in the term "Forgotten Kingdom" being applied to fungi. Having been used for a number of decades, with the earliest reference to the term being 'Fungi - the forgotten kingdom of life in the deep sea' (Lorenz and Molitoris, 1993), the term informs the reader that the principal problem facing mycology is simply a lack of awareness. The solution it suggests is to simply raise awareness. Whilst this should be beneficial, this has led to a proliferation of "and fungi" sentences, where fungi are briefly mentioned, often as part of a list of higher taxa, but not addressed in a meaningful capacity. This can, for example, be seen in the UK Government's 25 Year Plan to Improve the Environment, where fungi are mentioned only twice; once in an "and fungi" sentence and the second in a reference to plant diseases (HM Government, 2018). This shows a tacit disregard for fungi as organisms both beneficial to the environment and as components of the environment in their own right. The use of 'minority taxa' and 'marginalised collections', in contrast, informs us that the problem is systematic in its origin and any solutions with the capacity for meaningful impact are likely to be more complex than an afterthought at the end of a sentence.

Finally, whilst it is acknowledged that these definitions are broad enough to be applied to a wide range of taxonomic groups. With the spectrums of interest and neglect being both broad and relative, it is important in applying these terms to note the magnitude of the differences between marginalised collections of prominent taxa and of less prominent taxa. Whilst insects may be underserved in comparison to vertebrates, fungi are much more substantially underserved than either.

## A Brief History of Fungal Collecting

As this paper focuses on fungi, it is beneficial to give a brief history of British mycology and mycological collecting, highlighting trends that help explain the distribution of historical collections and the contemporary organisation of mycology in the United Kingdom, as well as to focus on some of the more unique aspects in mycological history that are potentially useful in construction of engaging narratives with modern audiences. It also aims to familiarise museum and collections professionals with the names of some of the more notable mycologists whose specimens may form part of their collection. Those interested in a more in-depth history should consult the works of G. C. Ainsworth (Ainsworth, 1976; Ainsworth, 1981). Papers by Ramsbottom (Ramsbottom, 1948a; Ramsbottom, 1948b), and Webster

Webster, 1997) should also be consulted, with the former also writing a history of Scottish Mycology (Ramsbottom, 1963). Local mycological histories have also been written for several regions including Essex (Ramsbottom, 1934a; Ramsbottom, 1934b; Ramsbottom, 1935), Norfolk (Cooke, 1937) and Yorkshire (Blackwell, 1961; Watling, 1982).

Within Great Britain, mycology as a formal discipline can largely be seen as starting with the work of Reverend Miles Berkeley (1803-1889), widely seen as the 'founding father of British mycology' (Ainsworth, 1987), whose work in compiling the first serious list of British fungi (Berkeley, 1836) brought both himself mycology to attention. Before this, study and collection of fungi was of course still practiced, though largely by isolated individuals (the most prominent example being James Bolton (Watling and Seaward, 1981)), and only a small percentage of their collections survive. Before mycology had established an identity independent of botany, we see fungal collections treated much the same as botanical collections and much of the surviving material consists of thinly sectioned fruit bodies pressed in much the same way as herbaria specimens.

Through Berkeley's work establishing mycology as a discipline, we see a gradual shift away from pressed-sections towards dried-fruitbodies stored in packets (the exception being rusts and smuts, which continue to be pressed with their host plant). His published works, alongside his collaborator Christopher Edmund Broome (1812-1886), created a foundation on which others could build upon and germinated an interest in mycology as a general interest in nature study seized the emerging middle-classes (Allen, 1987). This fledgling interest was extended upon by the deliberately populist works of Mordecai Cubitt Cooke (1825-1914), who also went on to found the first cryptogam-focused (lower plants and fungi) journal in Grevillea in 1872. The Gardener's Chronicle, established 1874, was also a popular outlet for mycological publications during this period.

This period of emergence for mycology is also concurrent with a period of intense civic pride. Described as an era of 'city states' (Hill, 1999), it saw naturalists of different regions compete to have the most impressive natural history output. Mycology being relatively new and of the time, was very much shaped by this outlook and today mycology is one of the few taxonomic disciplines that has a well-established network of independent local groups.

The donation by Berkeley of his mycological collection to Kew in 1879 marks a milestone in that it was the first substantial institutional mycological collection in Great Britain. Cooke, one of the few mycologists at the time, was brought in as the curator for Kew's fungi. This late establishment combined with an intently regional outlook meant that local museums were often the recipients of important mycological material, such as the Tolson Memorial Museum receiving Soppitt's collection, which in other disciplines was more likely to find its way to centralised national institutions. Cooke was hired on a specific contract for his individual talents and not for a prescribed role. Upon his acrimonious retirement in 1892, a permanent position was created and filled by George Edward Massee (1845-1917). Massee's reign at Kew saw increased specialisation within mycology, alongside the gradual beginnings of professionalisation (for a contemporary mycologist's view on professionalisation, see Grove, 1892). He was the last head of mycology at Kew to not hold a university degree.

Massee's period at Kew also saw the formation of the British Mycological Society in 1896 (Figure1). Finding its origin partially in the Woolhope Club but perhaps more importantly in the forays of the Yorkshire Naturalists Union (YNU), it was the second national mycological society formed behind only the Société mycologique de France in 1884. However, the regional tensions inherent within Mycology, combined with an ever-growing pool of expertise, let to Massee resigning the society and the Presidency and instead taking up the role of Chairman of the YNU's Mycological Committee with many Yorkshire mycologists following (Ramsbottom, 1917a; Ramsbottom, 1917b; Ramsbottom, 1948b). Both continued to work relatively independently, with the YNU favouring depositing its samples at Kew with Massee and the BMS instead favouring the British Museum. The collections were reconciled in 1961 which saw the Natural History Museum and RBG, Kew sign the Morton Agreement where all non-lichenised fungal collections were transferred to Kew, and all lichens and bryophytes went to the NHM.

Massee's death in 1917 marked the end of the 'Yorkshire rebellion' and the subsequent rallying around the British Mycological Society as the representative British mycological institution (Ramsbottom, 1926). This was further cemented in 1918, when a soft coup led to the transition of power in the BMS from Carleton Rea (1861-1946) (who simultaneously held the roles of Editor, Treasurer, and Secretary) to the up and coming John Ramsbottom (1885-1974) (General Secretary

*Figure 1: Photograph taken in Huddersfield following the agreement to form the British Mycological Society. Top: George Edward Massee, Rev. William Fowler, James Needham. Bottom: Charles Crossland, Mordecai Cubitt Cooke, Carleton Rea. Photographer: Alfred Clarke. (Reproduced with permission of Tolson Memorial Museum Huddersfield)*

And Co-Editor with Rea), Elsie Wakefield (1886-1972) (Secretary), and Arthur Anselm Pearson (1874-1954) (Treasurer). They held their respective roles for several decades, as well as occupying the top mycological positions in the country, and their period is marked as one of accord between professional and non-professional mycologists. This active collaboration also saw an increase in collections deposited in Kew over local herbaria, likely due to the ease of accession.

During the Second World War, rationing and the presence of "more-knowledgeable refugees led to an increased interest in foraging and thus to fungal identification" (Phillips, 2000; Smith, 1946). The BMS saw an uptake in membership and local groups were also revitalised by this renewed interest. The deaths of Rea and Pearson in 1946 and 1954, respectively, along with the professional retirement of Ramsbottom and Wakefield in 1950 and 1951 resulted in a complete and rapid overhaul of British mycological leadership. Those taking up the mantle, such as EJH Corner (1906-1996) at Cambridge and RWG Dennis (1910-2003) at Kew, generally showed a greater interest in international mycology authoring authoritative texts on a number of regions and actively travelling in pursuit of collection. The British Mycological Society also held joint meetings with the Societe Mycologique de France, conducted in both English and French (Orton, 1954). Finally, post-war Britain embraced a biology that was increasingly institutionalised and technical in its outlook (de Chadarevian, 2002; Strasser, 2002) and, as a result, professional mycologists became increasingly disconnected from amateur mycology as the professional discipline became more and more detached from the field.

Field mycology saw another boom in interest in the late 1970s and early 1980s, which saw the development of mushroom foraging as a recreational hobby and of foragers as a distinct, often counter-cultural, community (Mabey, 2006; Steinhardt, 2018; Svanber and Lindh, 2019). Both meeting the demands of this community and helping its formation, books such as "Food For Free" (Mabey, 1972), "Mushrooms and Other Fungi of Great Britain and Europe" (Phillips and Shearer, 1981) and "Mushrooms and Toadstools: A Field Guide" (Kibby, 1979) provided entry-level access to the discipline (Palmer, 2003), which had become increasingly complex over the past hundred years. The genetic revolution, set loose in large part by the development of PCR in 1980s (Bartlett and Stirling, 2003), saw mycology raised in greater profile (in 1996, Saccharomyces cerevisiae became the first eukaryote to have its genome sequenced; Goffeau *et al.*, 1996) but facilitated a greater gap between professionals and amateurs, the former now having access to a tool more accurate in its identification than morphological qualities. The Association of British Fungal Groups, now the Fungal Conservation Trust, formed in 1996, in part as an attempt to better meet the needs of amateur mycologists.

Whilst it is perhaps too early to say, we are likely entering into a new era in British mycology. Certainly, interest in mycology has increased substantially in the past few years. Much of this interest has again been centred around foraging which, to speculate, has likely seen an increase in interest due to the increase in climate awareness and the mainstreaming of "green" living. To what extent this renewed interest in foraging will transfer to a more academic amateur mycology remains to be seen, though, historically, the trend is promising. The Lost and Found Fungi Project (http://fungi.myspecies.info/content/lost-and-found-fungi-project), a volunteer/citizen-science based project co-ordinated from RBG, Kew, has proved successful in bringing attention to neglected fungal species and also shown a wider public interest in recording and conserving fungi for their own intrinsic biodiversity value. Furthermore, the decreasing cost of genetic research has increasingly allowed amateurs to partake in experimental genetic work with promising results (e.g. Pembrokeshire Fungus Recording Network, 2017).

Finally, it is important to note and highlight the relative youth of mycology as a discipline and of its societies, alongside the low prestige associated in exploring the lower taxa, arguably made it more accessible to women and those of a lower class. Nor was it a token accessibility but one that was largely allowed, encouraged, and centred their participation as both experts and leaders (Maroske and May, 2018). Between 1900 and 1950, the BMS had nine years with female presidents, remarkably high for the time, and Elsie Wakefield, alongside being head of mycology at Kew, also served as secretary of the society between 1918 and 1936. Furthermore, Annie Lorrain Smith (1854-1937) and Gulielma Lister (1860-1949 ) were amongst the first group of women admitted as Fellows to the Linnaean Society (Linnaean Society of London, 1905) and were recognised international authorities in lichens and myxomycetes respectively.

Amongst the general middle class contingent apparent in most natural history societies, working class figures such as James Needham (1849-1913) and Henry Thomas Soppitt (1858-1899) stand out and were robustly celebrated by their contemporaries (Blackwell, 1961). Whilst this is argued to be because of their class status (Alberti, 2001), working-class mycologists produced concrete additions to their field and their obituaries emphasise their quality of work over their class. The collections of James Needham have previously been characterised in this journal (Baker, 2016). Even many of the most prominent figures in British mycology were often defined primarily by their money troubles, such as Mordecai Cubitt Cooke (English, 1987) and Harry Marshall Ward (1854-1906) (Ayres, 2005). Importantly, this trend can also be seen in many other minority taxa (Blockeel, 1981; Secord, 1994) and is a narrative that helps distinguish minority taxa from the histories of zoology and botany, so often filled with monied expeditions and gentleman practitioners. These narratives can be used by museums today to craft compelling stories that are able to reach a wide audience often underrepresented in the history of natural history.

**The Value of Fungal Collections**

As one final preliminary point, it is perhaps prudent to talk through many ways that collection can be valuable for research. This has been extensively explored for a range of natural history collections (Pettitt, 1997; Suarez and Tsutsui, 2004) and in general these applications also hold true to fungal collections. However, mycological collections have several unique properties that influence their value to curators, researchers, and members of the public.

Fungal collections, like all biological collections, can be sampled for DNA. This has seen particular success in dried fungal samples (Brock, Döring, and Bidartondo, 2009; Bruns, Fogel, and Taylor, 1990; Dentinger *et al.*, 2016). Spirit collections have shown less success in DNA extraction. In assessing recent Boletus edulis Bull, 1782 collections for whole genome sequencing¸ spirit collections were found to have on average a DNA concentration <25% that of equivalent dried collections. However, the concentration was suitable for majority of spirt samples for sequencing to be carried out (unpublished data, see Smith, 2016). In mycology, the ITS region is widely recognised as the primary barcode marker for mycological taxonomy, though it is not without issues (Hofstetter, *et al.,* 2019), and alternative genetic regions have been put forward and used (Molitor, *et al.*, 2010).

Minority taxa are substantially underrepresented amongst sequence databases. Currently just over 10,000 fungal species are represented in the NCBI Reference Sequence Database (NCBI, n.d.), falling far short of the over 120,000 known species described and estimated millions in existence

(Mueller and Schmit, 2007). Additionally, fungal species sequences on GenBank are often misidentified or lacking in voucher specimens (Nilsson *et al.*, 2006). Here, museum fungal collections can be immensely useful in providing barcode sequences which relate back to voucher species with verified and authoritative species determinations. Even if a species already have verified sequences online, additional sequences are still of use in research (e.g. in population genetics) through providing geographic or temporal range. Many fungi have noted functions as bioaccumulators and thus bioindicators of their surrounding environment at their time of growth (Moore, Duncan, and Burgess, 2008), chemical analysis of historic collections may also be of interest to researchers and ecologists. Chemical analysis of herbaria specimens has been productively carried out in pursuit of a range of research questions and is increasingly designed to minimise damage to collections (Kao, *et al.,*, 2018; van der Ent, *et al.,* 2019).

The associated collection label information is also important, finding value in assisting conservation assessments as well as modelling the future distributions of species given climate change (Wollan, *et al.,* 2008). Within the UK, the online Fungal Records Database of Britain and Ireland (FRDBI), available at http://frdbi.info/, provides an easy format for records to be uploaded and combined with other historic and contemporary records. This centralises records and increases the accessibility of collections, facilitating both big-data approaches to research as well as enabling studies that require samples with specific characteristics.

Fungal collections also have a substantial social, historic, and cultural value (Pettitt, 1997). Packets detail the location of individuals and some collections also provide additional contextual information, such as events surrounding the collection. The method of collection is also important and, whilst anachronistic collection methods such as snuff boxes provide unique curatorial challenges, they also provide valuable information on the material practice of science and the social practices of collection.

## A proposed solution

Despite the immense value of mycological collections, both scientifically and historically, they remain at substantial risk, particularly given their extensively provincial distribution. Austerity and government cutbacks have caused increasing loss of funds to museums, which are disproportionately likely to affect museums owned, or formerly owned by local authorities (Museums Association, 2018). This can lead to museum closure, which again disproportionately affects local authority museums (Larkin, 2018), with the effect that remaining regional museums often hold conglomerate collections of multiple closed museums. Furthermore, loss of funding can lead to loss of storage and, as a result, a more aggressive rationalisation strategy. This is likely to disproportionately affect minority taxa, such as fungi, where their cultural, historical, and scientific value is often unable to be accurately appraised by individuals involved, such as curatorial staff, and their documentation is more likely to be scarce and outdated.

In such a situation, how then do we best curate marginalised collections? Assuming similar to present levels of funding and staffing, we are primarily left with three potential options: keep things as they are, surrender the collection to a specialist or larger organisation, or engage with taxa-specific societies. Here the latter option is favoured but it is perhaps beneficial to explore the likely consequences of the other two options.

Regarding the first and, at present, most popular option, the opinion of many curators is that leaving the collections untouched minimises loss and ensures their availability for a future curator or volunteer to work on. However, this assessment ignores that degradation is constantly taking place. Particularly, if DNA is to be successfully extracted and sequenced then there is already a time limit for specimen assessment. Whilst future technology is likely to be able to extend this time limit, this cannot be taken for granted. Furthermore, leaving collections untouched means that they do not get redetermined and can reduce accessibility, with specimens arranged and filed under outdated synonyms and taxonomies.

The second option, of donating collections to a larger or more specialist collection, is also found wanting. Besides the obvious criticism of not fixing the problem but merely passing it on, it also denies the pointedly local characteristic of British mycology. Important for more than just sentimental reasons, this can reduce curators' and researchers' ability to contextualise their collections and thus reduce their utility.

The third option is to engage with taxa-specific societies in order to access expertise, which is currently not available and, in doing so, increase the utility of collections. Taxa-specific societies exist for most if not all minority taxa (Table 1), though some represent multiple taxa (slime moulds and oomycetes are both considered the domain of mycology due to historic classification

| Taxa | Taxa Specific Societies | Websites |
|---|---|---|
| Fungi (incl. Slime Moulds and Oomycets) | British Mycological Society | www.britmycolsoc.org.uk/ |
| Algae | British Phycological Society | www.brphycsoc.org/ |
| Bryophytes | British Bryological Society | www.britishbryologicalsociety.org.uk |
| Lichen | British Lichen Society | www.britishlichensociety.org.uk/ |
| Ferns | British Pteridological Society | www.ebps.org.uk |

*Table 1: Examples of Taxa Specific Societies within the UK.*

(Money, 1998)). They produce their own publications and organise both academic and field meetings. Members are often highly active and possess both broad and specialist knowledge, including the history of their discipline, which is important both in understanding the taxonomy and also the reliability of the historic determination. This can be accessed by curators in order to help find the most compelling narrative interpretation of the collections with which to engage the general public or potential funders, or to improve the documentation and update the identification of specimens.

In mycology, due to its previously detailed history, taxa-specific societies exist at a local level. Currently, forty local and regional groups are affiliated with the British Mycological Society (a list of these groups can be found at https://www.britmycolsoc.org.uk/mycology/recording-network/groups) with new groups still being formed and some other groups choosing not to affiliate. Local groups function independently from each other and the British Mycological Society, with different aims and focuses governed by their members' interests, however, most have the general purpose of recording fungi present within the region which is usually achieved through a mixture of individual and group forays.

Importantly, mycologists, as with other amateur naturalists focused on minority taxa, have at least a rudimentary understanding of collections care. The difficulty in field identification often necessitates collection for further study and maintenance of a reference collection for later work. Whilst specific training is a necessity, the collections-orientated mind-set of minority-taxa specialist volunteers should help alleviate the concern of deliberate or accidental damage to collections that is associated with handling of museum specimens by non-staff members.

Engagement with taxa-specific societies is not without precedent. Collaboration has primarily been focused in the area of public engagement. UK Fungus Day, which is every year at the beginning of October, has proved a good opportunity to facilitate collaboration between museums and fungal groups, with noted successes across the country (Cullington, 2019; Harries, 2014; Maddy, 2016).

Other events have been held independent from the banner of UK Fungus Day; Whitby Museum, in collaboration with the Whitby Naturalists' Club and supported by the British Mycological Society, organised an exhibition focused on fungi to celebrate the club's centenary that ran through the second part of 2013 (Harries, 2014; "Have a funghi day out at Whitby Museum's latest exhibition," 2013). Outside of engagement, there has principally been collaboration on the individual level with mycologists working with museums to produce indexes to specific collections (i.e. Seaward, 1971, and, to a lesser extent, Seaward, 1983), which are particularly useful in reorienting museum and collections professionals after there has been a break in curation. Additionally, an active collaboration has recently started between the Norfolk Fungus Study Group and Castle Museum seeking to catalogue the collections. Outside of mycology, museums have formally housed the collections of taxa-specific societies such as with the British Bryological Society housing its collection within the National Museum Wales. Members of the British Bryological Society have also assisted in the curation of historic collections into modern herbarium folders (Preston, Fisk, Tregaskes, and Gardiner, 2018). Other projects have sought to collate data on minority collections across a range of regional and national museums, including Mollusca Types in Great Britain (https://gbmolluscatypes.ac.uk; Rowson *et al.*, 2018) and Seaweed Collections Online (http://

seaweeds.myspecies.info/), often with input from non-professional taxonomic specialists.

There is also a substantial benefit to volunteers. It gives them access to a wider reference collection on which to base their own studies. It also connects them to their natural societal heritage and can help revitalise the study of minority taxa in the region, providing a focal point for the community to gather and share resources and knowledge. Finally, the social aspects and benefits of societies (Orr, 2006) are often under-utilised and, through collaborating with taxa-specific networks, museums can increase engagement with the local community and serve as cultural hubs.

## Conclusions

Minority taxa are, at present, often neglected by both curators and the general public. This is likely tied to their traits that make them difficult to research and unattractive. However, they have powerful narratives, both in their often-inclusive histories and in their capacity for discovery. Though these narratives are present, there is often a skill-gap that prevents curators and other museum and collections staff from accessing them. Whilst we recognise the importance of naturalists in collections, there has been little focus on the fact that natural history is better described as a collection of sub-specialisms with distinct needs and processes as opposed to a single entity. Whilst restricted budgets limit our responses to this deficit in knowledge, it can be accessed through stronger partnerships with taxa-specific societies. For fungi, these societies are highly active and localised with many members understanding basic collections care by dint of keeping personal reference collections, thus reducing risk of unnecessary damage. Members are also able to add value to collections through updating taxonomies, providing engaging narratives, and being able to effectively advocate for collections to funders.

These societies can be easily contacted and can often help facilitate contact with local groups and individuals, or those that are specialists of certain groups. For those wanting to reach a wider audience, taxa-specific societies produce members journals and newsletters, such as Mycologist News, Field Mycology, Field Bryology, and the British Lichen Society Bulletin¸ which are good homes for articles on interesting marginalised collections that can do much to highlight the value of museum collections in developing the taxonomy, ecology, and history of minority taxa. Collaboration with taxa-specific societies provides an opportunity for museum and collections professionals to increase the utility of and engagement with their collections, particularly those which are oftentimes ignored. There is much to gain, little to lose, and thousands of untold stories in the nooks and crannies of museum stores.

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# Flecs: a novel LEGO® tool for bound herbarium clamping

Steen Dupont[1,2] and Ranee Prakash[1]

[1] Natural History Museum London, Cromwell Road, SW7 5BD London, United Kingdom
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[2] Corresponding Author: steen.dupont@nhm.ac.uk
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**Abstract**

A discussion of some of the current methods used for keeping herbaria volumes open during conservation and digitisation are discussed, and a solution to the physical challenges of digitising bound herbarium volumes with restricted opening capabilities is presented. The Flexible LEGO Clamping System (Flecs) is a collapsible page clamping system capable of holding open herbarium volumes with very restricted opening capabilities, while being versatile enough to deal with specimen position, volume thickness, volume position and repetitive use during mass digitisation.

**Keywords**: Botany, herbarium, imaging, conservation, digitisation, Samuel Browne, Hans Sloane

## Introduction

Digitisation of museum specimens has been a priority for natural history museums for decades, and for the past 5 years the NHM London has given digitisation new incentive through a dedicated Digital Collections Programme that is focused on the many challenges digitising an estimated 80 million specimens creates. A recent pilot project aimed at digitising late 17th century bound volumes of herbarium specimens collected by Samuel Browne from Fort St George, India (now part of Chennai). The volumes have a restricted degree of opening and the project resulted in a novel tool designed to hold herbarium volume specimen folios in place during digitisation, study and conservation.

The practice of collecting and preserving botanical specimens is surprisingly young compared to the history of botany. In a discussion on the origin of Herbaria (1885), Saint-Lager suggests one of the earliest examples of herbaria was the one used by Luca Ghini in Pisa in 1544. The primary argument for the late use of herbaria was the high price and scarce availability of paper. Paper became affordable as a mounting material after the invention of printing in the mid fifteenth century (Saint-Lager, 1885). The invention of herbaria made plant specimens easily transportable allowing specimens from different localities or flowering periods to be compared and used as references which contributed significantly to the wealth of knowledge on the world's flora (Staern 1971). Through the efforts of some of the largest botanical collections in the world including New York Botanical Garden herbarium (NY), the Smithsonian National Museum of Natural History (US), the Paris herbarium (P), Naturalis (L), Royal Botanic Gardens Victoria (MEL), Royal Botanic Garden Edinburgh (RBGE), Royal Botanic Gardens, Kew (K) and the Natural History Museum London (BM) good progress has already been made on the imaging of herbarium sheets and the results of several large scale efforts are already accessible. Digitisation efforts to date however have mainly focused on loose herbarium sheets that lend themselves well to rapid digitisation

]workflows (Thiers *et al.,* 2016). Bound herbarium volumes present a more complex challenge than that of loose sheets, but are as valuable in their own right, usually representing a single collector's effort in a time period or location, some volumes are historically important as even though they are pre-Linnaean, for example, the Hermann bound volumes and the Clifford Herbarium at NHM were used by Linnaeus to designate many new type specimens.

The NHM London has more than 650 bound herbarium volumes including the 265 herbarium volumes that make up the invaluable Sir Hans Sloane botanical collection. As part of the NHM London initiative to digitise its natural history collections the challenge of preserving and digitising historic herbarium volumes was addressed. Herbaria are experiencing rapid changes in the way collections are now managed and used: mass digitisation initiatives, focused either on entire herbaria or subsets of specimens, such as types, have revolutionised the way in which researchers are using herbarium collections (Carine *et al.,* 2018). There is an appetite for access to herbarium data, online open-access herbaria meets this, but digitisation speed lags behind, in part because we need innovation in techniques, tools and protocols for handling herbarium specimens. In this paper, we investigate the various methods of handling bound herbarium volumes and present a new tool: the flexible LEGO clamping system for herbarium volumes (Flecs), for holding open difficult to open folios.

Bound volumes can present a series of challenges for digitisation most of which are related to a combination of the volume binding, the fragile nature of individual folios and degradation and positioning of specimens. The same properties that make paper an appropriate mounting material (e.g. thin, stiff, breathable and with absorbing properties) also lead to inevitable conservation problems over time. The Samuel Browne collection that is bound in two volumes from 1692-1698 provides good examples of herbarium volumes that show the specific characteristics that are challenging to digitisation. The very limited opening of the volumes presents a specific challenge for both conservation, digitisation and research as access to the folios for inspection or for imaging is in many cases very restricted. The restricted opening and page drape of herbaria can in part also be explained by the volume binding itself. As is outlined by Conroy (1987) some of the problems faced with the use of extension guards with a stiff spine, which is what we see in Herbaria volumes, is that this binding type does not allow for the folios to drape properly when the book is opened (Conroy 1987).

The solutions currently used to secure folios of bound volumes during conservation and imaging were considered prior to designing a novel solution. The methods used on books such as glass plates that press the underlying folio flat for imaging or the application of suction for page fixation are not ideal as there are delicate botanical specimens on the folio and on subsequent folios that could be damaged. Two other options, the polyethylene strip and the snake weight that, at first, looked viable unfortunately were not appropriated due to either the fragile nature of the specimens or because of the acute angle at which the herbarium volumes need to be held at during imaging.

A polyethylene strip that is fastened over the edge of the folio is appropriate for folios where botanical material does not extend to the edge of the folio. However, if there is a risk of the polyethylene strip coming into contact with the specimens on the folio there is risk of damage much like when using the glass plate.

A snake weight is a versatile and commonly used tool during conservation and book scanning. The snake weight is a row of lead weights or lead shot in a cloth sleeve that can be folded, draped or spread across a folio to distribute weight where necessary to keep a folio secure. Herbarium volumes with very restricted opening however have to lie with the spine flat and the folios near vertical during imaging. In this position, the snake weight cannot be draped over the folios without also touching the edges of the underlying folios which might cause damage.

Other solutions such as leaded weights or general clamps were not considered usable as the upright position of the book meant that folios were always at an angle creating a downward slope unsuitable for solutions that required a horizontal surface to be stable without sliding or falling off. Another approach frequently used during examination of volumes is to work in pairs (one holding the folio and the other taking notes/studying). However, this option may not be practical most of the times and in such cases, the Flecs is an efficient and practical tool.

To be able to work on and digitise herbarium volumes with a restrictive opening it is important that the mechanism used:

- is easy to apply during repetitive digitisation
- can accommodate the variability in specimen position on the folio

- can accommodate the variability in the thickness of the herbarium volume as folios are turned
- has a way of providing a variable amount of pressure depending on the nature of the volume
- is stable when used and will not damage the herbarium specimen during use.

We believe that the Flecs tool presented here addresses the challenges described above and is a novel way to manage volumes with restricted opening. We feel this tool is worth presenting to peers, librarians and academicians with manuscripts, rare books and historic volumes and hope they will find this useful and practical.

**Material and Methods**

Critical to imaging herbarium volumes with a very restricted opening is achieving optimal imaging angles for the individual folios with specimens and associated data. The Browne herbarium volume spine and folios did not allow a proper spine throwback or folio drape to allow folios to settle when the book was opened. To alleviate these drawbacks a completely novel imaging setup with three innovative solutions was designed that together enabled us to achieve an image of folios from as optimal a view as possible.

*Camera positioning*

To allow for the individual variation in drape that the volume folios expressed, the imaging camera was placed on a 5 axis support arm allowing the camera to be placed as parallel to the folio to be imaged as possible thereby reducing the folio skew in the image taken (Figure 1).

*Spine pivot and adjustable book cradle*

To compensate for the spine stiffness a new book cradle was developed. The new book cradle features a free spine support that allows the independent movement of the spine thereby increasing the book opening without applying any external pressures (Figure. 2). The newly designed book cradle was further positioned on a turntable that made it possible to rotate the book to image the opposite folio.

*Flecs page clamps:*

Prototypes and the final mechanism were made using LEGO (Figure 3), a modular toy that lends itself exceedingly well to prototyping as well as

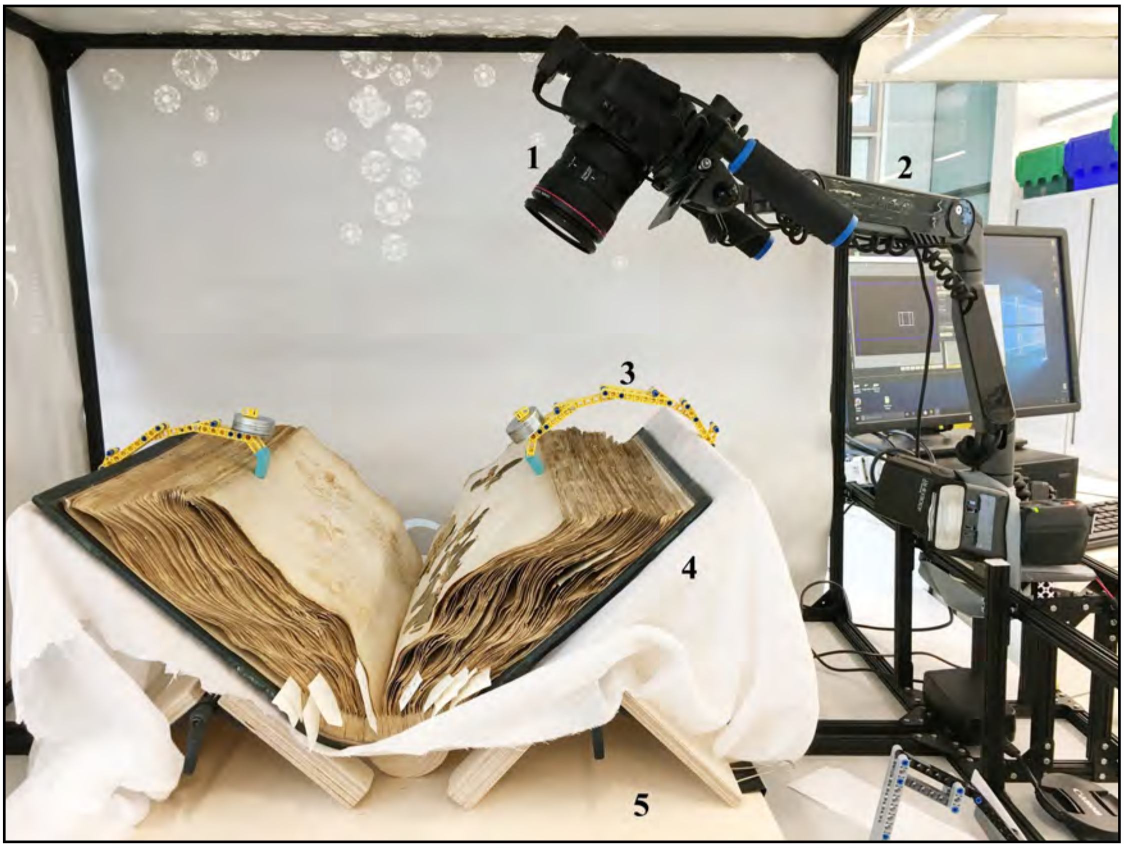


*Figure 1. The Herbarium Imaging Equipment (HerbIE) including DSLR camera (1), adjustable swivel arm (2), Flecs (3), Book cradle (4), and turntable (5).*

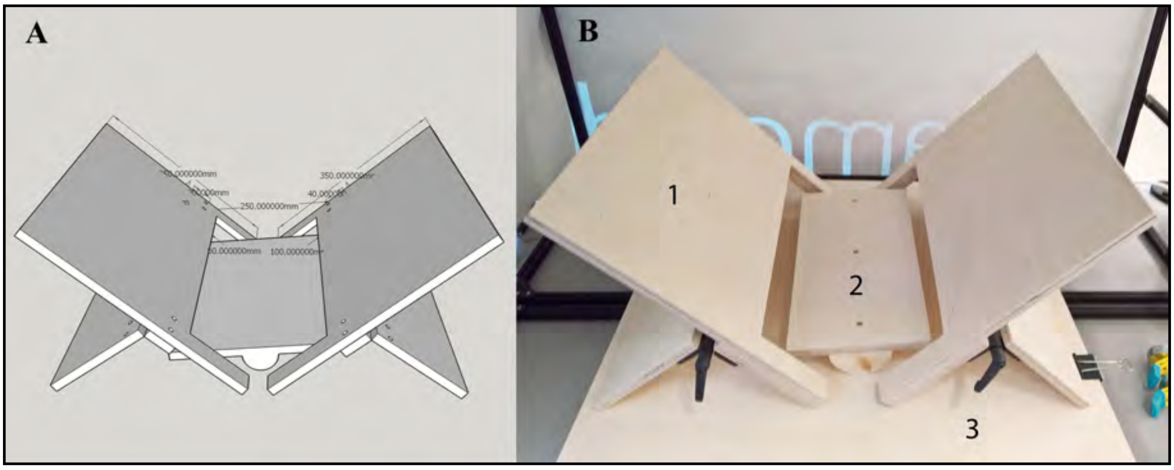


*Figure 2. Herbarium volume cradle schematic (A) and actual model (B) including the book cover supports (1) tilting spine support (2) and a turntable base (3)*

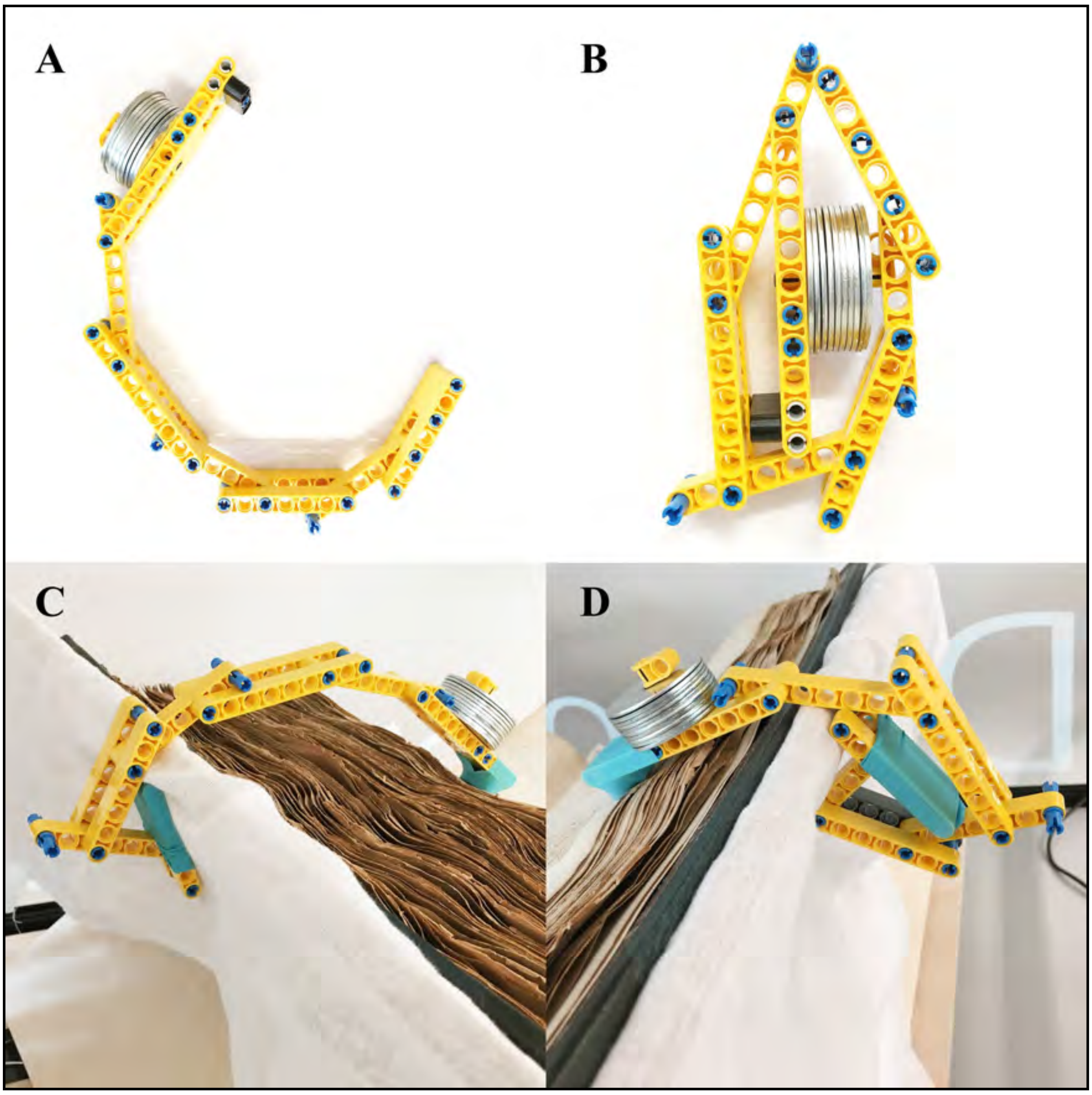


*Figure 3. The Flexible LEGO clamping system (Flecs) shown in a fully extended position (A), compact position (B) and in two various clamping positions as used during imaging (C and D).*

final product production (Dupont *et al.*, 2015). LEGO is made of acrylonitrile, butadiene and styrene (ABS) that is a hard durable plastic with good chemical resistance (Rutkowski and Levin, 1986) and was therefore not considered a risk to the folios or the specimens attached to them. In addition to the plastic LEGO bricks, 10 metal washers with M8 holes where used as weights and rubber sleeves made of lab grade rubber gloves were used to add friction to the mechanism. To finalize the design, create building instructions and generate a parts list the LEGO Digital Designer 4.2 (LEGO 2019) was used, the results of which can be seen in the supplementary material (Appendix 1). During the design process several curators and conservation technicians were regularly consulted on best practices for specimen handling as well as discussions of the use of materials that would come in to contact with the specimens.

**Results and Discussion**

The Flexible LEGO Clamping System (Flecs) is made up of 32 technic pieces with an estimated cost of £6 (https://www.lego.com/en-gb/service/replacementparts/sale). For the sake of the discussion below the joint that is placed on the herbarium volume page is called the head and the joint that overhangs the book cradle is called the tail (Fig. 3A-B). For a complete parts list and assembly manual for the Flecs (see Appendix I).

The mechanism was developed to emulate the versatility of the human finger and the way the fingers are used to hold open pages of a book by applying pressure and an outward directed frictional pull. To achieve both pressure and pull the Flecs was designed as a crescent that is rigid in its extended position, but collapsible at its six individual joints (Figure 3C). The location of the weights at the head ensures that, by changing the number of washers, a variable downward pressure can be applied while the crescent tail that overhangs the book cradle and the rubber sleeve at the head simultaneously produces an outward pull. The collapsible joints make it possible to adapt the Flecs to the varying distances between the herbarium volume cover and the open specimen folio (Figure 3D) depending on the position in the volumes of the folio being imaged. Furthermore, because the LEGO joints have enough friction to hold their positions, the Flecs can be shaped to lightly clamp the specimen folio and the book cradle thereby adding further stability.

The advantages of the Flecs when compared to currently used options is that the small footprint allows for the positioning of the mechanism on the folio even if specimens extend to the folio edge. The small footprint also ensures that no other area of the volume (including the edges of the underlying folios) are touched and this reduces the potential of damage during digitisation where the folios are turned on a regular basis and the securing mechanisms are repetitively applied.

There are several possible improvements that can be made to the proposed mechanism and the Flecs could be considered a prototype, but we believe the same argument used by Dupont *et al.* (2015) applies here. The Flecs is a solution to a problem using a globally available modular tool that is cheap and simple to build without further tools or modifications which opens up for further improvements and testing by the library and academic community.

**Acknowledgements**

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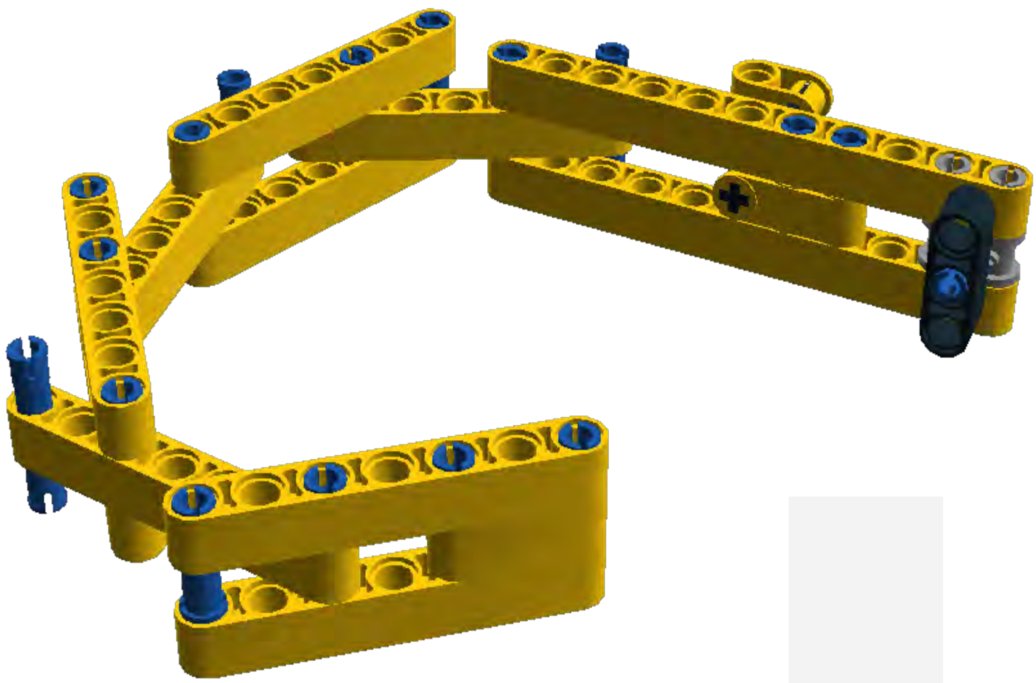
**Appendix 1:** for Flecs: a novel LEGO® tool for herbarium clamping.

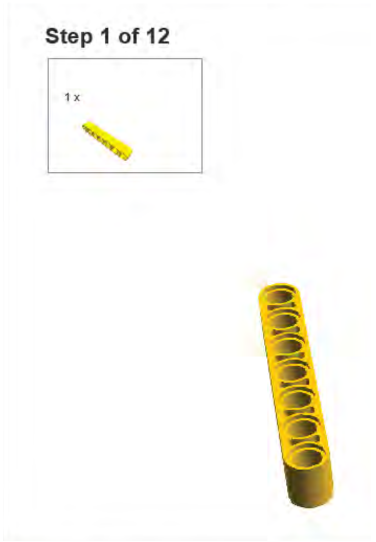
DIGITAL DESIGNER 4.2

Model name: Flecs
Number of bricks: 34

**Flecs finished model**



**Flecs components list:**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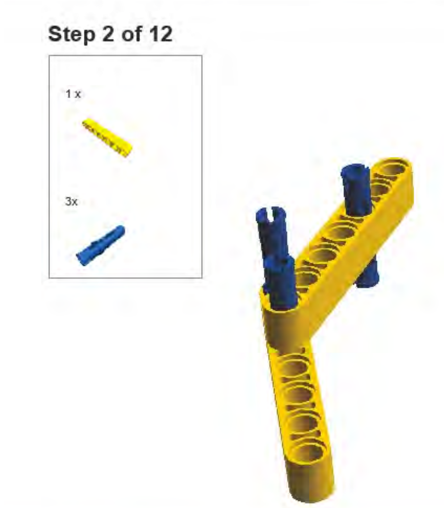
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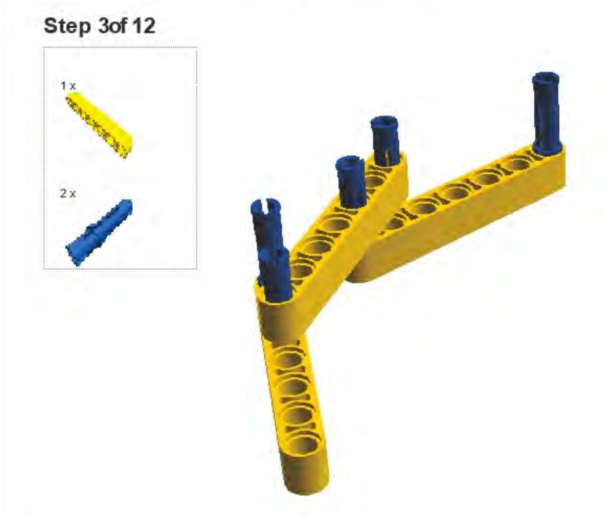
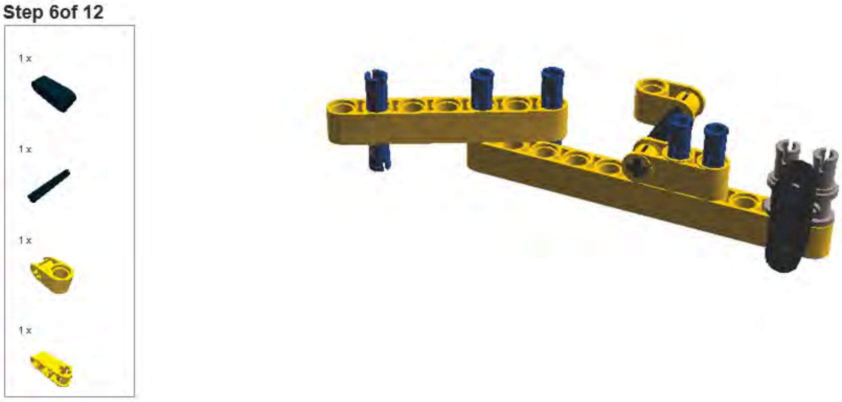
1 x
3x


Step 3of 12
1 x
2 x

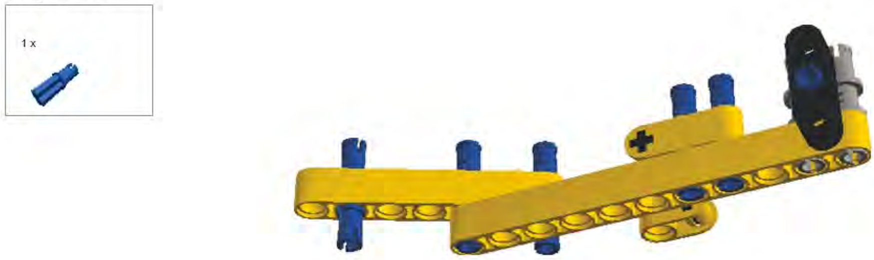

Step 4of 12
1 x
2 x
1 x

Step 5of 12

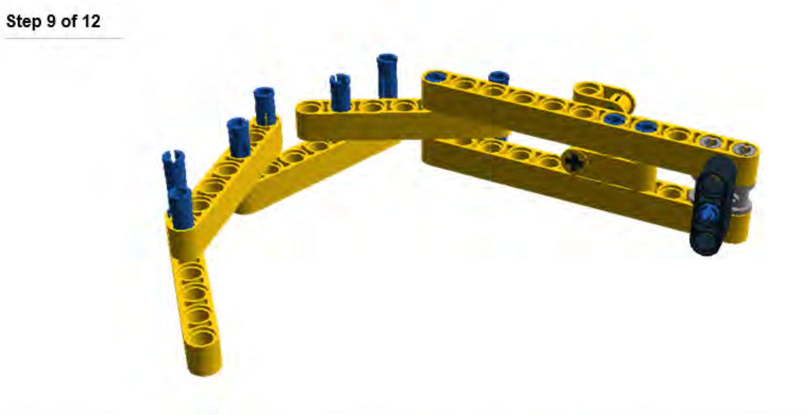

Step 6of 12

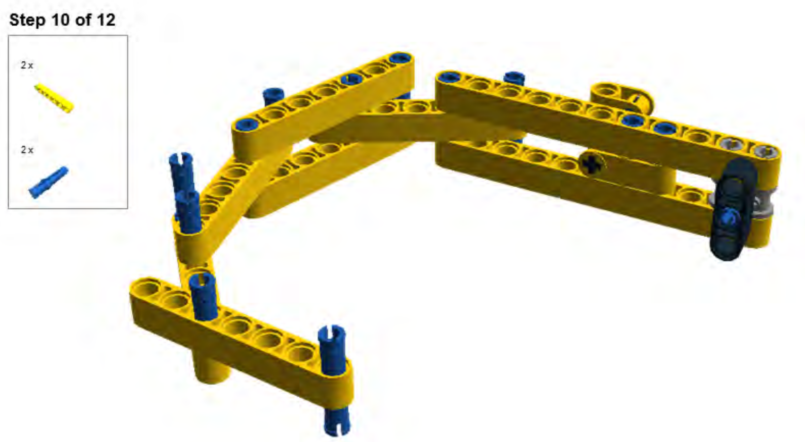


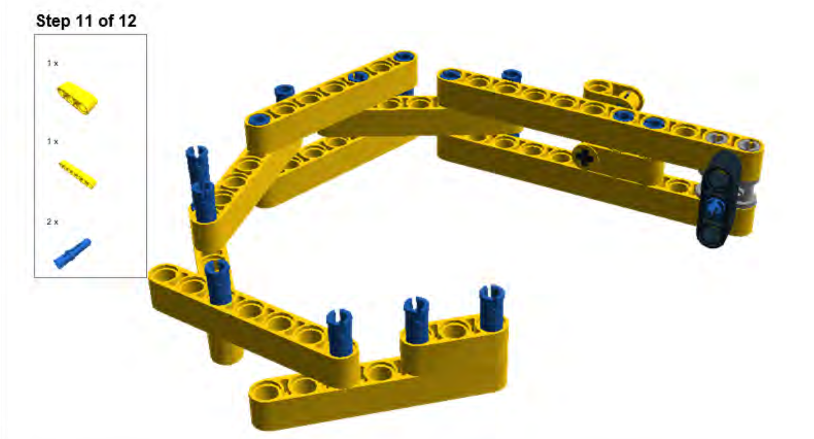

Step 7of 12




Step 8of 12


Step 9 of 12


Step 10 of 12
2 x
2 x


Step 11 of 12
1 x
1 x
2 x


Step 12 of 12
2 x
2 x

# *Anthrenus* species (Coleoptera; Dermestidae) found in UK museums with special reference to *A. museorum* Linnaeus, 1761, the museum beetle.

Graham J. Holloway[1*] and David B. Pinniger[2]

[1]*Centre for Wildlife Assessment and Conservation, School of Biological Sciences, The University of Reading, Reading, RG6 2AS, UK*

[2]*83, Westwood Green, Cookham, Berks SL6 9DE*

**Corresponding author: g.j.holloway@reading.ac.uk*

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**Abstract**

An important component of integrated pest management in natural history museums is the identification of pest insects. A small number of *Anthrenus* spp. can be encountered including *A. verbasci*, varied carpet beetle, and *A. sarnicus*, Guernsey carpet beetle. A species that would reasonably be expected to be found in natural history museums is *A. museorum*, museum beetle. However, the museum beetle is rarely, if ever, found indoors. A possible reason for this is provided. Identification of four *Anthrenus* spp. is considered including potential sources of confusion and levels of variation that need to be taken into account.

Key Words: *Anthrenus*, *Anthrenus museorum*, *Anthrenus verbasci*, *Anthrenus sarnicus*, IPM, pest management, carpet beetle.

## Introduction

Pest management is an integral part of day to day operations in many modern museums (Pinniger, 2015; Querner, 2015). Pest species, such as insects and mammals, can cause irreparable damage to museum specimens so it is essential to pay attention to where they come from, how to keep them out, how to deal with them if you find them. Different species of insect pests of museums have different life cycles; different origins, feed on different materials, and might be susceptible to different control methods. As a result of this, an essential component of integrated pest management (IPM) is to know your enemy, and this can only be achieved through accurate identification. Misidentification could result in inappropriate management mechanisms being put into place or spending resources on control when none is required.

Almost everybody working in the museum sector, in particular museums and heritage institutions housing natural history collections in the UK, will have heard of the varied carpet beetle, *Anthrenus verbasci* Linnaeus, 1767. In its natural environment, *A. verbasci* feeds on dead insects, skin, hair and other keratinous materials. Our own homes frequently contain an abundance of this type of resource derived from us, our pets, or dead insects in quiet corners, windowsills, attic rooms and so on. It is likely that *A. verbasci* and other species of Dermestidae have been associated with us for a long time (Woodroffe and Southgate 1954). In some types of museums *A. verbasci* is a major pest capable of destroying dried insect collections, stuffed animals, hair and woollen products.

One of the great challenges in museums housing these materials is to keep the building clear of dead insects, hair and dust (from visitors and staff) that can attract and maintain a population of *A. verbasci* even though the museum specimens might be free of the pest.

### *Anthrenus museorum* Linnaeus, 1761

*Anthrenus verbasci* is not the only *Anthrenus* species likely to be encountered in museums. One species that you might reasonably expect to encounter would be the museum beetle, *A. museorum*. The museum beetle is often quoted as a 'frequent and feared pest in museum collections' by eminent entomologists, a belief that has spread via electronic media (Háva, 2015). However, *A. museorum* is very rarely (if ever) found in buildings in the UK even though, again, it is often claimed to do so (Cooter, 1991; Háva, 2015). It has been proposed that it was once a pest in museums and has been superseded by other species (Peacock, 1993); we are not aware of any evidence to support this assertion. In fact, *A. museorum* appears to be quite a scarce species in the UK (NBN Atlas). This begs the question why Linnaeus named the species *Byrrhus* (later *Anthrenus*) *museorum* in the first place in 1761. In the middle of the 18th century there were very few natural history museums as we would recognise them today offering *A. museorum* very limited scope to achieve pest status in museums. However, many homes at the time housed curiosity cabinets which often contained natural history specimens. Perhaps it was here that *A. museorum* achieved notoriety. If this was the case it is odd that *A. museorum* is no longer a pest whilst *A. verbasci* clearly has pest status. *Anthrenus verbasci* was also described by Linnaeus in 1767. Perhaps it was realised that *A. verbasci* was the pest species but by then *A. museorum* had already been named and so the pest-status myth has persisted. There are records of *A. museorum* being collected from museums across continental Europe (Ackerlund, 1991); a critical examination of these records could be interesting.

### Identification of *Anthrenus* spp.

Reference to museum collections from the late 18th century, early 19th century indicates that entomologists appeared to have difficulty distinguishing various species of *Anthrenus* from each other (Holloway et al., 2018). The most likely species to confuse with *A. museorum* is *A. fuscus* Olivier, 1789. Holloway and Foster (2018) described how to distinguish *A. museorum* from *A. fuscus* (Figure 1). Both species are primarily covered in dark chocolate brown scales with similar distributions of golden coloured scales. With a stereo-microscope it should be possible to distinguish the segmented antennal club, characteristic of *A. museorum*, whereas *A. fuscus* has a single segmented club. An easier feature that can be seen with a simple hand lens is the distribution of patches of white scales on the elytra. Both species have three white spots close to the elytral suture ⅓, ½ and ⅔ the way of


*Figure 1. A:* Anthrenus museorum *(body length of specimen 2.9mm) and B: A. fuscus (body length of specimen 2.45mm). The white patches are particularly obvious in A. museorum. Images © Graham J. Holloway 2018*

along the elytra but *A. museorum* has bolder, larger spots. In particular the most anterior white spot is obvious in *A. museorum* but vague or even absent in *A. fuscus*. Also, *A. museorum* has an obvious spot white scales in the middle of the trailing edge of the pronotum; a feature not shared by *A. fuscus*.

We know very little about the natural breeding habitats of *A. museorum* and *A. fuscus*. It is possible that they live as larvae under loose bark on old trees feeding on carcases of insects caught by spiders. In any event, the discovery of a dark chocolate brown species of *Anthrenus* in a museum might not be cause for concern (although they sometimes appear in numbers in historic houses). Much greater threat comes from *A. verbasci* which is widely spread and abundant out of doors across the UK, in particular England and Wales. The identification of *A. verbasci* brings its own problems largely because, true to its name, its colour pattern is exceptionally variable (Figure 2 illustrates the range of colours and patterns that can be shown). This colour pattern range has clearly caused identification problems for entomologists for a very long time. For example, many of the *Anthrenus* spp. within Stephens' collection (late 18th, early 19th century) in the NHM, London, are incorrectly identified (Holloway et al., 2018). Examination of the characteristically narrow, lozenge shaped scales on the elytra of *A. verbasci* (Figure 4A) will confirm identification and should immediately distinguish the species from other candidates, including *A. museorum* and *A. fuscus*. The only other *Anthrenus* species that a museum worker is likely to come across is the Guernsey carpet beetle: *A. sarnicus* Mroczkowski, 1963 (Figure 3). This s pecies can cause considerable damage to natural history (e.g. taxidermy and insect collections), woollen and other specimens rich in keratin. Its colour pattern differs from *A. verbasci.* The scales on the back of the insect are a mixture of white, grey with some orange and the individual scales are much broader than *A. verbasci* and triangular shaped Figure 4B), a similar shape to *A. museorum* and *A. fuscus* but the body colour is very different.


*Figure 2. The range of colour patterns typically exhibited by* Anthrenus verbasci *(average body length of specimens 2.9mm). Images © Graham J. Holloway 2018*

*Figure 3. Adult* Anthrenus sarnicus *(British Museum, London, 2015) (body length of specimen 4.1mm). Image © Graham J. Holloway 2018*

Here we have considered the species of *Anthrenus* that could be found in museums. The degree of threat posed varies hugely among species. Accurate identification of any *Anthrenus* found in a museum setting is of great value when deciding on a suitable and cost-effective course of action. As always, IPM managers should remain vigilant and seek assistance if they are unsure of the identity of a specimen. New *Anthrenus* spp. are establishing themselves in the UK (Foster and Holloway, 2015). To date there is no evidence of any of these newly established species posing a threat, but the identity of any individuals trapped or collected during IPM activities should be confirmed and recorded (e.g. www.whatseatingyourcollection.com/recordings.php).

**Acknowledgements**

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A

B

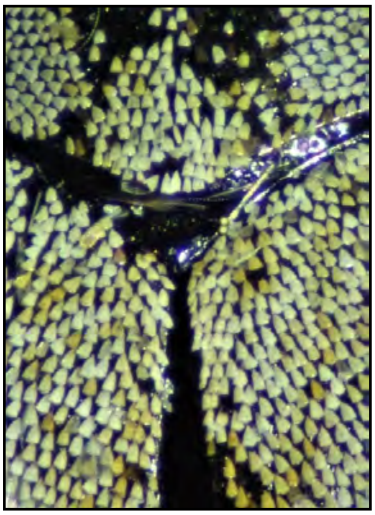

*Figure 4. A: shape of scales on the dorsal surface of* A. verbasci, *B: shape of scales on the dorsal surface of* A. sarnicus. *Image © Graham J. Holloway 2018*

# Cleaning Osteological Specimens with Beetles of the genus *Dermestes* Linnaeus, 1758 (Coleoptera: Dermestidae)

Yaneth Muñoz-Saba,[1,2*] Juan Carlos Sánchez-Nivicela,[2,3,4] Carol M. Sierra-Durán,[4] Juan Camilo Vieda-Ortega,[2,4] Germán Amat-García,[1] Ricardo Munoz,[5] Diego Casallas-Pabón,[2,6] and Nathaly Calvo-Roa[2]

[1]*Institute of Natural Sciences, National University of Colombia, Bogotá D.C., Colombia*

[2]*Evolution and Ecology of Neotropical Fauna Research Group*

[3]*Instituto Nacional de Biodiversidad del Ecuador, Pasaje Rumipamba 341 y Av. de los Shyris, Postal code 17–07–8976, Quito-Ecuador*

[4]*Biology Program, Faculty of Sciences, National University of Colombia*

[5]*University of La Salle, Bogotá D.C., Colombia, Neogen – Animal Safety, USA,*

[6]*Applied Biodiversity Foundation (ABF Colombia)*

**Corresponding author: adam.smith@nottinghamcity.gov.uk*

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**Abstract**

Within many biological collections around the world, it is known that *Dermestes* beetles are used in the preparation of osteological material, as part of the collection management protocols. Despite the fact that the use of these beetles is common, management so that the yield of a colony is optimal is not entirely clarified. In this study, we present the conditions and procedures in the management of a colony of dermestids in order to provide a standard system within the collections. The colony must be kept in an isolation infrastructure, under controlled conditions of temperature (23.26 to 28.54 °C), relative humidity (52.43%) and darkness. The material intended for osteological cleaning should be introduced into the colony without viscera, eyes, tongue, brain, skin, hair or feathers, and large areas of muscle. If the material is dehydrated or has been preserved with chemicals, these should be treated beforehand with distilled or deionized water (to rehydrate or wash, respectively). After the beetles remove all soft tissues, the material should be cleaned with ammonia to remove fat and beetle eggs. Subsequently, the skeleton or bones are dried at 40 °C. The dermestarium should be cleaned every two to three months to prevent the colony from decreasing due to contamination.

**Keywords:** Biological collections; beetles of the genus *Dermestes*; cleaning bones.

## Introduction

The identification of many vertebrate species, especially mammals and in some cases fish, amphibians, birds and reptiles, requires the examination and comparison of osteological characters (presence of canaliculi, grooves) that can only be studied with clean skeletons. Cleaning is one of the phases of curatorship in many scientific disciplines, including archeology and anthropology (Leeper, 2015). Even so, specimen cleaning is not always appropriate, since information is lost from bones, cartilage, muscles, tendons, veins, arteries. The decision to clean a skeleton should be based on the need to obtain information at the osteological level.

When any cleaning process is carried out, damage and instability to the osteological specimens may result, either by the reactions that occur between the reagents or water with the bones, proteins or minerals. Two principles should be followed-the "principle of least", that is, the process must be carried out in the shortest time possible and with the least amount of reagents; and the "principle of durability", which seeks to enhance the useful life of collections (Simmons and Muñoz-Saba, 2005a).

Due to the lack of protocols that clarifies the need to clean osteological specimens and specify the steps to follow and elements to be cleaned, specimen preparators, and taxonomists proceed according to their criteria or traditionally process, but not necessarily in the most suitable manner. An innovative way to clean bones is through the use of beetles of the genus *Dermestes* (Meeuse, 1965). However, there is little available data on their biology and the optimal environmental conditions for the maintenance of beetle colonies (Franco, *et al.*, 2001).

Simmons and Muñoz-Saba (2005a), and Leeper (2015) present the following considerations that must be taken into account to make a decision about the cleaning bones: (1) why is bone cleaning necessary?; (2) when a specimen should be cleaned?; (3) how a skeleton should be cleaned?; (4) how long will the cleaning process take?; (5) what information will be lost in the of cleaning bones?; (6) can the specimen support the procedure?; (7) what criteria allows choosing the best cleaning process?; (8) will the specimen remain stable after cleaning?; (9) how will the procedure affect the useful life of the specimen?; (10) what is the purpose of the specimen in the collection?; (11) are articulation or other elements required?; (12) how much fat is acceptable?; and (13) specimen bleaching?.

As curators, it is a great responsibility to maintain a dermestarium in optimal conditions to prepare the samples in the best way. This article establishes a protocol for cleaning osteological specimens with *Dermestes* beetles, essential in the curation processes of zoological collections, based on literature review and the authors' experience. The purpose of this publication is to clarify why the cleaning process must be carried out and the procedures to be performed, and thus avoid irremediable damage and loss of its information.

## Existing methods of cleaning bone material

Some traditional methods for cleaning bone material (Simmons and Muñoz-Saba, 2015b; Brito de Oliveira, 2018 and references cited therein) include:

1. Bacterial maceration—placing the specimens in cold water, with or without the addition of enzymatic detergents.
2. Bacterial maceration—placing the specimens in hot water, without the addition of enzymatic detergents.
3. Chemical cleaning with sodium hydroxide or potassium hydroxide, followed by immersion in a solution of ammonia or sodium perborate solution to neutralize the reaction.
4. Manual cleaning.
5. Cleaning with proteolytic enzymes (specific proteins: papain, pepsin, trypsin) (Offele, *et al.*, 2007; Leeper, 2015).
6. Cleaning with organisms—larvae of the genus *Dermestes* (Dermestidae: Coleoptera) (Hall and Russell, 1932; Borell, 1938; Tiemeier, 1939; Russell, 1947; Meeuse, 1965; Sommer and Anderson, 1974; Hefti, *et al.*, 1980; Valcarcel and Johnson, 1981; Williams and Rogers, 1989; Jannett and Davies, 1993; Franco, *et al.*, 2001; Simmons and Muñoz-Saba, 2005b; McDonald, 2006; Offele, *et al.*, 2007; Leeper, 2015); isopods (Isopoda: Malacostraca) (Maiorana and Van Valen 1985; Warburg, 1993); mealworms (Allen and Neill, 1950); clothes moth larvae (Banta, 1961); and crabs (Sealander and Leonard, 1954).
7. Composting and burials (Leeper, 2015).

Maceration in hot water or cleaning skeletons with enzymatic detergents or chemical products (such as hydrogen peroxide or carbon tetrachloride) are common practices, but they are not recommended because they may damage the bone, causing porosity and deterioration over time. It is possible that these techniques affect not only the soft tissue but also the morphology and molecular integrity of the bone tissue, therefore, information loss may result. Preferred cleaning methods include maceration in cold water (without detergents), and cleaning with biological organisms (Simmons and Muñoz-Saba, 2005b; Offele, *et al.*, 2007; Leeper, 2015).

Beetles of the genus *Dermestes* are the main organism used for cleaning bones in biological collections. The advantages include: (1) less monitoring time required (Russell, 1947, Hooper; 1950; Brito de Oliveira, 2018); (2) the articulation of the skeleton can be maintained if the specimen is removed before the cartilage is ingested or of the ligaments joining the phalanges and some small bones (e.g., sesamoid) are not consumed in their entirety (Leeper, 2015); and (3) the deterioration of the bone tissue is minimal, which allows research at the molecular level. Other processes cause the DNA to be degraded by hydrolysis and oxidation (Arismendi, *et al*., 2004; Offele, *et al*., 2007 Leeper, 2015).

*Problems with cleaning with Dermestes*

Cleaning with beetles of the genus *Dermestes* is complex, and when the colony is not at its peak of activity it may be considered to be an inefficient method as it takes days or months to complete the process (Leeper, 2015), while other methods require only hours or days (Thompson and Robel, 1968). The colony must be maintained in a location away from the biological collections in order to prevent the beetles from escaping and infesting the collection.

The maintenance of the colony can also be a common problem, as the population may suddenly decrease in numbers, probably due to variations in environmental conditions; therefore, the dermestarium, must provide appropriate conditions of temperature, humidity and light (Sealander and Leonard, 1954; Leeper, 2015; Mori, 1979).

Unlike other methods of osteological preparation, the process carried out with beetles does not end when the specimens are removed from the colony- the bones must still be degreased, especially in animals with large bones that remain yellow and produce a strong odour (Hamon, 1964), for example, species of orders Artiodactyla, Carnivora, Cetacea, Cingulata, Perissodactyla, Pilosa, Primates, Rodentia (Hystricomorpha), Sirenia. Controlling the amount of time that the material is in the beetle colony is fundamental, because the bones may be damaged by dermatosis (the ingestion of bony tissue by the beetles). Special care must be taken with thin bones, because the beetles tend to make small holes in bones in order to reach the marrow (Leeper, 2015). The beetles may cause the roots of teeth to become translucent as they remove the pigment from dental plaque (Offele, *et al*., 2007).

## Results

*Dermestes Linnaeus, 1758 (Coleoptera: Dermestidae)*

The beetles of the genus *Dermestes* measure between 2 and 12 mm as adults and 7 mm in the larval stage. The coloration is dark with yellow or white patterns. The adults are photophobic and prefer warm, humid, and dark environments (Russell, 1947; Valcarcel and Johnson, 1981; Muñoz -Saba and Simmons, 2005; McDonald, 2006). Dermestids are characterized by four stages of development: egg, larva, pupa, and adult. They have a development time of about 45 days. The larval stage is the longest (30 days), characterized by rapid growth and high consumption of food. Larvae ingest more soft tissue than adults (Leeper, 2015). The pupa has a duration of one week. Five days after the adult's emergence, the females begin laying eggs, reaching an average of 426 in 100 days (Russell, 1947; Valcarcel and Johnson, 1981).

The species of beetle used for the cleaning of bone material in the Zoological Collections of the nstitute of Natural Sciences (ICN) of the National University of Colombia is *Dermestes carnivorus* Fabricius, 1775, which reaches 7 to 8 mm in adult stage, has elytra with fine yellow hairs, albino pubescence in the abdominal sternites, and two marked areas of black hairiness in the fourth abdominal sternite. Sexual dimorphism is manifested by the presence in males of a pubescent tuft in the middle of the abdominal sternite room (Delobel and Tran, 1993) (Figure 1).

Environmental requirements for *Dermestes carnivorus* are shown in Table 1. At higher temperatures, the beetles become dehydrated (Valcarcel and Johnson, 1981), and at lower temperatures the population size decreases (Hefti, *et al*., 1980); If the beetle colony is maintained at high temperatures, individuals will disperse to cooler microclimates (McDonald, 2006), generally under the specimens to be cleaning and in the deepest of the dermestarium.

The dermestarium must be able to maintain the correct level of relative humidity (Valcarcel and Johnson, 1981), this will allow the proper development of the colony. A Very high relative humidity causes the growth of mold and bacteria, which are harmful to both pupae and larvae (Meeuse, 1965; Williams and Rogers, 1989). Providing a dark environment is another important factor because the beetles are phototropically negative (Valcarcel and Johnson, 1981; Muñoz-Saba and Simmons, 2005; Leeper, 2015), therefore, the activity is affected by this.

The environmental conditions of the room where the colony is located are affected by the temperature and relative humidity of the external environment (Leeper, 2015), therefore, it is recommended follow the proposal of Simmons and Muñoz-Saba (2005c), referred to as the theory of enclosures, based on the fact that it is easier to control the environmental conditions of a small enclosure (a microenvironment) than in a large room. The proliferation of beetle frass and the

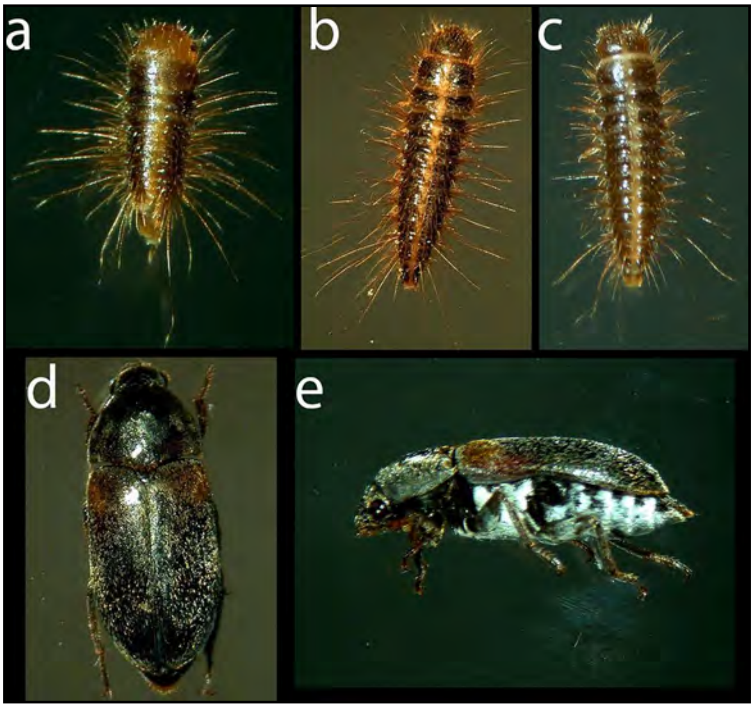


*Figure 1. Dermestes carnivorus Fabricius, 1775. The different stages of larvae development: (a) stage I; (b) stage II; (c) stage III; and adults in (d) dorsal view, and (e) lateral view. The diagnostic characters are highlighted. Image: Yaneth Muñoz-Saba, 2019*

presence of deteriorated inorganic material should be avoided. In general, conditions that are ideal for pests result in a considerable reduction of the beetle colony.

*Diet*

Dermestids consume primarily carrion and vegetable and animal fibers such as skin, meat, fish, hair, horn, and wool (Russell, 1947; Valcarcel and Johnson, 1981). The beetles prefer muscle tissue (because it is a source of protein) over tissues that are denser in collagen, which they tend to ingest only after the muscle tissue has been consumed (Leeper, 2015). Larvae eat bones, wool, silk, skin, feathers, leather, glue, and cellulose-based textiles; adults also consume nectar, and pollen, particularly from white flowers (Muñoz-Saba and Simmons, 2005).

*Reproduction*

In order to promote egg production, the ambient humidity and the amount of fat available to the colony must be carefully regulated. Some fat must remain in the carcass to be cleaned as about 15% fat is necessary for a balanced diet (Valcarcel and Johnson, 1981), without which the beetles are smaller and lay fewer eggs (Russell, 1947). Most dermestid species thrive in relative humidity of about 52.43% (Table 1).

Although a high number of adult beetles are required to maintain a functioning colony for breeding purposes, the growing larvae consume the greatest amount of food and are the most important bone cleaners (Hall and Russell, 1932).

| References | Temperature (°C) | |
|---|---|---|
| | Minimum | Maximum |
| Hall and Russell, 1932 | | 28.88 |
| Hefti, et al., 1980 | 22.00 | 28.00 |
| Leeper, 2015 | 20.80 | 30.20 |
| Meeuse, 1965 | 28.00 | 30.00 |
| Muñoz-Saba, obs. pers., 2003 | 20.01 | 26.31 |
| Russell, 1947 | 21.11 | 29.44 |
| Sommer and Anderson, 1974 | 27.00 | 29.00 |
| Valcarcel and Johnson, 1981 | 23.89 | 26.67 |
| Average | 23.26 | 28.54 |

*Table 1. Environmental conditions required by Dermestes.*

## Colony Infrastructure

*Building*

To avoid inadvertent contamination of to the collections, the beetle colony should not be kept in the same building as the collections. The space where the colony is located should be equipped with an air extractor (to reduce the odor from the colony), an oven, several terraria, and a flat bench for the curation of the material (stainless steel is preferred), with a stainless-steel pot for washing (Figure 2).

*Top*

The lid of the dermestarium or cabinetry must seal completely so that no beetles can escape (Valcarcel and Johnson, 1981), and be equipped with a pair of external aluminum handles on the upper surface (about 7 cm from the widest part and 11 cm from the mesh) to facilitate removal (Figure 2d). For example, in a dermestarium that measures 52.30 cm long, 36.20 cm wide, and 25.50 cm high, the lid should be 51.00 cm x 34.80 cm with a hole 13.00 cm in diameter in the center, covered with 1.0 mm stainless steel mesh and attached with silicone (Figure 2f).

*Substrate*

Each dermestarium should contain a small dish of water about 100 mm tall, located in one corner, covered with gauze that is attached to the dish with an elastic band to prevent the beetles from falling in and drowning (Valcarcel and Johnson, 1981). The water in the dish provides the necessary humidity for the maintenance of the colony (Figure 2e). If a water dish is not included inside the dermestarium, use an atomizer to spray water on the specimens to keep the tissues soft (Leeper, 2015). The walls of the dermestarium should not be sprayed, as this is ineffectual (because the water evaporates quickly), does not moisten the cotton, and the glass sides will remain humid and attract fungi (Sommer and Anderson, 1974).

The substrate inside the dermestarium should be composed of sheets of acid free cotton fiber (Valcarcel and Johnson, 1981). The use of loose fabric is recommended to allow aeration and to permit the frass to fall to the bottom of the dermestarium and thus avoid staining the specimen that is being cleaned. The use of gauze (100% cotton) is not recommended, because its mesh allows the larvae and pupae to pass through, and emerging

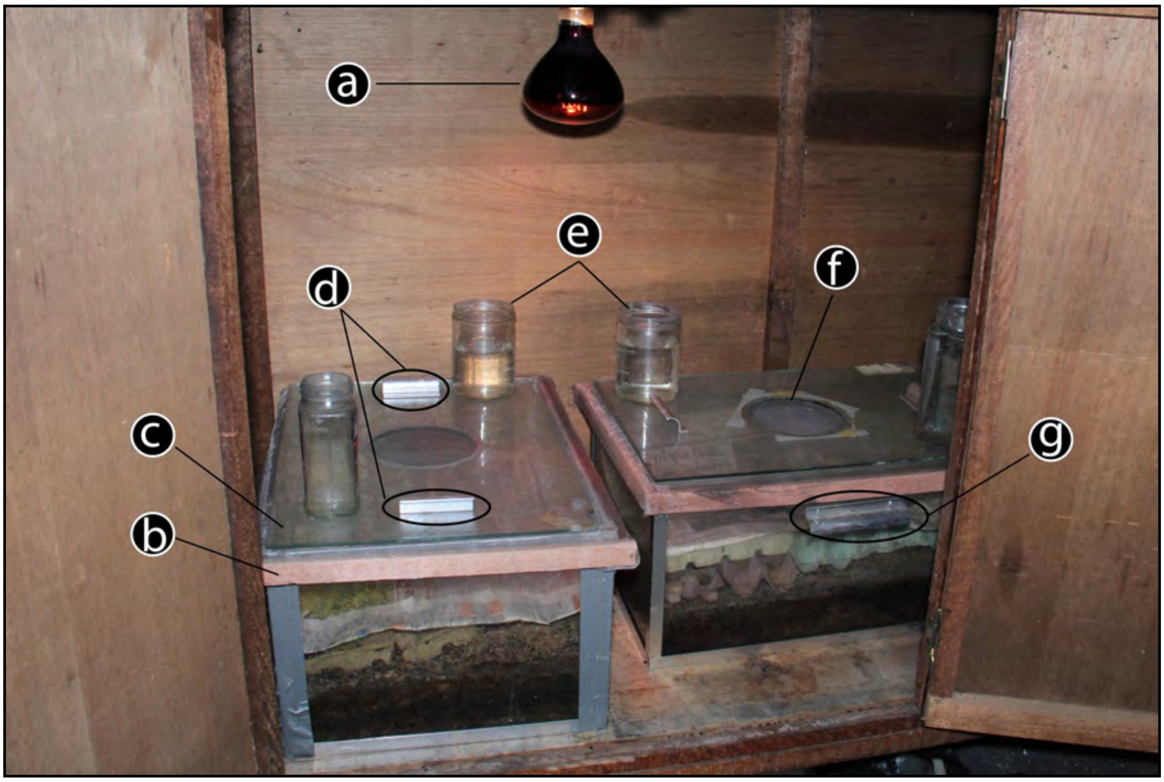


*Figure 2. Area with dermestarium where the Dermestes colony is located. (a) UV lamp; (b) safety frame lined with metal mesh; (c) glass lid; (d) glass lid handles; (e) jar with water; (f) ventilation hole in glass cover; (g) dermestarium handles. Image: Juan Carlos Sánchez-Nivicela, 2019.*

adults will become trapped in it. The cotton layer should have a thickness equivalent to one quarter of the height of the dermestarium to provide a suitable place to house eggs, larvae, and pupae (Sommer and Anderson, 1974) (Figure 3a).

*Container where the material is located*

Each specimen to be cleaned should be placed in a corrugated cardboard container in which the larvae can pupate (Tiemeuer, 1939) (Figure 3c, d). The use of metal or Plexiglas containers (PMMA, Polymethyl methacrilate) has also been proposed (Valcarcel and Johnson, 1981), but these materials do not provide the correct conditions for the pupae. Containers of synthetic material are not advisable because they cannot harbor pupae and may be consumed by the beetles, causing probable intoxication and subseqent death. The containers should not be removed from the dermestarium because if so, the pupae will be lost. When the containers deteriorate, they should be disposed of after being carefully inspected with a magnifying glass for pupae; when pupae are found, they should be placed in another container, not in the cotton, so as not to vary their environmental conditions excessively.

*Cleaning the dermestarium*

1. Remove the cotton substrate from the dermestarium and dispose of it in a bag labeled as biological waste. The fragments of cotton should be examined meticulously for pupae and eggs with a magnifying glass. Transfer the adults, eggs, larvae and pupae to another clean dermestarium to avoid reducing the population size (Valcarcel and Johnson, 1981).
2. Wipe the inside of the dermestarium with a clean, dry cloth to remove organic matter and dust.
3. Wash the inside of the glass with warm water (23-25 °C), applied evenly with a clean cloth.
4. Use a non-foaming alkaline detergent that does not contain chlorine, applied evenly with a clean cloth.
5. Wait five minutes.
6. Scrub the inside of the dermestarium with a clean cloth to better incorporate the detergent and act on organic matter and biofilms.
7. Wait five minutes.
8. Rinse away the detergent with warm water (23-25 °C) until no residue remains.
9. Allow the dermestarium to dry completely at room temperature.

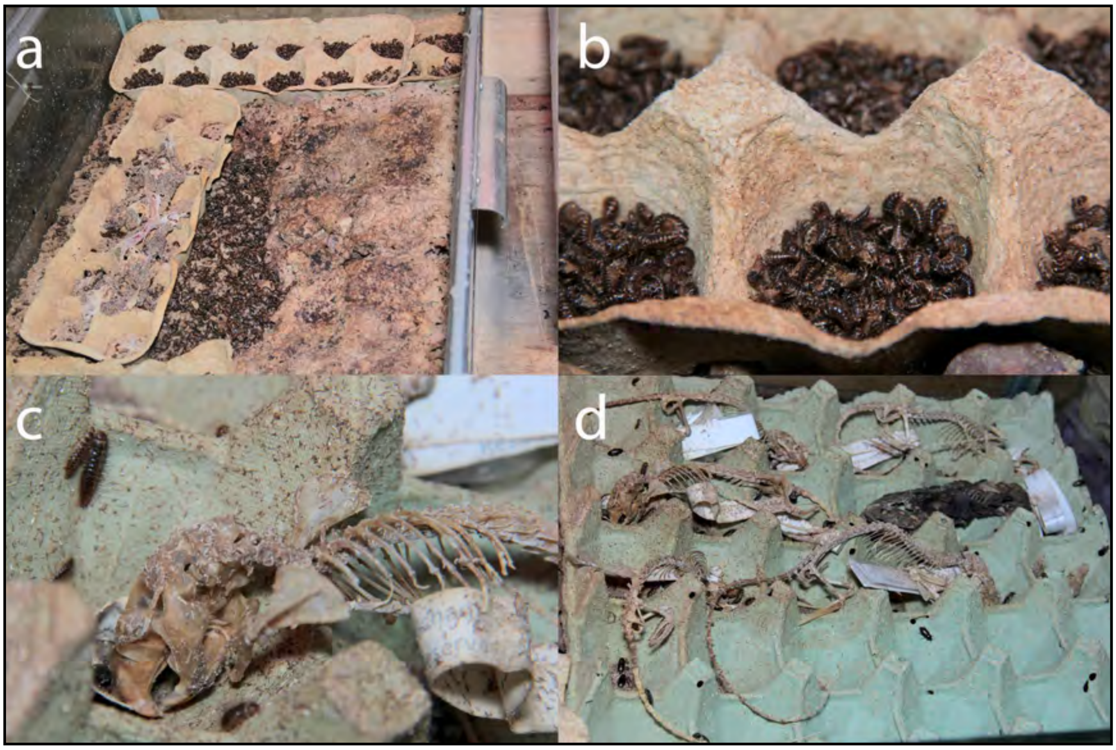


*Figure 3. Inside view of the dermestarium: (a) Substrate and corrugated cardboard containers; (b) dermestid larvae in the substrate; (c, d) larvae and adults of dermestid beetles feeding on the remains. Image: Juan Carlos Sánchez-Nivicela, 2019.*

10. Apply a disinfectant that does not contain chlorine, iodine, or alcohol. A disinfectant based on quaternary ammonium, acids, or hydrogen peroxide should be used.
11. Allow the dermestarium to dry for 48 hours at room temperature.
12. Carry out a final wash with distilled or deionized water if a strong odor remains.
13. Allow to dry for 48 hours at room temperature.

*Curation of specimens while undergoing cleaning*

Protect specimen tags and labels by covering them with transparent tape (e.g., Tesa® magic tape, Bezt®, Scotch®) or by enclosing them in a Mylar envelope that is taped shut around the string of the tag. Tags and labels are generally made of materials that the beetles will consume so they may be damaged (resulting in information loss). To the specimens that undergo the process of the solution of concentrated such as chicken broth, beef broth, or fish broth, must be protect yours the labels by covering them with transparent tape and a resealable polyethylene or polypropylene bag; at the end of this process the bag is removed (the broth dilutes the adhesive of the tape). Original labels should not be discarded no matter how badly damaged they are, but rather protected with a covering of inert plastic (e.g., polyethylene or polyester). The information from damaged labels should be transcribed on a new, acid-free paper label (Simmons and Muñoz-Saba, 2005a). All specimens being skeletonized should be labeled (McDonald, 2006). If a specimen does not have any information associated with it prepare a label using good quality acid-free paper and a technical pen with black carbon ink. The label should include the letters NN and the specimen should be assigned a number. Attach labels to the specimen before beginning the cleaning process, using a soft thread.

*Determine how the specimen is preserved: e.g., fresh, dehydrated, or in alcohol or formaldehyde*

It is necessary to know if the samples were stored in a reagent, to define the procedure prior to the entry of the specimens into the dermestarium. If they are not carried out, the population of *Dermestes* will decrease considerably.

*Freshly preserved specimens: fresh material*

1. Extract the internal organs from the specimen, including the tongue, eyes, brain, viscera, skin, hair, or feathers (Borell, 1938; Tiemeuer, 1939; McDonald, 2006) with care to avoid damage to the bony cavity. These tissues should be removed to avoid contamination from decomposition and subsequent degradation (Williams and Rogers, 1989) and to speed up the cleaning process. The carcass need to be skinned.
2. Make incisions in the muscle masses to provide easy access for the larvae and adult beetles.
3. For large vertebrates separate the skull at the second cervical vertebra (C2-axis) to avoid breaking the occipital. This allows the beetles to easily enter the vertebral column and cranial cavity.
4. Place the specimen in a corrugated cardboard container and set it in the dermestarium. Each specimen should be placed in a separate container to avoid mixing of skeletal elements. In some cases, small parts or small bones may become detached from the specimen and may be moved about by beetles. If the specimen is located directly on the cotton, the small bones that become loose or break off (or even small skulls) may be lost in the cotton (Figure 3d).
5. Check the colony 24 hours after introducing the new material to be cleaned, and again after that at least once every 48 hours. The length of the cleaning process depends on the size of the specimen to be prepared and the activity level in the colony. Small specimens (e.g., skulls of birds, bats, shrews, mice) should be examined daily in an active colony to avoid damage to small bones such as the hyoid or the nasal cartilages, which are important characters for the identification of species (Carleton, 1980; Griffiths, 1982; Weissengruber, 2002; McDonald, 2006). Larger specimens may be checked less frequently.
6. Take the small and medium skulls by hand, approach them to the light bulb, between 5 to 10 seconds, with the purpose of skull heating, the larvae migrate from the narrow structures. With fine-tipped forceps, the larvae are collected and locate in the aquarium.
7. Extract the specimens from the beetle colony when the bones are clean but before they are disarticulated (McDonald, 2006) (Figure 4a, b).
8. Place the cleaned specimens individually in heat-resistant glass jars. Using a plastic funnel, add to each jar a solution of one part 40% ammonia and four parts of distilled or deionized water (Russell, 1947). If necessary, turn the skulls using fine-tipped forceps to allow the ammonia to enter through the foramen magnum so that the skull will submerge. The specimens should be left in the ammonia for 3 to 6 hours to eliminate eggs, larvae, and pupae of beetles that are inside the specimens. The fat present in the specimens,

especially in long bones, is also reduced or eliminated with this procedure (Tiemeuer, 1939; McDonald, 2006).

9. Extract the bones from the ammonia and filter the contents of the jar through a plastic funnel containing four overlapping layers of clean gauze to collect small, loose bones. This procedure must be performed very carefully; search for small bones with the help of a magnifying glass (Figure 4a).
10. To eliminate the ammonia and its odor, wash the jar, fill it with distilled or deionized water, and place the bone material in the jar for 12 hours. Then and filter it again to locate any small bones that have become loose.
11. Change the water again and repeat after 12 hours.
12. Check the specimen for remnants of muscle or tendons—if any remain, remove them carefully using fine-tipped forceps.
13. Gently wash the bones with a soft bristle brush using slight circular movements. Use particular care with small bones (e.g., the hyoid). Rinse the bones with distilled or deionized water (Meeuse, 1965). This procedure is carried out to remove adherent grease and dirt that can lodge in cracks and rough surfaces, especially on large specimens (Sommer and Anderson, 1974; Leeper, 2015). The fat could later attract collection pests.
14. Verify that there are no larvae or adult beetles among the bones. If any are found, extract them using fine-tipped forceps, being careful not to damage the specimen (Borell, 1938). The larvae may lodge in the cranial cavity, the neuronal channels of articulated skeletons, or any other small cavity or crevice. It is important to make sure that the beetles, in all their stages, are eliminated from the bones. Any remaining live beetles will continue to feed on the bones (McDonald, 2006), and dead beetles will become food for other pests. Only those remnants of *Dermestes* located in completely inaccessible places (e.g., deep in the nasal turbinates, inside the tympanic bullae) may not be eliminated because the preservation of the specimen is prioritized and trying to remove them would cause too much damage to the bones.
15. Place the cleaned specimen in a heat-resistant glass jar. Dry it for 24 to 48 hours, depending on the size of the animal, in an oven at a temperature of 40 °C (Sommer and Anderson, 1974).
16. Remove the specimen from the oven, allow it to cool, and then remove it from the jar.
17. Remove and discard the string attached to the labels. Labels usually become separated from specimens during the cleaning process, and


*Figure 4. Osteological specimens: (a) Individuals recently removed from the dermestarium (left), bone collection (center) and storage process (right); (b) Individuals medial size (left) and small size (right) after the cleaning process; (c) Skulls totally clean (include degreasing process) in medial size (left) and small size (right). Image: Juan Carlos Sánchez-Nivicela, 2019.*

the remaining string may become food or a niche for collection pests (Muñoz-Saba and Simmons, 2005).

18. Store the specimen with its tags and labels in a resealable polyethylene or polypropylene bag the size of appropriate size, or in a rigid polystyrene or acid-free paper box (Figure 4a).

*Dehydrated specimens*

Dehydrated specimens may be placed individually in heat-resistant glass jars that are filled with distilled or deionized water and left for 24 hours to rehydrate, then processed following steps 3 to 19 above.

*Specimens preserved in fluid, with chemicals, or otherwise contaminated*

Specimens that are in a fluid preservative (e.g., formaldehyde or alcohol), that have been contaminated with chemicals such as borax or phenol, or are contaminated with fungi or other organisms must be cleaned before processing. Place such specimens in individual heat resistant glass jars and immerse then in distilled or deionized water for 24 hours (Meeuse, 1965). After processing as described in step 3 above, the specimen may need to be coated with animal fat or vegetable oil to make it palatable to the beetles (Laurie and Hill, 1951; Hooper, 1956). Alternatively, the specimen may be treated with a concentrated solution made with cubes of instant broth that has been allowed to cool, this reduce the cleaning time of chemically preserved osteological material, and also facilitated dermestid cleaning of a maggot-contaminated specimen (Nicholson and Smith, 2010). Submerge the specimen in the cooled broth for 12 hours, then dry in an oven for 6 hours at a temperature of 40 °C, then process through steps 4 to 19 above.

*Considerations to the process*

To minimize the dehydration of tissues, it is recommended that specimens to be cleaned should not be dried prior to placing them in the dermestid colony (Valcarcel and Johnson, 1981), with the exception of specimens previously preserved in fluid or otherwise chemically dehydrated. Specimens that are not completely cleaned despite being exposed to the dermestids for a long time should be isolated to force the larvae to eliminate the remaining traces of tissue (Borell, 1938). Fresh specimens should not be added to a dermestarium once the processing of other specimens has begun as the beetles tend to prefer fresh material.

Should the beetle colony decrease considerably, a piece of meat with fat should be added to encourage the beetles to pupate (Borell, 1938; Russell, 1947; Meeuse, 1965). When the colony is not checked frequently (e.g., on weekends or holidays) a piece of meat with fat wrapped in moist cotton may be added to the dermestarium to provide an adequate nest for the eggs and pupae; this will ensure that the colony has enough soft tissue for the larvae, but keep in mind that the beetles will abandon older osteological material for fresh meat (Leeper, 2015).

If treating the cleaned bones with ammonia (steps 9 to 19) cannot be carried out immediately, the specimens should be placed in a resealable polyethylene or polypropylene bag and frozen to a temperature of -18 to -20 °C (McDonald, 2006).

*Specimen history*

All procedures and processes carried out during the preparation of osteological material by *Dermestes* beetles (hydration, elimination of chemicals, cleaning, degreasing, drying) should be recorded as part of the permanent specimen record (e.g., in catalogs and databases). This information is important because how specimens are prepared often affects their use in subsequent research (e.g., DNA sequencing).

*Cleaning time*

Under ideal conditions, an active dermestid colony can be expected to clean fresh small skulls and skeletons in three to ten days (Tiemeuer, 1939; Meeuse, 1965; Hefti, *et al*., 1980; Leeper, 2015). Large specimens and those that have been dehydrated or subjected to some chemical treatment will require more time (Meeuse, 1965), as much as 20 to 30 days. The length of time required in the dermestid colony depends on (1) the condition of the colony (2); how the specimen is preserved (fresh, dehydrated, in fluid); (3) the size of the specimen; and (4) the amount of tissue to be removed (Meeuse, 1965).

The useful life of a colony is two to three months before the accumulation of larvae and frass reduce its efficiency to a very low rate (Meeuse, 1965), this depend of use and of care. Because of this, it is necessary to clean the terraria and transfer the adults, larvae, pupae, and eggs to two other terraria every two or three months.

## Risks of working with beetles of the genus *Dermestes*

The following considerations must be taken into account when working with colonies of beetles of the genus *Dermestes* and when cleaning osteological material:

*Diseases*

Direct contact with the larvae should be avoided because shed hairs and frass may cause skin allergies (e.g., contact dermatitis). The frass may also cause irritation of the respiratory tract (Tiemeier, 1939; Meeuse, 1965; Simmons and Muñoz-Saba, 2005).

*Pests in Collection*

*Dermestes* beetles are a common pest in biological collections, where they feed on a wide variety of materials, especially skins, feathers, hair, wood, paper, wool, silk, and dried fruits (Muñoz-Saba and Simmons, 2005). Therefore, care must be taken to avoid dermestid infestations in the collection (McDonald, 2006).

*Biosecurity*

Due to the biological risk incurred in cleaning osteological material with beetles of the genus *Dermestes*, the following precautions should be taken:

*Personal protective equipment*

Industrial coveralls should be worn to prevent clothing from becoming impregnated with the odors that are produced in the process as well as contamination from insect frass. Use of a long-sleeved lab coat (preferably disposable) is recommended, as well as the use of a nylon head covering, safety glasses or goggles, a well-fitting dust mask, and nitrile gloves.

*Biological and chemical residues*

The Biosecurity Protocols for Biological and Chemical Residues established by each institution must be followed.

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# Weep no more: conservation of an iron-nickel meteorite from Canyon Diablo, Arizona

Lu Allington-Jones

*The Natural History Museum, Cromwell Road, London SW7 5BD*

*Email: l.allington-jones@nhm.ac.uk*

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**Abstract**

This article documents the treatment of a fragment of the asteroid that created the Barringer meteor crater, officially known as the Canyon Diablo Meteorite. This includes investigations into the condition of the specimen, evaluation of techniques used in meteorite and archaeological iron conservation, and the eventual treatment with tannic acid of an NHMUK specimen.

**Keywords:** meteorite; conservation; iron; tannic acid; ochtahedrite; storage

## Introduction

Meteorites are an invaluable source of information on the early history of the solar system, the composition of planets, the proportions of elements present in the solar system, and how impacts of large meteorites have altered Earth's history and could affect our future. Current research focus includes the study of pre-solar grains to understand our parent stars, how the physics of flight in our atmosphere shapes meteorites, detecting the presence of biological compounds, and the use of non-destructive micro-computed tomography (3D imaging) in conjunction with scanning electron microscopy. Some meteorites remain unaltered for millions, if not billions, of years but, despite an estimated fall of 2900-7300 kg per year of meteorites within the 10g – 1kg range (and 8.7 events weighing over 1kg per year) (Bland *et al.*, 1996), many land in the oceans or climates within which deterioration is extremely rapid (Bevan, 1992). Undeteriorated specimens are very rare and are mostly discovered in the Antarctic, where the dry cold climate allows good preservation and low levels of contamination (Bland *et al.*, 2006). Meteorites are divided into three main groups: irons, stones and stony-irons, but there are many subclasses. The largest group of meteorites is the stones (mainly silicate minerals), once forming part of the outer crust of a planet or asteroid. Some stone meteorites (chondrites) contain tiny grains pre-dating the formation of our solar system. Achondrites include material from the moon, mars and asteroids (Lotzof, 2018). Iron meteorites form the second most common type and were once part of the core of a planet or large asteroid. The majority of iron meteorites contain 90-95% iron, plus nickel and trace elements. Iron meteorites are subdivided into classes both by chemical composition and structure. Structural classes are determined by studying their two component iron-nickel alloys: kamacite and taenite (Notkin, 2019). The stony-irons, account for less than 2% of all known meteorites. They are comprised of roughly equal amounts of nickel-iron and stone and are divided into two groups: pallasites and mesosiderites. The pallasites are thought to have formed at the core/mantle boundary of their parent bodies, revealing details about the structure of planets, whilst mesosiderites are believed to form when debris from a collision between two asteroids are fused together (Lotzof, 2018).

As a meteor travels through the atmosphere the frictional heating causes its surface to melt and vaporise. The melted material is stripped away, creating the characteristic indents (regmaglypts). As the meteor cools, the surface solidifies to form a thin shiny fusion crust (Bevan, 1992). When a meteorite hits the Earth, a crater may be formed but the bulk of material can be destroyed by vaporisation. At Meteor Crater in Arizona, 30 tonnes of meteorite fragments were discovered at the crater rim and in the surrounding plains, including the large Canyon Diablo specimen, currently at the Natural History Museum (NHM) in London (UK) (NHM BM. 1959.1052) which is the subject of this article.

*Storage of meteorites*

Different types of meteorites require different storage environments. Iron-nickel meteorites are better preserved in dry environments, which would be unsuitable for carbonaceous chondrites which contain up to 20 wt% water, mainly in phyllosilicates and hydrous sulphates such as epsomite, which will readily effloresce and cause delamination of the fusion crust if allowed to dry out (Bevan, 1992).

Contamination is a primary concern for meteorites, handling procedures and storage media must be strictly controlled, and a record of materials which have been in contact with the specimen should be made, for elimination of elements when research is undertaken. Meteorites can be identified by weight, avoiding the need to adhere labels to them (Bevan, 1992). Even if contamination is not a concern, contact with bare skin must be avoided because chlorides from sweat residues will accelerate iron corrosion (Walker, 1982) and finger-prints can often be observed on inappropriately handled specimens. Pollution can also be a source of acids, such as sulphuric acid, which are hygroscopic and will contribute to iron corrosion (Selwyn, 2004) and deterioration of calcium-based minerals. Materials that are considered appropriate for storage of meteorites at the NHM include glass, aluminium foil cleaned with isopropanol, and un-coloured platinum-cured silicone, polytetrafluoroethylene, polyester, polyethylene and polypropylene. Only unused plastic should be used to store meteorites, since plastic molecules are easily transferred between materials, leading to potential cross-contamination (Smith, 2017). Kebukawa *et al.* (2009) recommend that glass and polystyrene are the only suitable storage media for certain types of meteorite.

Meteorites should be stored at a stable relative humidity (0-10% for iron meteorites and 35-45% for carbonaceous chondrites (Almeida, 2019)). Double polythene bags are a protection from contamination, but they will only protect against changes in humidity if appropriately conditioned silica gel is included. Relative humidity can fluctuate dramatically in a sealed environment with no controls, when temperature changes. AMNH (2008) recommend a triple ziplock bag system to maintain low humidity but avoid contamination from silica gel dessicants: "The bag containing the sample (and is still open) is placed inside the bag containing desiccant. The desiccant bag is sealed, minimizing the amount of air in both bags, and left for 20 minutes. Once the allotted time has passed, the interior sample bag is sealed without opening the outer desiccant bag. The sample should no longer be in contact with the desiccant. Finally, the desiccant bag is placed inside a third Ziploc, which is then sealed, to ensure that there is no longer any air exchange."

At the NHM, a variety of storage techniques are used to safeguard the specimens. These range from a display case, constantly replenished with positive pressure nitrogen, to small microenvironments in the collections storage area with oxygen and/or humidity control where appropriate. Iron meteorites should be stored in anoxic environments similar to those constructed by Trafford and Allington-Jones (2017), these can be made dry by using oxygen scavengers such as RP-System A by Mitsubishi Gas Chemicals. Oxygen levels must be less than 3% to prevent corrosion (Walker, 1982). Certain specimens subjected to many years in the field, inappropriate storage or open display, however, have suffered from corrosion.

*Deterioration of iron meteorites*

The most damaging corrosion of iron meteorites is caused by moisture and air, accelerated by terrestrially derived chloride ions (Bevan, 1992). In a burial environment, at the interface between the iron and the corrosion products, iron (II) ions dissolve, accumulate and hydrolysis occurs, in turn leading to local acidification which increases the solubility of iron ions (Selwyn, 2004). The major corrosion products are akaganéite and goethite (Bevan, 1992). The former decomposes to form maghemite and goethite, releasing chloride ions to the corrosion front to re-initiate corrosion. In addition, the small crystal size of akaganéite means its water absorption capacity is very high (Bevan, 1992). Active corrosion can sometimes be identified because akaganéite is orange and goethite is brown (Knight, 1982).

Corrosion of iron is uneven due to the creation of cathodic and anodic areas (in electrochemical reactions positive ions flow from the cathode and oxidation occurs at the anode). At the cathode hydroxide ions are produced, increasing pH, and at the anode ferrous ion hydrolysis causes a reduction in pH. The acid increases the solubility, and causes dissolution of iron oxide-hydroxides (Turgoose, 1982). In addition, chloride ions will concentrate at the anodes, contributing to corrosion reactions by increasing the conductivity of the aqueous phase of electrochemical corrosion (Turgoose 1982). Chloride ions are not necessary for all iron corrosion, but they are the main accelerator (Turgoose, 1982; Watkinson, 1996).

Areas of active oxidation are porous and allow oxygen and moisture to react with the layers below and continue to oxidise (Logan and Selwyn, 2007). The chloride ion reacts with the iron to form a hydrous ferric chloride which is deliquescent and will then react with oxygen to continue a cycle of deterioration in the meteorite (Pickard, 2005). Small actively corroding pits form, containing acidic solution which promotes pit growth (Selwyn, 2004). This pitting corrosion is promoted by the presence of chloride ions (Selwyn, 2004). Chlorides are hygroscopic so they encourage electrochemical corrosion and also increase the conductivity of the solution (Walker, 1982). Chlorides are present in seawater, soil and groundwater so any meteorite find is likely to be contaminated. The presence of nickel can in some cases reduce the rate of corrosion reactions but it can also cause concentrated corrosion at weak points (due to an imbalance between anodes and cathodes) leading to local intense attack (Walker, 1982).

*Figure.1 The Canyon* Diablo specimen (NHM BM. 1959.1052) in its *old wooden crate.*

## The NHMUK Canyon Diablo specimen

The Canyon Diablo specimen is a coarse ochtahedrite meteorite IAB Og 2 (mostly iron and nickel) weighing almost 100 kg, from the Barringer Crater in Arizona (Figure 1). The asteroid is believed to have fallen 50,000 years ago and this fragment was collected in 1891 and acquired by the NHM in 1959. It was initially stored in a wooden crate in a dark storage area, lacking environmental control.

### *Condition*

Outline sketches of the specimen were created and used to form condition maps of each surface, a useful technique on objects for which pinpoint locations are difficult to describe (Figure 2). Approximately 60% of the surface is covered with a black compact and adherent layer of inactive oxidised iron, but 30% by a thin porous orange-brown corrosion layer, which is most prevalent around areas which show abrasion. 10% of the surface is composed of patches of orange akaganéite which has caused spalling as the crystals grow at the metal-rust interface (Selwyn *et al.*, 1999) (Fig. 3a). In the case of Canyon Diablo, environmentally derived chlorides may have been exacerbated by the presence of acids and salts derived from rodent urine at some point in the specimen's long history: the greatest concentration of spalling is located on the upper surfaces of the specimen and analysis using LEO 1455 VP SEM (variable pressure scanning electron microscope) revealed the presence of elevated levels of chlorides in these areas. Discrete patches of weeping iron were also observed (Fig. 3b). Weeping or sweating is caused by high humidity and high concentrations of chloride salts. When humidity decreases, the liquid precipitates as iron hydroxide oxide droplets and forms shiny crusts or orange blisters (Selwyn, 2004; Logan and Selwyn, 2007). In its liquid state, this is acidic and will eat away at the iron (Logan and Selwyn, 2007) so stabilisation or storage at low relative humidity is essential for weeping iron meteorites. The patches on the specimen correspond to areas which had been in contact with the wooden crate. These were presumably caused by the localised higher humidity and concentration of formic and acetic acids generated by the deterioration of the wood (Selwyn, 2004).

### *Possible stabilisation techniques*

The corrosion patches could be removed using airbrasive, a glass bristle brush, Waller sodium salts

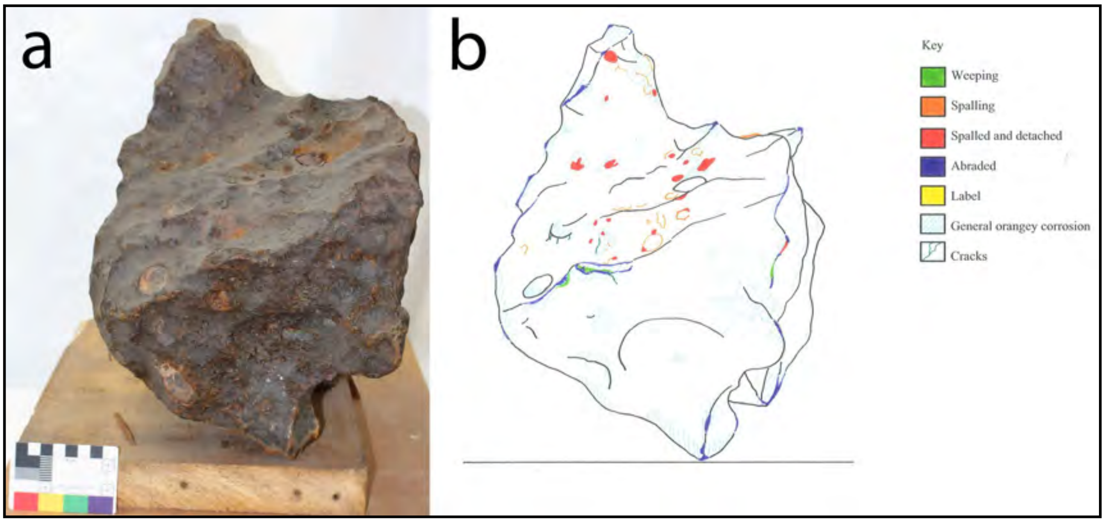


*Figure 2. (a) The Canyon Diablo specimen after removal from the crate; (b) A condition map of a similar elevation. Object maps are an excellent way of recording the condition of specimens which are difficult to describe verbally. They are quick and easy to refer to when checking future deterioration, and they can be invaluable in aiding pattern recognition which can lead to the identification of the cause of deterioration.*

solution (Waller, 1980), commercially available corrosion removers (such as Biox Gel) or with abrasive polishing compounds. Logan and Selwyn (2007) recommend that corrosion layers on archaeological iron are removed from objects by rubbing gently with fine steel wool (000 or 0000 grade) and a few drops of light oil (e.g. sewing machine oil). Clean, lint-free cloths wetted with mineral spirits are then used to wipe off the resulting oil/rust slurry. This is followed with a thin fresh coat of oil, applied with a clean cloth. Oil enhances the surface appearance of the object and leaves a film, which may act as a thin vapour barrier that temporarily protects the underlying iron against further corrosion.

Meteorite dealers have been known to use commercial products such as RustGuardIt, Rig, Rig2, Sheath, and WD40 to treat specimens (Twelker, 2018). Bathurst Observatory in Australia have traditionally used light oil, which requires removal and a reapplication every six months or a coating of a protective polyurethane (Pickard, 2005). They later adopted an alkaline treatment in which meteorites were wrapped in aluminium foil and immersed in hot water and sodium carbonate for 2-4 hours.

If left too long, formation of the mineral limonite (iron hydroxide) occurs, which can be rubbed off with a cloth. Several treatments were sometimes

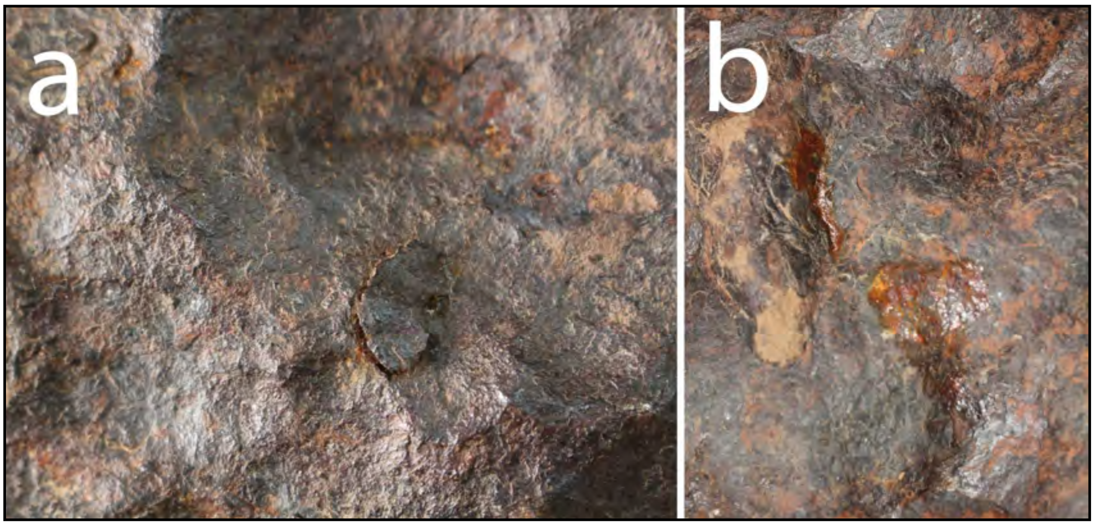


*Figure 3. (a) Spalling and (b) Weeping, on the Canyon Diablo specimen.*

found to be necessary to stop weeping and some re-treatment was found to be necessary in subsequent years (Pickard, 2005). Results have been mixed, depending on the type of meteorite treated - Pallasite slices have suffered recurrent weeping, but some Campo del Cielo specimens did not suffer a recurrence of corrosion for 12 years, and even one open-air specimen has not suffered significant deterioration (pers. comm. R. Pickard, Bathurst Observatory, 3 February 2018).

San Diego Natural History Museum (California) only use anoxic storage to prevent corrosion - after discovering that shellac and other coatings are ineffective (Shelton, 1995). Harvard University Mineralogical and Geological Museum and Museum National D'Histoire Naturelle (Paris) store selected specimens at 0% RH (Alonso-Perez, 2019; Gounelle, 2019), whilst The Centre for Meteorite Studies (Arizona State University) store iron meteorites at 10-15% RH and use nitrogen cabinets for carbonaceous chondrites (Garvie, 2019). Most institutions, however, do not have the financial resource or facilities to store specimens at specific environmental conditions. At the New England Meteororitical Services, all new acquisitions and any specimens which undergo sampling, are instead immersed in 99.9% alcohol warmed to 35°C for 10-15 minutes before air-drying, to remove contaminants such as lubricants from cutting blades. They have found that this treatment is effective to prevent most types of deterioration (Kempton, 2019).

Many treatments of archaeological iron are concerned with the removal of chloride ions since they are present in the majority of corrosion products on artefacts (1.6-14.0% of artefact content from marine sites, and 0.5-1.0% of artefact content from soil-based sites consist of chloride ions). The chloride content of archaeological artefacts far exceeds that of their burial environment, because the chloride ions carry the current to the anode during corrosion (Turgoose, 1982). In archaeological conservation, soluble salts were traditionally removed by immersion in water (Johnson, 1998). Other aqueous treatments include pressurised water and repeated boiling but both methods can cause physical deterioration (Watkinson, 1982) and lead to further severe corrosion (Blackshaw, 1982). Watkinson (1996) found non-aqueous extraction methods (ethanol and ethanoic lithium hydroxide) to be ineffective. Watkinson (1996) recommends alkaline sulphite treatment followed by Soxlet hot wash (immersion at 60°C over 60 days) to extract chlorides from archaeological iron. Watkinson (1996), however, warns of residual chemicals, physical damage and that no guarantee can be made that corrosion will not continue to occur.

The presence of chloride ions interfere with some treatment reactions, and a higher pH is necessary for passivation (Selwyn, 2004). Bevan (1992), however, warns that caustic immersion treatments pose great risks of leaching, reaction with mineral assemblages, and the production of more corrosion than had previously existed. Coating the surface of iron increases resistance in the corrosion circuit and slows the rate of reaction (Walker, 1982). Protective coatings like waxes and lacquers do not stop the transmission of water vapour and oxygen, however, they only reduce them. Crystalline waxes have good barrier properties and are more effective than films made from polymer solutions or polymer powder coatings, but they have low resistance to strain from thermal and mechanical shock, whilst solvent -free coatings delivered by spraying will not penetrate pores in corrosion products (Pascoe, 1982). In addition, when applied to porous corrosion layers, the coatings may be very difficult to remove if the object continues to actively corrode (Logan *et al.*, 2013). Waxes are particularly difficult to remove from heavily corroded iron surfaces, so are not normally recommended for use on rusted iron.

The use of iron-specific corrosion inhibitors would be risky on meteorites, since they can react adversely with other metals (Walker, 1982) but tannic acid has been used on archaeological iron for over 50 years. The treatment can produce a blue-black coating resembling uncorroded iron, and is suitable for iron stored indoors. The acid reacts with the corrosion layers to form ferric tannate, which will prevent the most susceptible areas from re-rusting in the short term (Logan and Selwyn, 2007). Tannic acid treatment allows iron to be stored at much higher relative humidity - up to 50% (Logan *et al.*, 2013) but will not protect specimens from exposure to even higher relative humidity levels (Selwyn, 2004) and may need repeat applications. Treated specimens therefore require periodic visual monitoring. The advantage of tannic acid is that it can be used to treat areas which are actively spalling, but where the flake is still attached, otherwise making akaganéite crystals inaccessible. If the object starts to re-corrode tannic acid can be re-applied easily and without the need to remove the previous treatment layer (Logan and Selwyn, 2007).

The hydrogen reduction technique (Barker *et al.*, 1982) also creates a blackened effect but was rejected as an option because oxidation occurs extremely rapidly after treatment if the iron is not coated with resin.

## Treatment

The specimen was removed from its wooden crate and dry-cleaned using latex-free additive-free polyurethane cosmetic sponge to remove particulate contaminants from the surface. This was followed by ethanol flooding and swabbing to remove rodent urine and mobile chlorides. Techniques were then trialled on small fragments which had previously become detached due to spalling.

*Initial trials on spalled fragments*

Air-abrasive techniques and steel wool removed the akaganéite from spalled fragments but left a shiny fresh surface behind, which would be sensitive to further corrosion (as exemplified by the corrosion haloes around abraded areas of the meteorite). The glass bristle brush failed to remove the akaganéite. Liquid abrasive polishing compounds were rejected because they would leave chemicals on the porous surface and sodium salts were rejected because they would remove the corrosion products completely, leaving a fresh surface exposed to corrosion. The tannic acid treatment described by Logan *et al.*, (2013) was trialled. This was adapted because the recommended technique was ineffective on the meteorite, presumably due to its higher nickel content or lower porosity than archaeological iron. The treatment solution was found to be more effective with a higher percentage of ethanol (the final addition of 100 ml water in the recipe was replaced with 100 ml ethanol), which acts as a wetting agent and aids penetration. The solution was used at 10% concentration (higher than the recommended dilution), heated to 50°C and applied by local flooding of the surface and agitated with a stiff brush. During heating a watch glass was placed on the beaker to prevent a disproportionate evaporation of the ethanol. SEM analysis showed the presence of phosphor in areas treated with tannic acid, which derives from the phosphoric acid used to adjust the pH and increase the amount of dissolved iron ions available for reaction with tannic acid. Phosphoric acid reacts with iron ions to form ferric phosphate, which also protects the iron (Logan *et al.*, 2013).

*Treatment of the specimen*

Curatorial staff were consulted following the initial trials and tannic acid was chosen for treatment of the specimen. One coat of tannic acid was applied to the entire surface of the specimen using a stiff brush and then allowed to dry, to stabilise the thin layer of oxidation covering 30% of the surface. The spalled craters were then treated with 2 or 3 additional tannic acid treatments, using a fine brush, until the orange akaganéite crystals had turned black.

The spalling areas (where slivers of metal had begun to peel away but were still firmly attached to the main specimen) were treated using a pipette and the solution was introduced to cracks using capillary action. The uncorroded areas of the meteorite were unaffected by the treatment but the areas of corrosion assumed a darker brown-black colour and an increased lustre (Figure 4). This resembled the fusion crust of fresher meteorites, a positive by-product of the stabilisation treatment (although care must be taken to record all treatments to avoid unethical deception). Two patches assumed a purplish-blue appearance, which was not acceptable to curatorial staff. These areas were treated with a thin film of Renaissance microcrystalline wax polish (a mixture of Cosmolloid 80 hard and BASFA microcrystalline wax), pre-tinted with raw umber and mineral black earth pigments (pers comm. JP Brown 11 September 2017) (Figure 5). The ferric tannate passivation layer was considered by conservation staff to provide a sufficient barrier between the wax and the meteorite in this instance.

An additional specimen, a portion of the Henbury meteorite IIIAB OM 0.9 (first found in 1931, Northern Territory, Australia) was also treated with tannic acid, with similar success (Figure 6).

## Results

After 12 months and 18 months respectively, the Henbury meteorite showed no active corrosion but the Canyon Diablo specimen showed fresh corrosion inside one especially deep regmaglypt. This may be because the original tannic acid treatment was not thorough enough in this area, or because vapour pressure is lower at concave meniscus so water can be trapped (Pascoe, 1982), or due to solubilisation of oxychlorides over time (which can occur at high RH) making them available for reactions (Rinny and Schweizer, 1982). The most likely explanation is, however, that the RH in the temporary storage environment went up to 72% for a short period of time, and over 60% RH for extended periods, far above recommended levels for objects treated with tannic acid. This regmaglypt was treated locally with tannic acid as recommended by Pelikán (1966) and Logan and Selwyn (2007) and no visible active corrosion has recurred after a further 12 months in storage.

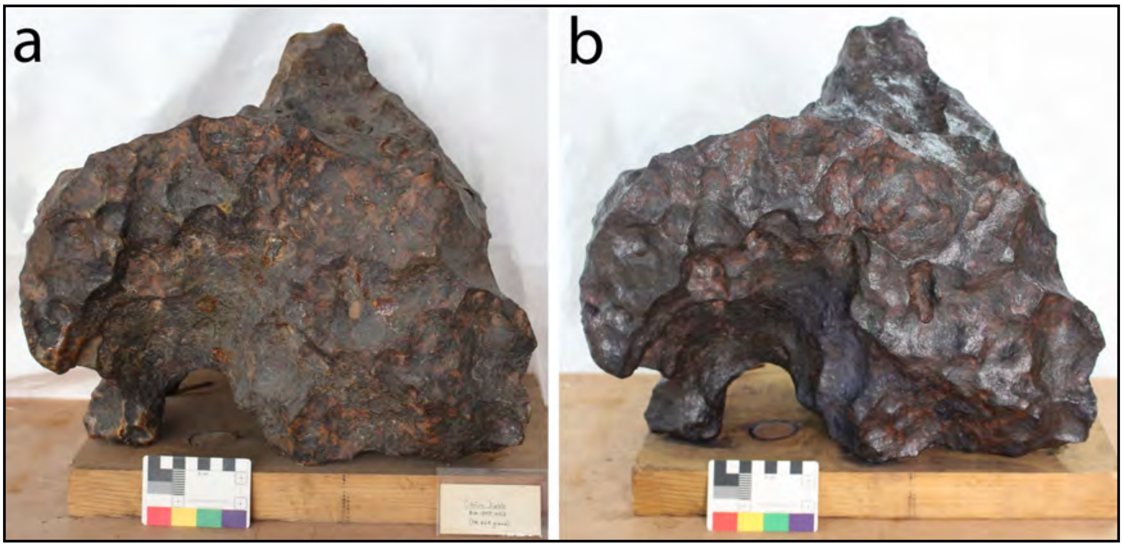


*Figure 4. The specimen (a) before treatment; (b) after treatment with tannic acid.*

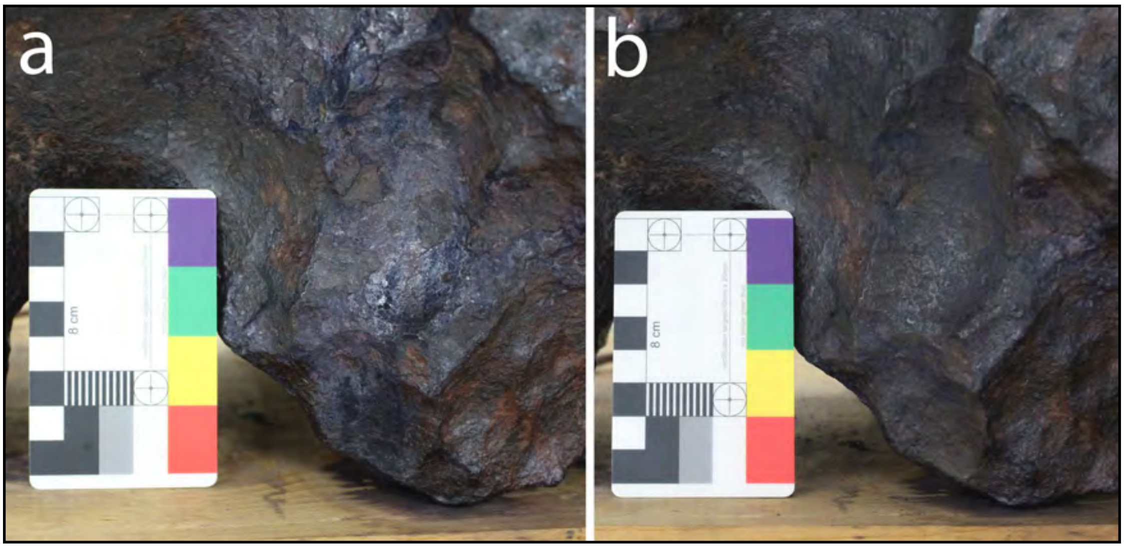


*Figure 5. (a) area on one face of the treated specimen, showing a bluish lustre (right-hand side of the image); (b) the same area after application of the tinted wax.*

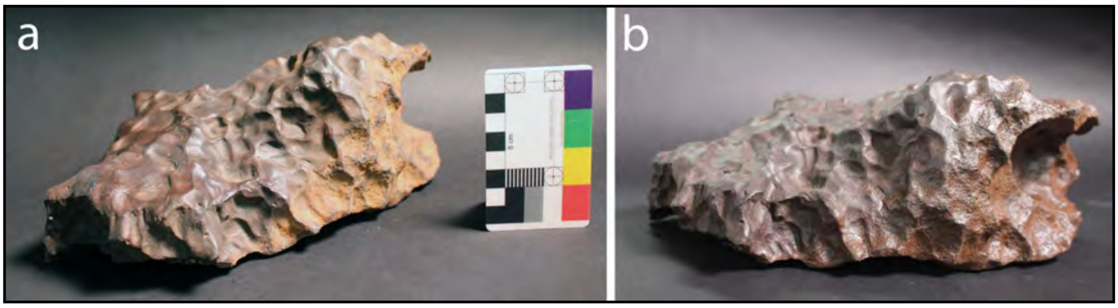


*Figure 6. Left: Henbury meteorite before treatment. Right: after treatment.*

## Conclusion

A suitable treatment must be chosen based on the research value held by a specimen and how analysis would be undertaken. In the case of this Canyon Diablo meteorite, preserving the core and improving overall appearance for exhibition was chosen at expense of preserving the crust chemistry. The crust had already become heavily contaminated and corroded through years of inappropriate storage and handling. Any areas of corrosion are in themselves already altered and likely to contain a suite of different minerals caused by oxidation, hydration, dehydration, acidic and alkaline regions, alternating structural layers, migration of ions (Tamura, 2008) and pollution. There are ethical concerns within the field of conservation regarding the removal of corrosion layers, since they are composed of original (although altered) material from the object. Curators and conservator were in agreement in this case, however, that the patches of active corrosion are detrimental to the stability and visual authenticity of the meteorite, and therefore should be removed or chemically stabilised. The conversion of iron corrosion to stable iron compounds such as magnetite is a widely accepted practice in the conservation of archaeological iron (Argyropoulos *et al.*, 2017). Iron meteorites which have suffered years of varied contamination and deterioration, due to improper storage conditions, may be stabilised using tannic acid, as long as conservation and curation staff are in agreement. If undesirable blue tints are created, these may be masked using tinted microcrystalline wax.

Chemical treatment should, however, never replace environmental control as a method of preservation and non-interventive options such as 3D surface scanning should be considered to capture physical properties in a digital format. Preventive conservation methods should be used to preserve the specimen in the long term. This type of meteorite should normally be stored below 35% relative humidity, and ideally below 12% (Watkinson and Lewis, 2004), but the tannic acid treatment should allow storage up to 50% RH. The specimen should be monitored regularly for further evidence of crystal growth and spalling.

### *Further work*

The treated meteorite must be displayed and stored in a stable relative humidity up to 50%. Its condition must be monitored at regular intervals and any deterioration compared with the post-treatment images and the condition maps, to identify the cause of any continued oxidation. The weeping areas were not porous so it is uncertain whether the tannic acid treatment will be effective in the long term. If continued oxidation is observed in these areas, a gel (perhaps thickened with Laponite RD containing sodium salts (Waller, 1980) or a poly(vinyl) acetate borate gel with chelators (Duncan *et al.*. 2017)), will be trialled to remove the oxidised iron and then the exposed surface will be treated again with tannic acid.

**Acknowledgements**

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# Cleaning historical tick specimens using an ultrasonic cleaner

Lidia Chitimia-Dobler[1] and Jason A. Dunlop[2*]

[1] *Bundeswehr Institute of Microbiology, Neuherbergstrasse 11, D-80937 Munich, Germany*

[2] *Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Invalidenstrasse 43, D-10115 Berlin, Germany*

**Corresponding author: Jason.Dunlop@mfn.berlin*

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**Abstract**

A method is described for cleaning ticks (Arachnida: Ixodida) preserved for decades in 70% ethanol using an ultrasonic cleaner. The advantages of this approach are that it is relatively inexpensive and does not involve the use of chemical reagents other than ethanol, such as when preparing ticks for scanning electron microscopy or as slide preparations. In a wider context the methods outlined here may be applicable to other relatively robust arthropods preserved in alcohol collections.

**Keywords:** Arthropoda, Arachnida, Ixodida, cleaning, ultrasonic cleaning, collections

## Introduction

Ticks (Arachnida: Ixodida) are an important group of ectoparasites which feed on the blood of vertebrates. About 900 valid species are currently recognized (Guglielmone *et al.*, 2010) and their significance as pathogen vectors in both humans and domestic animals means that there is a considerable body of research relating to their systematics and biology; see e.g. Soneshine & Roe (2013) for an overview. Museum specimens of ticks are a particularly important source of data. Museums can host the type specimens which underlie the identification of species, but even non-type records can provide valuable information on, for example, (historical) distribution patterns, host preferences and morphological variation within a given taxon. However, morphology-based studies of ticks held in museum collections are less effective when the objects are dirty and/or encrusted with detritus, which is often the case with specimens collected in the field. These artefacts can obscure characters necessary for correct identification, or hinder accurate measurements for techniques such as morphometrics. Using the tick collections from the Museum für Naturkunde Berlin as a test case, we demonstrate here a relatively cost- and time-effective method using ultrasonic vibration for cleaning specimens preserved, often for decades, in 70% ethanol.

## Methods

Specimens originate from the Museum für Naturkunde Berlin and have repository numbers under the traditional acronym ZMB (for Zoologisches Museum Berlin). This collection hosts ca. 225 valid tick species from throughout the world, with type series of about 160 species (Moritz & Fisher 1981), including historically significant specimens associated with Koch's (1844) groundbreaking study of tick systematics. Note that only about 60% of these type series belong to currently valid species. While some tick specimens in Berlin are pinned and dry or, less commonly, mounted on slides, most of the collection is preserved in 70% ethanol; as is typical for zoological wet collections. Many of the specimens date back to the mid to late 19th century, i.e. they can be up to 175 years old, with a geographical focus on Europe as well as former German colonies or major international expeditions carried out by German explorers.

For comparative purposes, examples of historical tick specimens in alcohol were photographed using a Keyence VHX-900F microscope (Itasca, Illinois, USA) both before and after the cleaning process (compare left and right panels of Figs. 1–2). Specimens were subjected to ultrasonic vibration at a low intensity for five minutes using a Bioruptor® Sonication System (Diagenode Bioruptor Standard). During this process specimens were still retained within their original vials, which usually contain ca. 2–15 ml of 70% ethanol. This ultrasound treatment can be repeated if necessary. Afterwards, the ticks were placed in a petri dish, still in ethanol, and were manually cleaned of any remaining adhering particles with a small paintbrush; typically sizes 0–2, depending on the sample size. The cleaned ticks were finally placed and dried on a piece of filter paper and manipulated to check from all sides that they were now fully clean. The manual cleaning step can also be repeated if necessary. Once the ticks are in a satisfactory condition they can be returned to the original vials and/or be studied and photographed under the microscope.

## Results

The ultrasound method proposed here can return historical tick specimens collected as early as the late 19th century to a near pristine condition. The detritus which adhered to the ticks was successfully removed and high-quality photographs of the clean specimens – including any microstructure and/or setae on their cuticle – are now possible. Figure 1a-d shows part of the type series of *Hyalomma rufipes* CL Koch, 1844 (ZMB 1073) collected pre 1844 from Senegal. Figure 1e–f shows a non-type specimen of *Ixodes bicornis* Neumann, 1906 (ZMB 16777) from Tirrialba in Costa Rica collected in 1913. Figure 2a–b shows a non-type specimen of *Amblyomma pomposum* Dönitz, 1909 (ZMB 15922) from Marromeu in Mozambique collected in 1976. Figure 2g–h shows a non-type specimen of *Rhipicephalus evertsi evertsi* Neumann, 1897 (ZMB 11454) from Mafeking in South Africa; date of collection not recorded.

## Discussion

Several methods for cleaning ticks have been proposed in the literature (e.g. Corwin *et al.*, 1979; Dixon *et al.*, 2000), although here the ticks here were specifically being prepared for scanning electron microscopy. The disadvantage of the Corwin et al. (1979) method is the use of a commercial glue, which is not universally available, but was useful for removing dirt particles from the integument of ticks, especially argasids (soft ticks). By contrast, Dixon *et al.*, (2000) proposed a method where they used wax solvent instead of detergents or ethanol. Nevertheless, this method is time consuming and relies on potentially dangerous chemicals like xylene and acetone. These make the techniques more expensive, and introduce additional health risks to the user, making them less appropriate for cleaning and curating large museum or university collections. Larval ticks can also be prepared in Hoyer's medium: a mixture of gum Arabic, chloral hydrate and glycerol (e.g. Stern & Sucena 2000). This is the most satisfactory substance for preparing whole mounts of larval ticks as the setae, the positions of which can be taxonomically important, are seen best when the juvenile specimens are mounted on slides; see also Clifford & Anastos (1960) for details.

Ultrasonic cleaning, often associated with immersion in 5% sodium (or potassium) hydroxide, has also been mentioned in the literature on ticks (e.g. Estrada-Peña *et al.*, 2004; Latif *et al.*, 2012; Barker & Walker 2014), although here the focus was on freshly collected material. In the Latif *et al.*, (2012) study the relatively soft-bodied tick *Nuttalliella namaqua* Bedford, 1931 required careful treatment prior to electron microscopy, namely gradual rehydration and then five 2–3 second bursts in an ultrasonic cleaning bath before the usual critical point drying technique. Barker & Walker (2014) suggested ultrasonic cleaning in a solution of sodium or potassium hydroxide, or if this is not available brushing them with detergent using the stumped bristles of an artist's brush. Although not explicitly stated in these studies, the sodium or potassium hydroxide evidently helps to remove adhering particles.

We demonstrate here that ultrasonic cleaning can also be carried out efficiently on wet samples without the need for additional chemicals beyond the 60–70% ethanol, which would be used for long -term storage anyway. The method is also applicable to historical museum specimens – as opposed to fresh material only – and facilitates the mobilization of high-quality morphological data from older material too. Further advantages of the methods proposed here are that it is relatively quick and, from a curatorial point of view, can be done on specimens still in their original museum vials.

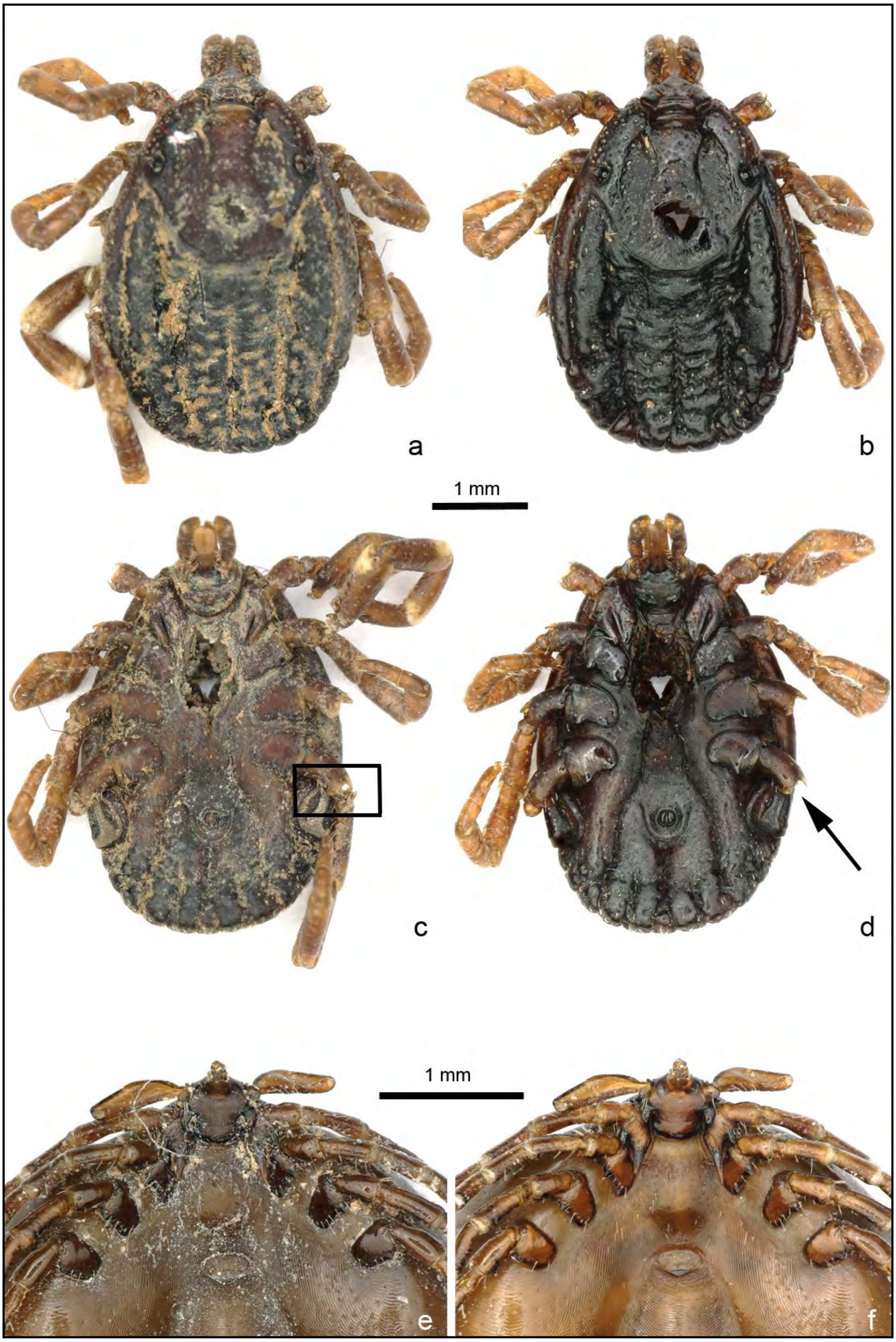


*Figure 1. Examples of cleaned ticks.* ***a–b.*** Hyalomma rufipes *CL Koch, 1844 (ZMB 1073: from type series) in dorsal view before (a) and after (b) cleaning.* ***c–d****. The same in ventral view before (c) and after (d) cleaning; note that the specimen was originally dried and pinned, and that one leg was weakened (box) and became disarticulated (arrow) during cleaning.* ***e–f.*** Ixodes bicornis *Neumann, 1906 (ZMB 16777), anterior region of engorged individual in ventral view before (e) and after (f) cleaning. Images © Lidia Chitima-Dobler, 2019.*

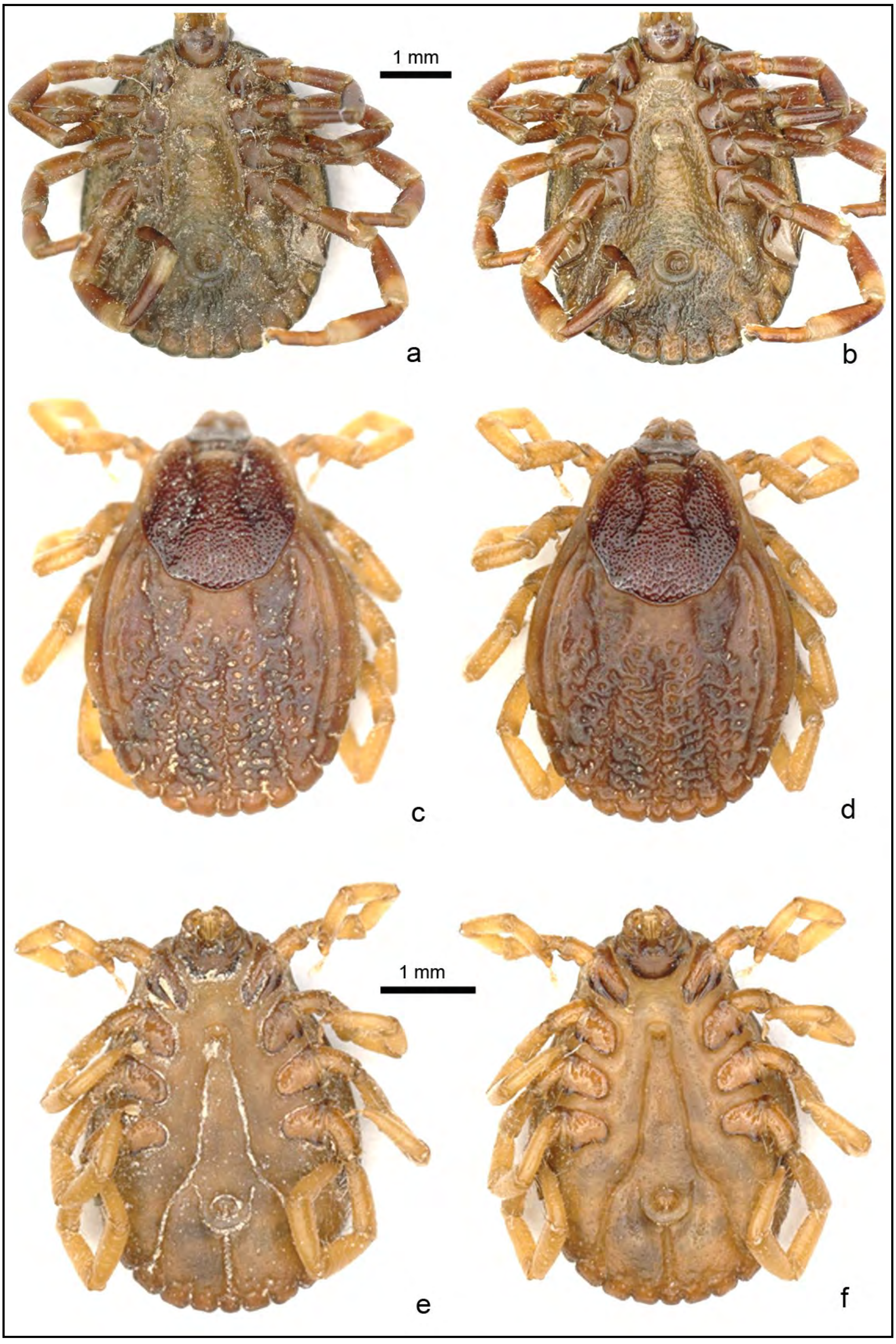


*Figure 2. Additional examples of cleaned ticks.* ***a–b.*** Amblyomma pomposum *Dönitz, 1909 (ZMB 15922) in ventral view, before (a) and after (b) cleaning.* ***c–d***. Rhipicephalus evertsi evertsi *Neumann, 1897 (ZMB 11454) in dorsal view before (c) and after (d) cleaning.* ***e–f.*** *The same in ventral view before (e) and after (f) cleaning. Images © Lidia Chitima-Dobler, 2019.*

Specimens only have to be removed for the manual cleaning stage with a paintbrush, minimizing risks of them being separated for too long from their original labels and/or being returned to the wrong vial. In other words, they do not necessarily need any new (temporary) labels during the cleaning process. The disadvantages are that the method does need the user to acquire a certain degree of expertise, and patience, to manipulate the ticks during the manual cleaning stage.

We suggest that this ultrasonic method could be applied to clean larger batches of ticks held in natural history collections. Similar methods have also been used to clean spiders and myriapods (Shear & Levi, 1970) and crustaceans (Felgenhauer, 1987). In the latter case ultrasonic cleaning and tumbling in 16% glycerine was used to remove any detritus adhering to the specimen; see also Haug *et al.*, (2011) for its application to gammarid crustaceans prior to imaging by scanning electron microscopy. Several studies have suggested ultrasonic cleaning prior to electron microscopy work on arthropods. Avern (1997) used it, combined with tissue maceration, as a way to clean the internal exoskeleton of arthropods, while Friederich *et al.*, (2014) noted is usefulness for cleaning insects and their (often dirty) mouthparts in particular. One to ten minutes of ultrasonic vibration has also been used to clean the spinnerets of spiders prior to electron microscopy (e.g. Coddington, 1989), and for ten minutes to clean genital preparations of spiders prior to drawing them (e.g. Haddad, 2007). Ticks have a relatively robust and compact body. Harrison (2012) used a similar ultrasonic technique to clean historical specimens of beetles – again typically quite robust arthropods – although it should be added that dry, pinned specimens would have to be rehydrated prior to cleaning. Harrison (2012) also noted that in order to prevent damage to the specimen the ultrasonic equipment should not be too vigorous and we also used a gentle setting here.

Despite this, we should note that in one case (Figures 1b, d) a hind leg did become detached from the body. This happened to the historically oldest specimen we tested: originally a pinned preparation which at some stage was transferred to alcohol. Figure 1c (box) reveals that the weakness in the leg joint was probably already present when the specimen was dry, thus caution may be needed when using these approaches on ticks originating from pinned collections. Essentially, the question is balancing the risks of limb disarticulation against the very obvious improvements (Figure 1d) in the quality of data which can be obtained from the cleaned body. Both Friederich *et al.*, (2014) and Schneeberg *et al.*, (2017) demonstrated that ultrasonic cleaning was not suitable for fragile or delicate insects (especially larvae) and recommended bathing them in potassium hydroxide instead. This alternative method may be appropriate for fragile tick material, and perhaps for other arachnid specimens too.

In a wider context, ultrasonic cleaning has been proposed as a conservation method in various branches of museology; for critical reviews see especially Caldararo (1994; 2005). Fossils can also be cleaned using ultrasonics (reviewed by Pojeta & Balanc, 1989), especially microfossils (Van Bael *et al.*, 2016) or subfossils in sediment cores (Nowak *et al.*, 2008), although here the risks of specimen damage again have to be balanced against the cleaning effect. In another case study, Rull *et al.*, (2016) cautioned that ultrasonics may damage mollusc shells. Still essentially related to natural history (i.e. organic) objects, Barton & Weick (1986) used ultrasonics to clean ethnographic featherwork and Cooke (1989) showed that these approaches were applicable to textile conservation too. Several studies also suggested that inorganic objects (clay tablets, metals) can be cleaned with ultrasonics (e.g. Spier, 1961; Lewis, 1981; Melniciuc Puică, 2005), sometimes in combination with chemical cleaning solutions.

**Acknowledgements**

We thank Anja Friederichs (Berlin) for curatorial assistance and the reviewers for helpful comments on the typescript and suggestions of additional references.

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# NatSCA 209 AGM and Minutes

Thursday 2$^{nd}$ of May 2019
National Museum of Ireland, Dublin

**Attendees:** Paolo Viscardi (PV), Miranda Lowe (ML), Roberto Portela Miguez (RPM), Jack Ashby (JA), Maggie Reilly (MR), Clare Brown( CB), Rachel Jennings (RJ), Yvette Harvey (YH), Jennifer Gallichan (JG) and Isla Gladstone (IG)

### 1. Apologies for absence

David Gelsthorpe (DG), Jan Freedman (JF), Holly Morgenroth (HM), Donna Young (DY) Paul Brown (PB) and Lucy Mascord (LM)

### 2. Minutes of AGM Thursday 26$^{th}$-27$^{th}$ of April, 2018.

This meeting was held at Leeds City Museum, and minutes were published in *Journal of Natural Science Collections* **6:** 112-117. There were no objections from membership and these were signed as a correct record of that meeting by the chair and secretary.

Proposed: Rebecca Machin     Seconded: Glenn Roadley

### 3. Chair's report

Welcome to the National Museum of Ireland, I'm glad you made it along to this year's AGM and conference on the theme of Dead Interesting: Secrets of Collections Success.

Since last year's conference in Leeds we have had a bit of a bumper crop of events, with the Skeleton Preparation Workshop in Portsmouth, run in conjunction with Historic England, a Caring for Natural Science Collections one day conference at the Oxford University Museum of Natural History, a Finding Funding day at the World Museum Liverpool and a Care and Conservation of Insect Collections day in partnership with Zoe Simmons in Oxford - our thanks again to Oxford and to Clare Brown, Lucie Mascord , Jen Gallichan, and Donna Young, who made these events happen.

In the last year we have also applied for funding from ACE for a project to help build a network of support for museums with natural history collections but no specialists in partnership with the South West and North West Development teams. Unfortunately we were unsuccessful, but there have been some positive steps arising from subsequent discussion with other Subject Specialist Networks SSNs and the Arts Council.

To address some of the bigger picture issues surrounding the role of subject specialists in the museums sector we have been working with other Subject Specialist Networks (SSNs) and currently we sit on the steering group for the SSN Consortium. This is an important group, as it joins together the voices of around 40 groups similar to NatSCA, amplifying the message that museum collections need knowledge to unlock their potential - something that has been flagged in the Mendoza Review, but which has become unfashionable - as we have seen with the situation in Leicester.

Through the SSN Consortium we have an opportunity to influence sector bodies, and we have already helped inform the Art Fund and Arts Council England about how the wider museums sector is supported by specialist groups and how they can better support the work we do. This has resulted in a new funding strand from the Art Fund and we are currently in discussion with Kate Bellamy of Arts Council England about how SSNs might be better supported and how we can better support natural sciences collections. We hope this will lead to greater capacity for us to support you.

We have also been helping to support the natural sciences collections sector by liaising with Defra to help inform them of the needs of museums with scientific collections with regards to Brexit & CITES - as you heard this morning from Clare and myself.

There is still plenty to do and as I alluded to earlier, there are real and deeply concerning issues relating to collections at risk in the UK, with ongoing attrition of posts, but I like to think that Ireland offers a glimpse of a somewhat more hopeful future, as we are starting to recover from the catastrophic loss of curatorial roles that we faced a decade ago at the height of austerity. It will take a significant shift in political thinking for change to come, but that shift may come sooner than we might expect, with Brexit up for grabs and a significant buy-in to the role and relevance of scientific collections from Europe in the shape of the emerging DiSSCo programme.

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Vote of thanks:
I would like to thank the National Museum of Ireland for making us so welcome this year - it's been f antastic to have NatSCA here, with an opportunity to build closer links with our colleagues just over the Border. My colleagues here in the Museum have been very helpful in making this meeting happen. I could be here all day thanking everyone who has been involved, but special thanks to Nigel, Matthew, Aidan, Eimear, Emma, Geraldine, Nieves and volunteers Erin and Antoinette.

Of course, it's not just colleagues in the NMI, but Colin Kelleher and the staff at the National Botanic Gardens and Martyn Linnie at Trinity College Dublin Zoological Museum who are helping to make this conference a great experience.

In a strange quirk of fate, the committee members who have been instrumental in pulling this conference together are all unable to actually make it. So I broadcast my thanks to Donna Young, David Gelsthorpe, Lucie Mascord, Jan Freedman and Holly Morgenroth. They're all on Twitter, so please share my appreciation for them, with them! Of course, the whole of the committee are essential in running NatSCA and I offer thanks to all.

I particularly want to thank people who are leaving the committee this year. Emma Louise Nicholls stepped into Isla's shoes as GCG rep while Isla was on maternity leave, but she's also done sterling work on the NatSCA blog over the last few years, sharing the goings on in the sector and keeping us in the loop. Rachel Jennings is another ex-blog manager who went on to take the mantle of Editor at our meeting in Derby. Rachel and has done fantastic work on improving our policies and peer review process for the Journal, but is now stepping down to focus on a new and more demanding role. We are also saying goodbye to two of our long-standing committee members from the NHM - Roberto Portela Miguez and Miranda Lowe. Both have been on committee for as long or longer than me and they have performed a variety of roles and done a huge amount to make NatSCA the open, vibrant and welcoming organisation it is today. I want to thank them both for all their support and help since I joined the committee and particularly since I became Chair. Your absence will leave a void.

I would very much like to thank our volunteers, who keep things running, namely Lilly Wilks, Glenn Roadley, Jen Gallichan, Gina Allnatt, Sam Barnett, Melissa Viscardi and the absolutely indispensable Justine Aw.

Speaking of indispensability, I want to finish by offering my special thanks to Holly for keeping us financially stable and healthy.

Finally I want to thank you all for attending - I hope you enjoy the conference and your time here in Dublin!

## 4. Treasurer’s Report

2018-2019 end of year

Accounts summary 01.02.2018 - 31.01.2019

| Income | 2018-2019 | | 2017-18 |
|---|---|---|---|
| **Institutional Subscriptions** | | | |
| Previous Years | 160 | | 119 |
| Current Year (bank) | 1,708 | | 1,651 |
| Current Year (PP) | | | |
| Future Years | 39 | | 40 |
| | | 1,907 | 1,810 |
| **Personal Subscriptions** | | | |
| Previous Years | 55 | | 60 |
| Current Year | 4,646 | | 4,295 |
| Current Year (PP) | | | |
| Future Years | 167 | | 80 |
| | | 4,869 | 4,435 |
| **Workshop Income** | | | |
| Skeleton | 1,300 | | |
| Funding | 52 | | |
| Conservation | 2,997 | | |
| | | 4,349 | 840 |
| **Conference Income** | | | |
| 2017 | 35 | | 15,359 |
| 2018 | 8,980 | | |
| | | 9,015 | 15,359 |
| **Other** | | | |
| Misc. | 50 | | |
| Bank interest | 27 | | 5 |
| | | 77 | 5 |
| **TOTAL INCOME** | | 20,217 | 22,449 |

| Expenditure | 2018-2019 | | 2017-18 |
|---|---|---|---|
| **Running costs** | | | |
| Committee Expenses | - 2,254 | | 2,181 |
| Cons Sub Committee | - | | 314 |
| | | | |
| Postage | - | | 27 |
| Data Protection | - 35 | | 35 |
| | | - 2,289 | 2,558 |
| **Workshops** | | | |
| Conservation | - 1,121 | | |
| Funding | - 32 | | |
| Skeleton | - 1,200 | | |
| | | - 2,353 | 217 |
| **Conference** | | | |
| 2017 | | | |
| 2018 | - 7,241 | | |
| | | - 7,241 | 7,056 |
| **Publications & Information Provision** | | | |
| 2017 Journal print & postage | - 2,750 | | |
| 2018 Journal print & postage | - | | 1,910 |
| | | - 2,750 | 1,910 |
| **Projects** | | | |
| 2017 Bill Pettit Fund | - 1,200 | | 733 |
| 2018 Bill Pettit Fund | - | | |
| | | - 1,200 | 733 |
| **Other** | | | |
| Bursaries | - 307 | | 315 |
| | | | |
| Website | - 360 | | 400 |
| Stationery | - | | |
| | | - 667 | 715 |
| **TOTAL EXPENDITURE** | | - 16,500 | 13,190 |

Excess Income over Expenditure 3,717

| | | |
|---|---|---|
| **OUTSTANDING EXPENDITURE** | | |
| **Cons Conference** | | |
| Kathryn Royce | £ 75 | |
| Evangelia Kyriazi | £ 75 | |
| Samuel Suarez Ferreira (Bainbr | -£ 55 | |
| Helena | £ 75 | |
| Beth Hamilton | £ 75 | |
| Anastasia van Gaver | £ 75 | |
| **Journal** | £ 1,916 | |
| | | £ 2,236 |
| **EXPECTED INCOME** | | |
| Late Membership | | £ 299 |
| | | £ 299 |
| Adjusted balance 31.01.2019 | | £ 39,176 |

| | | | | |
|---|---|---|---|---|
| **Cash Flow Statement** | | | | |
| | 01.02.2018 | Current a/c | 24,993 | |
| | | Deposit a/c | £ 12,403 | |
| | | Paypal a/c | | |
| | | | | £ 37,396 |
| | | | | |
| | 31.01.2019 | Current a/c | £ 18,683 | |
| | | Deposit a/c | £ 22,430 | |
| | | Paypal a/c | £ - | |
| | | | | £ 41,113 |
| | NB Adjusted balance | | | £ 39,176 |
| | | | | |
| | | | | £ 1,780 |

**Proposed: Nigel Monaghan Seconded: Karen Banton**

**Election of Ordinary Members of NatSCA committee:**

Below are the nominees for NatSCA committee posts to serve from 2019 to 2021 which have reached the secretary.

The membership secretary has checked to see that those proposed, those proposing and those seconding are all present members of NatSCA.

**Treasurer 2019-2021 Holly Morgenroth Exeter Museum**

Proposed: Roberto Portela Seconded: Miranda Lowe

**OM 2019-2021 Amanda Callaghan Cole Museum of Zoology**

Proposed: Paolo Viscardi Seconded: Maggie Reilly

**OM 2019-2021 Glenn Roadley Stoke-on-Trent Museums**

Proposed: Gina Alinatt Seconded: Paolo Viscardi

**OM 2019-2021 Lucy Mascord Lancashire County Council Museum Services**

Proposed: Natalie Jones Seconded: Patricia Francis

**OM 2019-2021 Isla Gladstone Bristol Museum and Art Gallery**

Proposed: Claudia Hildebrandt Seconded: Emma Nicholls

**OM 2019-2021 Jack Ashby University Museum of Zoology, Cambridge**

Proposed: Liz Hide Seconded: Matt Lowe

**OM 2019-2021 David Geltsthrope Manchester Museum**

Proposed: Lindsey Loughtman Seconded: Rachel Webster

| | | |
|---|---|---|
| **OM 2019-2021** | **Kirsty Lloyd** | **Natural History Museum, London** |

Proposed: Jan Freedman Seconded: Kirsty Lloyd

As there are no contested posts, no election is required. There were no objections to the candidates, membership accepted and elected the listed people en block onto committee to serve for three years for the treasurer and two years for other committee members.

Proposed: Rachel Jennings Seconded: Laura McCoy

**Already in post:**

| | | |
|---|---|---|
| **Chair 2017-2020** | Paolo Viscardi | National Museum of Ireland |
| **Secretary 2018-2020** | Yvette Harvey | RHS, Surrey |
| **OM 2018-2020** | Jan Freedman | Plymouth Museum |
| **OM 2018-2020** | Jennifer Gallichan | Cardiff Museum |
| **OM 2018-2020** | Maggie Reilly | Hunterian Museum, Glasgow |
| **OM 2018-2020** | Clare Brown | Leeds City Museum |

Rachel Jennings, Miranda Lowe and Roberto Portela Miguez agreed to step down from committee.

**5. Membership Secretary's Report**

**2018 Summary**
345 names on the database

8 FOC means potentially 337 paying members but there were, despite repeat reminders/demands, 33 non-renewals (31 personal and 2 institutional (FBA and Worcester). One of the personals has renewed for 2019 but the rest will be deleted form the database for 2019.

On the positive this means we ended the year with 52 institutional subs and 252 personal ie 304 paying members. This number therefore includes an impressive 63 new or returning members. There have been a number of retirements/resignations. Resignations mostly through people leaving the sector. I will flesh out this basic report for 2018 for the AGM report.

**2019 Summary**
Subs reminders have been sent out to all personal members – Justine contacts the Paypal payers and I contact those who pay by bank transfer, cheque or cash. Standing orders work tolerably well but there are a dozen or so members, who despite repeated reminders/begging have failed to update their SOs from £15 to £20.

Electronic invoices are sent out for institutional subs and MR is slowly (due to lack of time) working her way through those and hope to have all sent by the end of April.

Situation so far is this:
Institutional invoiced: 5
Institutional paid: 5 (different 5) but note already there are 8 new institutional members ie 13 institutional subs paid.

Personal paid: 147 including 19 new members so far. It is relatively early in the year so ok with this rate of payment.

Journal: mailing labels were supplied and sent to the printer/distributor. 230 hard copies were printed including some spares and those for copyright libraries. 106 members elected for no hard copy. Volume 6 has been uploaded to the website and a new password sent out to all paid up members for 2018 and to the new members for 2019. An email discussion has been had (PV,RJ, JA,HM,JF) about how to supply the electronic copy to those who don't want a hard copy. Downloading articles using the password is the default but probably isn't sufficient. 2 other suggestions emerged – send the pdf via WeTransfer(JF) or download the whole pdf using a password tba (JA). Need an action on this.

MR also had a discussion with Richard Chalmers from the printer (Dolman Scott, London) re any GDPR regs on supplying printed labels to them ie a third party. Been unable to get any clarity anywhere else so thought they might know. He consulted their distribution department who said they knew of no issue with printed (as opposed to electronically supplied labels.) They have a full GDPR policy on their website. AGM notification has been sent out to members. Note that Google Groups has been playing up a bit recently occasionally not allowing MR to add batches of new members. It also says it's changing stuff in May. MR may need assistance from the digitally literate amongst our number on this.

**6. Editorial Report**

Rachel Jennings confirmed that she stepped down from editorial role and that Jan Freedman currently looks after this.

RJ thanked all those that supported her in that role.

PV thanked RJ for delivering a high-quality journal and for the work done to date to improve and deliver it.

**7. Motion to dissolve NatSCA as charity and set up as CIO**

CB on behalf of committee asked members to vote on whether they are willing or not to accept the new constitution, set up a new NatSCA CIO and dissolve NatSCA as a charity.
The proposal was confirmed by more than a 2/3 majority of the personal members attending. A total of 36 voted in favour, so the motion was passed

**8. Conservation Report**

**Conservation group**

The meeting of the 27th March 2019 was cancelled. We will rearrange.
Two members of the group would like me to readdress the expense issue with the committee. LM reiterated the committee's initial response.

LM has a few suggestions for how the group might continue in light of this issue. It may be preferable to delay discussing this until the next non-AGM meeting.

1. Change set-up of meetings
2. Designated fund for expenses
3. Reduce group size

**National Trust Meeting 11th March 2019**

Prior to meeting LM sent an email to Katy Lithgow Introducing NatSCA and the conservation group, and outlining how they may support their activities. LM provided the minutes and email summary of previous group discussions about the use of non-pc materials in natural history conservation.

To summarise the meeting;

- The decision was made that non-pc/untested materials should not be used in the conservation of natural history materials. Namely Vanish carpet cleaner and Chemical Metal.
- Brief comments were made to update NT policies relating to radioactive materials, mercury and arsenic.
- The natural sciences section of the National Trust Manual of Housekeeping is being updated by Simon Moore.
- LM encouraged the NT to refer to specialist sources (i.e. NatSCA, GCG other institutions and the conservation group) to help develop their guidelines. Unfortunately the response was apathetic.

Icon
Icon 2019 in Belfast (12th-14th June 2019). Trade fair stands are £375 for charities and includes two complementary tickets to the conference (note these cost £475 per person for members).

There are NO natural science presentations at the conference. This is hugely discouraging as people did apply. A trade stand may be an opportunity to raise awareness.
There are options to leave a display or pop-up instead. Cost on application.

**9. Any Other Business**

Jack Ashby reminded attendees to fill in evaluation forms.
Jennifer Gallichan requested contributions for the NatSCA blog.

**10. Vote of Thanks**

**11. Next Committee meeting**

To be confirmed but options are Brighton and Leiden.

**Closed at 14:20 pm 02/05/2019**

# NatSCA Committee

## Honorary Officers



## Ordinary members




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